THE STRATIGRAPHY, STRUCTURE AND TECTONICS OF THE KUKUKUKU LOBE; PERMIT 22, PAPUA

by

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The contents of this thesis are original, except where duly acknowledged, and have not been previously submitted in any part for any form of university degree. This thesis is submitted to the University of Tasmania as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Andrew Kugler, Jr.
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ABSTRACT

The Kukukuku Lobe is a complex uplift of Miocene sediments. This uplift basically represents the inversion of a deep, marine trough - the Aure Trough - in which volcanic sandstones, mudstones and conglomerates - the Aure Group - accumulated to a thickness at least of the order of 10,000 meters during the Lower Miocene and early Middle Miocene. The argillaceous Toa Group (late Middle Miocene-Upper Miocene; 3,000 m.) overlies the Aure Group and is overlain in turn by the Era Group (Pliocene; 2,200 m.). These units were deposited marginally to an uplifted area of the Aure Group and were in large part derived from the Aure Group.

The tectonic history of the Kukukuku Lobe is traced by means of detailed stratigraphic and structural analyses, which reveal a sequential pattern of westward migrating depositional troughs (subsidence), followed a phase behind by westward migrating uplift and folding. The uplift and folding are oldest along the eastern side of the Kukukuku Lobe (Lower Miocene) and youngest along the western side (post-Pliocene), indicating a long-lived and essentially continuous deformational history.

The Kukukuku Lobe forms the eastern leg of the Purari Orocline, and the tectonic development of the Lobe - from the earliest-formed sedimentary trough to the latest deformation - records the manner and mechanisms by which the Purari Orocline has formed. The Purari Orocline is placed in a regional geological context by reviewing the gross tectonic framework of New Guinea, and the stress system which gave rise to both the Purari Orocline and the Kukukuku Lobe is identified. This stress system is then related to the regional tectonic pattern of New Guinea and the southwest Pacific.

I N T R O D U C T I O N - A R E A O F S T U D Y

Under the auspices of Professor S.W. Carey of the University of Tasmania, the Papuan Project was initiated late in 1961. Due to the efforts of Professor Carey, Oil Search Ltd. and Papuan Apinaipi Petroleum Company agreed to release confidential geological information on Papua and the Terriroty of New Guinea and, as well, give financial support to the Project, which had and has as its aim the study and synthesis of this data. Dr. J.G. Smith and myself, and Dr. R.P.B. Pitt of the Australian Bureau of Mineral Resources, undertook a tectonic study of Papua and the Territory of New Guinea, this study having resulted in three doctoral theses. Mr. J.E. Shirley and Mr. V.P. St.John undertook a study of the regional gravity, this work having resulted respectively in a Bachelor of Science Honors thesis and a doctoral thesis. Mr. J. Brooks of the Australian Bureau of Mineral Resources is currently studying the seismicity of New Guinea. The ultimate aim of the Papuan Project is to combine all of this research into a definitive tectonic study of New Guinea.

For the purpose of this study, Papua was divided into three regions. Dr. Smith was assigned the region to the west of the Aure Fault (generally, west of 145 degrees 00' E. Longitude Latitude). Dr. Pitt was assigned the region to the east of the Kapau River (generally east of 146 degrees 10' E. Longitude Latitude), and I the region between, known as the Kukukuku Lobe (see Plate III). Each of us has subsequently extended these areas into the Territory of New Guinea, and there has been some degree of inevitable and necessary overlap between areas.

The Kukukuku Lobe (Carey, 1938) is a rugged mountainous area, with a meridional trend and is flanked to the west and east by the swampy lowlands of the Delta Embayment and Lakekamu Embayment respectively. The Kukukuku Lobe rises rather abruptly from swamplands near the southern coast of Papua and gradually increases in elevation northward until it merges with the mountainous backbone of New Guinea at elevations in excess of 3,000 meters some 100 kilometers to the north (see Plate III).

My research on the Kukukuku Lobe has mainly involved a thorough review and synthesis of unpublished geological reports by the Australasian Petroleum Company (Oil Search Ltd.) on Permit 22 of Papua, which includes the region of the Kukukuku Lobe. A short five-week orientation survey in New Guinea was undertaken early in 1962 in the company of Professor Carey, Mr. G.A.V. Stanley and the other members of the Project. In November, 1963, one month was spent in a brief field survey in the Murua River area to the north of Kerema. Late in 1963, aerial photographs covering the southeastern part of the Kukukuku Lobe became available, and these were used in an effort to extend information and correlate from area to area. At this time, I also produced a photogeological interpretation (see Plate Ia) of the hitherto unmapped Armit Range in the northern part of the Kukukuku Lobe. In September and October of 1963, I spent five weeks gathering gravity data in the Australian Solomon Islands. This data has been incorporated into the theses of Mr. J.E. Shirley and Dr. V.P. St. John.

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1. STRATIGRAPHIC ANALYSIS

1.1 PRE-TERTIARY

1.1.1 PRE-CRETACEOUS

The nature of the rocks which underlie the Aure Trough in the region of the Kukukuku Lobe is unknown, as rocks older than Cretaceous are not known from this region. E.R. Stanley (1923) reported Devonian corals from rocks in the Karova River area, but this has since been invalidated (APC Rept. LE-1).

In the region of the Kukukuku Lobe, basement rocks are known only as derived constituents in Cretaceous, Miocene and Pliocene sediments. The derived constituents consist principally of basic igneous rocks and low-grade metamorphics (mainly phyllites, quartzites and occasionally schists), but granitic rocks and a wide variety of metamorphic fragments have been recorded. From a series of aerial reconnaissance flights, Carey suggested that metamorphic rocks may crop out in the area of the Kratke Ranges between ~~ween~~ the headwaters of the Vailala and Purari Rivers (APC Rept. WD). Pitt (1966) has photogeologically outlined metamorphics in this area (see fig. 1.1-1), and suggests a probable correlation with the metamorphics of the Bismarck Range (pre-Jurassic). In subsequent sections, I will refer to the probable exposures of metamorphic rocks in the Kratke Range as the "Kratke Metamorphics". To the east, metamorphics crop out in the Owen Stanley Ranges, and include rocks as young as Cretaceous (Cenomanian; refer Pitt, 1966; see figure 1.1-1).

1.1.2 CRETACEOUS

Rocks of undoubted Cretaceous age crop out only along the western boundary of the study area. These rocks are brought-up in a series of fault slices (fig. 1.1-1; locns. 1 to 4) and have been regarded as equivalent to the Paw Formation of Lower Cretaceous (Aptian - Albian) age (refer Smith, 1964). The best section (incomplete) of these rocks is approximately 520 m. thick, and consists of thin-bedded mudstones, massive tuffaceous sandstones and calcareous sandstones rich in molluscs (APC Rept. LI). These beds are disconformably overlain by limestones of early Lower Miocene age, but elsewhere in this area are overlain disconformably by limestones of Eocene age. It has been suggested that possibly 610 m. of this unit is exposed beneath the Eocene limestones on the Aure Scarp (APC Rept. LI), but these rocks have not been examined in the field (locn. 5). It is possible that some 3050 m. of beds exposed in the core of the Aiweriba Anticline (locn. 6) - the Aiweriba Beds - are of Cretaceous age (APC Rept. LI), but I regard these rocks as being most probably of early Lower Miocene age (refer 1.3.1-A).

A. DERIVED CRETACEOUS FAUNAS IN YOUNGER ROCKS

To the west of the Dude Anticline, derived Cretaceous faunas have been reported from the following localities (refer fig. 1.1-1; DK = derived Cretaceous):

LOCALITY		INDIGENOUS FAUNA	INFORMATION SOURCE
DK-1	Hohohoru Syn.	U. Miocene (Lower Murua)	APC. Rept. LH-2, Paleo. Append.
DK-2	Nakoro Ant.	" " "	APC. Rept. LJ, Paleo. Append.
DK-3	Hihova Ck.	" " "	APC. Rept. LM, Paleo. Append.
DK-4	Keari Ant.	" " "	APC. Rept. WI.
DK-5	Hihova Ck.	" (Upper Murua)	APC. Rept. LM, Paleo. Append.
DK-6	Nakoro Ant.	" " "	APC. Rept. WI.
DK-7	Upoia	" " "	" " "
DK-8	Hou Ck.	M. Miocene	" " "
DK-9	Iavokia Ant.	"	" " "
DK-10	Doroi'ia Ck.	"	APC. Rept. LH-2, Paleo. Append.

To the east of the Dude Anticline a derived Upper Cretaceous fauna has been reported from only one sample. This occurs in a sample taken from the Lower Miocene, Hell's Gate Sub-Group, from behind the Saw Mountains (DK-11).

It is noteworthy that all of the derived Cretaceous faunas, so far recorded, belong to the Upper Cretaceous. As metamorphic rock fragments and, to some extent, granitic rock fragments are common in the Miocene sediments, i.e. basement rocks were exposed in the source area during the deposition of these sediments, this tenuously suggests that the lower part of the Cretaceous was never deposited in the source area or that it was metamorphosed prior to the deposition of the Upper Cretaceous. The latter suggestion receives some support from the fact that no pre-Upper Cretaceous derived fossils have been reported from the Miocene rocks of this area. It is possible of course that this derived Cretaceous material came from a different source than the metamorphic and granitic fragments.

Assuming the hypothesis that pre-Upper Cretaceous beds in the Aure Group source area were metamorphic could have important implications because the Cretaceous rocks of the Owen Stanley Ranges are metamorphosed, while the Kubor and Bismarck Ranges expose a relatively unmetamorphosed section down to the Permian. This links the sediments of the Aure Group, in this area, more closely to a source in the Owen Stanley Ranges.

The fact that all but one sample containing derived Cretaceous fossils come~~s~~ from the area west of the Dude Anticline seems significant. This perhaps suggests, contrary to the above, that the source(s) of this derived material lay somewhere in a westerly direction from the Dude Anticline. This fact takes on more significance in light of the suggestion (refer section 1.3.2) that the Upper Miocene sediments were derived, in large part, from the area to the east of the Dude Anticline, *i.e.* there is no ready source for this derived material in the supposed source area. It is perhaps relevant that the Upper Cretaceous is missing from the Pio-Purari area, and that only Upper Cretaceous derived material occurs in the area to the southeast. This problem is further discussed in Section 1.3.2. .

1.2 E A R L Y T E R T I A R Y - P R E - M I O C E N E

Neither Paleocene nor Oligocene rocks have been recognised in this region. It has been suggested that some of the limestones exposed on the Aure Scarp could be transitional between the Eocene and Cretaceous (APC Rept. LI, p.36) and, therefore, it is not impossible that the Paleocene is in fact represented in these limestones.

1.2.1 EOCENE

In the area to the west and north of the Aure Fault, rocks of Eocene age are widely developed in a thin, shelf-limestone facies, contrasting markedly to the underlying Mesozoic geosynclinal facies (refer Smith, 1964). This marks the initial development of what I have termed the Puri Shelf, *viz.* the area in which Tertiary sediments are developed in a shelf-limestone facies (refer 1.3.1 and 3.4.1). This facies and, therefore, the Puri Shelf extends as far north as the south flank of the Bismarck Range (see figure 1.1-1; APC Rept. LW; McMillan and Malone, 1960; Smith, 1964). On the north flank of the Bismarck Ranges, the Eocene occurs in a dark mudstone-sandstone facies, at least 900 metres thick, representing a marine trough environment (*ibid;* also, Dow and Dekker, 1963). The northern edge of the Puri Shelf during the Eocene can, therefore, be placed approximately along the present trend of the Bismarck Range.

In my thesis area, the shelf facies of the Eocene is exposed in several fault-slices in the Pio River area (locns. 1 to 4) and again on the Aure Scarp. The Aure Scarp section (locn. 5) is approximately 200 m. thick (base faulted) and consists of both shallow-water and pelagic limestones with minor calcareous sandstones, gr~~e~~aywackes, grits and marls (APC Rept. LI). These beds are believed to be overlain disconformably by beds of early Lower Miocene age (refer 1.3.1). To the west, complete sections measuring between 60 and 150 m. thick and consisting of shallow-water detrital limestones (calcarenites) have been reported (APC Rept. LW).

These beds overlie beds of Lower Cretaceous age disconformably and are overlain disconformably by beds of early Lower Miocene age. Similar sections ~~ions~~ have been drilled at Puri (locn. 7), Wana and Iviri (see Plate II). The eastern edge of the Puri Shelf is not known, because to the east of the Aure Fault, the only known outcrops of Eocene are the small, very complexly faulted outcrops in the Hells Gate area (locn. 8). These rocks are described as brecciated siliceous marls, and dense, grey siliceous rocks with large dark chert concretions, and were correlated (principally on lithology) with the Port Moresby Group of Eocene age (APC Rept. LMA). It was estimated that 150 m. of these beds are exposed in an incomplete and disturbed section. These rocks are believed to be unconformably overlain by both the late Lower Miocene Hells Gate Sub-Group and by the Saw Mountains Limestone (Muiai Sub-Group) of early Middle Miocene age (refer 1.3-1, B and C). It is probable that beds of early Lower Miocene age unconformably overlie these rocks as well (refer 1.3-1A).

A. DERIVED EOCENE FAUNAS IN YOUNGER ROCKS

Derived Eocene limestone and Nummulites are common in the Lower Miocene Puri Limestone, and the Middle Miocene Pio Conglomerates of the Pio River area (DE-1; APC Rept. LW), and have been reported from early Lower Miocene conglomeratic beds in the Kariava Well (DE-3; refer 1.3-1A), from late Lower Miocene conglomerates in the Maropo section (DE-2; refer 1.3-1B), and from early Middle Miocene conglomerates in Karabure Creek (DE-5; APC Rept. LH-2, Paleo Append). Derived Eocene faunas are, also, recorded from Upper Miocene rocks in the lower Vailala area (DE-4). These latter occurrences are possibly recycled from the Aure Group, but the general paucity of these faunas within the Aure Group somewhat argues against this, and in a subsequent section I suggest they are very probably related to Upper Miocene uplift on either the McDowal Fault or the Ekiere Fault (refer 1.3.2-D). Because derived Eocene faunas are not known from the Aure Group in the general area to the east of the Dude Anticline (refer below), this suggests that the source of these faunas within the Aure Group lay in the shelf area to the west. Rickwood has fairly certainly shown that derived faunas in the Pio River region are best related to intermittent exposure and submarine erosion along the steep northern edge of the shelf area (APC Rept. LW), and I regard it as probable that these derived constituents within the Aure Group of the Vailala area were, in a similar manner, derived from the steep eastern edge of the Puri Shelf (refer 1.3.1-D).

Along the eastern boundary of the Kukukuku Lobe, and eastern margin of the Aure Trough, derived Eocene faunas and rocks are fairly common from the Hells Gate - Kapau River area (locn. 8, DE-6, DE-7). Eocene nummulitic limestones and cherts occur as stream boulders and as boulders in conglomerates of the Hells Gate Sub-Group, and detrital limestones of early Lower Miocene age commonly carry derived Eocene *Nummulites* (refer 1.3.1-A and B). These data indicate firstly that the nummulitic limestone facies as well as the chert facies of the Eocene was developed in some manner in this region and secondly, that these rocks were intermittently eroded so as to yield detritus to sediments of both early and late Lower Miocene age. It is noteworthy that large chert boulders, which very probably had their source in the Port Moresby Group, occur in the conglomerates of the Morai River Formation in the Morai-Eel Creek area (locn. 9 refer 1.3.1-C).

1.3 M I O C E N E

Rocks of Miocene age form about ninety-five percent of the outcrop in the region of the Kukukuku Lobe and have yielded the bulk of the stratigraphic data available. These rocks were deposited during a time of intense tectonic activity. Basically, they occur as extremely thick sequences (10,000 m. +) representing rapid accumulation in a series of narrow, deep-marine troughs, but important thickness and facies changes occur toward the trough boundaries.

Two major rock units can be recognised in the Miocene succession of this area. These are, a lower unit consisting in large part of sandstones - the Aure Group (redefined; refer 1.3.1) - and an upper, dominantly mudstone unit - the Toa Group (new term; refer 1.3.2). The Aure Group

(10,000 m. +) is of early lower Miocene to early Middle Miocene age and is believed to overlie Eocene rocks unconformably. The Toa Group (3,000 m.) is of late Middle Miocene to Upper Miocene age, and the basal formation of this group (Iavokia Mudstone) overlies the Aure Group unconformably in the southeastern part of this region. The Toa Group includes the "Murua Mudstones" of previous usage (see Jour.Geol.Soc.Aust.,Vol.8).

Because similar rock-types recur throughout the Miocene succession, correlations and subdivisions of this thick sequence have been based largely on paleontology. Macrofossils are extremely rare in these rocks, and the paleontological subdivision, itself, has been based principally on restricted forms of <u>larger</u> (benthonic) <u>foraminifera</u> and thereby correlated with the East Indies Letter stages (refer Table 1.3-I). The boundary between the Upper Miocene and the Middle Miocene, however, has been placed broadly at the level where <u>Globigerina</u> becomes dominant over <u>Orbulina</u> (see APC Rept. WI), and the upper Miocene per se has been subdivided on the basis of species of <u>Globigerina</u> (refer 1.3.2). This method of subdivision has proved extremely useful on a regional scale, but has met with only limited success in the area of the Kukukuku Lobe, and particularly within the Aure Group (refer, also, p.90, Jour.Geol.Soc.Aust., Vol. 8), because the depositional environment here represented is largely a deep-marine, rather than shallow-marine, environment. Consequently, the occurrence of larger foraminifera within the bulk of the Aure Group is rare, and this has led to difficulty and uncertainty in correlation within this group across the Kukukuku Lobe. This difficulty is mentioned here because the stratigraphy of the Aure Group necessarily became one of the main problems of this thesis, and although the stratigraphy can be <u>generally</u> set-out, many stratigraphic problems remain unsolved. In 1941, Stanley (APC Rept. LH-2, p.26) colorfully stated this problem as follows:

> "... <u>it is still impossible to decide for certain just where the trough of the Papuan geosyncline was located, say during the Upper Miocene (f3) times .... Dr. Carey has pointed out (APC Rept. LI, p.115) for the Purari area that the position of the thickness maxima within the geosyncline for the various states of the tertiary shifts progressively from south-west to north-east and across the geosyncline with increase of age</u> ..... the present

position is that the field geologists in that area (the Vailala - Kapau area - AK) are wondering amidst a veritable forest of columnar sections .... the temptation to make paleogeographic studies using the scanty (and often misinterpreted) facts at present available should be resisted until the time arrives when the reasoning can step by step be based on firmly established observations and stout bridges have been built across the yawning chasms, which at present daunt all but the hardiest adventurers."

1.3.1 THE AURE GROUP (AND EQUIVALENTS)

The Aure Group was originally defined by M.F. Glaessner as follows:

> "(an) alternating series of tuffaceous sandstones and mudstones with occasional limestones which overlie the Eocene nummulitic limestone in the Aure scarp and Maropo (Creek) section.... it corresponds to the broad paleontological unit referred to ... as the Orbulina zone." (in an A.P.C. company letter, refer APC Rept. LI, p.43).

The Aure Scarp section (Maropo and Pemem Creeks; refer later) was subsequently found to contain beds of early Lower Miocene age (APC Rept. LKE, LKD-10) as was the M'bwei River section (APC Rept. LR; refer later). The Aure Group was, therefore, extended to include beds below the Orbulina Zone, *viz.* beds of early Lower Miocene age.

In addition, I regard the Iavokia Mudstone, which has previously been regarded as the uppermost formation of the Aure Group, as the basal formation of the Toa Group. This is done firstly, because the Iavokia Mudstone is lithologically continuous with the overlying Upper Miocene mudstones, secondly, because it displays the same general pattern and distribution as the Upper Miocene mudstones and, finally, because the Iavokia Mudstone overlies the Aure Group unconformably in the south-eastern part of this region (refer 1.3.2).

The Aure Group can, therefore, be regarded as being of early Lower Miocene to early Middle Miocene (pre-Iavokia) age. It will become evident ~~ent~~ in the following discussions that the term "Aure Group" is a sack-term, in the most general sense, but it is widely known and widely used, and is useful to an extent. For these reasons the term is retained here.

Lithologically, the Aure Group can be described <u>generally</u> as consisting of massive to well-bedded volcanic (refer below) sandstones, mudstones and conglomerates which vary in proportion from area to area. ¶Only very limited petrological work has been done on the Aure Group. A.B. Edwards (1950) studied some samples, all most probably of Middle Miocene age, from the Kerema area and found these rocks to consist of (information summarized from Edwards, Table I, p.129):

a)	Plagioclase (chiefly sodic)	10–30%
b)	Volcanic rock fragments (chiefly andesitic)	5–35%
c)	Ferromagnesians (chiefly hornblende)	5–15%
d)	Sedimentary, low-grade metamorphic and plutonic rock fragments	1–25%
e)	Quartz and K-feldspars	0–10%
f)	Matrix (clastic, often replaced by calcite)	25–60%

The free mineral grains are predominantly fresh and angular, and frequently perfectly euhedral, whereas the rock fragments are commonly rounded. Chemical analyses of both sandstones and mudstones (*ibid*, p.138-140) revealed that these sediments are chemically very close to the composition of an "average andesite".

Edwards concluded that the rocks of the Aure Group were <u>second-cycle</u> products, derived principally from poorly consolidated andesitic tuffs, i.e. re-distributed tuffs as opposed to primary tuffs. It should be pointed out, however, that Edwards' study was very restricted areally, stratigraphically and in the number of samples examined (thirteen are reported). It is probable that primary tuffs occur elsewhere in the section and, from Edwards' data, possible that primary tuffaceous material occurs in the samples he examined but mixed with material derived from a different source. This can be shown by comparing Edwards' analysis of the Cupola section (9 km SE of Kerema) with that of the Auivera-Napere section (37 km NW of Kerema), which show significantly different results. With the exception of one sample (UN.381), all of Edwards' samples come from these two sections, which are compared approximately as follows (information summarized from Edwards, Table I, p.129; columns 8-12 from Cupola, 1-7 from Auivera-Napere):

CONSTITUENT	CUPOLA	AUIVERA-NAPERE
a) Plagioclase + Ferromagnesians	26%	64%
b) Ratio of igneous rock fragments to sedimentary rock fragments	4:3 (SRF predominate) in two samps.)	6:1
c) Sedimentary + igneous rock fragments consistently 10-20% higher in Cupola section		
d) Quartz	3-8%	trace - 0.2%
e) Orthoclase + 'granitic' rock fragments	present	absent

This comparison could be interpreted in several ways, one of which is that separate source areas have supplied sediment to these sections and, thereby, the possibility of mixing from multiple source areas must be admitted.

In the present context, the most important result of Edwards' study is to show that these sediments consist principally of material of volcanic origin, whether re-distributed or primary. This is in agreement with the several generalized field descriptions available, which commonly describe the sandstones as dark, tuffacous sandstones, rich in euhedral plagioclase and ferromagnesian minerals. Because these rocks are formed principally of volcanic material, I have chosen to use the non-genetic, descriptive prefix 'volcanic', in the sense of Fisher (1961) as a general descriptive term for these sediments, *i.e.* volcanic sandstones, volcanic mudstones and volcanic conglomerates. Translating Edwards' descriptions into Fisher's classification, these rocks are principally of the Epiclastic class and probably include 'tuffaceous epiclastic volcanic sandstones' as well as primary tuffs.

For reasons of its genetic implications, and in the light of Edwards work, I would prefer to avoid using the term "tuffaceous", which is the term that has been most commonly used in field descriptions of these rocks. Aside from implying a primary pyroclastic origin for the "tuffaceous" mater-~~er~~ial, it does not indicate as strongly as does the prefix volcanic that the rock as a whole is composed of volcanic material. For example, the terms "tuffaceous" and "non-tuffaceous" have frequently been used in field descriptions of these rocks, and it is difficult to judge from this exactly what is the composition of the "non-tuffaceous" sandstones. On this point, the samples which Edwards examined included samples which were described in the field both as "tuffaceous" and as "non-tuffaceous", *e.g.* the Murakawarra Sand (tuffaceous ; sample UK 790; APC Rept. LH-2, p.13; col. 8 of Table I of Edwards) and the Ouka Sand (non-tuffaceous; samples UK.559 and 562; APC Rept. LH-2, p.15; columns 3 and 4 of Table I of Edwards). The only noticeable differences between these sandstones, from Edwards' data, is that the Murakawarra Sand contains 5-10 percent more igneous rock fragments and 2.5 percent less pyroxene than the "non-tuffaceous" Ouka Sand. From this one example, it can be judged that the "tuffaceous" rock is virtually identical in composition to the "non-tuffaceous" rock, and that the reason for the distinction must be elsewhere.

A final point regarding the nomenclature and composition of these sediments is that Edwards chose to call these rocks "greywackes". In doing this, he took the view that a compositional classification emphasizes the nature of the source rock ((rather than the nature of the sediment per se as I would view it)) and ignores the processes of sedimentation. Poor sorting, graded-bedding and associated features such as scours and slumps, which he reports as characteristic of the Aure sediments, were his chief criteria. Without laboring the point, and aside from poor sorting, such sedimentary structures have been only very rarely reported from the Aure Group. This may be partly due to the fact that most of the field work was done in the late 1930's and early 1940's, but the fact that such features are occasionally described - if not named as such -

suggests that they are generally absent where not reported. I have examined sections at Cupola and in the Murua River, and although graded-bedding and some phenomenal slumps are present at Cupola (refer Photograph I), neither is a feature of the much thicker Murua River section. This, together with the reported descriptions of these rocks, leads me to believe that features such as graded-bedding, scouring and slumping although locally important, cannot as yet be regarded as a characteristic feature of the Aure Group as a whole. Because of this, and because I prefer a compositional classification, I have not accepted Edwards' classification of these rocks as graywackes. In order to avoid a possible and unnecessary error, however, the detailed descriptions of these rocks in the following pages are as the field geologists have reported them. It should be clear from the aforegoing pages, however, that in discussing the Aure Group we are largely dealing with volcanic detritus - both redistributed and probably primary pyroclastic material - of general andesitic composition.

The Aure Trough can broadly be defined as the area in which the Aure Group, or more generally a marine trough-facies of this age, was deposited. It is a composite trough, as will be discussed later (refer also 3.4.2). It was first recognized by Carey (APC Rept. LC), and first defined by Glaessner (APC Rept. WI) as the ".... area of thick Miocene sediments of alternating tuffaceous sandstone and mudstone development between the Lower and Middle Purari River in the west and the Tauri and Kapau Rivers in the east."

The Aure Trough, therefore, occupies the central and major portion of the Kukukuku Lobe and of my thesis area. As such, the following discussions will consider firstly the sections in the Aure Trough and thence move to the east, west and north for regional comparisons. To the east, in the general area of the Kapau River, the eastern margin of the Aure Trough - the Kapau Margin - can be recognized. To the west, generally to the west of the Purari and Aure Rivers, an area of contemporaneous shelf-limestone deposition - the Puri Shelf - can be recognized as marking the

TABLE 1·3-I

SUBDIVISIONS OF THE MIOCENE OF PAPUA

	LOCAL STAGE	A.P.C. CORRELATION AND USAGE		CORRELATION OF EAMES et al, 1962		TERMINOLOGY USED IN THIS THESIS		
		EAST INDIES LETTER STAGES OF VAN DER VLERK & UMBGROVE, 1927		EUROPEAN STAGES				MAJOR ROCK UNITS OF THE KUKUKUKU LOBE
MIOCENE	MURUAN	"g"	UPPER MIOCENE	SARMATIAN	UPPER MIOCENE	UPPER MIOCENE		TOA GROUP
	IVORIAN	"f3"		VINDOBONIAN	MIDDLE MIOCENE	MIDDLE MIOCENE	LATE M.M.	
							EARLY M.M.	AURE GROUP
	TAURIAN	"f1-2"	MIDDLE MIOCENE	BURDIGALIAN	LOWER MIOCENE	LATE LOWER MIOCENE		
	KERURUAN	"e"	LOWER MIOCENE	AQUITANIAN		EARLY LOWER MIOCENE		

TABLE I. 3 – II APPROXIMATE CORRELATION AND TERMINOLOGY OF ROCK UNITS* WITHIN THE AURE GROUP AND EQUIVALENTS IN THE REGION OF THE KUKUKUKU LOBE.

AREA	PURI	HORBU-TE CREEK		E. OF AURE FAULT	IMBRICATE BELT	KAROVA TROUGH		KAPAU RIVER AREA		
LATE MID. MIOCENE	IAVOKIA MUDSTONE							MAIPORA FORMATION		
EARLY MIDDLE MIOCENE (early "f 3") Pre – Toa	ORBULINA MARL	AURE GROUP	AREO GREYWACKE WADOME FORMATION HORBU SANDY MUDSTONE ?	MAROPO BEDS (Including "Lepidocyclina grits")	"UPPER ARENACEOUS SUBDIVISION" "CALCAREOUS SANDSTONE SUBDIVISION" "LOWER ARENACEOUS SUBDIVISION" ?	KAROVA SUB-GROUP	MORAI RIVER FORMATION IBAI CREEK SANDSTONE YUIANI TUFFACEOUS SANDSTONE ?	BE CREEK BEDS ?	MUIAI SUB-GROUP	(SAW MOUNTAINS LIMESTONE & POISON CK. MARLS)
LATE LOWER MIOCENE ("f1 – 2")	PURI LIMESTONE		NOT KNOWN	OBORU SANDSTONE (Ewe Greywacke) ?	NOT NAMED		RUMUA BEDS	WERR BEDS	HELLS GATE SUB-GROUP	(DOORWAY LIMESTONE) (KAPAU LIMESTONE) & HELLS GATE LMST.
								OBAGEWA CONGLOMERATE ?		
EARLY LOWER MIOCENE ("e")				M'BWEI BEDS ? AIWERIBA BEDS ?	NOT KNOWN		NOT KNOWN	YUYEBBA CREEK BEDS	NOT NAMED ?	
	DISCONFORMITY									
EOCENE	LIMESTONES			NOT KNOWN						PORT MORESBY GRP.

* MOST MAJOR 'ROCK UNITS' ARE TIME – ROCK UNITS BY DEFINITION. BUT THIS IS PROBABLY NOT STRICTLY THE CASE; SEE TEXT.

western boundary of the Aure Trough. It will be noted that this 'shelf area', while marking a shelf relative to the Aure Trough, is rightly regarded by Smith (1964) as an "unstable platform" as compared to the "stable platform" realm of the Fly Delta region. The area which I refer to as the Puri Shelf is, in fact, the northern semi-stable, or unstable edge of this platform realm. In the area to the west of the Aure Lineament, I have extended my coverage beyond the northern border of Papua and into the Bismarck Ranges. I have done this principally to demonstrate the spatial relationships between the Puri Shelf and the Aure Trough, and, my discussions are not designed to examine the geology of this area in full detail. Smith (1964) and subsequently Pitt (1966), offer~~s~~ more complete and comprehensive discussions of this area.

The main subdivisions of the Aure Group are the paleontological subdivisions corresponding to the early Lower Miocene, late Lower Miocene and early Middle Miocene (refer Table 1.3-I), and the rock units recognized will be discussed under these headings (refer Table 1.3-II). None of these units is completely known, either in terms of areal distribution ~~ion~~ or in terms of vertical distribution in the column. This is due to a combination of depth of exposure, lack of geological traversing, and a lack of definitive paleontological data. Informal rock unit names are introduced to facilitate discussion. To reduce unnecessary new terminology, Pitt (1966) and I have collaborated on terminology in the eastern part of this area, as our thesis areas overlap in the region of the Tauri and Kapau Rivers.

Columnar sections across the Aure Trough are presented in figure 1.3-3(enclosure).

A. EARLY LOWER MIOCENE ("e" STAGE); refer figure 1.3-1

<u>Aure Trough</u>

The only section of early Lower Miocene age which can be regarded as reasonably complete is that exposed on the Aure Scarp (Pemem Creek; locn. 13). This section together with the Maropo section has been taken as the type-section for the Aure Group (APC Rept. LI). Here, 580 m. of beds described as tuffaceous sandstones and hard mudstones with very minor argillaceous limestones and marl bands (APC Rept. LI) have been assigned to the early Lower Miocene on the occurrence of Spiroclypeus and Eulepidina (APC Rept. LKD). A covered interval of approximately 106 m. separates these beds from the underlying Eocene limestones and, as no angular discrepancy was detected, the contact is believed to be a disconformity. The top of these beds is separated from beds assigned to the late Lower Miocene by a break in section involving approximately 150-300 m. of section. The maximum possible thickness of the early Lower Miocene here, therefore, is about 1000 meters. Glaessner (APC Rept. LKD) suggested that the top of this section is faulted-out, but there is no real evidence for this (see also, APC Rept. LKE). It is not impossible, however, that an unconformity occurs at the top of these beds, as an unconformity at this level has been suggested in the M'bwei River section to the east, and is possible in the Kariava Well section (refer later). These beds can be referred to as the M'bwei Beds, as they are similar to beds of the same age exposed in the M'bwei River.

In the M'bwei River (M'bwei 'Sa'; locn. 18) 975 m. of dark hard tuffs, mudstones which are frequently carbonaceous, and thin argillaceous limestones and calcareous sandstones, containing Eulepidina, Miogypsina and Miogypsinoides in the basal portion, have been assigned to the early Lower Miocene (APC Repts. LI and LR). These beds, here called the M'bwei Beds (Carey's "fifth unit", Rept. LI), are the lowest beds exposed in the M'bwei River, and, the base was not seen. The top of the M'bwei Beds is placed at a lithological break at the base of a massive sandstone unit (the Ewe Gr~~e~~aywacke) which has been taken as the base of the late Lower Miocene stage (Oboru Sandstone). Carey (APC Rept. LI), suggested the possibility of a unconformity at the top of the M'bwei Beds, as dips steepen abruptly below the Ewe Gr~~e~~aywacke. The areal extent of the M'bwei Beds has not been defined. Section constructions suggest that they are present in New Years and Yoai Creeks (locn. 17 and 16; refer figure 2-3), but it is probable that these rocks do not crop out to the south of the Ivori River.

Farther to the east at the Albert Mountains Divide, which separates the Vailala River drainage from the Tauri River drainage (locn. 20), an unconformity was, also, suggested at the top of the M'bwei Beds (APC Rept. LI, plate 12), or base of the Oboru Sandstone equivalents (see figure 2-2a). Immediately beneath the possible unconformity, Carey measured about 760m. of tuffaceous sandstones and mudstones which he correlated lithologically with the M'bwei Beds. Beneath the M'bwei Beds, in a straight, west-dipping sequence on the west flank of the Aiweriba Anticline, Carey measured approximately 3,060m. of beds described as "..... hard blue-grey speckled sandstones.... (which may or may not be tuffaceous)... and dark shales...." (*ibid*, p.28). The base of this unit is not exposed. Samples from these beds, here called the Aiweriba Beds, were lost and, hence, paleontological information is not available. Because he believed the M'bwei Beds to be of pre-Tertiary age, and because the Aiweriba Beds underlie the M'bwei Beds, Carey suggested that the Aiweriba Beds were the equivalents of the Paw Formation of early Cretaceous age. However, because the M'bwei Beds have since been found to be of early Lower Miocene age, and because no signs of unconformity were observed, it is not improbable that the Aiweriba Beds are of early Lower Miocene age as well. My opinion regarding the age of the Aiweriba Beds is that they are of early Lower Miocene (perhaps to Oligocene?) age. Without evidence for an unconformity between these and the M'bwei Beds, I regard it as unlikely that they are of Pre-Tertiary age as I would expect that the Eocene is developed in a limestone facies here, and no such lithology was seen. The most likely alternative is that the Eocene is here developed in a trough facies, in which case it would not be unlikely that the Aiweriba Beds grade from early Lower Miocene to Upper Cretaceous (Senonian?) in age (refer Chapter 3). About 25 km. to the northwest, on the west flank of the Tuoa Anticline (locn. 19; refer Plate Ia), I have photogeologically mapped an unconformity which I regard as probably marking the base of the Aure Group. It is difficult to judge whether this unconformity occurs at the base of the M'bwei Beds or the base of the Aiweriba Beds, however, and I have not studied the photographs connecting these two areas.

At Kariava (locn. 14), the APC Kariava No. 1 well drilled through 945 m. (stratigraphic) of beds assigned to the early Lower Miocene. These beds are finer-grained and much more calcareous than the M'bwei Beds and, therefore, represent an environment more distant from the source and one more closely approaching shelf conditions. The upper half of these beds consists principally of sandstones, with less mudstone and minor thin limestones. The bottom half consists mainly of mudstones with thin sandstones and limestones (to 10 m. thick) scattered throughout. The base of the early Lower Miocene was not reached, but angular fragments of derived Eocene limestone occur in conglomeratic beds in the lowest 180 m. drilled and, for this reason, it is thought that the top of the Eocene was very nearly reached (information from APC Graphic Well - log LKD-10). The top of the early Lower Miocene was placed at <u>2557m</u>. (8,385 feet) in the well. At <u>2521 m</u>. (8,264 feet), the well passed from shallow dips (5-10°) into relatively steep dips (30-40°) which continued to steepen to total depth (refer Table 2-I). Because of the close correspondence between the paleontological boundary and the steepening of dips, this suggests the possibility of either an angular unconformity or a structural discontinuity at this horizon, *i.e.* separating the early Lower Miocene from the late Lower Miocene. McQueen (APC Rept. LKE, plate 8), suggested the possibility of a low-angle thrust at this general position, but either of the aforegoing solutions is a possibility.

About 20 km. to the southeast of Kariava (locn. 15), boulders and blocks of limestone to 5 m. in diameter and regarded as early Lower Miocene age, have been recorded from conglomerate beds of probable late Lower Miocene or Middle Miocene age (see APC 1:40,000 Map series, Paku East). These boulders could have been derived from a sequence similar to that drilled in the Kariava Well and, because of the character of the M'bwei Beds exposed to the north and east, must have been derived from a source (perhaps submarine?) which lay to the west or southwest.

The only other known early Lower Miocene rocks within the bounds of the Aure Trough as defined above, occur in small, complex and incompletely known outcrops in the Kapau and Tauri River area. In Yuyebba Creek (locn. 22), the Yuyebba Creek Beds (formerly referred to as the "Older Beds in Yuyebba Creek"; APC Rept. LH-2) consist of hard, calcite-and quartz-veined sandstones and mudstones with igneous fragments. Shell material, a sandy limestone, a siliceous "green Breccia" and a "dark conglomerate" occur among these beds (*ibid*, p.21). A fragmentary specimen of Eulepidina was found in the sandy limestone, and Glaessner suggested they were of early Lower Miocene (or Oligocene) age (APC Rept. LMA, Paleo. Append.).

The thickness of the Yuyebba Creek Beds was not determined as attitudes are steep and complex. These beds form a small, complexly faulted ~~out~~in-lier and are thought to be overlain unconformably by the Obagewa Conglomerate, which I regard as the basal member of the late Lower Miocene Hell's Gate Sub-Group (refer 1.3.1B).

To the south, in the Tauri River and Hells Gate Creek (locns. 23, 24), 60-90 m. of beds, which are probably equivalent to the Yuyebba Creek Beds, occur in a strongly faulted section. The known occurrences of these rocks are closely associated with outcrops of Eocene cherts and are probably unconformable on the Eocene (APC Rept. LMA). These beds consist of detrital limestones, which carry Eulepidina as well as derived Eocene Nummulites, and grade upward into conglomerates with basalt and chert pebbles (APC Rept. LMA). These beds were originally regarded as part of the Hells Gate Sub-Group, but it was, also, suggested that they perhaps represent an erosional remnant and are overlain by the Hells Gate Sub-Group unconformably (*ibid*, p.27). Because the Yuyebba Creek Beds are overlain by beds correlated with the Hells Gate Sub-Group, I regard it as probable that these beds are correlative with the Yuyebba Creek Beds and are unconformably overlain by the Hells Gate Sub-Group. Very small outcrops of basalts are reported from this locality (APC Rept. LH-2) and are probably part of the early Lower Miocene sequence.

To the north in the headwaters of the Kapau River, fine-grained basalts and hornblende andesites have been found overlying metamorphics (Fisher, 1935).

Further to the north and west, conglomerates, sandstones and mudstones with thick interbedded, massive limestones overlie the metamorphics in the Langimar River (locn. 21). The limestones have been dated as late Lower Miocene, and this suggests that the volcanics may be of early Lower Miocene age and overlain unconformably by the conglomerate - limestone sequence which is lithologically similar to the Hells Gate Sub-Group in the Lower Kapau area.

Because the Yuyebba Creek Beds contain shell material, thin sandy limestones and detrital limestones, it is probable that these beds represent a shallower environment than the M'bwei Beds and, therefore, an approach to the eastern edge of the Aure Trough. Further to the east, within the latitudes of this study, early Lower Miocene rocks are not known. This, together with the small amount of exposure, the unconformity at the top of this unit and the uncertain age of the Aiweriba Beds to the north, makes paleogeographic interpretations uncertain.

About 100-150 km. to the north of Kariava in the structural low between the Kubor and Bismarck Ranges, and again on the north~~west~~east flank of the Bismarck Ranges (locns. 1, 2, 3; refer Plate II), thick sections (to approx. 2,500 m.) of early Lower Miocene age have been reported. These rocks consist principally of coarse conglomerates, sandstones and mudstones with thick reefal limestones and volcanics (APC Rept. LW; McMillan and Malone, 1961; Dow and Plane, 1963; refer, also, Smith, 1964 and Pitt, 1966). In part, these beds overlie the crystallines of the Bismarck Ranges unconformably and in part are overlain unconformably by rocks of late Lower Miocene age. Regionally, these rocks can be considered as marking the northwestern extension of the Aure Trough (refer 3.4).

<u>Puri Shelf</u>

To the west of the Aure Scarp section, the early Lower Miocene occurs in a very thin (120-275 m.) limestone facies of fairly constant thickness, representing deposition on a relatively stable shelf (locns. 7-11).

The limestones vary from shoal types to argillaceous, pelagic types and thin, detrital limestones occur (APC Repts. LC, LI and LW). The pelagic limestone facies is widely known as the Puri Limestone Facies, for exposures of this type of limestone on the Puri Anticline (locn. 11). In the south, say south of the Pio River (locns. 8-12), the Puri Limestone includes limestones of late Lower Miocene age, but to the north the limestone development is confined to rocks of early Lower Miocene age. ~~In this area,~~ These rocks overlie rocks of Eocene to early Cretaceous age disconformably - an angular unconformity has nowhere been observed - and are conformably overlain by rocks of late Lower Miocene age.

To the west, the limestone facies of the early Lower Miocene occupies most of the foothills belt to the south of the Kubor Range (refer Smith 1964). In the Purari area, outcrops of these rocks are generally confined to the area north of the Purari Fault and Purari Thrust - Splay, but have been drilled in the Puri, Wana and Iviri Wells to the south (see Plates I and II). To the north, the limestone facies persists to as far as the Erun Anticline (locn. 7), where a complete section, 152 m. thick, of shoal limestones has been reported (APC Rept. LW). To the north of the Anuna Fault, beds of this age thicken markedly and occur in a mudstone facies with thick lenticular limestone developments (locns. 4, 5, 6) and, farther north become increasingly volcanic, coarsen and thicken into the thick conglomerate, sandstone and volcanic sections which occupy the area between the Kubor Anticline and Bismarck Ranges (locns. 1, 2, 3; APC Rept. LW). For this reason, Rickwood (APC Rept. LW) suggested that the Anuna Fault marked the northern edge of the early Lower Miocene shelf; sediments thickening and coarsening into a typical volcanic island-arc environment to the north and east. The northern edge of the shelf so placed lies about 30 km. to the south of the northern boundary of the Eocene limestone shelf.

The eastern edge of the early Lower Miocene shelf area is more difficult to define. Limestones of this age crop out to as far east as the Hou-Toila Fault-Zone, but farther east, between this fault-zone and the

Aure Fault, rocks of this age are down-faulted and not exposed. Rickwood (*ibid*) <u>assumed</u> that the Hou-Toila Fault-Zone marked the eastern edge of the early Lower Miocene shelf area, but this point is conjectural. Because regional facies changes in this area seem to be occurring from southwest to northeast, I would suggest that the graben area is probably underlain by the limestone facies as well (see figure 1.3-1).

B. LATE LOWER MIOCENE ("f1-2" STAGE); refer figure 1.3-2.

<u>Aure Trough</u>

It is necessary to preface the following discussions with the remark that rocks of late Lower Miocene age, while being fairly widely-spread are poorly known. To date, the age of this group of rocks has been determined principally by inference and exclusion, *i.e.* by assigning a late Lower Miocene age to a group of rocks occurring between rocks of known early Lower Miocene and early Middle Miocene age. The only definitive late Lower Miocene faunas found in the area between the Aure Scarp section to the west and the Idigue Anticline to the east occur in the Kariava Well-section, the Wommgo Creek section on the west flank of the Dude Anticline, and on the Yanne'ia Anticline. Faunas of this age are known from the Hells Gate Sub-Group of the Kapau-Tauri River area, however.

As a standard section for this age-group, I have adopted the exposures described from the M'bwei River section, in the vicinity of Oborus Creek on the west limb of the Dude Anticline (locn. 14; see figure 2-4). These beds, here called the <u>Oboru Sandstone</u>, form the fourth subdivision of Carey (APC Rept. LI), and are described as massive hornblende tuffs and graywacke sandstones. Minor pebbly sandstones and hard mudstones occur in this unit, and the base is marked by a massive sandstone known as the <u>Ewe Graywacke</u> (APC Rept. LR). The underlying M'bwei Beds and overlying Maropo Beds have been paleontologically dated as early Lower Miocene and Middle Miocene respectively (*ibid*). The Oboru Sandstone is about 2145 m. thick in this section (figure 2-2 shows 2105 m., but McWhae reported 2195 m; APC Rept. LR). A similar thickness of lithologically similar beds has been examined to as far east as the Albert Mountain Divide (locn. 16; APC Rept. LI), but the section could be somewhat thicker at this latter location as the age of the highest beds in the Karova Syncline is not known. A possible unconformity at the base of the Oboru Sandstone has been reported at this location and in the vicinity of the Haue'ia Anticline in the M'bwei River (locn. 15; *ibid*).

In the Maropo Creek section (locn. 12; forming the type-section of the Aure Group), a complete section, approximately 840 m. thick can be assigned to the Oboru Sandstone. These beds consist principally of thickly interbedded tuffaceous sandstones, tuffs and hard mudstone units which, themselves, may be well-bedded (APC Rept. LI; original correlation altered by Glaessner APC Rept. LH-2, Paleo, Append.). Minor marls and thin, argillaceous Globigerina limestones, also, occur. A coarse conglomerate unit, 40 m. thick, marks the base of this unit and includes pebbles of Eocene limestones, intermediate lavas, hornfels, phyllites and granitic rocks. One thick sandstone (180 m.), occurring about 425 m. from the base of the section is described as follows (APC Rept. LI, p.56):

> "600 feet of tuffaceous sandstones etc. Some of these beds are very coarse, grading into fine well-sorted breccias. Some on the other hand are fine-grained; others are pebbly". (Underlines mine - AK)

This description indicates that these rocks are probably primary tuffs and, as such, mark active volcanism during the deposition of this unit. The top of the Oboru Sandstone has been placed at the base of a 120 m. calcareous sandstone and mudstone which contains definitive Middle Miocene foraminifera (Lepidocyclina cf. orientalis; APC Rept. LH-2, Paleo Append.). A gap in the section, involving 150-300 m. stratigraphically, occurs at the base of this section, the next lowest beds examined (on the Aure Scarp; refer earlier) being correlated with the M'bwei Beds of early Lower Miocene age.

The top of the Oboru Sandstone, so placed in the Maropo section, corresponds closely to a series of changes in the heavy mineral assemblages which occur at about this level in this section. From a heavy mineral study of the combined Aure Scarp - Maropo section (APC Rept. LK), the following can be noted: (The datum referred to is the top of the Aure Group, and the top of the Oboru Sandstone occurs 1720 m. below this datum).

1. Marked fluctuations of volcanic detritus are confined to the upper 1830 m. (6000 feet) of the section.

2. Free apatite occurs at a maximum at 1739 m. (5700 feet).

3. Green biotite, wollastonite, lawsonite, chromite and tourmaline first occur at about 1730 m. (between 5780 and 5560 feet) and are very common to the top of the section.

4. Prismatic epidote does not occur below 1550 m. (5080 feet).

Although the data is limited and comparisons are not available, I would tentatively suggest that these data indicate a greater degree of mixing of non-volcanic (metamorphic) detritus with volcanic detritus above the general level of the top of the Oboru Sandstone, *i.e.* implying progressive exposure of older rocks in the source area or, perhaps, mixing of detritus from a second source.

About 25 km. SW of the M'bwei River section, the A.P.C. Kariava No. 1 Well (locn. 13) drilled through a complete succession of the late Lower Miocene stage (APC Rept. LKD, Plates 6 and 10). These rocks are conformably overlain by rocks of Middle Miocene age and possibly overlie the early Lower Miocene stage unconformably (refer previous section). A thickness of 1220 m. has been assigned to the late Lower Miocene (*ibid*), but I later argue that this probably represents repetition in the top half of the sequence and suggest that the true thickness in the well-section is approximately 625 meters (refer 2.2.1B). This section consists of interbedded sandstones and mudstones, with mudstones predominating in the upper (repeated) part and sandstones predominating in the lower part. Three minor fine-pebbly beds occur, and thin limestones to 10 m. thick are common toward the base (information from Graphic Well-log LKD-10).

To the south and ~~east~~ west of Kariava, the late Lower Miocene stage occurs only as incomplete and very imperfectly known sections. Aside from the small exposures of limestones of this age on the Puri Anticline (Puri Limestone; refer later), it is doubtful if rocks of this age crop out in the area to the west of the McDowal and Ekiere Faults and to the south of the Purari Thrust-Splay (locn. 10).

To the east of Kariava (some revision of previous correlations is here involved; refer next section), sections between 825 m. and 1220 m. thick, which can be assigned to the late Lower Miocene stage and the Oboru Sandstone, are exposed in the core region of the Dude, Urai'ia, Haue'ia and Murua Anticlines (locns. 17-27; refer also figures 2-2 and 2-3), but complete sections are not known. These sections consist principally of thick-bedded to massive tuffaceous sandstones with subordinate, but thick, interbedded mudstones. Pebbly and gritty intervals are not uncommon. In New Years Creek (locn. 17), the basal 1220 m. of the Oboru Sandstone are exposed, and a Lepidocyclina grit occurs about 305 m. from the base, but the specific age of the Lepidocyclina has not been determined (APC Rept. LR). In the Dude Anticline sections (locns. 18-21, 24), approximately the top 825 m. of the Oboru Sandstone is exposed, principally on the east flank of this anticline (APC Repts. LG, LH-1 and LH-2). In the Ivori River area (locn. 19), the top of the Oboru Sandstone corresponds to a marked change in lithology, the sandstones becoming notably tuffaceous below this level. Former correlation (APC Rept. LH-2, Paleo Append.), has placed the top of the late Lower Miocene (Oboru Sandstone) approximately 825 m. higher in the section, but I have placed this boundary at the top of the strongly tuffaceous sandstone unit, which also marks the lowest occurrence of Globorotalia menardii (APC Rept. LG, Paleo, Append, p.1; refer next section for discussion). On the west flank of this structure in Wommgo Creek (locn. 20), in a roughly equivalent position about 760 m. stratigraphically from the crest of the anticline, Glaessner records a late Lower Miocene fauna, including Austrotrillina howchini, Flosculinella bontangensis and Nephrolepidina, from a 10 m. grit interval (APC Company correspondence, Aug. 1, 1942, filed with Port Moresby Copy of Rept. LH). Derived early Lower Miocene forms (Eulepidina and Spiroclypeus) occur as well in these grits.

To the west of the Dude Anticline, in the area of the Imbricate Belt (refer 2.2.2) between the Ekiere Fault and the Yanne'ia Anticline, Glaessner (APC Rept. LH-2, Paleo, Append.) has recognised what he termed the "Lower Arenaceous Subdivision", which he tentatively regarded as being of late Lower Miocene age. The subdivision per se is possibly valid - this situation is very difficult to judge as these sections are so highly faulted - but, from both structural and paleontological arguments, I regard the greater part of the beds assigned to this unit as being of Middle Miocene age (refer next section). With this amendment, the only definite outcrops of beds of late Lower Miocene age in this area are those on the east flank of the Yanne'ia Anticline, where Glaessner recognized a late Lower Miocene fauna in samples from the basal part of the Doroi'ia Creek section (sample 467; locn. 23) and again from Yadimmia Creek (samples 1756 and 1751; locn. 22 APC Rept. LH-2, Paleo Append.). In the latter location, these beds are overlain unconformably by rocks of Upper Miocene age (Upper Murua Sub-Group), which shows clearly that the Yanne'ia Anticline was folded and eroded prior to the deposition of the Upper Murua Sub-Group. In Doroi'ia Creek, less than 300 m. of the late Lower Miocene stage is exposed and consists of thickly interbedded sandstones and mudstones with siltstones and calcareous bands, and the lowest beds exposed are foraminiferal mudstones (APC Rept. LH-1). These beds are characterized by a rich pelagic and poor benthonic foraminiferal fauna, indicating a relatively deep depositional environment (*ibid*, Paleo. Append. p.37).

Eastward from Doroi'ia Creek, the top of the late Lower Miocene can be correlated on lithological and paleontological grounds (revised correlation; refer next section) across the Dude Anticline, but the correlation of sections farther east becomes complicated. The complications arise firstly from a lack of palentological data and secondly, because two massive tuffaceous sandstone units occur; one being the Yuiani Tuffaceous Sandstone of Middle Miocene age, and the other occurring in the core of the Murua and Haue'ia Anticlines in the Nagwe Creek and Lohiki River sections (APC Rept. LH-1; locns. 26, 25). The tuffaceous unit in the Nagwe and Lohiki sections (840 m. +) could be either of late Lower Miocene age and equivalent to the Oboru Sandstone, or could in fact be the Yuiani Tuffaceous Sandstone repeated by faulting (refer next section). To the south, the Rumua Beds (1065 M. +), which directly underlie the Yuiani Tuffaceous Sandstone, consist of flaggy, interbedded sandstones and mudstones with occasional pebbly to conglomeratic sandstones (APC Rept. LE-1). These are the lowest beds exposed in the Murua River section (locn. 27) and are probably of late Lower Miocene age.

To the east of the Murua Anticline, the next major exposures of rocks of late Lower Miocene age occur in the Tauri River area, between the Idigue Anticline and the Kapau River (locns. 28-30). These rocks, here called the Werr Beds, occur in incomplete sections, but, by correlating across structures, at least 1342 m. of these beds are exposed, and possibly 1830 m. is exposed in a generally northeasterly-dipping sequence in Be Creek (locn. 30). Structural complications involving fault repetition, have been suggested in this latter section, however, (see Plate I; refer Pitt 1966 and APC Rept. LH-2), and the exposed thickness here quoted may be too great. The basal part of the Werr Beds consist of sandy, micaceous, sometimes foraminiferal mudstones and fine-grained sandstones, with minor calcareous mudstones and thin argillaceous limestones (APC Rept. LH-2). It has been noted *(ibid)* that the sand content within this part of the section diminishes eastward from the Idigue Anticline. The upper part of the Be Creek section, which presumably gives the highest exposures of the Werr Beds, consists of hard mudstones, calcareous sandstones and tuffaceous sandstones. The top of this section is cut by the Werr Fault.

About 150 m. from the base of the Be Creek section, a coarse conglomerate 30 m. thick occurs, which contains pebbles of igneous and schistose rocks, Miocene limestones and detrital limestones with derived Discocyclina and Eocene Discocyclina limestones. Cherts (?Eocene) and early Lower Miocene detrital limestones with derived Eocene foraminifera occur as stream boulders and are believed to be derived from this conglomerate (*ibid*). This conglomerate correlates approximately with a similar conglomeratic unit 300 m. thick, here called the Obagewa Conglomerate, which crops out on Obagewa Ridge six km. to the northeast (locn. 31) and overlies the Yuyebba Creek Beds (early Lower Miocene) unconformably. This conglomerate contains boulders of Eocene chert nummulitic limestone and volcanic rocks to 60 cm. in diameter. I regard the Obagewa Conglomerate as the basal member of the late Lower Miocene, whereas it has formerly been correlated with the Morai River Formation ("Enna Creek Beds") of Middle Miocene age (APC Rept. LH-2). My reasoning is as follows:

a) This conglomerate, in its derived content of Eocene chert and early Lower Miocene detrital limestones, is similar to conglomerates of the Hells Gate Sub-Group to the south (refer later). These fractions are not present in younger conglomerates.

b) The conglomerate is closely related spatially to both the Yuyebba Creek Beds and to the late Lower Miocene Kapau Limestone (refer later) which is, again, similar to the Hells Gate Sub-Group.

c) The Obagewa Conglomerate is part of a generally easterly dipping sequence which dips beneath the Kapau Limestone and, although structural complications possibly intervene (see Plate I), these are held to be minor as similar conglomerates are reported to underlie the Kapau Limestone. This indicates a late Lower Miocene age for the Obagewa Conglomerates and overlying sequence.

d) Lepidocyclina cf. ferroroi, a late Lower Miocene form, has been reported from the top part of the Werr Beds in Be Creek (sample not definitely in situ, however; APC Rept. LH-2, Paleo Append, p.5). The Werr Beds overlie the conglomerate correlated with the Obagewa Conglomerate and this, again, suggests a late Lower Miocene age for the Obagewa Conglomerate.

e) Globorotalia sp. has been recorded from the lower part of the Werr Beds exposed in the Wagewa Syncline, and Globorotalia menardii is not recorded from any of the samples from the Werr Beds (*ibid*). This is similar to the Hells Gate Sub-Group, in which Globorotalia sp. occurs; note is made that this form is replaced by Globorotalia menardii, in younger beds (APC Rept. LE-2, Paleo Append.).

Kapau Margin

The first indication that the eastern margin of the Aure Trough is being approached in the Kapau River region comes from the existence of the Obagewa Conglomerate and from the fact that this conglomerate overlies strongly deformed early Lower Miocene beds unconformably. To the east of the Yuyebba Fault (just west of locn. 31, see Plate I), which delimits the western edge of the Yuyebba Creek Beds, the late Lower Miocene section consists principally of thick limestones and conglomerates.

Overlying the Obagewa Conglomerate are about 600-1000 m. of sandstones, siltstones and conglomerates (composition similar to the Obagewa Conglomerate), with small lenticular limestone masses. These beds dip beneath a thick (975 m.) limestone unit - the Kapau Limestone (locn. 33; APC Rept. LH-2). The basal 400 m. of the limestone is massive and chalky, while the upper part is corralline and interbedded with marls and calcareous mudstones. Austrotrillina howchini occurs commonly in this unit, establishing its age as late Lower Miocene and, probably, places it in the lower part of this subdivision (*ibid*, Paleo, Append.). On slender grounds, it has been suggested that the Kapau Limestone is thrust over the underlying conglomerate sequence (by the "Kapau Fault", with a suggested throw of about 2400 m; APC Rept. LH-2), but if faulting is present here I regard it as relatively unimportant. This was, also, the suggestion of Osborne (APC Rept. LMA). Overlying the Kapau Limestone is a further 550 m. of conglomerates and lenticular limestones of late Lower Miocene age. These conglomerates contain pebbles of the Kapau Limestone, and probably overlie the Kapau Limestone unconformably (*ibid*). In support of this, this unit can be traced photogeologically into a tabular, gently dipping limestone mass on the north side of the Kapau River (locn. 32), where the contact with the underlying Kapau Limestone appears to be an unconformity (see Plate I). This unit, in turn, is overlain unconformably by coarse volcanic conglomerates of probable Middle Miocene age, marking the base of the Muiai Sub-Group (refer later). The beds from the base of the Obagewa conglomerate to the top of the late Lower Miocene conglomerates overlying the Kapau Limestone are regarded as equivalent to the Hells Gate Sub-Group (refer below).

In the Hells Gate area of the Tauri River, 20 km. to the south (locns. 34-37), a faulted series of lenticular limestones, coarse conglomerates, grits, graywackes and marls, with silicified mudstones near the base, crops out (APC Rept. LMA; LE-1, LE-2). Lavas and agglomerate are reported to occur near the base, but these are probably associated with the underlying early Lower Miocene. These beds are dated as late Lower Miocene, with Austrotrillina howchini occurring commonly in limestones (the Hells Gate Limestone) and siltstones from this sequence. Osborne (APC Rept. LMA) termed this sequence the "Hells Gate Formation", but I prefer the term Hells Gate Sub-Group because of the varied lithologies present and because the equivalent beds in the Kapau River area to the north are very thick and lend themselves to further subdivision. In the Hells Gate area, structually complex sections between 150 m. and 460 m. thick have been measured. Osborne (*ibid*) suggested that the Hells Gate Sub-Group was unconformable on the Eocene cherts exposed in this area, as this unit occurs to either side of the Eocene exposures and the conglomerates contain Eocene limestone and chert boulders. I regard this conclusion as generally true, but the unconformity is possibly at the top of a thin early Lower Miocene sequence, as beds of this age are closely associated with the Eocene outcrops as well (refer previous section), and the conglomerates of the Hells Gate Sub-Group contain boulders of early Lower Miocene limestones and volcanics (*ibid*). The Hells Gate Sub-Group is intensely deformed, with steep to vertical dips prevailing, and is overlain by the relatively undeformed Saw Mountains Limestone of Middle Miocene age (refer next section).

To the north, a conglomerate-limestone facies of late Lower Miocene age has been recorded in the upper Kapau and Langimar River area (east of locn. 38), where 915 m. of conglomerates, limestone, sandstones and mudstones have been mapped overlying metamorphic rocks (Fisher, 1935). The limestones have been dated as late Lower Miocene, thus establishing their equivalence ~~with~~ to the Hells Gate Sub-Group. Volcanics underlie these beds in the headwaters of the Kapau River and may be of late Lower Miocene age, but I tend to regard them as being of early Lower Miocene age (refer previous section).

The conglomerate - limestone facies of the Hells Gate Sub-Group well establishes that the eastern margin of the Aure Trough, for the late Lower Miocene stage, is being approached in the Kapau River area. From this, the term Kapau Margin is derived. As shown, the facies - change from the trough area to the west is quite rapid, which suggests that faulting probably controlled the trough margin. The occurrence of coarse conglomerates further suggests this. Conceivably, some of the faults mapped in this area were instrumental in the trough formation, *e.g.* the Yuyebba Fault, Werr Fault, Dala Fault. In addition, the unconformities at the base, top and within the Hells Gate Sub-Group indicate a high degree of tectonic activity at the trough margin, involving alternating periods of uplift and subsidence. While the thick limestones and good benthonic foraminiferal assemblages suggest a shallower environment than do the sandstones and mudstones to the west, the Hells Gate Sub-Group is still quite thick (2400 m.) in this area, indicating that the actual trough boundary lay still to the east of the Kapau - Hells Gate area.

Puri Shelf

As with the early Lower Miocene, the late Lower Miocene in the area of the Purari River occurs in a thin, argillaceous limestone facies - the Puri Limestone. The outcrops of limestones of this age, however, are generally confined to the area between the Purari Fault - Purari Thrust Splay and the Pio River (locns. 4-11). Limestones of this age crop out on the Puri Anticline (locn. 11) and have been drilled by the APC Puri No. 1 Well and, to the south, by the A.P.C. Wana and Iviri Wells (see Plate II). Limestones of this age are continuous with and transitional into the underlying limestones of early Lower Miocene age, and the whole limestone can be referred to as the Puri Limestone. The Puri Limestone is overlain conformably by beds of Middle Miocene age, *i.e.* by about 150 m. of marls at Puri and by 1500 m. of mudstones and sandstones to the north and east (refer next section).

In the Puri section (locn. 11), 305 m. of argillaceous, pelagic limestones are assigned to the late Lower Miocene (APC Rept. LI; Aust. Bur. Min.Res., Pub. No. 6). Toward the north and east, the limestones thicken and minor sandstones and mudstones become interbedded with the limestones. The limestones in the Eri River section are 535 m. thick, and a similar thickness is present in the Pio River section with a possible additional 150 m. of marls at the top (APC Rept. LI). To the west, in Webe Creek (locn. 5), the late Lower Miocene consists of 490 m. of argillaceous limestone overlain by 245 m. of interbedded marls, limestones and thin graywacke bands (APC Rept. LW). Quoting Rickwood (*ibid*, p.25),

> "....eastward from Webe Creek the limestone gradually passes into marls, mudstones and greywackes. The succession in the Ih-Su Creek section (locn. 6-AK) shows less limestone than the Webe Creek and finally in the Mare Creek section (locn. 4-AK) the Puri Limestone phase of the Taurian (late Lower Miocene - AK) has altered almost to Aure (geosynclinal) facies (of 520 m. exposed, thinly interbedded mudstones, limestones and greywackes form 335 m. of the section - AK)".

In the Pio area, derived Eulepidina, coarse limestone conglomerates and large slump folds are reported from late Lower Miocene sections, leading Rickwood to suggest that this marked the steep southern edge of the Aure Trough during this time (*ibid*). The line of facies-change shown on figure 1.3-2 is essentially Rickwood's, and he suggested that intermittent uplift and erosion to the south of this line formed the source for both the ~~both~~ conglomerates and the derived early Lower Miocene fauna.

About 35 km. to the northeast, in the Gorga Syncline (locn. 3), Rickwood measured a poorly exposed section about 2,300 m. thick, consisting principally of mudstones and siltstones with rare, thin greywackes. Farther to the north, to the north of the Kubor Anticline (locns. 1, 2), the late Lower Miocene consists principally of coarse conglomerates, volcanics and sandstones at least 2,500 m. to 3000 m. thick (*ibid* ; McMillan and Malone, 1960, and Dow & Plane, 1964). The top of the late Lower Miocene stage is not known in any of these sections and they, therefore, represent incomplete thicknesses. At location 2, these beds overlie the early Lower Miocene unconformably (Dow & Plane, 1964).

While the northern boundary of the Puri Shelf (and southern boundary of the Aure Trough) can, therefore, be fairly closely defined for the late Lower Miocene, the eastern edge of the Puri Shelf is again problematic. Rocks of this age are most probably not exposed to the south of the Purari Thrust-Splay and have not been examined to the east of the Hou-Toila Fault Zone.

It will be observed that the north edge of the Puri Shelf during the late Lower Miocene was located some 30 km. farther to the south than for the early Lower Miocene, continuing the trend previously recognized from the Eocene to the early Lower Miocene, *viz.* the southward replacement and transgression of the carbonate shelf area by the clastic trough area.

C. EARLY MIDDLE MIOCENE (EARLY "f3" STAGE ; PRE-TOA); refer figure 1.3-4

Aure Trough

Rocks of early Middle Miocene age (Pre-Toa) crop out widely in this region. Approximately 1480 m. of beds of this age crop out in a complete section in Maropo Creek (locn. 19), which can be taken as reasonably typical of the sections exposed between the Dude Anticline and the Ekiere Fault. These beds, here called the Maropo Beds, are underlain conformably by the Oboru Sandstone and overlain conformably by the Iavokia Mudstone. The section (APC Rept. LI and LH-2, Paleo. Append.) consists of thinly-to very thickly interbedded, sandstones, tuffaceous sandstones and mudstones, with the mudstones forming about 50 percent of the section. Foraminiferal mudstones are common and thin argillaceous limestones, marls and calcareous sandstones occur. Lepidocyclina cf. orientalis was identified from the basal member of this section (sample 301; APC Rept. LH-2, Paleo. Append.), establishing the age as Middle Miocene. Pebbly to gritty beds occur rarely and, about 120 m. from the base, a 135 m. thick conglomeratic unit occurs which is described as a pebbly and bouldery tuff grading into an ill-sorted agglomerate of "tillitic" appearance (APC Rept. LI, p.67). This "agglomerate" member is possibly a mudflow, as it would be difficult to visualize a source for coarse agglomerates in this location and agglomerates are not described elsewhere in the area.

I have attempted to trace the base of the Maropo Beds northward from the Maropo section, in the area to the east of the Aure Fault (see Plate Ia). This horizon can be traced with reasonable confidence to the west flank of the Dude Anticline, but it is doubtful that beds of this age crop out farther to the east.

Similar, but incomplete sections ranging between 915 m. to 1525 m. thick have been described from sections on the Suniyana and M'bwei Anticlines (locns. 20, 21; APC Rept. LF), the Ivori Junction and Hadina Anticlines (locns. 25, 23; APC Rept. LIA and LG) and from the M'bwei River (locn. 22; APC Rept. LI and LR). In the M'bwei River section, both the top and base of beds which can be correlated with the Maropo Beds are exposed, and a complete section about 1980 m. thick is reported (*ibid*). I regard it as probable that fault repetition interrupts the continuity of this section, however, (see figure 2-3) and would suggest a minimum thickness of 1280 m. is exposed here. The outcrop of the Maropo Beds in the M'bwei River is confined to the area to the west of the Dude Anticline. Although constructed sections suggest the presence of this unit in the Karova Syncline to the east, this is not certain. The upper 180 m. of these beds is described as consisting of sandstones, tuffs and mudstones with interbedded conglomerates, whereas the lower and major part of the section consists predominantly of mudstones with thick calcareous sandstones and thin argillaceous limestones (APC Rept. LI). The M'bwei section, therefore, is less coarse than the Maropo section, and the tendency to coarsen toward the west has been noted in the detailed mapping of the M'bwei section (APC Rept. LR) and the M'bwei Anticline and Suniyana Anticline sections (APC Rept. LF). This same tendency is shown by a complete section exposed and drilled on the Kariava Anticline.

The APC Kariava No. 1 Well (locn. 24), spudded-in approximately 238 m. below the top of the Aure Group (below the Iavokia Mudstone) and another 1190 m. of beds intersected by the drill were assigned to the Middle Miocene (APC Graphic Well-log LKD-4), giving a complete section approximately 1430 m. thick. In the surface section (about 900 m. exposed), these beds consist of interbedded mudstones, sandstones and siltstones and "... in general, the sandstones are grey to grey-blue, massive, cross-bedded (underlines mine -AK-), composed largely of tuffaceous materials, and often with igneous pebbles up to one inch or more in diameter ...." (APC Rept. LKC, p.13). Cross-bedding, which is reported to be common here, is extremely rare in other sections of this region. The bore-section, which is similar to the surface section, is commonly pebbly and frequently lignitic or calcareous, with two thin coal beds and several thin argillaceous limestones being recorded (APC Graphic Well-log LKD-4). The Kariava section is noteworthy firstly because it is commonly pebbly to conglomeratic, secondly in the frequent occurrence of cross-bedding and thirdly, because six Lepidocyclina intervals were recorded in the Middle Miocene of this well (*ibid*). Lepidocyclina-rich intervals are known to be restricted to only one or two thin intervals in sections to the north and east, *viz.* the Maropo, M'bwei and Hadina sections. These features suggest a shallowing environment toward Kariava and, further, suggest the possibility of a local source in the vicinity of Kariava or to the southwest.

To the west of Kariava, a section of the top part of the Aure Group, 1345 m. thick, has been described on the Horbu Anticline (locn. 16; APC Rept. LP; see figure 1.3-10). The upper 275 m. of this section consists of fine-to coarse graywacke with minor mudstones and calcareous members - the Areo Graywacke. The next 490 m. consists of interbedded mudstones, siltstones and graywacke sandstones with thin argillaceous limestones, calcareous sandstones and calcareous grits with igneous and metamorphic pebbles to one centimeter in diameter - the Wadome Formation. The lowest 580 m. of the exposed section consists of argillaceous siltstones and mudstones - the Horbu Sandy Mudstone. The Horbu Sandy Mudstone was correlated by Rickwood (*ibid*) on the basis of stratigraphic position with the "Lower Arenaceous Subdivision" (in the Upoia-Kerema area; refer later), which was believed to of late Lower Miocene age. Immediately to the north, however, in the Te, Suara, and Soho Creeks (locns. 15, 14, 13), Carey (APC Rept. LI) measured sections similar to the Horbu Anticline section, and the lowest mudstone unit is associated with calcareous grits of Middle Miocene age (*ibid*, p.52). For this reason, the Horbu Sandy Mudstone is regarded as being of Middle Miocene age and this unit, together with the Areo Graywacke and Wadome Formation, as equivalent to the Maropo Beds. In the Suara Creek section, an incomplete section approximately 1160 m. thick can be regarded as equivalent to Maropo Beds. The base of this section is faulted against beds of Upper Miocene age; the basal 610 m. consisting of soft Globigerina mudstones with thin calcareous sandstones and grits, presumably equivalent to the Horbu Sandy Mudstone. These are overlain by 395 m. of thinly interbedded calcareous sandstones, Globigerina mudstones and Orbulina marls - presumably equivalent to the calcareous Wadome Formation. The top of the section consists of 150 m. of tuffaceous sandstones and conglomerates. This unit is regarded as equivalent to the Areo Graywacke and is overlain conformably by the Iavokia Mudstone.

Sections generally similar to the Horbu and Suara Creek sections have been measured to the west and north. These sections will be discussed later in relation to the Puri Shelf, but it will be noted here that both the Horbu and Suara sections consist predominantly of mudstones, with a prominent portion of calcareous horizons. These sections are markedly finer-grained than the Maropo and Kariava sections and represent a transitional facies between the Aure Trough to the east and the Puri Shelf to the west.

In the area of the Imbricate Belt (locns. 27-37; refer section 2.2.2) to the south of Kariava, several incomplete, highly faulted sections of Middle Miocene age have been described (mainly in APC Rept. LH-2). These sections consist of about equal portions of tuffaceous sandstones and mudstones with sandstones becoming more important eastward from the Ekiere Fault toward the Yanne'ia Anticline (see figure 1.3.3a; refer APC Rept. LH-2, Plates 24 and 25). Pebble conglomerates occur rarely in these sections. The top of the Aure Group is frequently marked by the presence of the basal formation of the Toa Group - the Iavokia Mudstone - but the base is not known. The beds exposed in the Imbricate Belt are principally of Middle Miocene age and, therefore, are equivalent to the Maropo beds. Glaessner (APC Rept. LH-2, Paleo Append.) subdivided these beds into three units in this area (he, also included the Iavokia Mudstone as a subdivision of the Aure Group; refer section 1.3.2). Glassner's subdivisions, from top to bottom are as follows:

> "Upper Arenaceous Subdivision"-230-610m - thick sandstones with interbedded siltstones, mudstones and occasional thin argillaceous limestones and calcareous sandstones. Characterized by a fairly rich benthonic foraminiferal assemblage. Top placed at top of first major sand below the Iavokia Mudstone.

"Calcareous Sandstone Subdivision" - 610-915m. - lithology as above, with thin calcareous sandstones, and grits, usually bearing Lepidocyclina of Middle Miocene age, prominent but forming only a minor part of the section. Fauna characteristically of deep-marine character with shallow-water (foraminiferal) assemblages occurring only in the calcareous sandstones and grits. Top placed at highest calcareous sandstone and base at lowest calcareous sandstone.

"Lower Arenaceous Subdivision" - 1220m.; base not exposed - lithology as above, without calcareous sandstones.

The aforegoing scheme for subdivision is based principally on the recognition of the "Calcareous Sandstone Subdivision", and, as pointed-out by Stanley (APC Rept. LH-2), calcareous sandstones are much more widespread through the section than the subdivision suggests, occurring both above and below Glaessner's boundaries (see APC Rept. LH-2, Plates 24 and 25; refer M'bwei River section). These subdivisions, therefore, are of doubtful validity on a local scale and cannot be applied regionally and, for these reasons I regard them as generally invalid as defined. Glaessner regarded the "Lower Arenaceous Subdivision" as being of late Lower Miocene age because beds of this age are exposed in the lower part of the section on the east flank of the Yanne'ia Anticline (refer earlier), and because he believed the fauna of the "Calcareous Sandstone Subdivision" to be of basal Middle Miocene age, *i.e.* a late Lower Miocene age was not suggested from the occurrence of definitive faunas of late Lower Miocene age. From this, Glaessner regarded it as probable that the base of the Middle Miocene occurred no more than about 1220 m. below the Iavokia Mudstone in this area (APC Rept. LH-2, Paleo Append, p.16). Because of the general lack of distinctive late Lower Miocene faunas in this area, and because of the complex faulting, it is difficult to judge this statement, but I regard that it is probably in error. This is shown most simply by the combined Doroi'ia Creek - Yanne'ia Creek section.

The Doroi'ia Creek section (locn. 36) provides the only section in this area in which a paleontological boundary between the Middle Miocene and late Lower Miocene can be placed without undue complication (refer figure 1.3-3a). Glaessner (*ibid*) recognized a probable late Lower Miocene fauna from sample 467 near the base of this section. Previously, Stach (APC Rept. LH-1, Paleo. Append.) recognized a Middle Miocene fauna from sample 464, only 230 m. above the late Lower Miocene fauna. For convenience, I have placed the base of the Middle Miocene at the base of the thick sandstone immediately overlying sample 467 (see figure 1.3-3a). The Doroi'ia section can then be correlated along strike with the Yanne'ia Creek section three kilometers to the south (locn. 37). Together, these sections expose at least 1980 m. of beds of Middle Miocene age, with the base of the overlying Iavokia Mudstone not yet reached. The highest beds in the Yanne'ia Creek section have been correlated across several faults, by Stanley and Glaessner (APC Rept. LH-2, Plate 23), with the Pipo Creek section 10 km. to the northwest (locn. 32), where the Iavokia Mudstone is exposed apparently only a few feet stratigraphically above the highest beds of the Yanne'ia section (figure 1.3-3a). This correlation suggests that the Middle Miocene (Maropo Beds equivalents) is at least 2000 m. thick in this area, and suggests that much of Glaessners' "Lower Arenaceous Subdivision" (*ibid*; Plate 24) is probably of Middle Miocene age. Subsequent to the report in which he defined these subdivisions (APC Rept. LH-2), Glaessner, himself, came to the same conclusion, which is recorded only in APC company correspondence (Letter to chief geologist dated August 1st, 1942, and filed with Port Moresby Copy of Report LH).

In this general area, the section in the Aipa Hills, 15 km. to the southwest of the Yanne'ia Creek section (locn. 34), possibly exposes beds lower in the section than found in the Imbricate Belt to the north. Here, approximately 914 m. of mudstones with thin, fine-grained sandstones and argillaceous limestones occupy the core of the extremely complex "Aipa Structure" and are reported to underlie approximately 1890 m. of typical Aure graywackes (APC Rept. LAA). This fine-grained unit was not seen in the sections immediately to the north. Glaessner (APC Rept. LH-2, Paleo. Append, p.16) reports that a specimen of the Middle Miocene form Lepidocyclina cf. rutteni has been recorded from these beds, suggesting a Middle Miocene age. This would place these beds roughly equivalent to the Horbu Sandy Mudstones (refer earlier). It is also reported, however, that 17 samples from these beds contain "restricted" foraminifera typical of the Upper Miocene at Cupola (locn. 43; APC Rept. LCA, p.22). This type of problem has been encountered elsewhere in this region (refer APC Rept. LI, p.49-53; also, Geol.Soc.Aust.Bull.Vol 8, p.90) and is not easily resolved. However, I tend to regard these beds as infaulted Upper Miocene (Lower Murua Mudstone), rather than Middle Miocene (refer section 2.2.2). If these beds are in fact of Middle Miocene age, this stage would be at least 2750 m. thick at this location.

Pebble conglomerates occurring in the upper, graywacke-part of the Aipa section contain sub-angular pebbles of quartz, gneissic granite, phyllites, schists, andesitic lavas and older sediments (APC Rept. LAA). Siliceous wood fragments are, also, reported from these beds. These occurrences led Thompson to suggest that a granitic and metamorphic land mass and source area lay to the south or southeast of this area during the Middle Miocene (~~ibid~~ APC Rept. LAA). These same constituents are common in extremely coarse conglomerates at Cupola (locn. 43) and in the Murua River area (locns. 46-50) to the east, and the problem of a southerly source will be discussed later in this section.

Before discussing the sections to the east of the Yanne'ia Anticline, it will be beneficial to make some additional observations regarding the paleogeography of the area of the Imbricate Belt. Firstly, the Lepidocyclina grits, which characterize the "Calcareous Sandstone Subdivision", are very common over a fairly wide stratigraphic interval in the Middle Miocene of this area. A thin marker-bed, referred to as the "Detrital Limestone" occurs in the area between the Ekiere Fault and Napere Anticline (locn. 31). This bed is described as coralline, algal and foraminiferal limestone pebbles in a sandy matrix, with a thin detrital limestone at the top (APC Rept. LH-2). Both the limestone pebbles and matrix contain Middle Miocene Lepidocyclina (*ibid*, Paleo Append.). In Doroi'ia Creek, a bed near the top of the section contains blocks of limestone of Middle Miocene age to one meter in diameter (APC Rept. LH-1). It is noteworthy, that Lepidocyclina grits and similar occurrences have not been recorded from the area to the east of the Kevoro Syncline (locns. 38-42). Similarly, to the north, only two such grits are known from the Kariava, Hadina and Maropo sections, although six Lepidocyclina horizons occur in the Kariava section. Only one grit horizon is known from the Maropo Beds exposed on the Suniyana and M'bwei Anticlines and in the M'bwei River section. This distribution indicates that the grits were derived from a westerly direction and, in turn, requires that shallow-water limestones were present to the west. The occurrence of these "shallow-water" grits in association with the normal, pelagic fauna of the "Calcareous Sandstone Subdivision" suggests introduction by a turbidity current type mechanism.

The Lepidocyclina grits, "Detrital Limestone" and the limestone blocks in Doroi'ia creek have a parallel in the large, derived limestone blocks of Middle Miocene Age in the Upper Miocene Nakoro Breccia (locn. 17; refer section 1.3.2), which require a source of Middle Miocene shoal limestones in the approximate vicinity of the Ekiere Fault. From these considerations, it is regarded as probable that some part, say, the lower half ot the Middle Miocene is developed in a shoal-limestone facies in the vicinity of the Ekiere Fault to the south of Nakoro. This proposed shoal limestone facies is perhaps patchy but, from considerations of the Upper Miocene stratigraphy of the Nakoro area, it is not impossible that a general shelf area of Middle Miocene shoal limestones to the south of Nakoro has been completely overridden by the trough facies on the Ekiere Fault and associated faults of the Imbricate Belt (refer section 1.3.2; see figure 1.3-4). Certainly a general shallowing and thinning of the Middle Miocene toward the west is well established in the Puri area (refer later; Puri Shelf), but the aforegoing suggests a shallowing of the depositional basin (perhaps local) in the immediate vicinity of the Ekiere Fault. This is somewhat supported by the section drilled on the Upoia Anticline 10 km. to the west of the Ekiere Fault.

Here, the APC Upoia No. 1 Well (locn. 18) drilled through 760 m. of the Aure Group of Middle Miocene age, before entering Upper Miocene beds below a major thrust fault. The Middle Miocene consists of gr~~e~~aywackes and mudstones with pebble beds, calcareous gr~~e~~aywackes and mudstones and rare thin marls, argillaceous limestones and coal traces (APC Rept. LUC). All of these beds were assigned to the "Upper Arenaceous Subdivision", which, it will be recalled, is characterized by a rich benthonic foraminiferal fauna. To the east at Iavokia (locn. 30), the "Upper Arenaceous Subdivision" is only 230 m. thick and shows evidence of thinning toward the west across the Imbricate Belt (see APC Rept. LH-2, plate 24). The 760 m. thickness at Upoia is, therefore, anomalous unless it is regarded that the "Upper Arenaceous Subdivision", is basically marking a relatively shallow-water facies subdivision as indicated by the benthonic fauna. The apparent thickening of this unit toward Upoia can, therefore, be regarded as marking a shallowing of the depositional basin toward Upoia thereby yielding a "thicker" shallow-water faunal unit.

Whether Glaessner's thickness estimate of the early Middle Miocene (pre-Toa) in the area to the west of the Yanne'ia Anticline (1220 m.) or my own (2,000 m.) is accepted, it can be shown that this part of the section thickens very rapidly and markedly (to 3,400 m.) to the east of the Dude Anticline (locns. 39-56).

Lepidocyclina grits of Middle Miocene age have been recorded at several locations in the Kevoro Syncline (locns. 38-40; APC Rept. LH-1, LH-2, Paleo. Append.). In general, however, Stach (APC Rept. LH-1, Paleo. Append, p.4) notes that the vast majority of the samples from the area to the east of the Dude Anticline are of a pelagic, to deep-water character. The southernmost of the *Lepidocyclina* grit occurrences (locn. 40; sample 219, figure 1.3-3a) in Piyai'ia Creek, occurs near the trough of the Kevoro Syncline which plunges continuously to the southeast from this location (see Plate I). These beds can be correlated with a section measured on the southwest flank of the Urai'ia Anticline, eight km. to the south (locn. 41; see figure

1.3-3a; APC Rept. LH-1), and thence traced directly by photogeology into the Murua River section. It should be stressed that this is a straightforward correlation (see Plate I). For some reason this method of correlation was overlooked by the APC geologists, who carried the correlation across this folded area (principally on a lithological basis) rather than around the unfaulted plunging ends of these structures.

The Murua River section (locn. 46), gives the straightest and most continuous section in this region. This section was originally described by Pratt and Mackinnon (APC Rept. LE-1). I have examined the top two-thirds of this section in the field, and the following description represents Pratt and Mackinnon's section as I have altered it (refer figure 1.3-3a and Plate I). In this section 2800 m. of beds are exposed which can be assigned an early Middle Miocene age. An additional 610 m. of section is present at the top of this section in Eel Creek (locn. 49; see Plate I); this latter unit is missing in the Murua River section because of the unconformity which occurs at the base of the Iavokia Mudstone. Further, early Middle Miocene rocks could be thicker, as a definite paleontological base of the Middle Miocene has not been found in this area.

The Murua River section (locn. 46) can be taken as the type-section for the Karova Sub-Group.* The Karova Sub-Group is here defined as the sediments (and equivalent sections) occurring above the "Rumua Beds" (APC Rept. LH-2) and below the unconformity at the base of the Iavokia Mudstone (Toa Group) in the Murua River section (see figure 1.3-3a). This sub-group is of early Middle Miocene age (equivalent to the Maropo Beds) and consists of three formations, here called the

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* The term "Karova Sub-Group" is used here because a similar, although neither as straightforward nor as complete, section is exposed in Karova Creek (locn. 54). The term "Murua River Sub-Group" would be preferable, but this would cause confusion with the ill-chosen term "Murua Mudstone" of Upper Miocene age.

Yuiani Tuffaceous Sandstone (base), the *Ibai Creek Sandstone* and the Morai River Formation (top).

The *Yuiani Tuffaceous Sandstone* is 960 m. (3150 feet) thick, and overlies the "Rumua Beds" conformably. It consists principally of thickly bedded to massive, medium- to coarse-grained tuffaceous sandstones. The sandstones are commonly calcareous and concretionary and frequently laminated. Pebbly to gritty beds, large isolated mudstone boulders to 45 cm. in diameter and coarse sedimentary mudstone breccias (angular, irregular blocks and fragments of mudstone in a sandy matrix) occur in this unit, and coral fragments to 15 cm. in diameter occur in Titimawa Creek (locn. 46). Minor interbedded siltstone-mudstone units to eight m. thick occur, and a 90 m. mudstone occurs near the middle of this section. Aside from contorted laminae and sedimentary breccias, sedimentary structures are rare in this unit, but scour and fill structures are present near the top of the formation. The base of the Yuiani Tuffaceous Sandstone, as correlated with the Piyai'ia Creek section (locn. 40), falls just below the Middle Miocene *Lepidocyclina* grits in the Kevoro Syncline (sample 219; see figure 1.3-3a). From a sample which I collected near the top of the formation (sample 8 MR, figure 1.3-3a), Mr P.G. Quilty of the University of Tasmania (pers.comm) has recognized, from a rich pelagic foraminiferal fauna, *Orbulina universa*, *Globorotalia menardii menardii* and *Sphaerodinella seminulina subdehisens* which, in the circumstances, are indicative of a Middle Miocene age (slide 84026, Univ.of Tas. file). For practical reasons, I have provisionally taken the base of the Yuiani Tuffaceous Sandstone as marking the base of the Middle Miocene stage, but I am not convinced that beds of this age do not in fact extend lower in the section.

To digress, momentarily, I would like to point-out that species recorded ~~as~~ only as *Globorotalia menardii* and *Sphaeroidinella seminulina* are reported from several sections (APC Rept. LH-1 and LH-2 Paleo. Appends.), in samples occurring *below* the suggested base of the Middle Miocene, and are included in Glaessner's type fauna for the "Lower Arenaceous Subdivision" (APC Rept. LH-2, Paleo. Append.). The significance of the two sub-species recorded by Mr. Quilty from the Yuiani Tuffaceous Sandstone, as marking the approximate base of the Middle Miocene (see Eames et al, 1962; Bandy, 1964), was not known at the time the APC palentology was done (1941), and it is not known definitely if the species recorded by the APC paleontologists are, in fact, the same restricted sub-species found by Mr. Quilty. It is not unlikely that they are, however, as these same species are reported to be common in beds known to be of Middle Miocene age or younger, and the particular Globorotalia menardii recognized by the APC paleontologists is reported to give way to a form recorded as Globorotalia sp. in beds known to be definitely of Lower Miocene age (APC Rept. LE-2; Paleo. Append.). I have borne this in mind in my own correlations in this region, and, for the most part, where the aforementioned species are quoted, from the Aure Group they fall within the Middle Miocene stage of this correlation. Some fall below the suggested boundary, (see figure 1.3-3) however, which gives an additional reason for regarding the Yuiani Tuffaceous Sandstone only as a provisional base of the Middle Miocene. As a counterpoint, it will be noted that Globorotalia menardii menardii is said to extend into the very top part of the Lower Miocene (see Bandy, 1964).

In placing the boundaries of the Yuiani Tuffaceous Sandstone, I have shortened the "Tuffaceous Sandstone" unit in the Murua River section as originally reported by Pratt and Mackinnon (APC Rept. LE-1) by 136 m. (450 feet), because I recorded north dips at the axis of the Urai'ia Anticline (see Plate I), whereas Pratt and Mackinnon recorded only southerly dips in this section. Further, I have raised the top boundary 183 m. (600 feet) so as to include all of the markedly tuffaceous beds within this unit (see figure 1.3-3a).

The Ibai Creek Sandstone, which overlies the Yuiani Tuffaceous Sandstone, is 503 m. (1650 feet) thick in the Murua River section and consists generally of well-bedded, interbedded sandstones and mudstones in about equal proportions. The sandstones range from fine-grained to gritty and are commonly argillaceous and notably micaceous. Massive sandstones are reported from near the top of the unit (APC Rept. LE-1, Plate 7), and the bottom 150 m. is formed principally of mudstone.

The Morai River Formation overlies the Ibai Creek Sandstone. It is 1335 m. (4380 feet) thick in this section, and the top is marked by the unconformity at the base of the Iavokia Mudstone. An additional 610 m. of beds, which occur in the Eel Creek section eight km. to the east (locn. 49), are missing from the Murua River section at this unconformity, giving a total thickness of at least 1945 meters. The combined Morai River (locn. 47), Murua River and Eel Creek sections can be taken as the type-section for this formation. This formation consists principally of massive, coarse to pebbly sandstones and pebble to coarse-boulder conglomerates, the conglomeratic fraction consisting of plutonic, volcanic, metamorphic and sedimentary rocks. In the Murua River, the formation consists mainly of coarse, often concretionary, sandstones and pebbly sandstones with rare fine interbeds, and cobbles up to 10 cm. are common. The formation fines toward the Nani and Hake'ia Creek sections, six km. to the west (locn. 42), where the pebbly beds are both finer and more sporadic and fine interbeds thicken and become more common. To the east, in the Morai River and Naripo Creek (locns. 47, 48) and toward Eel Creek, the formation coarsens markedly becoming essentially a conglomerate unit, with extremely coarse boulder conglomerates common in the eastern sections. Boulders of diorite and intermediate to basic volcanics, generally irregularly shaped but rounded, to two meters in diameter are common in Naripo Creek and Eel Creek (APC Rept. LE-2 gives a good description of these conglomerates in Eel Creek - the "Eel Creek Conglomerate"). The conglomerates are generally massive to poorly bedded, but the bedding becomes better toward the west, *e.g.* Morai River, where they commonly occur in one meter to 10 m. beds which frequently show upward grading and scour the interbedded finer units. Granite, granodiorite, quartz and, to a less extent, metamorphic and chert boulders also occur in these conglomerates, ~~and~~ Large slump-blocks of sandstones and mudstones from 3 to 30 m. in length were seen in Naripo Creek and tributaries of Morai River. The conglomerates are a marine unit as is shown by the facts that they are commonly hard and calcareous, the fine interbeds are commonly foraminiferal and lumps of coral are not uncommon.

The Morai River Formation rapidly decreases in coarseness to the east of Eel Creek, where it was examined by Pitt (1966) in Sari and "Pinnacle" Creeks (locn. 50), ~~and~~ In the lower Karova River area (locn. 55; APC Repts. LE-1 and LE-2), ~~where~~ it consists principally of mudstones with interbedded sandstones and occasional pebble conglomerates. Further, while the Morai River Formation is commonly conglomeratic elsewhere in the region (refer later), it nowhere attains such a coarse and thick development as in the Morai River - Eel Creek area. The importance of this unit, here, lies firstly in its coarseness, which demands a very close and rapidly uplifted source and, secondly, in its composition which demands a plutonic, metamorphic, volcanic and sedimentary source terrain. No such source rocks are known in the area to the north and the source, therefore, must have lain to the south, say in the area of the present structural depression of the Muruwaie Syncline which is occupied the Toa Group and Rim Group. Osborne (APC Rept. LE-2), postulated that a volcanic island occurred in this immediate area, giving rise to the predominant volcanic content of the conglomerates and possibly affording a source for some of the tuffaceous material within the Aure Group as a whole. We have, also to deal with the plutonic, metamorphic and sedimentary components, however, and with the fact that volcanics per se (aside perhaps from tuffs and ash) are not associated with the conglomerates. This to me, together with the coarseness, suggests that the source rocks required (basement types, volcanics and sediments) were probably faulted-up to exposure to the south at the time represented by the Morai River Formation. This implies that much of the section older than the Morai River Formation is possibly stripped from beneath the area of the Muruwaie Syncline, which is now covered by a thick development of post-Aure sediments (refer sections 1.3.2, 1.4 and 2.4.5).

An additional observation concerning the Morai River section is necessary here. Four major folds (the Urai'ia and Haue'ia Anticlines and the Lohiki and Swanson Synclines - see Plate I) die-out within the basal part of the Morai River Formation in the vicinity of location 47 in the Morai River section. From a study of the aerial photographs, it appears that units can be traced through this region without obvious loss or addition of section (see Plate I), which indicates that neither major faulting nor unconformity gives rise to this condition. In addition, this part of the section in the Morai River is marked by several minor folds and numerous sedimentary mud-stone-breccias. I suggest, therefore, that the abovementioned major folds die-out at this level simply because the very coarse phase of the Morai River Formation did not participate in the folding, *i.e.* implying disharmonic folding within the sedimentary cover and, further, that the Morai River Formation was deposited before the folding began. That uplift and folding occurred shortly after the deposition of the Morai River Formation is shown by the unconformity at the base of the Iavokia Mudstone. The sedimentary mudstone-breccias in Morai River are, therefore, regarded as a closed-cast brecciation of generally unconsolidated sediments, resulting from the differential bedding plane movement involved at this level of structural disharmony.

Because of the character and thickness of the Morai River Formation in the Murua River area, I tend to regard the whole of the 1370 m. of the Aure Group exposed at Cupola (locn. 43) as belonging to this formation. These beds consist of medium-to coarse-grained tuffaceous sandstones with interbedded dark mudstones (APC Rept. LCA). Gritty, pebbly and conglomeratic beds are scattered throughout the section, with the pebbles generally about one centimeter in diameter but up to 40 cm. in locally coarse conglomerates. This section is generally similar to the Morai River Formation as exposed in the Murua River, and while not as coarse as in the Eel Creek area, the composition of the conglomerates is similar and poses similar problems regarding the source area. I have examined the very lowest part of this section in the Kerema area and on the beach near Cupola, where several well-exposed sedimentary features can be observed. These include: graded-bedding, scouring, sedimentary boudinage, closed-cast bedding-plane faulting, extremely coarse and numerous mudstone-breccias, intraformational folding, large load casts and flame structures, slump blocks to 15 m. long, sandstone dikes and sills, coal breccias, ~~and~~ large pods composed only of coarse mudstone and porphyritic volcanics, and armored mudstone balls to name a few (see Photograph I). These features attest generally to the markedly unstable conditions and extremely rapid deposition of these beds.

The basic sequence of the Karova Sub-Group in the Murua River, section is a lower unit of massive, tuffaceous sandstones followed by a well-bedded unit of interbedded mudstones and sandstones, which are not described as tuffaceous, followed in turn by a conglomerate-sandstone unit. This same sequence has been mapped and correlated as such in several sections in this area, the difference between my own and previous correlations being that I regard the whole sequence (the Karova Sub-Group) as being of Middle Miocene age, whereas previous correlations have, somewhat arbitrarily, placed the base of the Middle Miocene at the base of what is here regarded as the Morai River Formation. The previous correlation is now known to be in error, as Middle Miocene fossils have now been recorded from the Yuiani Tuffaceous Sandstone.

Incomplete sections displaying this general tuffaceous sandstone - bedded sandstone and mudstone - conglomeratic sandstone sequence and, hence, referable to the Karova Sub-Group (see figure 1.3-3), have been reported from the upper part of Karova Creek (locn. 54; APC Rept. LE-1), Ibai and Yuiani Creeks (locn. 51; APC Rept. LH-2), Nagwe Creek (locn. 45; *ibid*), Lohiki River (locn. 44; APC Rept. LH-1) and the Enna-Chauma-Idigue Creek section (locns. 53, 53; APC Rept. LH-2). The top of the Karova Sub-Group is not reached in any of these sections, and the base of the sub-group is exposed only in the Enna-Chauma-Idigue Creek section. These sections expose between 1910 m. (Nagwe Creek; locn. 45) and 3110 m. (Karova Creek; locn. 54) of the

Karova Sub-Group. In the composite Barren-Obira section (locn. 56), about 7 km. to the southeast of the Karova Creek section, Osborne (APC Rept. LE-2) measured about 610 m. of calcareous mudstones which Pitt (1966) places above the highest beds of the Karova Creek section on photogeological and structural grounds. Combining these two sections gives a total thickness of 3720 m. for the Karova Sub-Group, with the base not exposed and the top marked by the unconformity at the base of the Toa Group (see figure 1.3-3). Of the Lohiki River section, which was measured across several folded and faulted structures, Stanley states that there is a notable increase in coarseness toward the east, with both the sandstones and grits becoming coarser and coarse to medium conglomerates making an appearance in the top and eastern part of this section (APC Rept. LH-1). Illustrating this same tendency, conglomerates with limestone and igneous boulders to one meter in diameter occur in the Morai River Formation (formerly "Enna Creek Beds"; APC Rept. LH-2) in the Enna-Chauma-Idigue Creek section (locn. 52) and, whereas the Yuiani Tuffaceous Sandstone contains pebbles to 5 cm. in the Yuiani Creek section (locn. 51), pebbly beds are more common in this formation in Idigue Creek section (locn. 53) and boulders to 15 cm. in diameter occur (APC Rept. LH-2). In general, this coarsening toward the east within the Karova Sub-Group can be taken to indicate that a source area lay to the east. In addition, the Ibai Creek Sandstone, the full thickness of which is present in most of these sections, thickens from 503 m. in the Murua River section to 530 m. in the Karova Creek section (locn. 54) to 760 m. in the Ibai Creek section (locn. 51), before reducing to 685 m. farther east in the Idigue Creek section (locn. 53; see also, figure 2-2b). In the latter section the Yuiani Tuffaceous Sandstone, as well as being coarser than in sections farther west, is only 350 m. thick as compared to 960 m. in the Murua River section and at least 840 m. in the Yuiani Creek section. These data suggest that the axis of sedimentation for the Karova Sub-Group lay in the vicinity of the eastern limb of the Karova Syncline.

On the southwest flank of the Idigue Anticline, in the Idigue Creek section (locn. 53), the Yuiani Tuffaceous Sandstone is underlain conformably by about 430 m. of black siltstones and mudstones with sandy bands (APC Rept. LH-2). Because I have taken the base of the overlying pebbly tuffaceous sandstones as the base Karova Sub-Group and, therefore, as a provisional base of the Middle Miocene, I regard this lower siltstone-mudstone unit as equivalent to the "Rumua Beds" to the west and Werr Beds to the east, both believed to be of late Lower Miocene age. The tuffaceous sandstones of the Yuiani Tuffaceous Sandstone formation were not found on the northeast flank of the Idigue Anticline (APC Rept. LH-2, plate 25, col. 15), and the youngest beds exposed to the east of the anticlinal axis and eastward to the Werr Fault (locn. 59) are assignable to the Werr Beds of late Lower Miocene age (refer previous section). This, together with the fact that steep dips with overturning toward the southwest were recorded along the crest of this anticline, lead me to suggest that the Idigue Anticline is crestally faulted with the northeast flank upthrown by at least 610 m. This view is supported by a study of the aerial photographs, and I suggest that the crestal fault of the Idigue Anticline merges to the north with the Eruki Fault of Pitt (1966; see Plate I). In addition, beds believed to be of basal Middle Miocene age - the "Be Creek Beds" (refer later) - are thought to rest unconformably either on the Werr Beds, or on the early Lower Miocene Yuyebba Creek Beds, between the Werr and Yuyebba Faults. To the east of the Kapau River, the Muiai Sub-Group (refer later) of early Middle Miocene age rests unconformably on the Hells Gate Sub-Group of late Lower Miocene age. For these reasons, I suggest that the area between the Idigue Anticline and the Kapau River, which can be referred to as the Tauri Anticlinorium (refer 2.1.2), marked a structural high and source area during the early Middle Miocene (refer figure 1.3-4). The rocks of typical Aure facies, *viz.* the Karova Sub-Group, are confined to the area to the west of the Idigue Anticline and, for this reason, the eastern edge of the early Middle Miocene Aure Trough can be placed approximately at the axis of the Idigue Anticline, with the thickest development of the Karova Sub-Group occurring immediately to the west in the vicinity of the Karova Syncline. The term Kapau Margin has been introduced to signify the tectonically active eastern margin of the Aure Trough. During the early Middle Miocene, the Kapau Margin can be equated with the Tauri Anticlinorium, this mobile margin having migrated from the Kapau River area to the Idigue Anticline, some 10 to 15 km. to the west. For purposes of later reference, it will be convenient to refer to the early Middle Miocene part of the Aure Trough as the Karova Trough. The Karova Trough is regarded as a sub-unit of the Aure Trough and will be used to refer to the area of maximum deposition of the early Middle Miocene stage within the Aure Trough.

Before proceeding with the stratigraphy in the area to the east of the Idigue Anticline, it is necessary to draw attention to the fact that correlations between the Murua River section and the Nagwe Creek and Lohiki River sections to the north are somewhat uncertain (1.3-3b). The Rumua Beds, which are believed to be of late Lower Miocene age and which form the oldest exposures in the Murua River section, crop out in the core of the Murua Anticline. The anticline plunges strongly toward the southeast at this location, suggesting generally that the beds exposed in the Nagwe Creek and Lohiki sections to the north (locns. 45, 44; see Plate I) should be older. From a study of the aerial photographs, however, I have introduced the Piyai'ia Fault (see Plate I) between these sections. As an alternative to fig. 1.3-3b, I suggest that the sections to the north of the fault are down-faulted equivalents of the Karova Sub-Group. This allows the sequence found in Nagwe Creek, *viz.* tuffaceous sandstones followed upward by sandstones and mudstones followed, in turn, by conglomeratic sandstones, to be correlated directly with the Karova Sub-Group. Another reasonable alternate correlation, assuming minimum importance of the Piyai'ia Fault, would be to suggest that the conglomeratic sandstones found at the top of the Nagwe Creek section correlate with the base of the Yuiani Tuffaceous Sandstone rather than the Morai River Formation (figures 1.3-3 and 2-2b). This interpretation is indicated as more probable by my structural interpretation of the Imbricate Belt, which suggests that most of the Middle Miocene has slid off the Dude-Murua Anticlinorium, and requires that older beds be exposed to the east of the Dude Anticline (refer 2.2). If this is the case, then the lowest 1680 m. of the Nagwe Creek section and the corresponding part of the Lohiki section are probably of late Lower Miocene age or older.

Kapau Margin

The area between the Idigue Anticline and the Kapau River (the Tauri Anticlinorium structural unit) can be regarded as marking the Kapau Margin during the early Middle Miocene. The relationship of rock units in this area are poorly known because the area has been crossed by only one traverse in the Idigue Creek - Kapau River area (APC Rept. LH-2); the remaining traverses being confined to the Hells Gate-Saw Mountains area to the southeast (locns. 58, 62; APC Repts. LE-1, LE-2, LMA) making correlations and photogeology difficult. It is held, however, that this area acted principally as an uplifted source area during the early Middle Miocene, with only thin, intermittent deposition occurring in localized structural lows.

In the one traverse across this area, from the Idigue Anticline to the Kapau River, the only definite occurrence of beds of Middle Miocene age, is a faulted, synclinal ~~inlier~~ outlier occurring in Be Creek (locn. 59). These beds, the Be Creek Beds (APC Rept. LH-2), crop out between the Werr Fault and the Yuyebba Creek Beds to the east. The Be Creek Beds are faulted against the Werr Beds to the west and either faulted against (*ibid*) or unconformable on (Pitt, 1966) the Yuyebba Creek Beds to the east. From a study of the aerial photographs, I tend to agree with the APC fault interpretation of this particular contact (the Yuyebba Fault), but regard it as most probable that the basic relationship of the Be Creek Beds to older rocks is one of unconformity. The Be Creek Beds consists of about 460 m. of soft sandstones, mudstones, foraminiferal mudstones and thin calcareous sandstones with an additional 75 m. of basic lavas at the base (APC Rept. LH-2; see figure 1.3-3c). From one sample of these beds (sample 3082) Glaessner recovered six restricted late Lower Miocene foraminifera, two restricted Middle Miocene forms and three forms which occur in both stages (*ibid*, Paleo. Append.). On this basis, these beds were assigned an uppermost late Lower Miocene ("f2") age. Because these beds include the restricted Middle Miocene forms Lepidocyclina cf. orientalis and Cycloclypeus inornatus, and because of the associated lavas, I have grouped these beds with the early Middle Miocene and regard them as equivalent to the Yuiani Tuffaceous Sandstone. The exact age of these beds is somewhat of an academic question and one which I am not particularly qualified to answer. This fauna possibly indicates that the Yuiani Tuffaceous Sandstone actually extends into the very top part of the late Lower Miocene. The Be Creek Beds are very probably (but not necessarily) unconformable on either the Werr Beds or the Yuyebba Creek Beds, or both. Pitt (1966), has photogeologically traced an unconformity at the base of this unit (see Plate I), but I do not completely agree on this matter.

The best arguments for a probable unconformity at the base of the Be Creek Beds are firstly, the general lack of beds of this age over this area and secondly, the relationship displayed by beds of this age in the area to the west of the Idigue Anticline and, again, to the east of the Kapau River. To the east of the Kapau River, on the west limb of the Muiai Syncline (locn. 60), a series of conglomerates and marls approximately 1010 m. thick and defined as the Muiai Sub-Group* by Pitt (1966) crops out.

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* Pitt (1966, see figure 12 opp. p.56) includes the limestones and conglomerates immediately overlying the Kapau limestone as the basal member of the Muiai Sub-Group, whereas I have included this unit in the Hells Gate Sub-Group, and accepted Glasensner's correlation of this unit with the Doorway Limestone of late Lower Miocene age (APC Rept. LH-2, Paleo. Append; refer also, figure 1.3.3c). The thickness here quoted for this sub-group is Pitt's, with the limestone-conglomerate member removed.

The basal member of the Muiai Sub-Group is formed of 575 m. of coarse volcanic conglomerates, consisting of boulders of porphyritic andesite to 60 cm. in diameter set in a strongly tuffaceous matrix. These beds grade into graded sandstones toward the top and, thence, into the overlying mudstone-marl sequence (APC Rept. LH-2; see figure 1.3-3c). The base of this unit is an unconformity which can be traced by photogeology (see Plate I) into the unconformity at the base of the overlying Poison Creek Marl equivalent (Pitt, 1966). The unique occurrence of lavas within the Be Creek Beds forms a good lithological link with the volcanic conglomerates at the base of the Muiai Sub-Group, giving a good reason for correlating these units, and at the same time, a good reason for suspecting an unconformity at the base of the Be Creek Beds. ~~As~~ Because the volcanic conglomerate grades into the overlying marl unit, which was correlated paleontologically with the Maipora Formation by Glaessner (APC Rept. LH-2, Paleo. Append.), the conglomerate can fairly confidently be regarded as being of Middle Miocene age. I have followed Pitt (1966), however, and regard the overlying marl unit as equivalent to the Poison Creek Marl rather than the Maipora Formation, as photogeology clearly shows that the Maipora Formation (the basal member of the Toa Group and equivalent to the Iavokia Mudstone) is a stratigraphically younger unit.

To the south, the Saw Mountains (locn. 62) are formed principally by a rugged, tabular mass of coralline limestone 365 m. thick - the Saw Mountains Limestone. This limestone underlies the Maipora Formation unconformably and most probably overlies the Hells Gate Sub-Group and Port Moresby Group unconformably. The latter two groups are intensely deformed with steep to vertical and overturned dips prevailing, and structures within these units trend directly into the gently-dipping (10-30 degrees) Saw Mountains Limestone. This unconformity is fairly clear from a study of the aerial photographs. The Saw Mountains Limestone is, therefore, regarded as equivalent to the Karova Sub-Group to the west and Muiai Sub-Group to the northeast. I ~~therefore,~~ regard the Saw Mountains Limestone as being of early Middle Miocene age, but there is some doubt concerning the age of this unit. Firstly, Osborne (APC Rept. LE-2) regarded this unit as the basal member of the Maipora Formation. Stach (*ibid*; Paleo. Append.), however, recognized the faunal sub-zone characteristic of the Maipora Formation (a rich benthonic foraminiferal fauna referred to as the Orbulina-1 sub-zone) in marls overlying the Saw Mountains Limestone. I have equated these marls with the Maipora Formation. Further, Stach (*ibid*) correlated the Saw Mountains Limestone with the Poison Creek Marls (locn. 61), which are known to underlie the Maipora Formation. Secondly, whereas Stach recovered a Middle Miocene fauna from the top of the Saw Mountains Limestone (*ibid*; samples 334 and 338), he also recovered a late Lower Miocene fauna from the lower part of this unit (sample 339). This limestone, therefore, could straddle the boundary between the late Lower Miocene and early Middle Miocene. Towards the base, however, the limestone grades into marls from which Stach records Globoratalia menardii (sample 359A) and, as well, notes that this form is replaced by a form Globorotalia sp. in the Hells Gate Sub-Group of late Lower Miocene age (*ibid*, p.3 and p.20). This suggests that the form recognized as Globorotalia menardii is probably Globorotalia menardii menardii and indicates that these marls and, therefore, the Saw Mountains Limestone are no older than Middle Miocene (see Bandy, 1964). The suggested unconformity occurs at the base of these marls, which are about 150 m. thick, giving a total thickness of 515 m. for the Karova Sub-Group equivalent.

Toward the north in Poison Creek (locn. 61), the Saw Mountains Limestone grades rather abruptly into marls, siltstones, flaggy limestones and calcareous sandstones (APC Rept. LE-1). These beds, referred to as the Poison Creek Marl, contain a Middle Miocene foraminiferal fauna as well as corals (*ibid*, Paleo. Append.). Only the top 305 m. of these beds have been examined, but the total thickness is probably not greatly in excess of this (see Plate I). Pitt (1966) has photogeologically traced the unconformity which occurs at the base of the Muiai Sub-Group on the west limb of the Muiai Syncline southward to the base of the Poison Creek Marl (see Plate I), and I regard this as a probable interpretation.

Because of structural complexity, it is difficult to be definite about either the structural or stratigraphic picture in the area to the north-west of the Saw Mountains (locn. 58). It seems probable that the pebbly gr~~e~~aywackes and mudstones reported in the area of the Barrier Ridge (locn. 58; APC Rept. LE-1 and LMA) are part of the Morai River Formation as shown on Plate I. Because these beds lie to the east of the Idigue Anticline, I would suggest that they probably transgressively onlap older rocks. These beds occur adjacent to the Hells Gate Sub-Group to the east of Barrier Ridge, ~~and~~ Pitt has photogeologically mapped an unconformity at this position, but I think that a fault relationship is more likely at this location (see Plate I). It is notable that Pitt has, also, photogeologically mapped an unconformable outlier ~~inlier~~ of the Morai River Formation in the Wagewa Basin (locn. 57; see Plate I).

Puri Shelf

In the region of detailed study, the only exposure of rocks of early Middle Miocene age which represent a shelf environment are those which occur on the culmination of the Puri Anticline (locn. 12). Here, a thin development of foraminiferal marls, referred to informally as the Orbulina Marls (APC Rept. LI) can be assigned to the early Middle Miocene. These beds thicken from about 105 m. at the APC Puri No. 1 Well-site to about 185 m. on the eastern plunge of this structure. A large percentage of the rock is formed of tests of Orbulina, from which the name of the rock unit is derived. These beds overlie and grade into the Puri Limestone of Lower Miocene age, and are overlain sharply but conformably by mudstones of Middle Miocene age, which I have taken as equivalent to the Iavokia Mudstone. An exact palentological equivalence between these overlying mudstones and the Iavokia Mudstone as known to the east (refer 1.3.2) has not been established. I have, however, assumed this equivalence and regard the Orbulina Marls as equivalent to the Maropo Beds, Karova Sub-Group and Muiai Sub-Group.

Similar, thin sections, consisting principally of *Orbulina*-rich marls, have been drilled to the south at Wana, and to the northwest at Bwata and are exposed at Hathor Gorge (see Plate II; Geol.Soc.Aust. Bull Vol. 8; refer Smith, 1964). Farther to the southwest, the *Orbulina* marls give way to argillaceous limestones and limestones.

In the Puri area, the northern and eastern edge of this thin, marl development and, therefore, the Puri Shelf, can be placed somewhere between the Puri Anticline and the Bevan Fault (see figure 1.3-4). The north edge of the Puri Shelf, therefore, lay approximately 25 km. to the south of its position during the late Lower Miocene. ~~To~~ Toward the north and east ~~of~~ from the Puri Anticline, the first exposures of rocks of this age occur on the upthrown side of the Bevan Fault, and these exposures are already developed in a thick mudstone-sandstone, trough-facies at least 1300 m. thick (refer earlier - Te Creek area). To the north of the Purari River (locns. 1-10), several sections of rocks of this age have been measured. In these sections, the Iavokia Mudstone has not been recognized, because much of the underlying Aure Group is in a mudstone facies as well. These sections should, therefore, be understood as possibly including the Iavokia Mudstone. In contrast to the sections to the east of the Aure Fault, Carey (APC Rept. LI) notes both that *mudstones are predominant* over sandstones and that *conglomerates are absent* from these sections. The Pio section (locn. 5) gives a complete section 1615 m. thick. These beds are overlain conformably by mudstones of Upper Miocene age and are underlain by marls and limestones of late Lower Miocene age. These beds are similar to those exposed in the Te Creek area (except that the Te Creek section includes pebble conglomerates) in that about 60 per cent of the section consists of mudstones. The mudstones are described as marly, but argillaceous limestones do not occur. About 40 percent of the section consists of thin, interbedded tuffaceous sandstones. Judging from the Na-Hou Creek and Te Creek sections to the south (locns. 11, 15), it is not unlikely that the Iavokia Mudstone could perhaps make-up the top 460 m. of this section. This would leave an estimated thickness of *1155 m*. for the Maropo Beds equivalent in the Pio section.

Similar, but incomplete, sections to 1830 m. thick (locn. 4) have been described to the north and west of the Pio section. These sections consists principally of calcareous mudstones and graywackes, with thin argillaceous limestones important toward the base (APC Rept. LW). An important variation occurs in these sections, however, in that pebble to cobble conglomerates - the <u>Pio Conglomerates</u> - occur and increase in importance to the westward along the Pio River (west of locn. 8), where they occur as thin beds throughout the lower 180-300 m. of the section. The conglomerates occur in mudstones and limestones and most commonly contain pebbles of limestone to 10 cm. in diameter. The conglomerates, however, sometimes contain boulders to 1.5 m. in diameter and large slump blocks to 12 m. in length. As well, the conglomerates are commonly associated with large-scale slumping. The conglomerates show a complex history, and Rickwood (*ibid*) reported that the derived material of the conglomerates consists of: Cretaceous, Upper Eocene with derived Middle Eocene, early Lower Miocene with derived Upper Eocene, late Lower Miocene with derived Cretaceous, Eocene and Miocene, and Middle Miocene with material derived from Cretaceous through Lower Miocene beds. From this, Rickwood concluded that intermittent uplift to the south was important from the Eocene to the Middle Miocene, and he related the Pio Conglomerates per se and the associated slumping to uplift along the steep edge of the shelf area to the south. He termed this area of intermittent uplift the <u>Wana Swell</u> (*ibid*). In a subsequent section, I suggest a direct relationship between the Wana Swell and the <u>Purari Faulted-Anticlinorium</u> (refer section 2.4.3; and Smith, 1964).

To the northeast of the Pio River, in the Tu Basin (locn. 1), Rickwood (*ibid*), measured an incomplete section 2135 m. thick which he assigned to the Middle Miocene. This section is very poorly exposed but includes graywackes and graywacke conglomerates. Conglomerate, with pebbles to eight cm. in diameter are reported to be common in this area. The pebbles consist of well-rounded sediments, volcanics, quartz, diorite and granodiorite, indicating a northward source. In Hasa Creek (locn. 2), thin coals are reported interbedded in marine siltstones and mudstones. Rickwood interpreted this as representing a near-shore environment and, because rocks of Middle Miocene age do not presently extend northeast of the Aba Fault, he suggested that the area to the east of this fault was an uplifted source during the Middle Miocene. ~~As~~ Because beds of Middle Miocene age are not known from the Central Highlands in the area to the north of the Kubor Anticline, I would extend this observation and suggest that the whole of the Central Highlands between the Kubor and Bismarck Ranges was most probably uplifted and exposed during the Middle Miocene.

D. CONCLUSIONS

The Aure Trough, considered as a unit, can be taken to extend roughly from the lower Purari River in the west to the metamorphic backbone of the Owen Stanley Ranges (the Ekuti and Chapman Ranges) to the east, and from the middle Purari River (east-west section) in the south to the Bismarck Ranges in the north. The trough width is, thus, about 125 kilometers. The sediments deposited in this trough - the Aure Group - represent, primarily, a relatively deep-marine environment, but show evidence of a shallower environment toward the trough boundaries. It is not out of order to suggest that the Aure Group (the Karova Sub-Group, Oboru Sandstone, M'bwei Beds and Aiweriba Beds) is approximately 10,000 m. thick in the Karova Trough which, by virtue of the great thickness of the Karova Sub-group, probably marks the position of the maximum cumulative thickness of the Aure Group. It is clear, however, that the axis of the trough was not stationary, but migrated westward through time (see figure 1.3-5). This is best seen by comparing the configuration of the early Middle Miocene sediments (Karova Sub-Group, Maropo Beds) to that of the late Lower Miocene sediments (Oboru Sandstone, Rumua Beds, Werr Beds and Hells Gate Sub-Group). In fact, it appears that the thickest accumulation of the late Lower Miocene stage was uplifted and formed a source area (the Tauri Anticlinorium) for the early Middle Miocene sediments which accumulated to both the west (Karova Sub-Group) and east (Muiai Sub-Group). The tendency for the depositional axis to migrate westward (and southward in the area to the west of the Aure Fault) through time, is also well-established for the overlying Toa Group and Era Group (refer 1.3.2 and 1.4). By analogy, it is reasonable to suggest that the axis of sedimentation for the early Lower Miocene (M'bwei Beds, Aiweriba Beds and Yuyebba Creek Beds) probably lay to the east of the late Lower Miocene depositional axis.

To both the west and east, the Aure Trough was a steeply bounded feature. The relatively stable Puri Shelf lay to the west and south of the main trough area, and is characterized by thin, continuous, blanket-deposits of limestones and marls (the Puri Limestone and *Orbulina* Marls). The eastern trough margin, the Kapau Margin, is characterized by a reef-limestone - conglomerate facies, localized folding and unconformities, indicating marked tectonic activity. Complementary to, and reflecting the trough development, the Puri Shelf migrated to the south and west, and the Kapau Margin migrated westward through time. In the area to the west of the Aure Fault, the northern edge of the Puri Shelf migrated approximately 50 km. toward the south during the deposition of the Aure Group. Although it involves a higher degree of speculation, I have depicted an analogous westward migration of the eastern edge of the Puri Shelf in the lower Vailala River area. Similarly, the Kapau Margin can be depicted as migrating some 30 km. from the western edge of the Owen Stanley Ranges, which presumably supplied the igneous, metamorphic and derived Eocene material of the Yuyebba Creek Beds and Hells Gate Sub-Group, to the Idigue Anticline during this time. The Muiai ~~Hells Gate~~ Sub-Group is unconformable on the Hells Gate Sub-Group, indicating that localized uplift and folding occurred along the Kapau Margin.

A sympathetic southward migration of the northern margin of the Aure Trough can be inferred in the area to the west of the Aure Fault. Localized uplift and folding is associated with this margin, also, as shown by (see figure 1.3-5): 1) basal early Lower Miocene conglomerates on the flanks of the Bismarck Ranges, 2) the unconformity between the early and late Lower Miocene in the structural low between the Bismarck

Range and Kubor Anticline, 3) late Lower Miocene conglomerates to both the north and south of the Kubor Anticline and 4) the occurrence of Middle Miocene conglomerates to the south of the Kubor Anticline and absence of beds of Middle Miocene age in the area to the north.

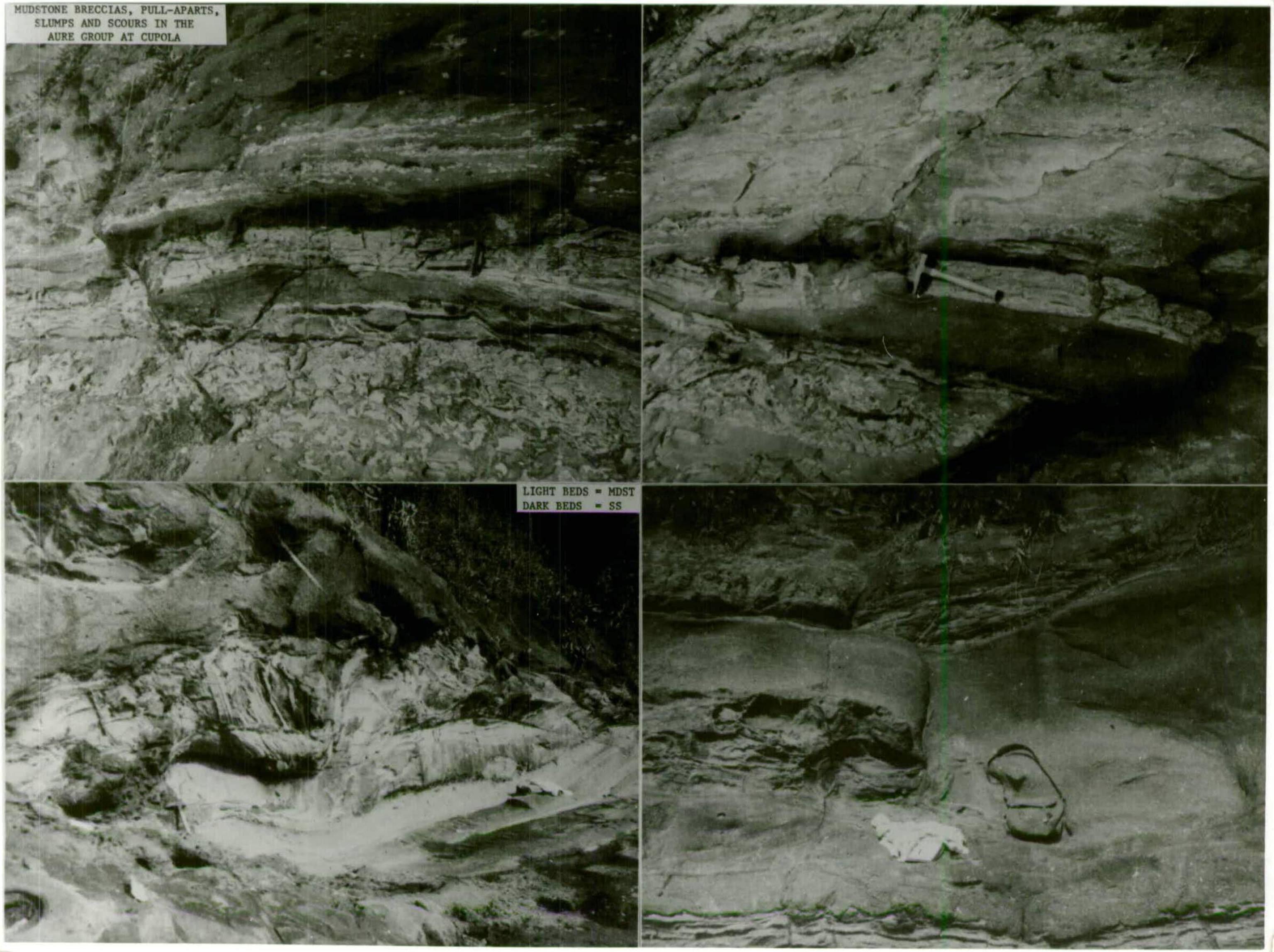
It is notable that the Aure Trough in the area to the south of the Bismarck Ranges is characterized by volcanics, whereas volcanics as a rule are lacking from the areas to the south of the Kubor Anticline and to the east of the Aure Fault. It can, therefore, be suggested that the tuffs and tuffaceous material within the lower part of the Aure Group in the latter area were possibly derived from a northerly volcanic source. This is somewhat indicated by comparing the strongly tuffaceous Oboru Sandstone to the finer, less-markedly tuffaceous Werr Beds, the supposed correlate to the southeast. Volcanics, which may be either of early or late Lower Miocene age, are known from both the upper Kapau - Langimar area and from the Hells Gate area, however, and indicate a volcanic source along the eastern margin of the trough as well.

The Aure Trough was essentially outlined and bounded by faulting. This is shown generally by the deepwater character and by the thickness and coarseness of these sediments, and by the extreme rapidity with which thickness and facies changes occur at the trough margins. Faulting and tectonic instability along the northern edge of the Puri Shelf is well-known, principally by Rickwood's work (APC Rept. LW) in the Pio-Purari region. By analogy, I have assumed a similar configuration for the eastern edge of the Puri Shelf in the lower Vailala River area. This is somewhat indicated by:1) derived Eocene in the late Lower Miocene (Oboru Sandstone) in the Maropo section, 2) derived Eocene in the early Lower Miocene of the Kariava Well-section, 3) the increase in conglomerates to the southwest toward Kariava in the Maropo Beds (early Middle Miocene), 4) the Lepidocyclina grits, "Detrital Limestone" and large isolated limestone blocks in the area to the west of the Dude Anticline and south of Kariava and 5) by the probable development of Middle Miocene shoals in the vicinity of Nakoro. It can, therefore, be suggested that these phenomena are related to the steep, tectonically active <u>eastern</u> edge of the Puri Shelf in the same manner that the <u>Pio Conglomerates</u> are related to the northern edge of this shelf. Faulting <u>within</u> the Aure Trough is indicated by the marked thickness increase of the Karova Sub-Group to the east of the Dude (or Yanne'ia) Anticline and the associated shallowing toward the west, and by the composition and extraordinary coarseness of the Morai River Formation in the Morai-Eel Creek Area.

A <u>southerly source</u> during the early Middle Miocene is strongly indicated by the conglomeratic constituents of the Aipa, Cupola and Morai-Eel Creek sections. This source could perhaps be related, as well, to the faulted, but more deeply exposed, eastern edge of the Puri Shelf extended through this area, but may relate to an entirely different feature (the Coastal Trend, refer section 2.4.5). Insufficient depth of exposure makes this difficult to judge. Volcanics and sediments as well as "granitic basement" were eroded from this source, which was possibly associated with active volcanism. Rocks older than the Morai River Formation must have, to some degree, been removed from this source area and, therefore, a complete section of the Aure Group is probably not preserved in the area of the Muruwaie Syncline and, again, to the south of the Cupola and Aipa sections.

The detail of the continuation of isopach and facies trends across the Aure Fault and <u>Aure Lineament</u> (refer 2.4.1) constitutes one of the most important and most formidable problems in this region. All trends, including structural trends, are either discontinuous or make a sharp bend at the Aure Lineament, forming the feature known as the Purari Orocline (refer 2.4.1). Although the Aure Group is not well known along the Aure Lineament to the north of the Purari River - Aure River junction, and is largely covered by younger sediments to the south of this junction, it is clear that isopach and lithofacies trends must make a sharp bend at this lineament. The sharpness and rapidity of the necessary bend is such as to indicate a probable discontinuity at this lineament. This is most apparent for the Lower Miocene trends. I have, therefore, interpreted this to mean that isopach and lithofacies trends are in fact discontinuous at, and offset by, the Aure Lineament. This disjunct is greatest for early Lower Miocene trends and least (if disjunctive at all) for early Middle Miocene trends. I have interpreted this to mean that movement (in a dextral sense) along this lineament has been of a long-lived, secular nature and, therefore, older trends show a greater degree of offset at the Aure Lineament than do younger trends (refer, also, 2.4.1 and 3.4). This implies that the Aure Lineament was an active tectonic element throughout the deposition of the Aure Group.

A further complication of the isopach and facies trends of the Aure Group, and particularly of the ~~U~~upper, early Middle Miocene, part of this group, is introduced by the strong thrust faulting in the Vailala-Purari region. Because this thrusting is directed toward the southwest, the facies and isopach trends as we presently see them must be displaced somewhat to the southwest of their original position. The degree of displacement proposed, is dependent on how this faulting is interpreted. In later discussions (refer 1.3.2 D and 2.2), I suggest that the Ekiere Fault and associated structures to the east of this fault are confined largely to the Middle Miocene part of the Aure Group. It is proposed that these structures have resulted from 'bedding plane' slippage, off the Dude-Murua Anticlinorium to the east, on a basal decollement represented by the Ekiere Fault. The decollement is believed to occur at about the level of the base of the Middle Miocene and, therefore, sediments above this level will have been displaced toward the southwest. The amount of displacement is believed to be of the order of 10 to 20 kilometers (refer 1.3.2.D). This interpretation makes it plausible to suggest that the trough facies of the Middle Miocene, which we see presently exposed between the Ekiere Fault and the Dude Anticline, has overridden a more shelf-like facies of this age, now present beneath the Ekiere Fault (refer figure 2-30).



MUDSTONE BRECCIAS, PULL-APARTS, SLUMPS AND SCOURS IN THE AURE GROUP AT CUPOLA

TABLE 1.3 – III – SUBDIVISION OF THE TOA GROUP

<table>
<tr><th></th><th></th><th></th><th></th><th></th><th>AREA</th><th>MENA BASIN</th><th>HORBU SYNCLINE</th><th>NAKORO</th><th colspan="2">VAILALA TROUGH</th><th>COASTAL TROUGH</th></tr>
<tr><td rowspan="8">TOA GROUP</td><td rowspan="7">UPPER MIOCENE</td><td rowspan="7">TERTIARY "g"</td><td rowspan="7">GLOBIGERINA ZONE</td><td rowspan="3">G.TRILOBA - BULLODIES Sub - Zone</td><td rowspan="3">UPPER MURUA SUB - GROUP</td><td colspan="2">HOWME MUDSTONE</td><td rowspan="2">HURO BEDS</td><td rowspan="3">UPPER MURUA MUDSTONE</td><td rowspan="3">PAWRO FACIES</td><td rowspan="3">UPPER MURUA
BAIYAHO LST.
MUDSTONE</td></tr>
<tr><td rowspan="2">BOA SANDSTONE</td><td>HURO SANDSTONE</td></tr>
<tr><td colspan="2">HORUPA BEDS</td></tr>
<tr><td rowspan="4">G.SUBCRETACEA-INFLATA Sub - Zone</td><td rowspan="4">LOWER MURUA SUB - GROUP</td><td rowspan="4">LOWER MURUA MUDSTONE</td><td rowspan="2">PORUDA</td><td>MUDSTONE</td><td colspan="3" rowspan="4">LOWER MURUA MUDSTONE</td></tr>
<tr><td>SANDSTONE</td></tr>
<tr><td colspan="2">RARAKO MUDSTONE</td></tr>
<tr><td colspan="2">NAKORO FORMATION</td></tr>
<tr><td>LATE MIDDLE MIOCENE</td><td>LATE "f3" STAGE</td><td>ORBULINA ZONE (Top Part)</td><td colspan="7">IAVOKIA MUDSTONE</td><td>MAIPORA FORMATION</td></tr>
<tr><td colspan="12">AURE GROUP</td></tr>
</table>

1.3.2 THE TOA GROUP

A thick section, consisting predominantly of mudstones, overlies the Aure Group along the west flank, and around the southern plunge of the Kukukuku Lobe. In common usage, these mudstones are known generally as the Murua Mudstones, or Murua Group, the name being derived from a very poorly exposed and poorly known section in the Murua River. The Murua Mudstones form the *Globigerina* zone of this region and have been equated with the Upper Miocene, thereby giving rise to the ~~local~~ Muruan stage of local terminology

In most sections, however, a relatively thin (about 300 m. ±) mudstone unit belonging to the top part of the *Orbulina* zone (late Middle Miocene) is present immediately beneath the Murua Mudstones and above the sandstones typical of the Aure Group. This mudstone is commonly known as the Iavokia Mudstone which, by virtue of belonging to the *Orbulina* zone, became known as the uppermost formation of the Aure Group.

The Iavokia Mudstone and the Murua Mudstones together, however, form a meaningful stratigraphic and tectonic unit which unconformably overlies the Aure Group around the southern plunge of the Kukukuku Lobe. A term which recognizes the significance of this mudstone section as a unit is preferable to the previous, purely paleontologically-defined subdivision and, therefore, the term Toa Group is introduced and used here. This name is derived from the previously discarded term "Toa Series", which was the name used for the thick mudstone section overlying the Orbulina Marls (early Middle Miocene) and underlying the Era Group (Pliocene) in the Era-Purari area, *i.e.* the section equivalent to the Iavokia Mudstone and the Murua Mudstones (APC Rept. LI).

The Toa Group can now be defined as the predominantly mudstone section overlying the Aure Group and its equivalents and underlying the Era Group and its equivalents.

The basal formation of the Toa Group is the Iavokia Mudstone of late Middle Miocene age. To the east of the Murua River the Iavokia Mudstone and its time equivalent, the Maipora Formation, are unconformable upon the Aure Group and its equivalents. The top of the Iavokia Mudstone corresponds to the boundary between the Upper Miocene and Middle Miocene and, most commonly, can be determined only by paleontology.

The Iavokia Mudstone is overlain conformably by mudstones of Upper Miocene age - the "Murua Mudstones" or "Murua Group" - corresponding to the Globigerina zone. These mudstones have been paleontologically subdivided into two sub-zones; a lower Globigerina subcretacea-inflata sub-zone and an upper Globigerina triloba-bulloides sub-zone, locally referred to as the Lower Murua and Upper Murua respectively (APC Repts. LD, LE-2). These bio-zones commonly correspond to recognizable rock units, but in places, *e.g.* in the area to the east of Kerema, the mudstones are essentially homogeneous and subdivision is effected only in terms of the bio-zones. The top of the G. triloba-bulloides sub-zone, and the top of the Toa Group, corresponds to the boundary between the Upper Miocene and Pliocene and is commonly marked by coarse sandstones at the base of the Pliocene.

Both the Upper Murua and the Lower Murua are locally very thick, *viz.* 1500 m. each, and have commonly been subdivided into formations. As such, the terms Upper Murua Sub-Group and Lower Murua Sub-Group are here introduced. These terms correspond to the G. triloba-bulloides and G. subcretacea-inflata sub-zones respectively and to terms such as Upper Murua and Lower Murua of previous usage. The subdivisions and terms I will use in this text are shown in Table 1.3-III.

The basic configuration of the Toa Group is that of a deep, marine trough, or foredeep, girdling an area of uplifted Aure rocks to the east and north. The main axis of deposition for the Toa Group (see figure 1.3-6) is located well to the west and south of the main axis of sedimentation for the underlying Aure Group, and the depositional axis of each of the main subdivisions of the Toa Group migrated progressively to the south and west through time (refer later). The Toa Group, therefore, represents a fundamental regression from the area of uplift (the Dude-Murua Anticlinorium and Tauri Anticlinorium; or the Kukukuku Lobe) and, as well, a continuation of the transgression of clastics onto the area of the former Puri Shelf.

Within the depositional 'basin' of the Toa Group, three main, and rather separated, depositional troughs and a contemporaneous structural high can be recognized. To facilitate discussion, these are named and informally defined as follows:

<u>Purari Trough</u> - This trough trends roughly NW and occupies the general area of the lower Purari River drainage or, broadly, the area to the southwest of the Ekiere Fault. The thickest and most extensive development of the Toa Group occurs in this trough. To the south and west of the axis of this trough, the Toa Group thins over the present area of the Delta Embayment.

<u>Vailala High</u> - This high trends northwest and is centered roughly over the line of the Ekiere Fault. It was an area of markedly thin, and irregular deposition of the Toa Group and separated the Purari Trough from the Vailala Trough to the northeast.

<u>Vailala Trough</u> - This trough trends northwest and marks a subsidiary, but thick, accumulation of the Toa Group to the northeast of the ~~Purari Trough~~ Vailala High. It occupies the general area of the middle Vailala River drainage or, broadly, the area to the northeast of the Ekiere Fault

Coastal Trough - The axis of this trough roughly parallels the coast and marks the thick accumulation of the Toa Group around the southern plunge of the Kukukuku Lobe in the area of Rim Ridge and the Muruwaie Syncline.

All of these elements were mobile during the deposition of the Toa Group and migrated to the west and south through time. Hence, more exact definitions and descriptions are left to following discussions.

Typically and predominantly the Toa Group consists of thick Globigerina mudstones (3,500 m. max.) representing a moderately deep to deep, marine environment. Infrequent, but widely scattered occurrences of molluscan beds and conglomerates with coralline limestone blocks occur in the upper part of the Toa Group, indicating a tendency toward a shallowing depositional environment.

The Toa Group thins and rises unconformably onto an uplifted area of Aure sediments to the east and north as is shown by its present distribution, by the unconformity at the base of the Iavokia Mudstone around the southern end of the uplift and by the unconformity at the base of the Upper Murua shoreline-facies (Pawro Facies - refer later) on the western side of the uplift. The early uplift to the east and north of the depositional area centered generally along the axis of Aure Group sedimentation - more specifically along the axis of the Dude-Murua Anticlinorium (refer section 2.1.1), and this uplift of Aure sediments formed a major source area for the Toa Group. The uplift grew and spread through time, shifting the eastern and northern limit of sedimentation to the west and south.

The Toa Group, while being predominantly a mudstone unit, shows appreciable variations in lithology and thickness in each of the main subdivisions recognized, and much of this variation is due to contemporaneous structural development within the sedimentary basin.

A. IAVOKIA MUDSTONE (and MAIPORA FORMATION); refer figure 1.3-7

The Iavokia Mudstone is the basal formation of the Toa Group, and is widely known as the first mudstone unit overlying the sandstones of the Aure Group. The Iavokia Mudstone is of late Middle Miocene age, and the top is marked by the faunal boundary between the Middle Miocene and the Upper Miocene. Lithologically, the Iavokia Mudstone is continuous with the overlying Upper Miocene mudstones. Formerly, the Iavokia Mudstone has been regarded as part of the Aure Group but, because it is continuous with the Upper Miocene mudstones and because it reflects the same basic depositional pattern as these mudstones, I have chosen to regard the entire mudstone section overlying the Aure Group as a unit. Further, on the northern side of the Coastal Trough, the Iavokia Mudstone and its time equivalent - the Maipora Formation - unconformably overlie the Aure Group.

Because this is the first time that the Iavokia Mudstone has been discussed in its regional context, it will be of value here to quote the complete description of this unit from the type area at Iavokia (locn. 8):

> "This formation consists of 900-1000 feet of dominantly fine grade sediments whose lithological characteristics are by no means unique. Mudstones of similar appearance are interbedded both in the Aure Group at stratigraphically lower horizons and also in the overlying Murua group. Careful examination failed to provide means of distinguishing individual exposures in the field. Typically, the formation consists of thin alternations of silt and mud with occasional "Puri type" limestones, and thin, current bedded layers of silt grade containing cream, dark grey and carbonaceous grains. There are also occasional calcareous sandstone beds up to a few inches thick and occasional beds a foot or so thick of laminated silts, the fissility being due to thin layers of carbonaceous debris. Except for this, there is a notable absence of fissility, and the formation is tough, forming the main topographic divide. Vertical gradation in grain size is notable - each thin bed having a fine sandy or silty base up to an inch or so thick, grading into the overlying mud layer, the top of which is sharply defined. Fossils are never very notable unless small cream grains noted in the current bedded layers are indeed small, worn foraminifera.

The appearance of outcrops in the stream bed is rather striking. Bands of various shades of grey alternate with thin pale streaky beds - the current-bedded layers - with an occasional cream marl band and an occasional salmon pink band. This latter coloration is external only, the layer internally being pale grey, presumably a marl containing finely disseminated pyrites. The frequent low waterfalls and chutes show irregular ribs due to the superior hardness of the silt layers." (APC Rept. LYC, p.3-4).

The paleontology of this unit is quoted from ~~described by~~ Glaessner as follows (APC Rept. LH-2, Paleo. Append, p.10):

(a) Orbulina varies in abundance from common to rare.

(b) The majority of the benthonic forms are rare in number of specimens.

(c) Nodosaria arundinea and Nonion nikobarense are present in most of the samples, often in considerable numbers.

(d) Uvigerina peregrina, Bulimina ovata, and Planulina wuellerstorfi are sometimes common.

(e) Cibicides, Rotalia beccarii, Elphidium and Bolivina (except sp.13) are rare.

(f) Single worn specimens of Operculina occur.

(g) A peculiar form related to Thurammina occurs among the numerous arenaceous forms.

In the Purari Trough, the Iavokia Mudstone conformably overlies the Aure Group and has its thickest development (525 m.) in the Te Creek area (locns. 3, 4), where it consists principally of blue, lignitic, foraminiferal mudstones with some tuffaceous sandstones and thin argillaceous limestones (APC Rept. LI, plate 10). Toward the west, the Iavokia Mudstone thins to 430 m. in the Na'a - Hou Creek section (locn. 2; APC Rept. LT) and to 260 m. on the Puri Anticline (locn. 1; APC Rept. LI). To the northeast, over the Vailala High, the Iavokia Mudstone thins, but retains its general character as a mudstone unit. Commonly, thin, marly, calcareous sandstones and sandstones are developed in relatively thin, anticlinal sections, whereas only mudstones are developed in the, generally thicker, synclinal sections. This possibly indicates that the Iavokia Mudstone was deposited on and around developing folds in this area.

Neither the Vailala Trough nor the Coastal Trough were strongly defined features at this time (refer figure 1.3-7). Similarly, the proposed source area to the east and north at this time is mainly an inferred feature, as a shoreline facies is not preserved in the Iavokia Mudstone, and a well-defined thinning over this high cannot be definitely proved at this point. The inference is made principally on the fact that the Iavokia Mudstone unconformably overlies the Aure Group around the southern plunge of the Dude-Murua Anticlinorium and Tauri Anticlinorium, or along the northern edge of the Coastal Trough (locns. 21-32; refer section 2.1).

Although it was widely held that an unconformity of some nature must separate the structural complex to the north from the smooth swing of the Rim Ridge to the south (refer Plate I), the exact stratigraphic position of the unconformity - at the base of the Iavokia Mudstone - has not been previously recognized. The unconformity can be inferred in the Murua River and Naripo Creek (locns. 21,22) where dips in the Iavokia Mudstone diverge from those in the underlying conglomerates of the Morai River Formation (refer section 1.3.1-C), and is most strongly marked eastward toward Pa'atavi Creek (locn. 23) where these conglomerates strike directly into the base of the Iavokia Mudstone. In these localities, the basal beds of the Iavokia Mudstone contain thin calcareous mudstones, calcareous sandstones and argillaceous limestones (information here is from personal field observation). As this unit is traced farther eastward it changes progressively into a marl-mudstone facies (locns. 23, 25) and thence into a limestone-marl facies (locns. 28-31). Pebble to cobble conglomerates occur in the sections to the east of Pa'atavi Creek (locns. 23-27), but are absent from the Barren-Maipora Creek area farther east (locns. 28, 29), indicating a local derivation from the coarse conglomerates of the Morai

River Formation immediately to the north (locn. 34). The calcareous facies is known as the Maipora Formation, and at the type locality in Maipora Creek (locn. 29), it consists of a basal coralline limestone with minor interbedded marls (the Maipora Limestone) 360 m. thick, which is overlain by 195 m. of poorly exposed marls. A mudstone pellet conglomerate occurs at the base of this unit and was believed to mark either a fault or an unconformity (APC Rept. LE-2). A similar conglomerate occurs at the base of the Maipora Formation in Barren Creek (*ibid*), and Pitt has observed an unconformity at this position in a tributary of Karova Creek (Pitt, 1966, locn. 27). The unconformity at the base of the Iavokia Mudstone in the Murua River area can be traced photogeologically through these locations and, therefore, an unconformity at this level is fairly strongly established. The age of these beds has been established as Middle Miocene, corresponding largely to the Orbulina-1 sub-zone of Stach (APC Rept. LE-2, Paleo. Append.). F~~u~~arther to the east, on the eastern flank of the Saw Mountains (locns. 30, 31), 150-180 m. of marls and silts (locn. 30) overlie the Saw Mountains Limestone. The basal part of these beds grades into sandstones and conglomerates toward the north, the conglomerates containing corals, limestone and igneous boulders (locn. 31). Here, these beds were believed to overlie the Saw Mountains Limestone unconformably (APC Rept. LE-2). Stach (*ibid*, Paleo. Append.) correlated marls at the base of this unit with the basal beds of the Maripora Formation in Yamuti Creek and Poison Creek, five kilometers to the north (locn. 32). For this reason, and because an unconformity at the base of the Maipora Formation has been established to the west, I have correlated the 150-180 meters of marls, sandstones and conglomerates overlying the Saw Mountains Limestone with the Maipora Formation.

The Saw Mountains Limestone has formerly been regarded as part of the Maipora Formation (APC Rept. LE-2), but it is fairly clear that the Saw Mountains Limestone is older and is unconformably overlain by the Maipora Formation (refer also section 1.3.1-C). As in the area to the west, the Maipora Formation is here overlain conformably by Upper

Miocene mudstones. It is noteworthy that the Maipora Formation thickens from 150-180 m. in the Saw Mountains to 480 m. in Yamuti Creek and to 270 m. in the Kerodo Anticline 2.5 km. to the east (locn. 33), revealing the nature of the Saw Mountains limestone mass as a syndepositional high during the deposition of the Maipora Formation.

The importance of the unconformity at the base of the Iavokia Mudstone cannot be over-stressed, as it gives us a rather precise date for the initial uplift and folding of the Dude-Murua Anticlinorium, *viz.* late Middle Miocene - post-Morai River Formation. The Dude-Murua Anticlinorium is an integral structural feature which can be traced in excess of 100 km. to the north (refer section 2.1.1). For this reason, the western boundary of the anticlinorium (the Dude Anticline) can be taken to reasonably mark the hinge-line and effective eastern limit of Toa Group deposition in the Vailala Trough. From the character of the sediments only, this is quite clear for the Upper Murua Sub-Group, but must to some extent be inferred for the Lower Murua Sub-Group and the Iavokia Mudstone (refer 1.3.2B,C).

The Maipora Formation, in its limestone development and general calcareous content, would seem to represent a generally shallower depositional environment than the Iavokia Mudstone. This point is supported by the fact that the Maipora Formation, relative to underlying beds, is marked by an increase in benthonic foraminifera and concomitant decrease in pelagic forms (APC Rept. LE-2; Paleo. Append.), whereas the Iavokia Mudstone is marked by a decrease in benthonic forms and increase in pelagic forms (APC Rept. LH-2, Paleo, Append.). The shoaling represented by the facies change from the Iavokia Mudstone to the Maipora Formation, therefore, indicates a local rise in the depositional basin, from a relatively deep, marine environment to the west to a shelf environment to the east. The Maipora Formation is most strongly developed to the east of Karova Creek (locn. 26), suggesting that the local shoaling was probably related to the structural line of the Murua Anticline (see figure 1.3-7). While the presence of this marl-limestone facies indicates a structural rise toward the east, it indicates as well that a major source area is <u>not</u> being approached in this direction, and lends support to the proposed source area to the north and northwest. Overall, the mudstone facies is concentrated in a belt around the western and southern side of the Dude-Murua Anticlinorium, reflecting the importance of this uplift as a source area during this particular time.

B. LOWER MURUA SUB-GROUP; refer figure 1.3-8

Purari Trough

In the Purari Trough, to the SW of the Ekiere Fault, the Lower Murua Sub-Group is composed dominantly of mudstones, but most commonly contains thick sandstone members. The Lower Murua overlies the Iavokia Mudstone conformably and, as a rule, is overlain conformably by the Upper Murua Sub-Group. The exceptions to the rule occur ~~on~~ at the eastern edge of depositional basin (locns. 30, 31), where the Pawro facies of the Upper Murua is unconformable on the Lower Murua and older beds.

The thickest development of the Lower Murua is recorded in the Te Creek section (1590 m., locn. 1). The Lower Murua, here, has not been formally subdivided but is described (APC Rept. LI) as follows:

(Top)	960 m.	(3200 feet)	- mudstones with some siltstone and sandstone.
	330 m.	(1100 feet)	- hard sandstones with thin-bedded siltstones and marly mudstones, sometimes lignitic.
(Base)	300 m.	(1000 feet)	- hard, thin-bedded, often lignitic siltstones and sandstones.

To the west, complete sections of the Lower Murua have been measured on the north flank of the Puri Anticline. These sections thicken toward Te Ck., from 420 m. in Pide Ck. to the west (locn. 2) to 690 m. in Suai Ck. to the east (locn. 3) and consist of soft gray mudstones with minor siltstones and thin calcareous sandstones (APC Rept. LI). Similar, but incomplete sections occur to the north (locn. 4), with minor slump structures, scour and fill and graded-bedding occurring, indicating occasional influxes of sandy material (Morgan, 1960). Only two minor occurrences of Upper Miocene rocks are recorded to the north of the Purari Fault (locns. 5, 6). These occur as small synclinal outliers ~~inliers~~, the thickest section being 750 m., and have been assigned to the Lower Murua Sub-Group. These beds are described only as soft mudstones (APC Rept. LI ~~LC~~).

To the southeast of Te Ck., the Lower Murua Sub-Group has been commonly subdivided into three basic formations. Subdivision of the Lower Murua was put into effect by Carey (APC Rept. LJ) in the Nakoro area (locn. 7), where he recognized the <u>Orevi Beds</u> (base) <u>Nakoro Beds</u>, <u>Rarako Beds</u> and <u>Poruda Beds</u> (top). The Orevi Beds are now regarded as the Iavokia Mudstone (APC Rept. LNC, LNC-1 and LNC-6; Stanley, 1960, p.169). These basic units have been fairly widely recognized in the area to the west of the Ekiere Fault, but later work has altered Carey's original definition and interpretation. Rickwood (APC Rept. LNC), has subsequently subdivided and described the section in the Nakoro area as follows (*ibid*, p.5-9):

(base) <u>Nakoro Formation</u> - 232 m. (772 feet)* - A 90 m. sand (Nakoro Sandstone) marks the top of this unit and is underlain by 142 m. of mudstones and siltstones with at least three distinct sandstone members. The sandstones "are generally tuffaceous in character, being rich in angular feldspar and ferromagnesian material" (*ibid*, p.5).

<u>Rarako Mudstone</u> - 360-390 m. (1200-1300 feet) This unit consists essentially of mudstones, which are often carbonaceous or calcareous. Marls and scattered pebbles occur, and three thick sandstone wedges occur in this formation around the northwesterly plunge of the Nakoro Anticline.

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* This figure was calculated from Rickwood's map, LNC-1, deducting the thickness of beds regarded as belonging to the Iavokia Mudstone.

Poruda Sandstone - 195-225 m. (650-750 feet). This unit consists of blue-gray sandstones, which are often calcareous and carbonaceous. Calcareous concretions are common, and rare pebbly and shelly beds occur towards the southeast end of the structure. Banded calcareous mudstones are common near the middle of this unit.

Poruda Mudstone - 90-300 m. (300-1000 feet). This unit shows marked thickness variation thickening consistently from 90 m. in the SE to 300 m. around the northwest plunge of the Nakoro Anticline. A high carbonaceous content and very thin bedding to banding are characteristic of this formation. Rickwood's description of this unit is one of the best available for any of the mudstones in this region and is quoted here:

"The formation shows great variation in argillaceous types though almost all are carbonaceous. Some of them, especially in the northwest, are specific of this formation.... a zone of dark concretionary mudstones with white pipe-like structures 1½" in diameter and 6" long... a strong benthonic element in the fauna.... a hard white flecked black and cream-brown limestone (occur-AK).... Generally occurring above this zone, only with a much greater lateral distribution, are very finely laminated black carbonaceous mudstones with fine white calcareous bands which weather to a reddish brown. The bands are usually not more than one tenth of an inch thick.... It is these muds which are prone to slipping.

(....Other mudstone types occur which are not specific to the Poruda. These are massive dark mudstones with flint-like concretions (like those of the Poruda sandstone), banded calcareous mudstone with calcareous pellets, shelly mudstone and silty members are especially prominent to the southeast.... varying from finely laminated to gritty laminated and massive types" (p.8).

Rickwood notes that the basal Upper Murua Sub-Group (Horupa Beds) is possibly locally unconformable on the Poruda over the NW plunge of the Nakoro Anticline. (*ibid*, p.9). It is worthy of mention, that a suspected unconformity between the Upper and Lower Murua has also been reported from the ~~Aro Aro~~ Aroaro area 25 km. to SW (locn. 14; APC Rept. LH-2, p.8).

As can be gathered from the above descriptions, and as has been stressed by workers in this area, the Lower Murua is ~~very~~ quite variable in this area, particularly within the Rarako and Poruda. The marked thickening of the Poruda (and Rarako), the sandstone wedges in the Rarako and the possible local unconformity at the top of the Poruda Mudstone are all best explained by assuming that the Nakoro Anticline had begun growing by this time. Both Carey and Rickwood have noted the common occurrence of "contemporaneous slump" structures within the Poruda Mudstone and Carey states that ... "quite large slump folds which show up on the dip map ..." are developed (APC Rept. LJ, p.9). This further helps to point to the instability of the Lower Murua depositional basin and possibly relates to the contemporaneous growth of the Nakoro Anticline.

Several sections, similar to that of Nakoro but generally less completely exposed, have been described from the region to the southwest of the Ekiere Fault, and all of the above named formations have been recognized or can generally be inferred from described sections. The Horbu Syncline section 25 km. to the north of Nakoro (locn. 8), has required re-interpretation because of ambiguity and conflicting statements in the report covering this area (APC Rept. LP). My interpretation is compared to Rickwood's earlier interpretation in figure 1.3-10.

A re-interpretation of the structure and stratigraphy of the Beleppa-Hahi area, 35 km. to the south of Nakoro (locns. 9, 10), allows an approximate column for the Lower Murua Sub-Group to be built-up by reasonable lithological correlation (refer section C). In Herehere and Harea Creeks, at the south end of the Upoia Syncline (locn. 10), the basal 850 m. consist light-gray foraminiferal mudstones with rare thin siltstones and sandstones (APC Rept. LM, p.8; the reader should refer to p.9 of this report as thicknesses I have given have required interpretation of an ambiguous statement). Approximately 30 m. from the base of this unit a massive, gritty to pebbly, often carbonaceous and shelly sandstone occurs which affords a good correlation with the Nakoro Sandstone of the Nakoro Formation. The overlying foraminiferal mudstones can, therefore, be regarded as the Rarako Mudstone, with the top not exposed. In the Beleppa-Hahi area (locn. 9), the top part of the Lower Murua Sub-Group is exposed (APC Rept. LM, p.10). The Upper 150-210 m. consists of blue-gray, micaceous and foraminiferal mudstones with thin sandstone bands and very rare molluscs. This unit was previously referred to as "Ungrouped Tertiary Sediments". Beneath this, occurs 255 m. of blue-gray sandy siltstones and silty mudstones with carbonaceous and calcareous bands and rare pockets of molluscs, referred to as the "Mudstone Group" (*ibid*, p.10). By their position at the top of the Lower Murua and because of the carbonaceous and calcareous content, I suggest that these beds correlate broadly with the Poruda of the Nakoro area. This unit, in turn, overlies a unit referred to as "Ungrouped Tertiary Sediments" which consists of "... very fine blue foraminiferal mudstones with oil odours." (*ibid*). Only the top 75 m. of this unit is exposed in straight section. This unit affords a reasonable correlation with the foraminiferal mudstones herein correlated with the Rarako Mudstone in Herehere and Harea Creeks (locn. 10). As the top of the Rarako mudstone equivalent is not exposed at the latter location, it is not known whether this and the Beleppa-Hahi section overlap or whether the Herehere section completely underlies the Beleppa-Hahi section. At any rate, if these sections completely overlap, the minimum thickness of the Lower Murua Sub-Group present here must be at least 1315 meters. It should be noted that the Lower Murua here is markedly less sandy than at Nakoro and probably represents a somewhat deeper environment.

In contrast to the Beleppa-Hahi composite section, the Lower Murua section exposed in Avaii Creek in the Horohoru Syncline (locn. 11), is 1011 m. thick (top not exposed) and consists principally of siltstones and cross-bedded silty sandstones which frequently contain molluscs, or are rich in foraminifera (APC Repts. LYC, LUD). The top part of the section is of a distinctly shallow-water, deltaic character and was originally thought to be the Upper Murua, Pawro Facies (refer later). Compared with Nakoro, this section is somewhat coarser, and appears to represent a shallower depositional environment. As at Nakoro, contemporaneous slump structures are reported from the upper part of this section. This thick section has not been satisfactorily subdivided, but a thick, 21-195 m. sandstone occurs at or near the base of the Lower Murua in this area - the <u>Orevi Sandstone</u> - which can be correlated approximately with the Nakaro Sandstone, and the presence of the Poruda in the top part of the section has been established (APC Rept. LYC, Paleo. Append.). McCormick (APC Rept. LUD), regarded the uppermost beds of the Avaii section as equivalent to the Rarako Mudstone, but this is apparently in error. The contact with the Upper Murua is exposed approximately 4.5 km. to the north of the Avaii section along the trough of the Horohoru Syncline (locn. 12). Assuming a maximum northward plunge of two degrees between these locations indicates that approximately 156 m. of Lower Murua is present above the highest beds examined in the Avaii section. This gives a total thickness of 1167 m. for the Lower Murua in this syncline. The Avaii section is, therefore, roughly equivalent to the thickest development in the Nakoro section. In contrast, at Upoia (locn. 13) about 9 km. to the west of the Avaii section, the Rarako Mudstone is notably thinner (189 m. in a complete subsurface section; APC Rept. LUC, Plate LUC-1), than at Nakoro (360-390 m.). This indicates that the major thickness changes in this area occur <u>across</u> the structural trends, rather than along them, and possibly indicates that the Upoia Anticline was a relative high during deposition.

Before leaving the Purari Trough, which marks the area of thickest and deepest Lower Murua sedimentation, it is important to point-out the occurrences of derived faunas within this sub-group. These occurrences are indicated on figure 1.3-8, where it can be observed that all ~~of these~~ are located in the area to the SW of the Ekiere-Fault.

<u>Vailala High and Vailala Trough</u>

To the northeast of the Ekiere Fault, the Vailala High became a very marked depositional feature during the Lower Murua, and the Lower Murua Sub-Group has a very different aspect than in the Purari Trough to the SW of this fault. Over the Vailala High, the Lower Murua occurs in a very thin, mudstone-siltstone-marl facies, the distribution of which reflects deposition over and around contemporaneous structural highs. To the east of the Vailala High, the Lower Murua thickens rapidly into the Vailala Trough (figure 1.3-8). We have, thus, both extraordinarily thin (60 m.; locn. 21) and extraordinarily thick (1200 m; locn. 29) Lower Murua sections in this area. In addition, the Lower Murua possibly overlies the Aure Group (? and Iavokia Mudstone ?) unconformably on the Vailala High. This points to a general and marked instability of this part the depositional 'basin' and indicates that contemporaneous local structural development was occurring.

The Lower Murua Sub-Group consists almost entirely of mudstones in these sections and has not been subdivided. These beds can, therefore, be referred to as the Lower Murua Mudstone.

Sections measured across the Vailala High and Vailala Trough are summarized in Table 1.3-IV. A line trending along the trace of the Kariava Anticline separates the thin sections of the Lower Murua to the west (60-330 m.) from the thick sections to the east (approx. 500-1200 m.; refer figure 1.3-8) and indicates the presence and importance of this structure during the deposition of the Lower Murua. The line of the Kariava Anticline can, therefore, be taken to mark the eastern edge of the Vailala High. It has been suggested, without definite proof, that the Lower Murua Mudstone is unconformable on the Aure Group at the northwestern end of the Kariava Anticline (locn. 25; APC Rept. LKA). I have photogeologically mapped an unconformity at the base of the Lower Murua Mudstone in the area west of the Maropo section (locn. 27). The photogeological horizon followed, is actually the boundary between the ridge-forming sands of the Aure Group and the more subdued topography of the overlying mudstones. It is possible that the overlying mudstones include beds which belong to the Iavokia Mudstone, as these sections (locns. 26, 32, 33) were described before the Iavokia Mudstone was recognized.

TABLE 1·3 – IV

SUMMARY OF SECTIONS OF TOA GROUP MEASURED TO EAST OF EKIERE FAULT

REFER FIGURE 1.3-8 — VAILALA HIGH ←→ VAILALA TROUGH

LOCATION	18	19	20	21	22	23 – 24	25	32	26	27	28	29
APC REPORT	LP	LP	LP	LP	LP, LKA	LP	LIA – LKC	LI	LI	LI ; LKD-10	LF ; LKA ; LKC	LF
TOA GROUP: UPPER MURUA MUDSTONE	VERY THIN MUDSTONE & SILTSTONES	24M Coralline siltstones	92M Coralline siltstones	70M mudstone and siltstone	162M sandy and calcac mudstone with molluscs mudstone conglomerate at base.	92M pale grey mudstone	214M mudstone, calcareous and shelly sandstones and grits basal mudstone conglomerate ?	absent PLIOCENE	1037M sandstone and mudstone	1220M sandstones, mudstones and sandy mudstone	120M+ mudstone — top not	120M+ mudstone reached —
TOA GROUP: LOWER MURUA MUDSTONE	MUDSTONE & SILTSTONE UNCERTAIN THICKNESS; -THIN-	158M Mudstone and marls ?	107 M Mudstone and siltstone ?	61M Mudstone and siltstone ?	113M+ foraminiferal mudstone	(absent) AURE ?	✱ 336M grey foram. mudstone with silty sandstone and carbonaceous mudstone	458M mudstone ?	488M mudstone ?	✱ 823M mudstone with 90m of tuffaceous sandstone and minor pebble cobble conglomerate and grits ?	✱ 686M mudstone	1220M siltstone and mudstone with thin sandstone.
TOA GROUP: IAVOKIA MUDSTONE	?	100 M Mudstones and marls (assumed to be the Iavokia Mudstone. ? AURE	? absent or sandstone ? GROUP	absent or sandstone ?	183 M mudstone with soft sandstone	GROUP	✱ 183M mudstone with calcareous sandstone ✱ adjusted	? AURE	GROUP	238M foraminiferal mudstone with thin tuffaceous sandstone becoming important toward top	✱ 226M mudstone	342M siltstone and mudstone with calcareous and marly bands towards base

— EASTERN EDGE VAILALA TROUGH —

LOCATION	30	31	15 ⊙	39 ⊗	40 ●	41	17 ⊙
APC REPORT	LR	LH-2	LH-2	LH-2	LH-2	LH-2	LG
TOA GROUP: UPPER MURUA MUDSTONE	92M Congl. with coral boulders and mudstones; 143 M Mudstones with shelly and calcareous sandstones	PAWRO FACIES 564M Mudstones siltstones and sandstones with molluscs; lenticular limestones — NE	NOT	305M Foraminiferal siltstones and sandy to gritty to pebbly coralline mudstones	90M Grey sandy limestone with shelly mudstones	Coralline limestones (Daudo Creek limestone)	NOT
TOA GROUP: LOWER MURUA MUDSTONE	396M Mudstones with sandstones and 30M of calcareous sandstone at base	732 M Foraminiferal siltstones and mudstones	REACHED	(ABSENT) AURE GROUP		? ABSENT	REACHED
TOA GROUP: IAVOKIA MUDSTONE	214M Mudstone with basal 76M formed of tuffaceous sandstone	397M Mudstones	275-427M *Mudstone; Several faulted sections*	● Refer figure 1.3-7 ● Refer figure 1.3-9		?	168M+ Mudstones with thin sandstones and marls near base

TABLE 1.3 – V

SUMMARY OF SECTIONS OF THE TOA GROUP MEASURED
IN THE COASTAL TROUGH

REFER FIGURE 1.3-9

LOCATION		° 21	34	° 23	35	36	37	38	30 – 31	32	33	
REFERENCE		LCA	LE – 1	KUGLER	LE – 2	LE – 2	LE – 2	LE – 2	LE – 2	LE – 2	LE – 2	
TOA GROUP	UPPER MURUA MUDSTONE	660M Mudstones with thin sandstone; limestone member near middle and shelly sandy mudstones at top	VERY POORLY EXPOSED MUDSTONE ? 1310M ?	NOT EXAMINED	915M Mudstone; sandy in places; thin basal conglomerates	915M Mudstone; sandy in places; thin basal conglomerates	1220M Mudstones; thin basal conglomerates	1220M Sandy mudstones with thin calcareous sandstone at top	NOT EXAMINED IN THESIS REFER PITT, 196~~7~~6			
	LOWER MURUA MUDSTONE	975M Foraminif. Mudstones; sandy material very rare		Massive dark mudstones with thin sandstones and calcareous mudstones	610M Mudstones	610M Mudstones	610M Mudstones with thin marly limestone at base; somewhat sandy	610M Mudstones with thin sandstones and limestones near base; basal 122 M is conglomerate sandstones	° REFER FIGURE 1.3-7			
	IAVOKIA MUDSTONE	427M Mudstones with a few silty and sandy mudstones	* 427M Foraminiferal mudstones with basal 135 M formed of thinly interbedded calcareous sandstones and mudstones	440M Mudstones and marls with some interbedded coarse sand-stones near top and pebble conglomerates in lower part	* 440M Marls and pebbly marls with pebbly sandstones and pebble conglom-erates in lower 220M	300M Mudstones, pebbly mudstone and conglomer-ates; poorly exposed	488M Marls with thin limestones and mudstone pellet conglomerate at base	565M Marls with basal 366M formed of argillaceous limestone; mudstone pellet conglomerate at base	150 – 180M Marls with coarse sands and conglomerates at base	488M Foraminiferal siltstones with thin calcareous sandstones and limestones	275M Marls with conglomerates at base	MAIPORA FORMATION

* Am~~m~~ended; refer section 1.3.1

○ figure 1.3-7

In the Vailala Trough to the east, the thickest measured sections (locns. 29, 31) are described as "... grey, well-bedded to thin sandstones" (locn. 29; APC Rept. LH-2, p.11). Similarly, the thinnest sections are described as mudstones and siltstones with occasional marly intercalations (locns. 18-24; APC Rept. LP and LKA) and ".... grey foraminiferal mudstones; soft light blue-grey clayey mudstones, laminated silty sandstones, and foraminiferal carbonaceous mudstones..." (locns. 25; APC Rept. LIA, p.5). It is remarkable, in view of both the thickness variations present and the apparent closeness of the source area to the east and north (refer figure 1.3-8), that the mudstone facies is so consistent and that <u>sand grade material</u> and <u>shallow-water characteristics</u>, as might be expected, are so <u>notably lacking</u>. Therefore, although the area of abnormally thin sections must have represented a contemporaneous struct~~ion~~ural high, the environment was not a particularly shallow one. Further, the source area to the east and north was probably of relatively low relief and chiefly supplied fine detritus to the depositional basin. This leads immediately to the conclusion that much of the sand grade and coarser material in the Purari Trough ~~of~~ to the SW must have been derived from the Vailala High.

<u>Coastal Trough</u>

To the south, the Coastal Trough (locns. 33-38) represents a third major area of Lower Murua deposition, which is very similar to and more or less continuous with the Vailala Trough. The "Murua Mudstones" received this name for the section of these mudstones in the Murua River of this area (locn. 33; APC Rept. LE-1), but these beds are very poorly exposed in the Murua River and form a very poor type-section. These sections, although thick (600-975 m.), consist almost wholly of mudstone and have not been subdivided. Again, these beds will be referred to as the <u>Lower Murua Mudstone</u>. Summarized descrip~~t~~-tions of these sections are presented in Table 1.3-V.

The northernmost of these sections (locns. 35-38) are 600 m. thick and consist of "... massive to thick-bedded blue-grey mudstones, often silty and micaceous, especially towards the top, and with occasionally hard calcareous bands, sometimes sandy" (APC Rept. LE-2, p.23; from a description of the undivided Upper Miocene of this area). The eastern sections (locns. 37, 38) become sandy to conglomeratic, and include brown marly limestones at the base of the section (*ibid*), and coarse blue-gray sandstones occur at the base of the section in Pa'atavi Creek (locn. 39; personal field observation). Farther toward the east, the Lower Murua Mudstone continues to coarsen as the entire Upper Miocene consists principally of sandstones and coarse conglomerates in the Yamuti-Fish Creek area about 25 km. to the north-east of Maipora Creek (locn. 38; refer Pitt, 1966).

Toward the south at Cupola (locn. 34), the Lower Murua Mudstone thickens to 975 m. and consists of foraminiferal mudstones, similar to those described above, with only very rare occurrences of sandy material (APC Rept. LCA). Belford (*ibid*, Paleo, Append. p.5), noted a decrease in the abundance of benthonic foraminifera toward the base of these beds, which indicates a shallowing of the depositional environment toward the top of this unit. The southward thickening toward Cupola is taken to indicate that the Cupola Structure had not yet begun to develop (refer next section).

Both the top and base of the Lower Murua Mudstone in this area appear to be basically conformable contacts, but Laing has suggested a slight unconformity at the base (Pap/22/38, p.15). The base of this unit is generally gradational with the underlying Iavokia Mudstone in the west, and the time equivalent marls and limestones of the Maipora Formation to the east. The base is determined paleontologically and corresponds to the Upper Miocene-Middle Miocene boundary (APC Repts. LE-2, LCA and LMA, Paleo. Append.). At Cupola (locn. 34) the top can be determined only by paleontology, but the top is generally marked by a conglomerate at the base of the Upper Murua Sub-Group in the area to the north (locns. 35-37).

C. UPPER MURUA SUB-GROUP; refer figure 1.3-9

Purari Trough

The Upper Murua Sub-Group (figure 1.3-9) has its thickest and most extensive development in the Purari Trough, with the axis of the trough being located immediately to the southwest of the Bevan Fault.

The thickest sections described (1,500 m.) occur in the area of the Mena Basin (locns. 2-5). Here, the Upper Murua Sub-Group has been subdivided into an upper mudstone formation - the Howme Mudstone - and a lower sandstone formation - the Boa Sandstone (APC Rept. LT).

In the Boa Creek type-section (locn. 2), the Boa Sandstone is 900 m. thick and consists mainly of thickly bedded to massive sandstones with common pebbly bands. The pebbles consist of quartz, igneous and metamorphic rock fragments. The Boa Sandstone is conformable on the Lower Murua Sub-Group and is overlain conformably by the Howme Mudstone.

The Howme Mudstone at this location is 600 m. thick and is described as dominantly a mudstone unit with a large number of bentonitic horizons. There is a marked increase in sandstone members within this formation from the east toward the west end of the Mena Basin (*ibid*). This unit is overlain conformably by the Era Group (Pliocene).

To the northwest of the Mena Basin, the Upper Murua Sub-Group thins to 930 m. in the Puri-Pide section (locn. 1), where the section has not been subdivided, but is described as mudstones and siltstones with a prominent calcareous sandstone - the "So-oi horizon" - at the base (APC Rept. LI). To the south of the Mena Basin, I have calculated the thickness of two undescribed sections from the geological map of the Kuku Basin (Puri East Sheet LZ-7; locn. 4, 5). The Upper Murua Sub-Group thickens from 1245 m. on the west limb (locn. 4) to 1695 m. on the east limb (locn. 5) where the Boa Sandstone is 1,000 m. thick and the Howme Mudstone 695 meters. Molluscan beds are reported to be numerous near the middle of this section in Sa-ori Creek (Puri East Sheet LZ-7; locn. 5). These calculated sections fit well with sections described from the east limb of the Goigi Basin (locn. 9; APC Rept. LP; see revised cross-section figure 1.3-10 of this thesis). Here, however, the Boa Sandstone equivalents are finer grained (the Horupa Mudstone and Huro Sandstone of APC Rept. LP) and consist principally of well-bedded mudstones and laminated carbonaceous siltstones, with fine calcareous sandstones and sandstones. A thick sand is developed at the base of the section, and a coarse-grained to pebbly sandstone 150-185 m. thick occurs at the top (Huro Sandstone). Sub-rounded to sub-angular chert, metamorphic fragments and quartz are the chief pebble constituents (information from APC Rept. LP). Attention should be drawn to the fact that Rickwood correlated the ~~thick,~~ highest pebbly sandstone in the Horbu Syncline (locn. 8; refer figure 1.3-~~9~~ 10) with the Huro Sandstone, whereas I have correlated it with the basal Horupa Sandstone. If Rickwood's correlation is correct, it implies a great thinning of the entire Upper Miocene section across the Bevan Fault, but his correlations cannot be conclusively argued.

To the east of the Kuku Basin and to the east of the Bevan Fault, an incomplete section of 854 m. of sandstones, siltstones and subordinate mudstones ~~have~~ has been described from the McDowal Syncline section (APC Rept. LI and LC; locn. 6). A conglomerate with igneous pebbles occurs at the base of this section, and lignitic plant remains occur in the lower part of the section. These beds have been reported as conformably overlying the Lower Murua on the west limb of this syncline, but a study of the aerial photographs suggests that the Upper Murua rises unconformably onto the Aure Scarp (McDowal Fault), on the east limb of this syncline (refer Plate I). This is probable, as the Upper Murua appears to have been deposited against the scarp of this fault f~~u~~arther to the south (refer later).

Approximately 55 km. to the SSE of the Mena Basin at Nakoro (locn. 7), thick sections (900 m.) of mudstones with thick sandstone members have been described. On the basis of these sandstone members, the section has been subdivided into two formations (APC Repts. LJ and LNC). The lower formation - the Horupa Beds - is 156-300 m. thick, thickening markedly toward the northwest end of the Nakoro Anticline, and consists of gray-green mudstones and siltstones with hard calcareous bands and a thin sandstone. These beds are frequently carbonaceous at the top. The base of the formation is formed by a thick sandstone which frequently contains pebbles of quartz, quartzite and chert. This basal sand is locally coarse at the northwest end of the Nakoro Anticline where an abrupt flattening of dip occurs; this led Rickwood to suggest a local unconformity between the Horupa Beds and the Lower Murua Sub-Group (information from APC Rept. LNC). (Regionally, however, the Upper Murua is conformable over the Lower Murua in the Purari Trough.) This probable unconformity, together with the northwest thickening of the Horupa Beds, indicates contemporaneous growth of the Nakoro Anticline during this time. This can be seen more dramatically by comparing the thickness of the Horupa Beds here (300 m. max.) with the thickness in the Kuku Syncline (990m; locn. 5).

The Huro Beds overlie the Horupa Beds conformably. An incomplete section 600 m. thick has been measured in the Eako Syncline (locn. 11). This unit consists of thickly interbedded sandstones and mudstones. The sandstone members commonly consist of interbedded flaggy sandstones and shelly mudstones. The base of the unit is marked by strong sandstones which are gritty and shelly in part, and a minor pebble grit to pebble conglomerate occurs about 75 m. from the base. This conglomeratic member coarsens notably to the southwest, where it contains pebbles of quartz, quartzite, felsite, sandstone and chert to 5 cm. in diameter, as well as massive corals to 30 cm. and molluscs (*ibid*).
This conglomerate occurs at approximately the same stratigraphic level as the Nakoro Breccia (refer later), which suggests that this section of the Huro Beds is very nearly complete.

The Horupa Beds ~~and~~ together with the basal sandstone of the Huro Beds are regarded as equivalent to the Boa Sandstone. This implies that the main body of the Huro Beds is equivalent to the Howme Mudstone, and indicates a general coarsening of this part of the section from the northwest toward the southeast. The basal part of the section, however, must fine in this direction.

About 105 m. above the base of the Huro Beds in the Horohoru Syncline (locn. 10), a sedimentary breccia composed of derived Middle Miocene limestone fragments and blocks occurs. This interval has been named the Nakoro Breccia and extensively described by Carey (APC Rept. LJ). To the north, on the eastern limb of the Goigi Basin, the Nakoro Breccia occurs approximately 90 m. above the top of the "Huro Sand" (refer later) and about 510 m. below the Pliocene. The Nakoro Breccia is an extremely important unit in its paleogeographic implications and is discussed fully later in this section.

To the west of Nakoro in Vara's Basin, and on the flanks of the Mekori and Pairi Anticlines (locns. 12-14), thick but incomplete sections of the Upper Murua Sub-Group occur. These sections have previously been described as part of the Pliocene succession (APC Rept. LJ, p.18 and plates 5 and 7), but subsequent paleontological study has shown these beds to belong to the Upper Murua (*ibid*, Paleo. Append.). The following description is adjusted from the original as required by the paleontological appendix of APC Rept. LJ. The Huro Beds here (locn. 13) are approximately 750 m. thick. The top 600 m. consists of mudstones and sandy mudstones with occasional sandstone bands and molluscan-rich bands. The basal 90-150 m. is formed of thickly interbedded sandstones and mudstones which have been correlated with the basal sandstone of the Huro Beds at Nakoro. These sands are generally lignitic and argillaceous, frequently fossiliferous and often carry pebbles of chert and quartz (*ibid*, p.18). These beds are overlain conformably by the Era Group (Pliocene) in Vara's Basin (locn. 12) and, on the west flank of the Pairi Anticline (locn. 14), are underlain by 195 m. (base not exposed) of interbedded sandstones and siltstones which can be assigned to the Horupa Beds.

Graphic stratigraphic columns (APC Rept. LC, plate 7) indicate an overall decrease in sandy material within the Huro Beds from east to west across this area, and this is suggested as well by comparing this section with that at Nakoro.

A marked decrease in sandy material toward the south from Nakoro is, also, evident. An incomplete section described from the Dowa Syncline (Beba Creek, locn. 15) is 1040 m. thick (top not reached) and consists of very foraminiferal mudstones with occasional silty bands and a basal sandstone 23 m. thick (the Piamorra Sandstone; APC Rept. LH-2). To the south and east of this section (locns. 16, 17) a basal Upper Murua sandstone (the Aroaro Sand) is a quite prominent feature. It attains a thickness of 135 m. (locn. 17) and is frequently pebbly to conglomeratic, with pebbles of quartz to 4 cm. in diameter (locn. 16). At Aroaro (locn. 16), this sand is associated with thin argillaceous limestones and mollusca and is believed to be locally unconformable on the Lower Murua Sub-Group (APC Rept. LH-2). This section occurs adjacent to the Kuku Fault, on the upthrown side, and possibly indicates pre-Upper Murua movement on this fault.

The tendency for the Upper Murua to fine toward the south is continued to Hohoro (locn. 18), where the section consists almost entirely of foraminiferal mudstones, with only minor sandy mudstones and rare thin argillaceous limestone and fine-grained sandstone bands (APC Rept. LHB). A maximum of 420 m. of the top part of the Upper Murua Sub-Group is exposed here, and the base is marked by an extensive and transgressive zone of 'plastic' or running mudstones of the same age (*ibid*). These running mudstones appear to be associated with diapirism within the Upper Murua Sub-Group (refer section 2.2.3). A total section of the Upper Murua here is probably not greatly in excess of 1,000 m. thick, but the APC Hohoro No. 2 Well drilled through approximately 2100 m. of mudstones which are described as occasionally silty, calcareous and carbonaceous. These beds were assigned to the Upper Murua, but the geology here is complex, and I have suggested that this represents a tectonically thickened section (refer section 2.2.3). It is noteworthy that the basal Upper Murua in the well-section consists only of occasional thin sandstones interbedded with mudstones in the bottom 15 m. of the Upper Murua.

About 30 km. to the east of Hohoro (locns. 19, 20), a thick section of the Upper Murua has been reported (APC Rept. LM). Here, the Upper Murua occurs in two distinct facies units; a ? lower, relatively deep-water foraminiferal mudstone facies to the east (locn. 20); and to the west (locn. 19), an ? upper, shallow-water facies (<u>Pawro Facies</u>, refer later) consisting of blue-gray mudstones rich in mollusca and containing large blocks of colonial corals to 60 cm. in diameter (*ibid*). The 'normal' foraminiferal mudstone facies is estimated to be no more than 1050 m. thick (top not reached), but this assumes a straightforward section and the section is probably faulted (locn. 20; refer Plate I). The shallow-water facies is reported to be at least 570 m. thick (locn. 19; top not reached), and Stanley (*ibid*) suggested that an angular unconformity separates these beds from the Lower Murua. Glaessner, however, placed the paleontological boundary between the deep-water and shallow-water facies 270 m. from the top of Stanley's 570 m. section (locn. 19) and regarded the lower contact with the Lower Murua as a fault contact (*ibid*; Paleo. Append.). This problem cannot be conclusively solved with the data in hand, but I am inclined to accept Stanley's description and interpretation. This section dips off the Eako-Keari Fault, and this fault can be related genetically to the Bevan Fault, which probably began development late in the Lower Murua or early in the Upper Murua (refer later, also, section 2.2.3). A late Lower Murua structural high along this fault, as is required by Stanley's interpretation, is not unlikely for this reason. In addition, a structural high along this fault early in the Upper Murua offers a probable solution for the locally coarse to conglomeratic basal sands at Aroaro and Akauda (locns. 16, 17), and explains the coarsening toward the <u>southwest</u> of the basal conglomerates of the Huro Beds in the Eako Syncline (locn. 11). Further, even if the contact in question is a fault contact, the presence of a shallow-water facies here is difficult to explain, unless a contemporaneous high over the Eako-Keari Fault is assumed, as a thick development of the deep-water facies occurs to both the east and west of this section. The total thickness of the Upper Murua at this location is difficult to judge, but is probably at least of the order of 1050 meters, with the top not reached. The general picture envisioned here, is one of the Upper Murua thinning toward a local shoal area, over the developing Eako-Keari Fault, from relatively deep-marine troughs to both the east and west.

A brief note is necessary here regarding the section exposed in the Beleppa-Hahi area (locn. 21; APC Rept. LM). A thick, north-dipping section described from this area was assigned to the Upper Murua on the basis that the structurally lower part of the section was of this age and this part of the section was known to be overturned (*ibid*, p.11). The section in question was, therefore, inverted for presentation (Plate LM-4, Col. 1), but it is clear from the paleontological appendix accompanying the field report that the section (Plate LM-4 Col. 1) should <u>not</u> have been regarded as inverted because as presented, it demands an inverted faunal succession (*ibid*, Paleo. append. p.1-2). Following this reasoning, most of the section described in Report LM as Upper Murua is, in fact, Lower Murua (refer section B)*, and a fault, separating the overturned beds from the normal section, is required (refer section 2.2.1-F). After making the alterations required by this discussion, this leaves only the basal 585 m. of the Upper Murua exposed in this area (composite of cols. 3 and 4 of Plate LM-4). These beds in ascending order, are formed of the upper 150-180 m. of the "Ungrouped Tertiary Sediments," the "Petroliferous Group" and the "Ungrouped Tertiary Sediments" (uppermost) of APC Rept. LM. The beds consist principally of massive gray, carbonaceous and sometimes silty, foraminiferal mudstones. The middle 150 m. of the section (the "Petroliferous Group") contains thin, coarse siltstones and calcareous sandstones, interbeds, and frequently smells of petroleum. Comparing

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* For completeness, in Column 1 of Plate LM-4, all beds below sample No. 75 are regarded as Upper Murua, and all samples above No. 75 can be regarded as Lower Murua. The abovementioned fault probably passes through the covered interval at the <u>base</u> of the section, or at the <u>top</u> of the column as drawn in Plate LM-4.

this section with Hohoro to the west, it is noteworthy that sands occur in this section which is located farther toward the supposed contemporaneous high along the Eako-Keari Fault.

The Upper Murua Sub-Group of the Purari Trough can now be summarized. It consists dominantly of foraminiferal mudstones which locally attain a thickness in excess of 1500 meters. During this time, the trough was an area of essentially continuous deposition, as both the upper and lower contacts are regionally conformable. An important sandstone development occurs in the Mena Basin area (locn. 5) and again in the Nakoro region. In the Purari Trough, probable local unconformities occur along with local thickness and facies changes, suggesting contemporaneous structural growth within the trough. A strong basal sandstone unit, which is commonly pebbly to conglomeratic, is a feature of all of the sections except those located to the far south and southwest (locns. 18-21).

All of the thickest sections occur immediately to the west and south of the Bevan Fault. To the east and north of this fault, the Upper Murua is either absent or occurs as small, incomplete outcrops in synclinal sections. For these reasons, I suggest that the Bevan Fault had begun growth by this time and delimited the thickest development of the Upper Murua to the north and east (refer also, section 2.2.3). In the north, the strong sand development in the lower part of the section (~~and~~ Boa Sandstone) is best explained as the result of a local high developed on the upthrown side of the Bevan Fault immediately to the north. Negative evidence in support of this is the fact that rocks of the Upper Murua Sub-Group are nowhere found to the north of this fault. To the south and east, the Upper Murua Sub-Group is found to the immediate northeast of the Bevan Fault (locn. 6; 640 m.), but the top is not preserved and the complete thickness is not known. I suggest, however, that the Bevan Fault marked a structural rise within the basin and that the Upper Murua thins across this structure toward the northeast. That this is true <u>generally</u> can be seen by the fact that the Upper Murua is developed in a very thin, shallow-water facies over the Vailala High, but I would suggest a specific relationship to the Bevan Fault. Before describing sedimentation over the Vailala High, however, it is important to digress for a more complete discussion of the Nakoro Breccia.

The salient points about the Nakoro Breccia are firstly, that it contains numerous irregular fragments and blocks of Middle Miocene limestone to 1.5 m. in diameter, and derived Middle Miocene *Lepidocyclina* occur in the marly matrix of the rock; secondly, the vast majority of the derived fauna is of Middle Miocene age, but derived Cretaceous foraminifera occur as well. Thirdly, the breccia occurs at approximately the same stratigraphic position wherever found. Finally, although the known occurrences of this breccia stretch over a distance of approximately 50 km. in a line parallel to and on the southwest side of the Ekiere Fault, none of the occurrences is more than about 10 km. distant from the Ekiere Fault. For these reasons, and because, a southwesterly source would involve very improbable assumptions, Carey (APC Rept. LJ) concluded that the breccias were derived from a steep submarine scarp along the Ekiere Fault. A necessary corollary to this conclusion is that we must assume that reef limestones were developed near this fault line during the Middle Miocene. Although no such limestones are known from the Middle Miocene rocks of this area, this has proven a reasonable assumption (refer section 1.3.1).

The problem of derived Upper Cretaceous and Eocene foraminifera within the Upper Murua of this region finds a solution in, and lends support to, Carey's solution for the Nakoro Breccias (refer, also section 1.1 and 1.2). These occurrences are plotted in figure ~~1.3-9~~ 1.1-1, where it is quite clearly seen that ~~all~~ the reported locations lie to the southwest of the Ekiere Fault. The nearest exposures of Eocene and Cretaceous rocks at present are on the Aure Scarp (locn. 23), and it is significant that derived fauna of these ages are extremely rare in the Aure Group to the northeast of the Ekiere Fault (refer sections 1.1 and 1.2). It is imminently probable, therefore, that this derived fauna had its source in a contemporaneous scarp along either the line of the Ekiere Fault or the supposed concealed continuation of the McDowal Fault. Further, the chert and igneous pebbles in Upper Murua conglomeratic beds (see figure 1.3-9) find their most ready source in the Eocene limestones and lower Aure Group conglomerates such as presently exposed on the Aure Scarp to the north, and are probably best related to the supposed contemporaneous scarp along or near the Ekiere Fault.

Another phenomenon relating to a probable scarp in this area during the Upper Murua are the extensive slump zones reported from these rocks at the northwest end of the Iavokia Anticline (locn. 5). The slumps occur in sandy, carbonaceous mudstones and are described as follows:

> "Chaotically bedded sediments have been noted in two stratigraphic positions. They are about 100-150 feet thick, overlain and underlain by well bedded sediments... This formation is obviously such as could be formed by the submarine slumping of a formation consisting of thin-bedded, fine grained sediments containing occasional thin beds of sandstone and marl". (APC Rept. LYC, Append. II, p.3).

The basic conclusions of this discussion of the Nakoro Breccia and related phenomena is that <u>the Upper Murua sediments appear to have been deposited against a contemporaneous scarp of the Ekiere Fault</u>, and that <u>this scarp formed a source of sediment for the Purari Trough to the southwest of this fault</u>. This being the case, the suggested unconformity against the Aure Scarp (McDowal Fault) in the McDowal Syncline (locn. 6) possibly represents the original configuration of these sediments against the scarp. This implies that most of the movement on this fault is pre-Upper Murua. To the south, however (locns. 10,20), the Upper Murua is clearly overridden by the Ekiere Fault, indicating some post-Upper Murua movement on this fault.

Vailala High and Vailala Trough

A necessary extension of the aforegoing interpretation of the Ekiere Fault as a contemporaneous scarp, is that the Upper Murua would be expected to show a great facies and thickness change across this fault, and this is seen to be exactly the case. To the northeast of the Ekiere Fault, the Upper Murua thins across the Vailala High to as little as 24 m. - with conformable relationships above and below! - before thickening again into the Vailala Trough. The Upper Murua then thins toward the eastern (and northern) edge of the Vailala Trough, where a shore-line facies (Pawro Facies) is preserved in unconformable relationship with the underlying units.

Sections measured over the Vailala High have been summarized in Table 1.3-IV. These sections vary between 24 m. and 210 m. + in thickness and consist~~s~~ principally of calcareous mudstones and coralline siltstones. Local basal conglomerates, the pebbles consisting of reworked sediments, occur on the southwest flank of the Keka Dome (locn. 28) and the Ivori Junction Anticline (locn. 31) where they are overlain by calcareous sandstones, grits and shelly beds. An unconformity at the base of the Upper Murua has been suggested on the southwest flank of the Keka Dome (APC Rept. LKA), and the Upper Murua has been mapped as unconformably overlying the Aure Group on the northeast flank of the Iori Anticline (APC Rept. LP). In the northernmost of these sections, it seems probable that an intra-Upper Murua unconformity occurs, but this point could not be satisfactorily argued without a field-check.

To the east of the Vailala High, the Upper Murua thickens into the Vailala Trough (locns. 32-36), the axis of which was located to the west of the Lower Murua depositional axis. The thickest section occurs in Maropo Creek (locn. 34) where 1220 m. of mudstones, sandstones and siltstones are assigned to the Upper Murua (APC Rept. LI). In this area, the Upper Murua conformably overlies the Lower Murua, but is unconformably overlain by Pliocene sediments in the Paun Basin (locn. 38).

The section on the eastern edge of the Vailala Trough is best described in the Pawro Basin. In Pawro and Apokia Creeks, on the western limb of this basin (locn. 36), the Upper Murua is conformable over the Lower Murua and is conformably overlain by the Pliocene. A complete section 555 m. thick has been described (APC Rept. LH-2), consisting of richly to sparsely foraminiferal mudstones and cross-bedded sandy siltstones. The section coarsens and becomes more calcareous toward the base, where calcareous concretions and thin limestones occur. These beds indicate a shallow-water environment and are known as the Pawro Facies. Eastward across the basin, these beds become unconformable on the Aure Group (locn. 38), and consist principally of shelly, conglomeratic siltstones which contain boulders of the underlying rocks. As well, the Upper Murua is probably overlain unconformably by the Pliocene here. Similar sections,with an unconformity at the base, have been measured along the eastern edge of the Vailala Trough (locns. 39-42). Locally thick limestones, to 75 m. thick, are developed (locns. 39-41), and shelly conglomerates, grits and mudstones predominate in the Isa Syncline section (locn. 42), where an intra-Upper Murua unconformity has been reported (APC Rept. LR). An unconformity between the Upper and Lower Murua in the Suniyana Syncline (locn. 43), also, seems probable from a study of the aerial photographs. It is clear that these sections represent an Upper Murua shoreline facies, marking the eastern edge of the Vailala Trough and the western edge of the uplifted source area (Dude-Murua Anticlinorium; refer section 2.1.1) at this time. It is worthy of note that the axis of the Pawro Basin shifts progressively eastward across the basin upward through the section, from the Lower Murua through the Pliocene, suggesting essentially continuous folding of this basin throughout this time.

Coastal Trough

To the southeast, the Coastal Trough continued to receive thick sediments (to 1200 m.) during the Upper Murua. In this area the Upper Murua, which consists principally of mudstones, has not been formally subdivided and can be referred to as the Upper Murua Mudstone. The relationships with the underlying Lower Murua Mudstone and overlying Rim Group (Pliocene) are conformable.

Four similar sections are described on the northern side of the trough (locns. 45-48). These thicken from 900 m. in the west (locns. 45, 46) to 1200 m. in the east (locns. 47, 48) and are described as mudstones which are sandy in the upper part. A conglomeratic unit about 150 m. thick occurs at the base of the western sections (locns. 45-47), consisting of conglomerates, grits and sandstones with shelly, pebbly mudstones near the base (APC Rept. LE-2 and LMA). The conglomerates contain igneous boulders to 25 cm. in diameter. The distribution of the basal conglomerate suggests local derivation from the coarse conglomerates exposed immediately to the north (refer Morai River Formation, section 1.3.1-C), as similar conglomerates are not exposed to the north of the easternmost section (locn. 48) where a basal conglomerate is not found.

On the south side of the Coastal Trough at Cupola (locn. 44), a section 660 m. thick has been described (APC Rept. LCA). The basal 270 m. of this section consists of gr~~e~~ay foraminiferal mudstones with occasional mulluscs. These are overlain by a 90 m. interval of interbedded mudstones, sandstones and calcareous sandstones with a shelly grit, and the top of the section consists of 300 m. of gr~~e~~ay, silty mudstones which are foraminiferal and shelly. The sandy and shelly interval near the middle of the section grades into limestone (the Baiyaho Limestone) to the northwest.

The Cupola section, therefore, is thinner than the sections to the north and, with the molluscan content and limestone development, represents a more shallow depositional environment. This can be taken to indicate that uplift of the Cupola structure probably began at this time, the sediments thinning and the environment shallowing toward this structure. This implies that the Muruwaie Syncline was a depositional syncline from this time onwards. ¶The presence of the source area to the north of the Coastal Trough is indicated firstly, by the basal conglomerates in the northern sections, secondly by the lack of these conglomerates in the Cupola section and thirdly, by the presence of sandy material in the top part of the northern sections and its absence in the Cupola section, *i.e.* indicating an overall decrease in grain-size away from the source area.

D. CONCLUSIONS

The data for the Toa Group and my interpretation of these data are summarized in the form of the isopach and lithofacies maps of figures 1.3-6 through 1.3-9.

In each of the three main depositional troughs, the Toa Group is essentially a relatively deep-marine, foraminiferal mudstone unit. Approximately 3100 m. of this facies accumulated in the Purari Trough (figure 1.3-6), clearly demonstrating that strong subsidence of the depositional basin was a dominant feature throughout the deposition of this thick group. The area of strongest subsidence migrated to the southwest during this time (compare figure 1.3-8 with 1.3-9). Following a phase behind the strong subsidence, the uplifted area to the east and north increased in area and spread to the southwest. This can be seen firstly from the position of the Upper Murua shoreline and secondly, from the fact that the Upper Murua, particularly in the area to the east of the Ekiere Fault, represents a shallower depositional environment than the underlying beds. In addition, molluscan-rich beds and cross-bedded units, although infrequent, are scattered throughout the Upper Murua Sub-Group in the Purari Trough, suggesting a tendency toward shallowing conditions during this time. It is probable, therefore, that the floor of the depositional basin was being regionally uplifted at this time in spite of the strong local subsidence which was occurring. Each of the aforementioned features, *viz.* southwestward migration of both subsidence and uplift and the tendency toward a shallowing depositional basin, continued and became more accentuated during the Pliocene (see section 1.4).

As illustrated in figures 1.3-6 through 1.3-9, the Toa Group was deposited in a series of sharply defined and, for the most part, deep troughs. In the most general sense, this indicates that a broad "folding" of depositional basin was occurring during the deposition of this group. The amplitude of this "folding" was of the order of 1500 meters. More specifically, however, the deepest troughs and the thickest accumulations of sediments can, in the first instance, be related to recognized major faults. This is most clearly seen for the Upper Murua Sub-Group (figure 1.3-9). The thickest development of the Upper Murua occurs just to the southwest, and on the downthrown side of the Bevan Fault. In addition, the case has been argued that the Upper Murua was deposited against a contemporaneous submarine scarp of the Ekiere Fault. That this was in fact a <u>submarine</u> scarp is indicated by the fact that thick, relatively deep, marine sediments (at least 1200 m.) were deposited against the scarp, while a very thin development of shallow-marine sediments of this age (210 m. max.) is almost always present on the upthrown side. The absence of the Lower Murua over the Iori Anticline and the concentration of sandy material to the west of this scarp, however, indicate at least some degree of emergence and erosion on the upthrown side (the Vailala High). The areal extent of the emergent area is difficult to judge at present, because the area east of this fault is covered by thick Pliocene and Recent sediments to the north, and exposures to the south are too deep.

The Lower Murua Sub-Group is related to the McDowal Fault in the same manner as the Upper Murua is related to the Bevan Fault in that the thickest development of the Lower Murua occurs immediately to the southwest, and on the downthrown side of the McDowal Fault. This situation is particularly evident in the Te Creek area, where the McDowal Fault is thrust over the thickest known section of the Lower Murua (1590 m.). In contrast, on the upthrown side of the McDowal Fault, the Lower Murua has its thinnest known development (60-330 m.). In considering the Lower Murua in relation to the McDowal Fault, however, an additional factor is introduced by having recognized that the Upper Murua Sub-Group was deposited against the scarp of both this and the Ekiere Fault, *i.e.* implying the existence of these scarps in the Upper Murua. By realizing that these faults are essentially Upper Murua features, we can then observe that isopachs for the Lower Murua in the Te Creek area trend directly into the trace of the Ekiere Fault near McDowal Island (locn. 40). In a subsequent section (refer section 2.2.1), I argue that the Ekiere Fault is a relatively flat thrust-sheet which has overridden the McDowal Fault to the south of McDowal Island, and I now suggest that Ekiere thrust-sheet has completely overridden the thickest and deepest part of the Lower Murua as shown in figure 1.3-11. The amount of thrusting involved at the front, or toe, of this thrust-sheet is of the order of 10 km. (refer figure 1.3-11), and the major part of the thrusting occurred either late in the Lower Murua, or very early in the Upper Murua. It should be emphasized that the McDowal Fault, which marks the north-eastern edge of the thickest Lower Murua, has itself overridden this side of the trough.

The idea that the thickest part of the Lower Murua in the Purari Trough has been overridden by the Ekiere Fault, suggests that the isopachs and lithofacies map for this sub-group can be restored, to a large degree, simply by restoring the Ekiere Fault to a pre-thrust position. This is done in figure 1.3-11. Assuming that the folding of the Ekiere thrust-sheet has resulted in an additional 10 km. of movement at the back, or heel, of the thrust-sheet (refer section 2.2.1; see figure 1.3-11), the most conspicuous result of this restoration is that it replaces the thick development of the Lower Murua and Iavokia Mudstone in the Vailala Trough to a position adjacent to the late-Middle Miocene structural rise over the Dude-Anticline (and west flank of the Dude-Murua Anticlinorium). This restoration, therefore, reveals a good reason why this thick section occurs and, as well, enhances the argument for regarding the Dude-Murua Anticlinorium as a structural unit which delimited the eastern edge of the Vailala Trough.

The second major result of this interpretation and restoration is that all folding and faulting which can be genetically related to the Ekiere thrust-sheet can then be regarded as having developed principally during the deposition of the Upper Murua Sub-Group. This case is argued in a subsequent section (refer section 2.2.1), and these structures can be enumerated as follows: (refer Plate I).

Cross Fault A	"Haha Fault"
Yoai Anticline	Iova Syncline
Yoai Syncline	Heawa Syncline - Paun Basin
M'bwei Syncline	Kariava Anticline
Isa Syncline	Ivori Junction Anticline
Iala Anticline	So-oi Anticline
Suniyana Syncline	So-oi Syncline - Keke's Basin
Suniyana Anticline	Ekiere Fault
Maugwi Anticline	Faulting of Imbricate Belt.
Hadina Anticline	

In addition to the abovementioned Upper Murua deformation above the Ekiere thrust-sheet, I have recognized the presence of a structural high (the Vailala High), over the area between the Kariava Anticline and the Ekiere Fault, during the deposition of the Iavokia Mudstone and the Lower Murua Sub-Group. This structural high, as can be seen from the restoration of figure 1.3-11, is probably best related to early uplift on the McDowal Fault (now overridden by the Ekiere Fault), which marked the steep eastern edge of the Purari Trough at this time.

I have, also, outlined areas of localized folding and faulting within the Purari Trough during the deposition of the Upper Murua Sub-Group. These structures are the <u>Nakoro Anticline</u>, and the <u>Eako-Keari Fault</u> and (?) the <u>Upoia Anticline</u>. The character of the Rarako Mudstone and the Poruda Mudstone on the Nakoro Anticline suggests that this anticline may have actually begun development during the latter part of the Lower Murua, as does the probable unconformity at the base of the Upper Murua Sub-Group at the south end of the Upoia Syncline. In a subsequent section, all of these structures are related genetically to the Bevan Fault (refer section 2.2.3-F), which is held to have delimited the eastern edge of thickest sediment accumulation in the Purari Trough during the deposition of the Upper Murua Sub-Group. Development of these structures at this time is, therefore, not unexpected.

In the Coastal Trough, the most important deformation recognized is the late Middle Miocene uplift and folding of the Dude-Murua Anticlinorium to the north of this trough, which is marked by the unconformity at the base of the Toa Group along the northern edge of this trough. Uplift of the Cupola structure during the deposition of the Upper Murua Mudstone is postulated to explain the thinning and shallowing of this unit toward this structure.

Finally, a comment is necessary regarding the source area(s) of the Toa Group. Although the Toa Group is a markedly finer unit than the underlying Aure Group, this can in no way be taken to indicate that the Toa Group represents a tectonically quiet period, as demonstrated above. Nor, can we assume that sediment supply was substantially less during the deposition of the Toa Group, as large thicknesses (to 3100 m.) of these sediments accumulated over a large area (refer figure 1.3-6). The principal factor that governed the overall grade of the Toa Group must have been, therefore, that the source area, which consisted almost totally of Aure Group sediments, yielded little more than mudstone-grade clastics to the depositional basin. This conclusion is consistent with the nature of the Aure Group, which consists almost entirely of unstable mineral components that would be expected to weather to mud-grade particles very rapidly. In such an environment as this, it should perhaps be considered that the rare influx of sands represent, generally, the same extreme conditions that in other environments yield conglomerates, and conglomerates per se become elements of major interest, *e.g.* the influx of sandstone members in the Nakoro Area in association with the scarp of the Ekiere Fault to the east, and the thin basal conglomerate of the Huro Beds in the Eako Syncline in association with the Eako-Keari Fault to the west.

1.4 P L I O C E N E

The Pliocene rocks of this region, like the Toa Group, were deposited marginally to both the uplifted and actively rising Kukukuku Lobe to the east and the Central Ranges to the north. During the Pliocene, however, both the axis of sedimentation and the intra-basinal structural highs shifted farther to the west and south, and the uplifted source areas to the east and north increased in size. These differences, however, are an expected extension of the basic pattern established for the underlying Toa and Aure Groups. The Pliocene sediments, therefore, represent a continuation of the regression from the Kukukuku Lobe and a further encroachment of clastics on to the area of the former Puri Shelf.

In contrast to the underlying Toa Group, the Pliocene rocks of this region have the general character of the molassic type of sediment. The Pliocene is basically a sandstone unit with minor mudstones and conglomerates and is, therefore, a coarser unit than the Toa Group, reflecting the increased area, and probably amount, of uplift in the source area. In addition, the Pliocene rocks show abundant evidence of shallow-water deposition. The lower part of the Pliocene section is generally of a shallow-marine nature, whereas the upper part is commonly fresh-water to brackish with minor marine intercalations. Coal beds are common in the upper part of the Pliocene, and non-marine deposits commonly mark the top of the section.

As with the Toa Group, Pliocene rocks were deposited in three distinct troughs, corresponding to the Purari Trough, Vailala Trough and Coastal Trough; these troughs were separated by tectonically active structural highs. The axis of the largest and most important of these depositional troughs, the Purari Trough, occurs immediately to the south and west of the Kuku Fault, where approximately 2150 m. of Pliocene sediments accumulated. From the axis of this trough, Pliocene sediments then thin to the west over the present area of the Delta Embayment. The second largest trough, the Coastal Trough, coincides closely with the trough of the Muruwaie Syncline. Probably not more than 915 m. of Pliocene sediments accumulated along the axis of this trough. In the Vailala Trough a maximum of about 610 m. of Pliocene sediments accumulated in the form of fairly restricted basins. A fourth area, the Tuoa Basin (refer Plate Ia), possibly contains Pliocene sediments, but this basin is known only from photogeology and will not be discussed further.

The Pliocene in the aforementioned areas has been subdivided as shown in Table 1.4-I (figure 1.4-1). These subdivisions basically delimit rock units, and a strong sand development commonly occurs at or near the palentological boundary between the Pliocene and the Upper Miocene. In areas where the basal Pliocene is in a mudstone facies, however, the base of the Pliocene can only be placed by paleontology. Paleontologically, the base of the Pliocene has been taken at the first appearance of species of <u>Rotalia</u>, <u>Elphidium</u> and Miliolidae (APC Rept. WR). A marked increase in benthonic faunas (including macrofossils) and concomitant decrease in pelagic faunas generally occurs at this boundary as well (APC Rept. LE-2).

With the exception of the area of the Paun-Pawro Basin, the Pliocene has been mapped as conformably overlying the Upper Miocene. In the latter area, the Pliocene overlies Upper Miocene rocks unconformably.

1.4.1 <u>THE PURARI TROUGH ; ERA GROUP</u> (Figure 1.4-1, Locations 1-16)

The Kuku Fault effectively marks the southern and western limit of important surface deformation in this region, and the axis of thickest accumulation of Pliocene sediments in the Purari Trough (approx. 2165 m.) occurs immediately to the south and west of this fault.

Era Group

The Pliocene rocks of this area have been called the <u>ERA GROUP</u> (APC Rept. LJ; Paleo. Append.) because of the thick section (2165 m.) of this group exposed in the Era River (locn. 1). This section has been described as follows (APC Rept. LC):

Upper Group (Depot Sandstone) - 610 m. (2,000 feet) -

Thick sandstones and fine-fissile sandstones with clay, mudstones, coals and a few thin limestones. The coals occur in seams from 35 cm. to 6 m. thick in the upper and lower parts of this unit.

Middle Group - 1035 m. (3,400 feet) -

Alternating sandstones and argillaceous sandstones with calcareous grits and thin limestones. The more calcareous members are very fossiliferous.

Lower Group (Rapids Sandstone) - 518 m. (1700 feet) -

Hard thick sandstones, calcareous sandstones, mudstones and grits with intercalated limestones.

To the west and north, lithologically similar sections have been measured in greatly reduced thicknesses (see figure 1.4.1). On both the north and south flanks of the Puri Anticline (locns. 5, 6), cross-bedding is common in sandstones, and on the south flank of this structure (locns. 6) the top 305 m. is composed of non-marine sandstones (Bur. Min.Res.Pub.No.6, p.12).

Pliocene rocks have not been found to the north of the Purari Fault (except for Plio-Pleistocene volcanics), and this, together with the known northward thinning and previously established depositional patterns, makes it highly unlikely that Pliocene sediments ever accumulated to any great thickness to the north of this fault.

To the east, the Era Group has been commonly divided into an upper sandstone facies, the <u>Vaiviri Formation</u>, and a lower mudstone facies, the <u>Ekoa Formation</u> (Report LJ, p.16-20).

At Orloli (locn. 7), the <u>Vaiviri Formation</u> is at least 1645 m. thick. The lowest beds exposed, a 120-150 m. calcareous sandstone unit, are believed to approximately mark the base of this formation. This formation consists principally of thick, ill-sorted and angular, irregularly bedded and often cross-bedded sandstones with interbedded siltstones and mudstones. Toward the base of the section, shelly layers become common and cross-bedding in the sandstones becomes less frequent.

Throughout the lower 1065 m. of section irregular, lenticular sub-bituminous coals to 1.8 m. thick are common, and lignitic bands occur in the upper part of the section. The top 245 m. to 305 m. of the section is non-marine and is formed of conglomerates with interbedded carbonaceous sandstones and mudstones. This conglomeratic unit is conformable, but could be of Pleistocene age. (Information from APC Rept. LOA, p.6-8).

An additional 915 m. of Pliocene beds, presumably belonging to the Ekoa Formation, are believed to be exposed beneath the Vaiviri Formation at the eastern end of the Orloli Anticline, but these beds have not been examined in the field. It has been estimated that the total thickness of the Era Group present in any one section here is not greatly in excess of 2135 m. (APC Rept. LOA). ¶A similar but much thinner section (approx. 765 m.) of the Vaiviri Formation has been measured on the north flank of the Hohoro Anticline. In this area, grits and conglomerates, with quartz and volcanic pebbles to 8 cm. and small sedimentary boulders to 15 cm. occur in the formation (APC Rept. LHB, p.16).

The Ekoa Formation, as originally described (APC Rept. LJ, p.18) includes beds of Upper Miocene age (*ibid*, Paleo. Append.). It is commonly and correctly regarded, however, as a sandy mudstone and mudstone facies occurring at the base of the Pliocene section in this area. The best descriptions of this formation comes from the Hohoro area (locn. 8). Here, the Ekoa Formation equivalent has been sub-divided into two units (APC Rept. LHB, p.13-15). The lower unit, the Hohoro Formation, varies between 295 m. and 410 m. in thickness and consists of alternating mudstones, sandy mudstones, calcareous mud-stones and sandstones. The sandstones are laminated and often cross-bedded and rare grits with pebbles to 6 mm. occur. The upper unit, the Doabea Formation, consists of blue-gr~~e~~ay mudstones with, interbedded thin calcareous bands. Carbonaceous mudstones and shelly bands are common. The Doabea Formation varies in thickness from 190 m. to 290 meters (information from APC Rept. LHB, p.13-15).

The sandy Hohoro Formation is thickest at the northwest end of the Hohoro Anticline, where the muddy Dobea Formation is thinnest. Conversely, the Dobea Formation is thickest at the southeast of the Hohoro Anticline where the Hohoro Formation is thinnest. The maximum total thickness of these two units present in any one section is about 580 m., suggesting that they are facies variants of a single unit which coarsens toward the northwest.

To the north of Hohoro (locns. 11-14), the Ekoa Formation is represented by 60 m. to 185 m. of mudstones which are rich in molluscs (APC Rept. LJ, p.18). It is noteworthy that these beds commonly contain a derived Upper Miocene fauna (APC Rept. LJ, Paleo. Append.). Farther north in the Goigi Basin (locn. 15), 610 m. of sandy mudstones have been assigned by lithological correlation, to the Ekoa Formation (APC Rept. LP). In view of the fact that the Ekoa Formation is only 90 m. thick in Vara's Basin (locn. 14), 25 km. to the south, and 90 m. thick in the Mena Basin (locn. 16), 25 km. to the north, I regard it as probable that much of the supposed Ekoa Formation in the Goigi Basin is really the Vaiviri Formation in a sandy mudstone (versus sandstone) facies. This conclusion is upheld by the description of the Vaiviri Formation in the near-by Vara's Basin (locn. 14), where this formation is described as consisting of:

> "....occasional beds (underlines are mine -AK) of massive sandstone ten to fifty feet in thickness, separated by richly fossiliferous silts and mudstones" (APC Rept. LJ, p.20).

It will be recalled that the Vaiviri Formation is basically a sandstone at Orloli, to the west, and the conclusion is, therefore, that the Vaiviri Formation changes to a finer "Ekoa-like" facies toward the east.

Similarly, out of a total estimated thickness of about 1280 m. for the Era Group in Iruba Creek (locn. 9), the bottom 1125 meters have been assigned to the Ekoa Formation (APC Rept. LJ), leaving 155 m. in the Vaiviri Formation. Comparing this with the Hohoro sections to the south (locn. 8), we see that the thickness of the sandy Vaiviri

Formation is reduced nearly five times from Hohoro (765 m.) to Iruba Creek (155 m.), whereas the Ekoa Formation nearly doubles in thickness from Hohoro (600 m.) to Iruba Creek (1125 m.). As the total thickness of section between these two points is relatively constant, this strongly suggests that Era Group as a whole becomes finer-grained toward the northeast, *i.e.* from Hohoro toward Iruba Creek, and that the Vaiviri and Ekoa formations have an interfingering facies relationship.

In addition to the change to a finer-grained facies toward the east (and northeast) within the Era Group, I regard it as most <u>probable that this group</u> also <u>thins greatly toward the east</u> in this area. The thickest section measured in the Era Group anywhere to the east of the Kuku Fault is a section approximately 960 m. thick measured in the Vara'sBasin (locn. 14; APC Rept. LC, figure LC-7). Approximately 60 m. of conglomerates occur at the top of this section, and I have correlated this conglomerate unit with that occurring at the top of the Orloli and Iruba sections. This suggests that the Vara's Basin section is very nearly a complete section, and that the total thickness of the Era Group deposited in this area was probably not greater than, say, 1,000 meters. This can be compared with 2135 m. of the Era Group present at Orloli, and implies that the total thickness of the Era Group reduces by about half from west to east across the Kuku Fault.

The only argument against eastward thinning within the Era Group here, is that Glaessner estimated the Era Group to be about 2440 m. thick in the Orovoi Syncline (locn. 10; APC Rept. LJ, Paleo. Append. p.7). He based his estimate, however, on the assumption that the Orovoi Syncline does not exist, *i.e.* he believed the section between the Kuku and Eako-Keari Faults to be a straight, homoclinal section dipping to the northeast. This assumption is erroneous I believe, and is contrary to the mapping of the field and photogeologists. For this reason, I believe my conclusion of eastward thinning is more nearly correct, and regard Glaessner's estimated thickness of 2440 m. to be too great by about half.

The marked reduction in thickness to the eastward across the Kuku Fault having been noted, I would now suggest that a structural high (the western edge of the Vailala High) along the incipient Kuku Fault probably delimited the main axis ~~basic configuration~~ of ~~the~~ thick Pliocene accumulation in front of this fault. This implies that the Kuku Fault had begun development not later than the earliest Pliocene. In addition, contemporaneous structural growth within the trough area to the southwest of this fault can be inferred from the rapid thickness and facies changes within the Ekoa Formation toward the present structural high represented by the Pairi-Mekori anticlinal trend, *viz.* sandstones increase and the Ekoa Formation thins from 1125 m. (locn. 9) to 60 m. (locn. 11) toward this trend. This formation again thickens to about 900 m. to the west of this anticlinal trend at Orloli (locn. 7).

The conclusion that the Era Group is both thinning and decreasing in grain-size toward the east, *i.e.* toward a major source area (refer figure 1.4.1), is somewhat anomalous in that we should normally expect coarsening in this direction. The anomaly can to some extent be resolved by realizing firstly, that <u>all</u> Pliocene sections to the east of the Kuku Fault are somewhat finer-grained than sections to the west and secondly, that an important source area also existed to the north. The implications here are ~~simply~~ that the northern source supplied coarser sediment than the eastern source, and that the coarser element of the Era Group (particularly to the west) is basically derived from the northern source.

1.4.2 <u>THE VAILALA TROUGH</u> (figure 1.4.1, locns. 17-24)

Information on the Pliocene of this area is very scant, and no formal subdivision has been proposed.

In the Paun Basin (locn. 21), the sediments grade from marine at the base to non-marine at the top. These rocks rest unconformably on Upper Miocene beds in this basin. The section consists largely of conglomerates, conglomeratic sandstones, siltstones and clays with minor coals and lignites. The conglomerates contain pebbles from all of the underlying rock groups. The section thins from 975 m. in the southwest part of the basin to 490 m. in the northeast part. In conjunction with this, the non-marine part of the section thickens toward the northeast with a concomitant decrease in thickness of the marine section (APC Rept. LJ). A shore-line, therefore, existed in this area and moved progressively from northeast to southwest across the basin during the Pliocene.

Basal coralline limestones to 4 m. thick have been locally mapped around the So-oi Anticlinal nose and on the flank of the homoclinal uplift of the Ekiere Fault (locns. 17-20; APC Rept. LP, p.10), indicating that these structures were already structural highs in the earliest Pliocene. These beds overlie a very thin, marine section of the Upper Murua Mudstone conformably (refer Table 1.3-IV).

In the Paku Syncline and at Iori (~~loncs~~ locns. 23, 22), non-marine sandstones and conglomerates are present which are believed to be of Pliocene age. (APC Rept. LKA, p.18).

Toward the alluvium-covered trace of the Ekiere Fault, the Pliocene is mapped as unconformable on the Aure Group (refer Plate I).

The Pawro Basin (locn. 24) represents a similar section to that of the Paun Basin. Here as well, the section grades from marine at the base to non-marine at the top. The sections consists principally of strongly cross-bedded silty sandstones. Mudstones and molluscan-rich beds occur at the base, and coarse-grained to pebbly sandstones occur near the top. Lignitic to pyritic, non-marine sandstones with pebble lenses are the highest beds exposed. A coralline limestone occurs near the base of the section on the eastern limb of the basin. The total Pawro section decreases in thickness from 1005 m. on the west limb of the basin to 790 m. on the east limb, while the non-marine part of the section <u>increases</u> from 285 m. in the west to 365 m. on the east limb (APC Rept. LH-2; p.5). This indicates a general progression of a shore-line from east to west across this basin during the Pliocene.

A. PETROLOGY OF THE ERA GROUP

Very little work has been done on the petrology of the Era Group, but Zehnder (APC Rept. WS) has done a regional study which presents some pertinent observations on the Era Group of the lower Purari River area.

Quartz becomes progressively more abundant and ferromagnesian minerals progressively less abundant upward in the section from Aure to Era sediments. In addition, sorting becomes better and grain weathering more pronounced upward from Aure to Era sediments. The simplest explanation of these facts is that the ~~Murua~~ Toa Group represents re-cycled Aure sediments and the Era Group, in turn, re-cycled ~~Murua~~ Toa Group (or third-cycle Aure Group).

Also, of special significance are the observations that the Era Group of the lower Purari River area was found to contain very little ferromagnesian material, and that rounded schist fragments are virtually absent. These same constituents are relatively abundant in the ~~Murua~~ Toa and Aure sediments of other areas, *e.g.* at Cupola, but are virtually absent from the ~~Murua~~ Toa and noticeably less common in the Aure sediments of the Lower Purari River area. This could imply that Era sediments of the lower Purari area were derived in large part from a relatively local source of Aure and ~~Murua~~ Toa sediments, *e.g.* such as the proposed Vailala High (see figure 1.4-1).

1.4.3 <u>THE COASTAL TROUGH; RIM GROUP</u> (locns. 25-31)

The Rim Group was originally described as the "Rim Formation" by Osborne (APC Rept. LE-2, p.25) as follows:

"The sediments holding up the Rim Ridge (locns. 27-31 -AK) are dominantly fine-grained, although arenaceous and occasionally gritty to conglomeratic, but higher in the section coarser sandstones, grits and conglomerates with pebbles up to two inches in diameter form a prominent horizon around the Malalaua Anticline, and on the south-east plunge of that structure more conglomerates appear".

The lower, fine-grained part of the section is marine and is now called the Rim Formation, whereas the upper, conglomeratic part is non-marine and is referred to as the Malalaua Formation (APC Rept. LMA, p.10-12).

The Rim Formation as described in the Malalaua Hills (locn. 30) is 245 m. thick and consists mainly of soft, fossiliferous, massive to thin-bedded, fine-grained quartzose sandstones and siltstones. Several lenticular, calcareous concretionary bands with molluscs are present and, near the top, a 15 m. unit of gritty sandstone and conglomerate and a 3 m. coralline limestone occur (*ibid*). The Rim Formation grades into the underlying Upper Murua Mudstone, and a transitional faunal zone occurs between these units. The contact with the overlying Malalaua Formation is sharp but conformable.

The Malalaua Formation is approximately 150 m. thick and consists largely of conglomeratic sandstones, conglomerates and grits (locn. 30). The conglomerates contain small boulders, to 20 cm. in diameter, of varied volcanics, diorite, quartz, metamorphic rocks and cherts. The grade of the conglomerates decreases toward the base of the formation. The formation is believed to be non-marine both because it is unfossiliferous, and because silicified logs are found in the lower part of the formation. The formation is believed to be Pliocene because it is conformable on the underlying Rim Formation, but the formation could be of Pleistocene age (*ibid*, p.11-12).

Similar sections, consisting principally of fine-grained sandstones, have been measured on the south limb of the Muruwaie Syncline (locn. 26; APC Rept. LCA, p.8-9). Here the Rim Formation is 610 m. thick, while the Malalaua Formation is 120 m. thick (Pap/22/38, p.15). Thin lignite bands and foraminiferal mudstones occur in the lower part of the Rim Formation. No conglomerates are present in the Rim Formation and, as well, the Malalaua Formation is finer-grained than in the Malalaua Hills (locn. 30). Here, the Malalaua Formation consists principally of fine-to coarse-grained sandstones and very rare pebble conglomerates and pebbly sandstones with pebbles to two cm. in diameter. Fossils are not reported from the Malalaua Formation, and the formation is probably non-marine, as in the type area. The Malalaua Formation is overlain conformably by the Pleistocene Firu Formation.

The main source of the Rim Group undoubtedly lay in the uplifted sediments of the Kukukuku Lobe to the north. This is shown particularly well by the concentration of chert pebbles in conglomerates. Chert pebbles in the Rim Formation become common to the northeast of Malalaua Hills and, in both the Rim Formation and Malalaua Formation, become common to the west of Maipora Creek (APC Rept. LMA, p.10). The only chert outcrops known in this area occur in areas to the west of Maipora Creek and to the northeast of the Malalaua Hills (locns. 32, 33), which closely ties the chert pebbles to these local source areas. From depositional patterns proposed in discussions of the Toa Group (refer section 1.3.2), it is possible that the Cupola Structure and areas to the immediate west acted as a minor source areas during the Pliocene (see figure 1.4.1).

Summarizing, the Rim Group is broadly similar to the Era Group in that both are shallow-marine deposits which grade upward into non-marine beds, and both groups are dominantly sandstone units. Both groups, therefore, reflect the gradual emergence of this region throughout the Pliocene. The Rim Group, however, is basically of finer-grade, contains no coals and is much thinner than the Era Group.

1.4.4 <u>CONCLUSIONS</u>

The information available on the Pliocene sections is summarized in the form of the isopoch and lithofacies map of figure 1.4-1.

The Pliocene of this region is basically a shallow-marine to littoral deposit which grades to non-marine in the uppermost part of the section. Comparing with the underlying Toa Group, this indicates that regional uplift was a dominant factor during the Pliocene deposition, and this conclusion is borne-out by the coarseness of the Pliocene sediments. In spite of this, however, the great thickness of Pliocene sediments, *viz.* 21~~1~~65 m., present in the Purari Trough in a relatively constant facies shows that <u>active local</u> subsidence continued during the Pliocene.

The overall shape of the Pliocene 'basin' was controlled by an area of major uplift to the north and east. The shape of the basin in detail, however, is complex and reflects the control of more localized structures. The incipient Kuku Fault appears to have been the most important of these 'local' structures, and the thickest Pliocene was deposited in a trough immediately to the west of this fault. Extending from this, and having recognized the probable development of the Bevan Fault during the Upper Murua (refer 1.3.2-C), it seems probable that the present line of synclinal basins between the Kuku and Bevan Faults was already a structural low during the Pliocene. Localized, intra-basinal sources probably emerged on the Vailala High to the east of the Kuku Fault in the area of the Ekiere and Bevan Faults, and, possibly, at Cupola. The So-oi Nose was locally uplifted in the earliest Pliocene, and the Pairi-Mekori Anticlinal trend appears to have begun developing during the earliest Pliocene.

In each of the three main areas of Pliocene sedimentation outlined, Pliocene rocks are folded and faulted, the deformation being particularly intense in the region of the Kuku and Bevan faults (refer Chapter 2). <u>Post-Pliocene</u> deformation, therefore, is quite clear. The character, distribution and overall configuration of the Pliocene depositional basin shows, also, that strong tectonic movements were taking place <u>during</u> Pliocene deposition. As well, <u>pre-Pliocene</u> deformation has previously been demonstrated, all of which leads to the general conclusion that deformation was essentially continuous in this region throughout the Pliocene.

1.5 QUATERNARY

Non-marine Quaternary sediments girdle the western, southern and southeastern margin of the uplifted Pliocene and Miocene exposures of the Kukukuku Lobe (figure 1.5-1), reflecting the same general distribution as does the Toa Group, with the main areas of sedimentation ~~ion~~ shifted still farther away from the central uplift.

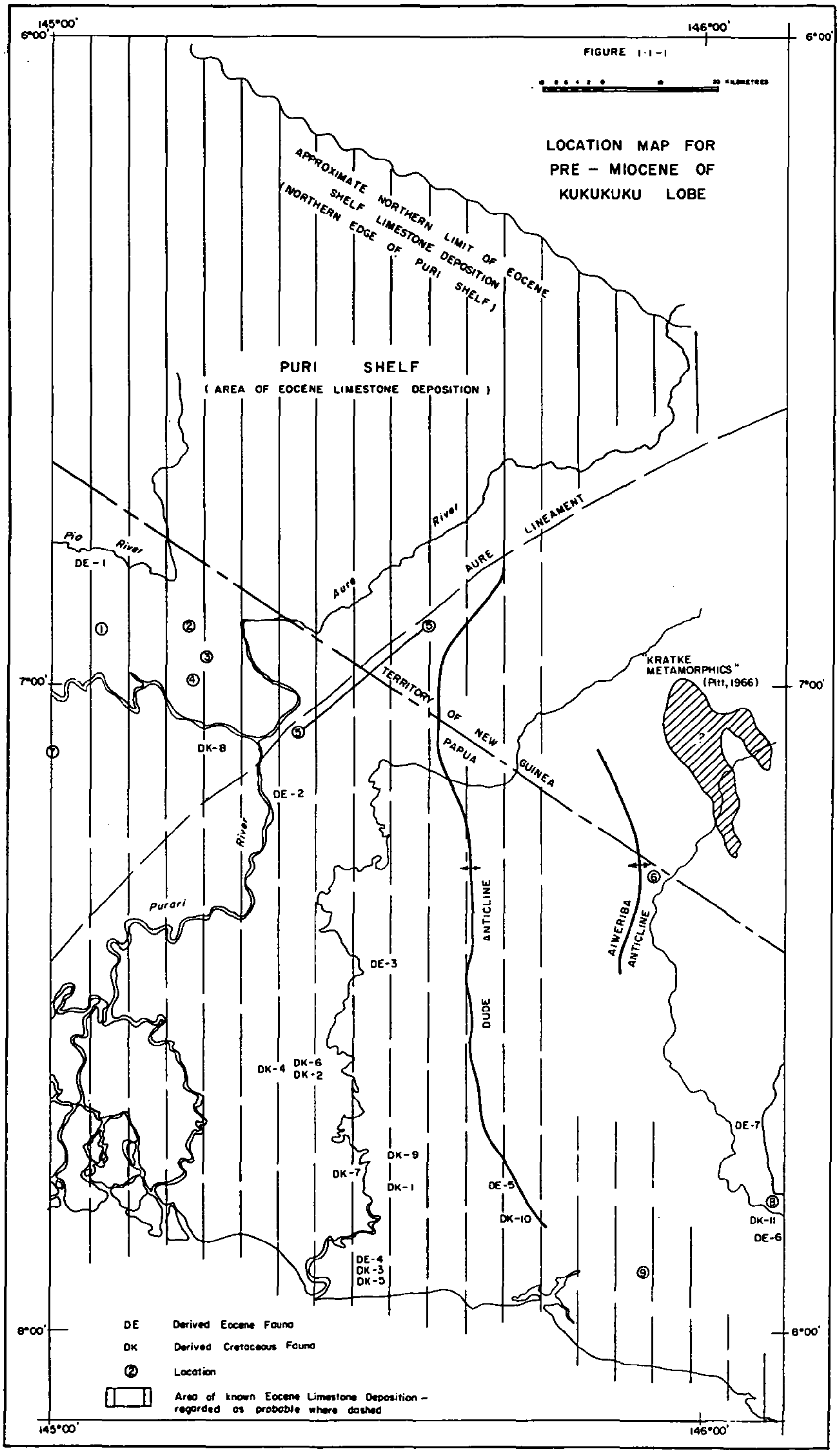
The main areas of Quaternary sedimentation are the Delta Embayment to the west (refer Smith, 1964) and the Lakekamu Embayment to the east (refer Pitt, 1966). To the south, in the Muruwaie Syncline (locn. 1, Coastal Trough), approximately 430 m. of non-marine to paralic sediments occur, which have tentatively been regarded as Pleistocene (Laing, 1959) but could be of Pliocene age. These beds are paleontologically undated, but were equated with the Pleistocene <u>Firu Formation</u> (APC Rept. LMA), which crops out in the Malalaua area to the east (locn. 2). These beds consist of massive, fine-grained sandstones and siltstones with clays and conglomerates, and both leaf impressions and fresh-water fossils occur in these beds. At Malalaua, and again at Koaru (locn. 3), the Firu Formation is about 50 m. thick and overlies Pliocene beds (the <u>Malalaua Formation</u>) unconformably (APC Rept. LMA), whereas the supposed correlate in the Muruwaie Syncline rests conformably on the Pliocene, and ~~are~~ is folded with the Pliocene.

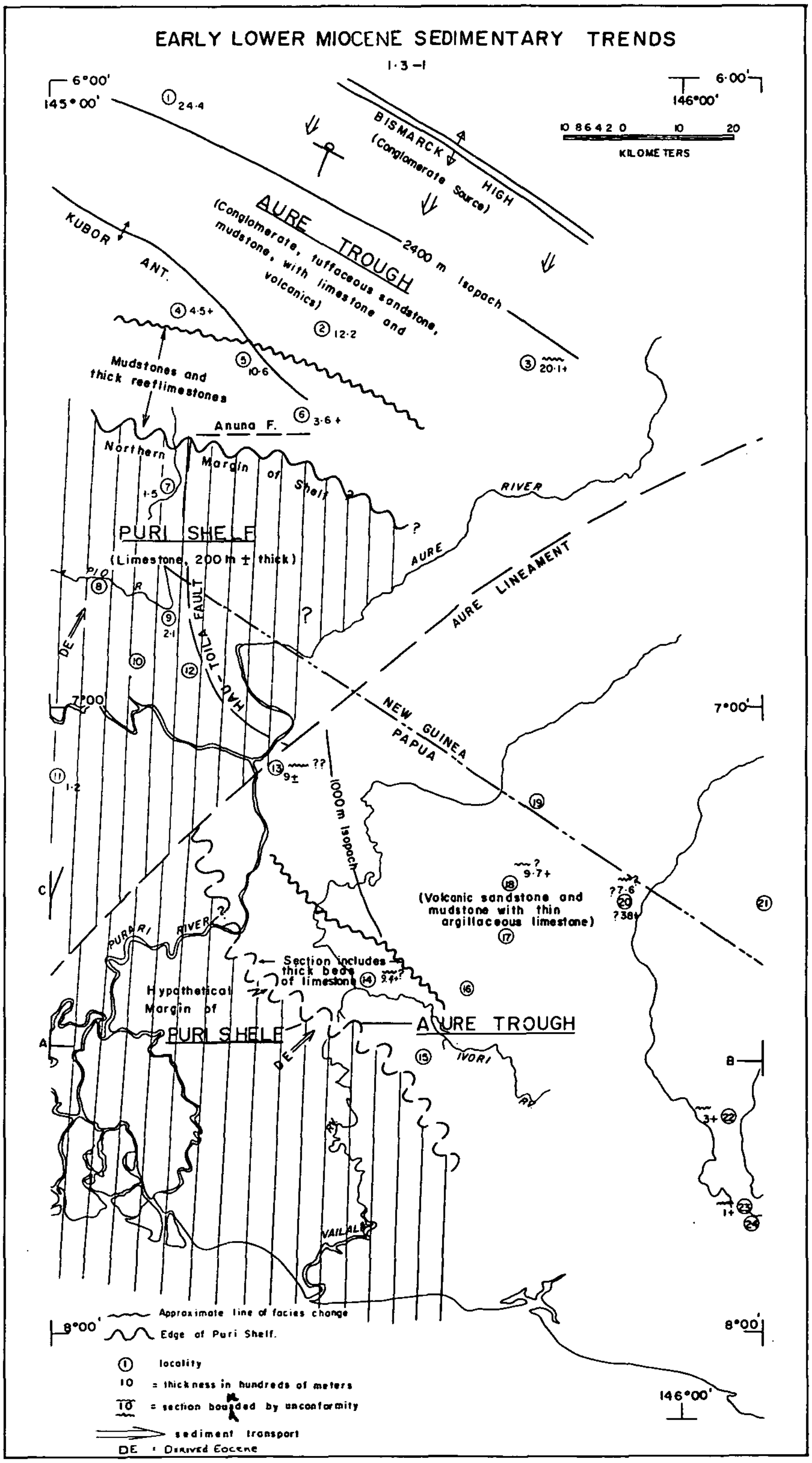
In contrast to the localized subsidence implied by the Firu Formation in the Muruwaie Syncline, small outcrops of raised coralline limestones of Pleistocene age are reported from the southeast end of the Cupola Structure (locn. 4; <u>Silo Limestone</u>; APC Rept. LCA), and again from the

Aipa Hills (locn. 5; the Bluff Limestone; APC Rept. LAA), at elevations of 65 m. and 45 m. respectively. Both limestones are of the order of 155 m. thick and both overlie the Aure Group unconformably. Dips up to 65 degrees are recorded in the Bluff Limestone, indicating that localized faulting as well as uplift has affected these limestones. About 10 km. to the northwest of the Aipa Hills and six km. from the coast, limestone boulders, which are described as similar to the Bluff Limestone, occur in a group of low hills at an elevation of probably less than 30 meters (locn. 6; APC Rept. LM).

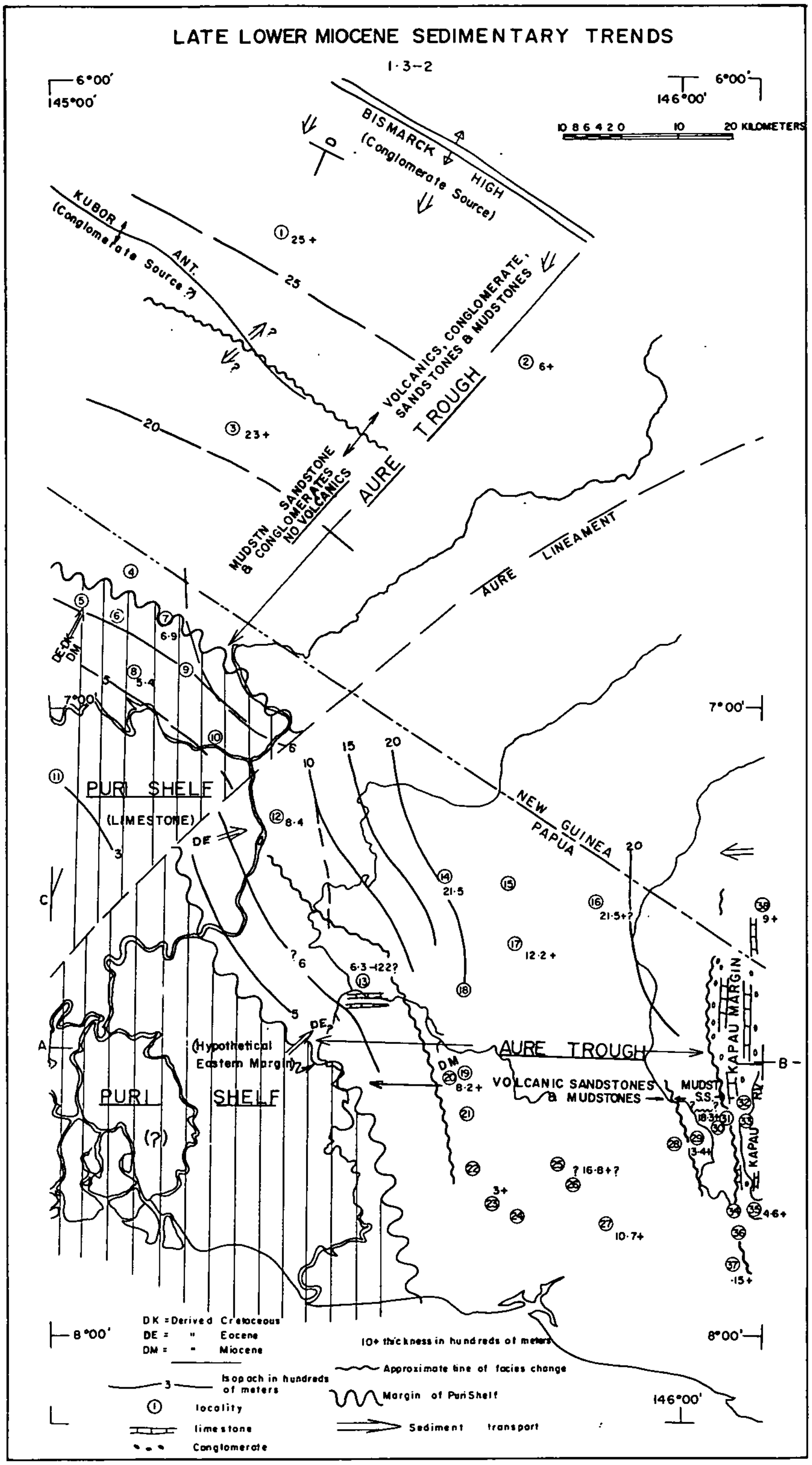
In the Middle Vailala River area, raised boulder terraces have been frequently reported. Near Kariava (locn. 7), these terraces occur at elevations up to 100 m., and contain igneous boulders up to two meters in diameter (APC Rept. LKC). Both the elevation and boulder size decrease southward toward the Pemani area (locn. 8; APC Rept. LP). The source and mode of transport of such large boulders is somewhat of a problem, but the source most probably lay to the northeast in the volcanic mantle of the recently discovered and presently active volcano, Mount Yelia. Gravel, boulder and clay terraces are, also, reported from the Kerema area (locn. 9) at elevations just above beach level. The boulder source in this case, was probably the conglomerates of the Aure Group (Morai River Formation).

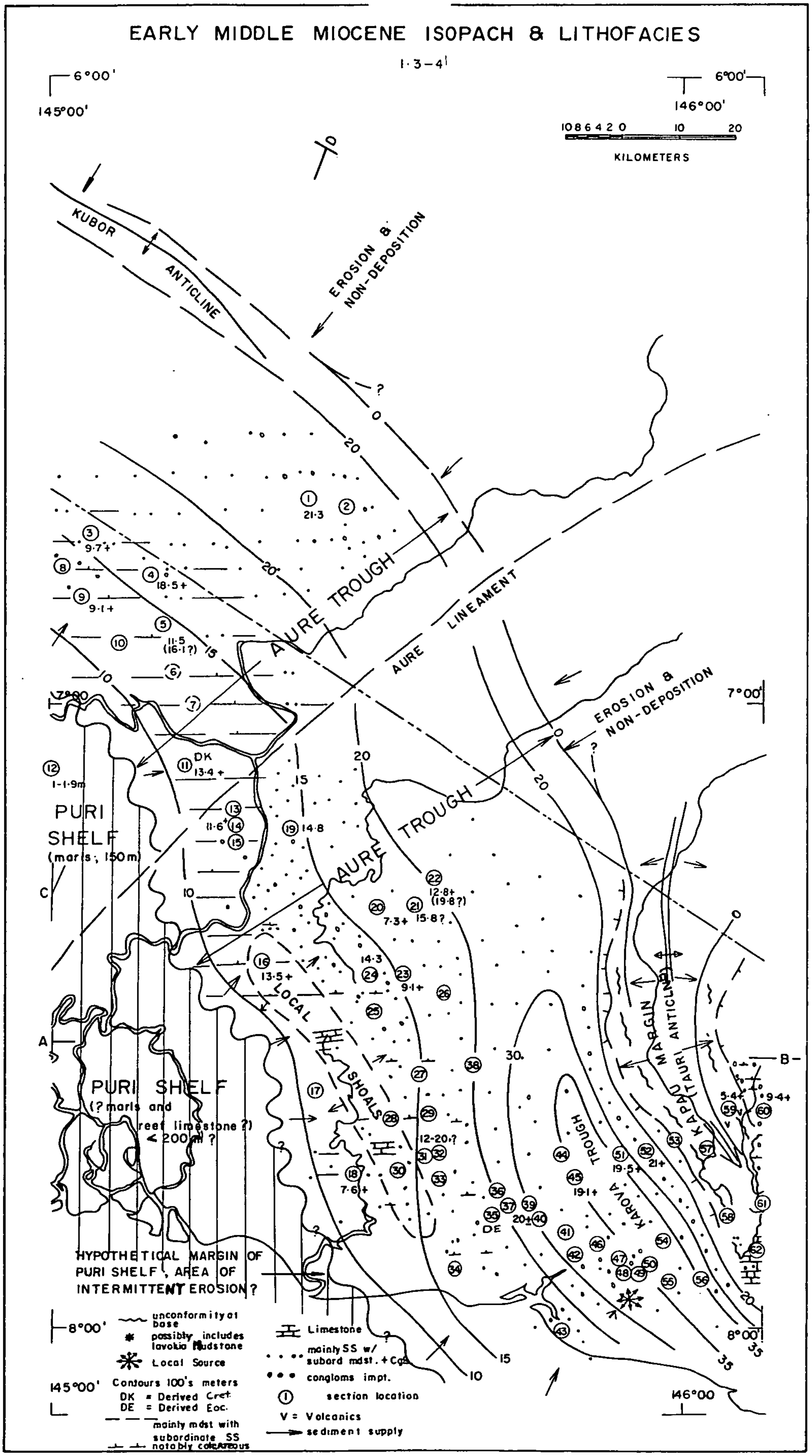
The Quaternary sediments of this region have been treated very summarily here, firstly because very few detailed observations have been made on these sediments and secondly, because the main areas of Quaternary sedimentation lay to the east and west and out of my thesis area. The broad distribution and fundamentally non-marine character of these sediments, however, indicates that the basic sedimentary pattern established for the Toa Group and Era Group continued through the Quaternary. Localized faulting, down-warping, and uplifting has affected these sediments, indicating that tectonic activity did not stop with the Pliocene. Regional uplift in the area of the Kukukuku Lobe during the Quaternary is indicated by the overall distribution of these sediments and by features such as the raised boulder terraces and, most probably, the raised coralline limestones.


145°00'
146°00'
6°00'
7°00'
8°00'
FIGURE 1-1-1
LOCATION MAP FOR
PRE – MIOCENE OF
KUKUKUKU LOBE
APPROXIMATE NORTHERN LIMIT OF EOCENE
SHELF LIMESTONE DEPOSITION
(NORTHERN EDGE OF PURI SHELF)
PURI SHELF
(AREA OF EOCENE LIMESTONE DEPOSITION)
Pio River
Aure River
AURE LINEAMENT
TERRITORY OF NEW GUINEA
PAPUA
Purari River
"KRATKE METAMORPHICS"
(Pitt, 1966)
DUDE ANTICLINE
AIWERIBA ANTICLINE
DE-1
DE-2
DE-3
DE-4
DE-5
DE-6
DE-7
DK-1
DK-2
DK-3
DK-4
DK-5
DK-6
DK-7
DK-8
DK-9
DK-10
DK-11
DE Derived Eocene Fauna
DK Derived Cretaceous Fauna
Location
Area of known Eocene Limestone Deposition – regarded as probable where dashed



EARLY LOWER MIOCENE SEDIMENTARY TRENDS
1·3—1
6°00'
145°00'
146°00'
KILOMETERS
BISMARCK HIGH
(Conglomerate Source)
AURE TROUGH
(Conglomerate, tuffaceous sandstone, mudstone, with limestone and volcanics)
2400 m Isopach
KUBOR ANT.
Mudstones and thick reeflimestones
Anuna F.
Northern Margin of Shelf
PURI SHELF
(Limestone, 200 m ± thick)
HAU-TOILA FAULT
AURE RIVER
AURE LINEAMENT
NEW GUINEA
PAPUA
7°00'
1000m Isopach
(Volcanic sandstone and mudstone with thin argillaceous limestone)
Section includes thick beds of limestone
PURARI RIVER
Hypothetical Margin of PURI SHELF
AURE TROUGH
IVORI RV.
VAILALA
DE
8°00'
Approximate line of facies change
Edge of Puri Shelf.
locality
= thickness in hundreds of meters
= section bounded by unconformity
sediment transport
DE = Derived Eocene


LATE LOWER MIOCENE SEDIMENTARY TRENDS
1·3-2
6°00'
145°00'
146°00'
6°00'
10 8 6 4 2 0 10 20 KILOMETERS
BISMARCK HIGH
(Conglomerate Source)
KUBOR ANT.
(Conglomerate Source ?)
VOLCANICS, CONGLOMERATE, SANDSTONES & MUDSTONES
AURE TROUGH
MUDSTN SANDSTONE & CONGLOMERATES NO VOLCANICS
AURE LINEAMENT
NEW GUINEA
PAPUA
PURI SHELF
(LIMESTONE)
KAPAU MARGIN
KAPAU RV.
AURE TROUGH
VOLCANIC SANDSTONES & MUDSTONES
MUDST. S.S.
(Hypothetical Eastern Margin)
PURI SHELF
(?)
7°00'
7°00'
8°00'
8°00'
146°00'
DK = Derived Cretaceous
DE = " Eocene
DM = " Miocene
10+ thickness in hundreds of meters
3 Isopach in hundreds of meters
Approximate line of facies change
Margin of Puri Shelf
locality
limestone
Sediment transport
Conglomerate


EARLY MIDDLE MIOCENE ISOPACH & LITHOFACIES
1·3–4
6°00'
145°00'
6°00'
146°00'
10 8 6 4 2 0 10 20
KILOMETERS
KUBOR ANTICLINE
EROSION & NON-DEPOSITION
AURE TROUGH
AURE LINEAMENT
EROSION & NON-DEPOSITION
7°00'
PURI SHELF
(marls; 150m)
PURI SHELF
(?marls and reef limestone?)
< 200m ?
LOCAL SHOALS
TROUGH
KAROVA
MARGIN
KAPAU (TAURI ANTICLINE)
HYPOTHETICAL MARGIN OF PURI SHELF, AREA OF INTERMITTENT EROSION?
8°00'
145°00'
146°00
8°00'
unconformity at base
possibly includes Iavokia Mudstone
Local Source
Contours 100's meters
DK = Derived Cret.
DE = Derived Eoc.
mainly mdst with subordinate SS
notably calcareous
Limestone
mainly SS w/ subord mdst. + Cgl
congloms impt.
section location
V = Volcanics
sediment supply

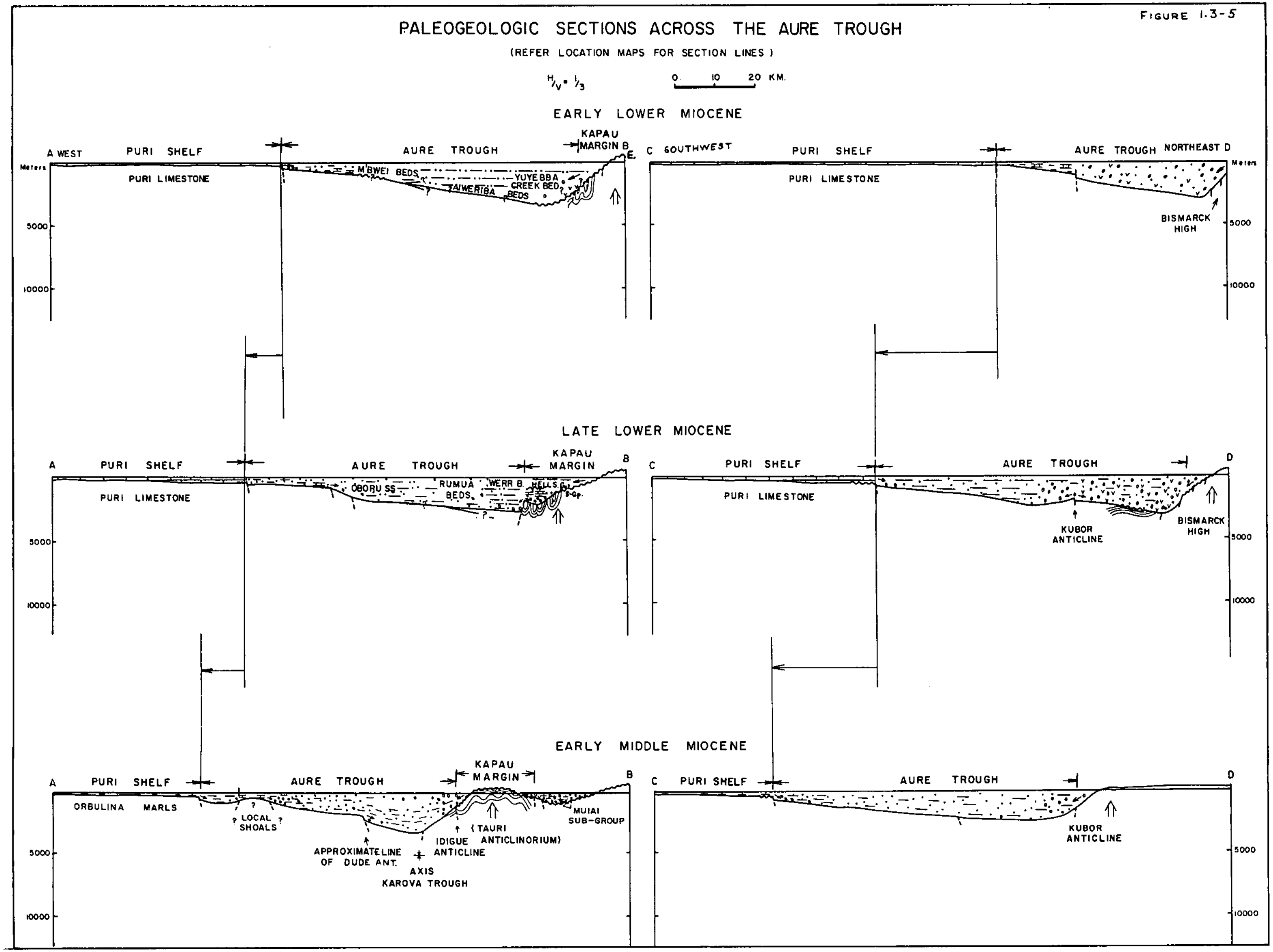


FIGURE 1.3-5
PALEOGEOLOGIC SECTIONS ACROSS THE AURE TROUGH
(REFER LOCATION MAPS FOR SECTION LINES)
H/V = 1/3
0 10 20 KM.
EARLY LOWER MIOCENE
A WEST
PURI SHELF
AURE TROUGH
KAPAU MARGIN
B
Meters
PURI LIMESTONE
M'BWEI BEDS
AIWERIBA BEDS
YUYEBBA CREEK BED
5000
10000
C SOUTHWEST
PURI SHELF
AURE TROUGH
NORTHEAST D
PURI LIMESTONE
BISMARCK HIGH
LATE LOWER MIOCENE
A
PURI SHELF
AURE TROUGH
KAPAU MARGIN
B
PURI LIMESTONE
OBORU SS
RUMUA BEDS
WERR B
HELLS
C
PURI SHELF
AURE TROUGH
D
PURI LIMESTONE
KUBOR ANTICLINE
BISMARCK HIGH
EARLY MIDDLE MIOCENE
A
PURI SHELF
AURE TROUGH
KAPAU MARGIN
B
ORBULINA MARLS
LOCAL SHOALS
APPROXIMATE LINE OF DUDE ANT.
AXIS KAROVA TROUGH
IDIGUE ANTICLINE
(TAURI ANTICLINORIUM)
MUIAI SUB-GROUP
C
PURI SHELF
AURE TROUGH
D
KUBOR ANTICLINE

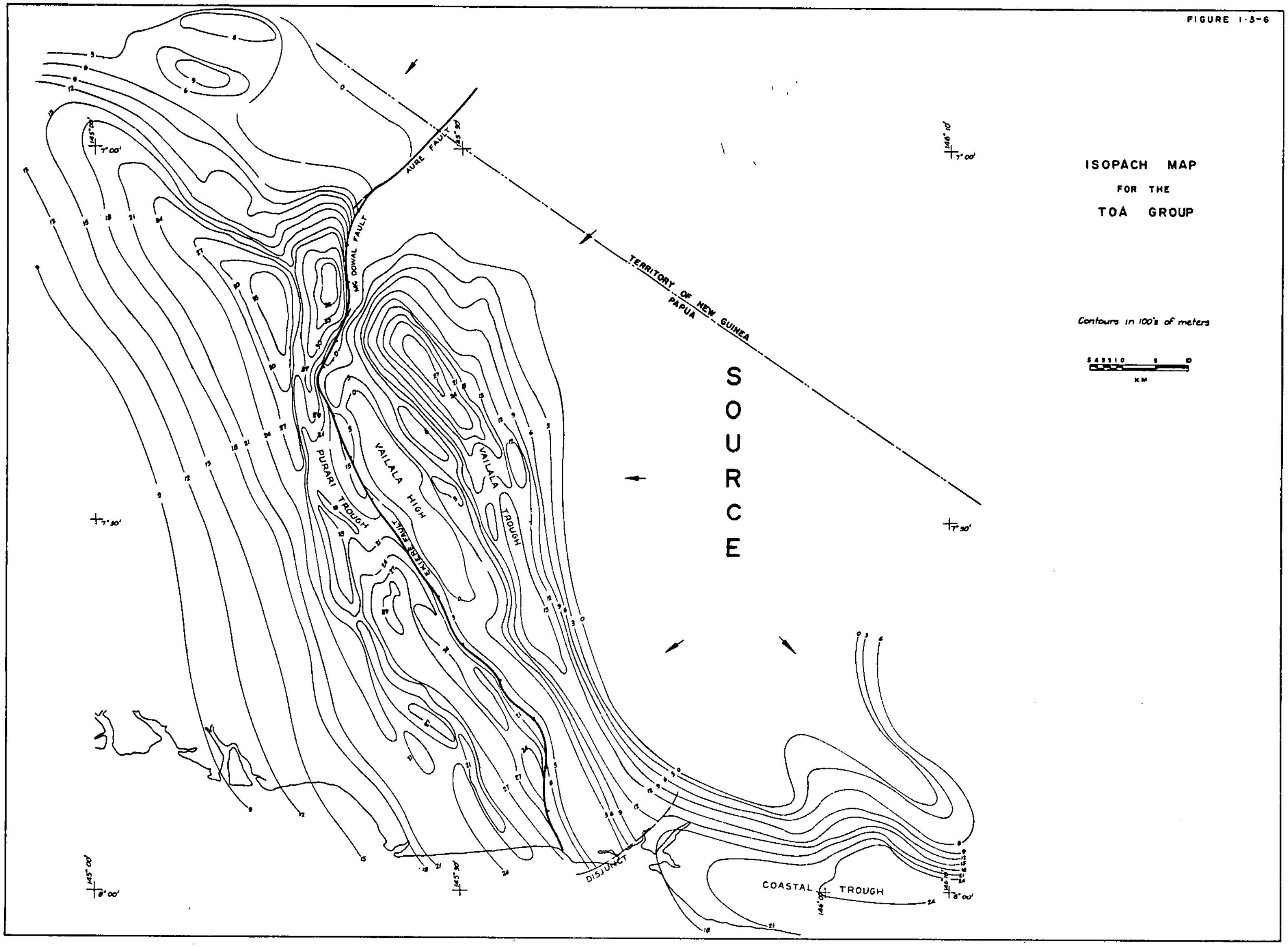


FIGURE 1·3-6
ISOPACH MAP
FOR THE
TOA GROUP
Contours in 100's of meters
KM
SOURCE
TERRITORY OF NEW GUINEA
PAPUA
AURE FAULT
McDOWAL FAULT
EKIKRE FAULT
PURARI TROUGH
VAILALA HIGH
VAILALA TROUGH
COASTAL TROUGH
DISJUNCT
145° 00'
145° 30'
146° 00'
146° 10'
7° 00'
7° 30'
8° 00'

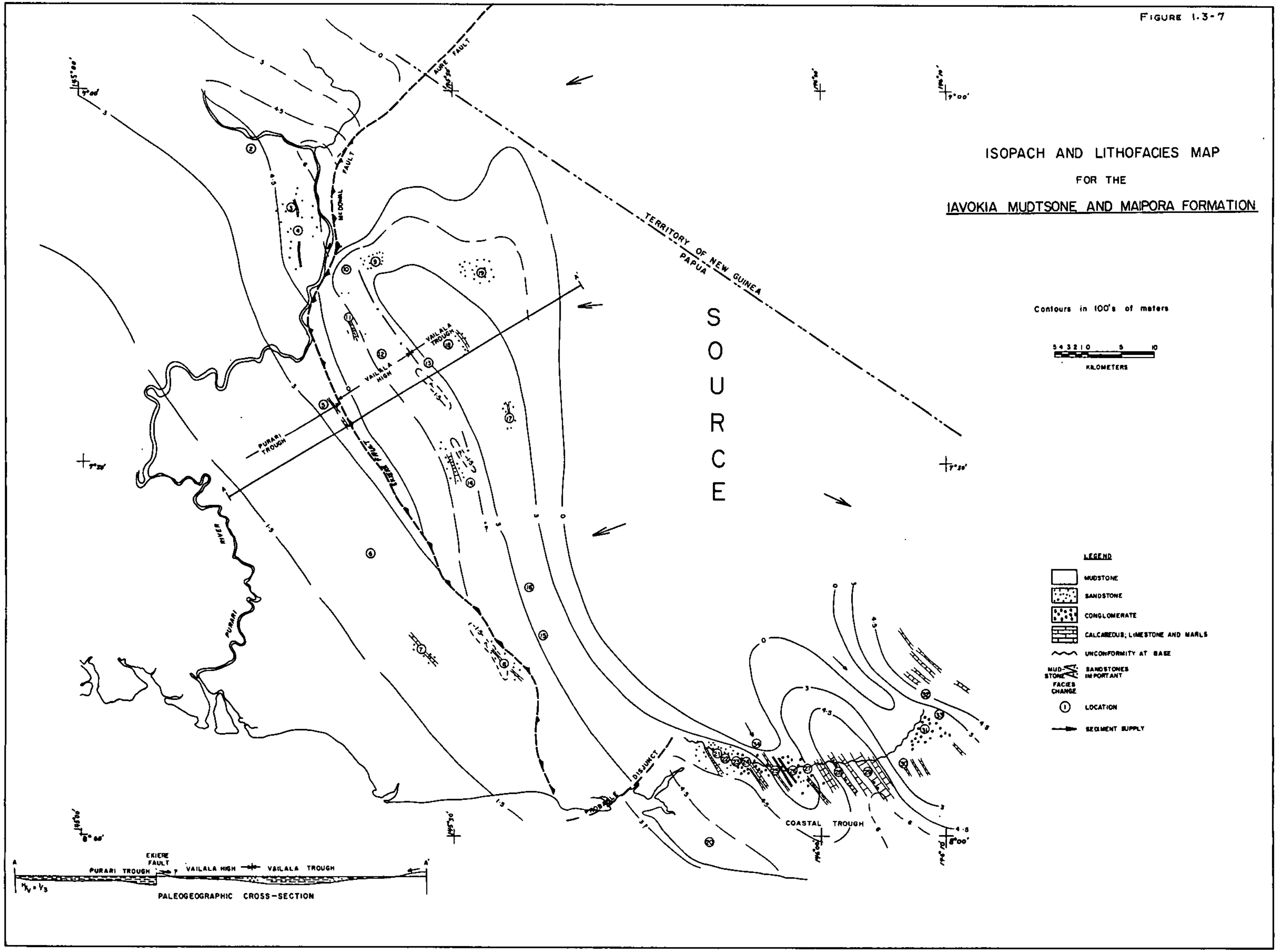


FIGURE 1.3-7
ISOPACH AND LITHOFACIES MAP
FOR THE
IAVOKIA MUDTSONE AND MAIPORA FORMATION
Contours in 100's of meters
KILOMETERS
LEGEND
MUDSTONE
SANDSTONE
CONGLOMERATE
CALCAREOUS; LIMESTONE AND MARLS
UNCONFORMITY AT BASE
MUDSTONE SANDSTONES IMPORTANT FACIES CHANGE
LOCATION
SEDIMENT SUPPLY
SOURCE
TERRITORY OF NEW GUINEA
PAPUA
AURE FAULT
McDONAL FAULT
VAILALA TROUGH
VAILALA HIGH
PURARI TROUGH
PURARI RIVER
PROBABLE DISJUNCT
COASTAL TROUGH
EKIERE FAULT
PALEOGEOGRAPHIC CROSS-SECTION

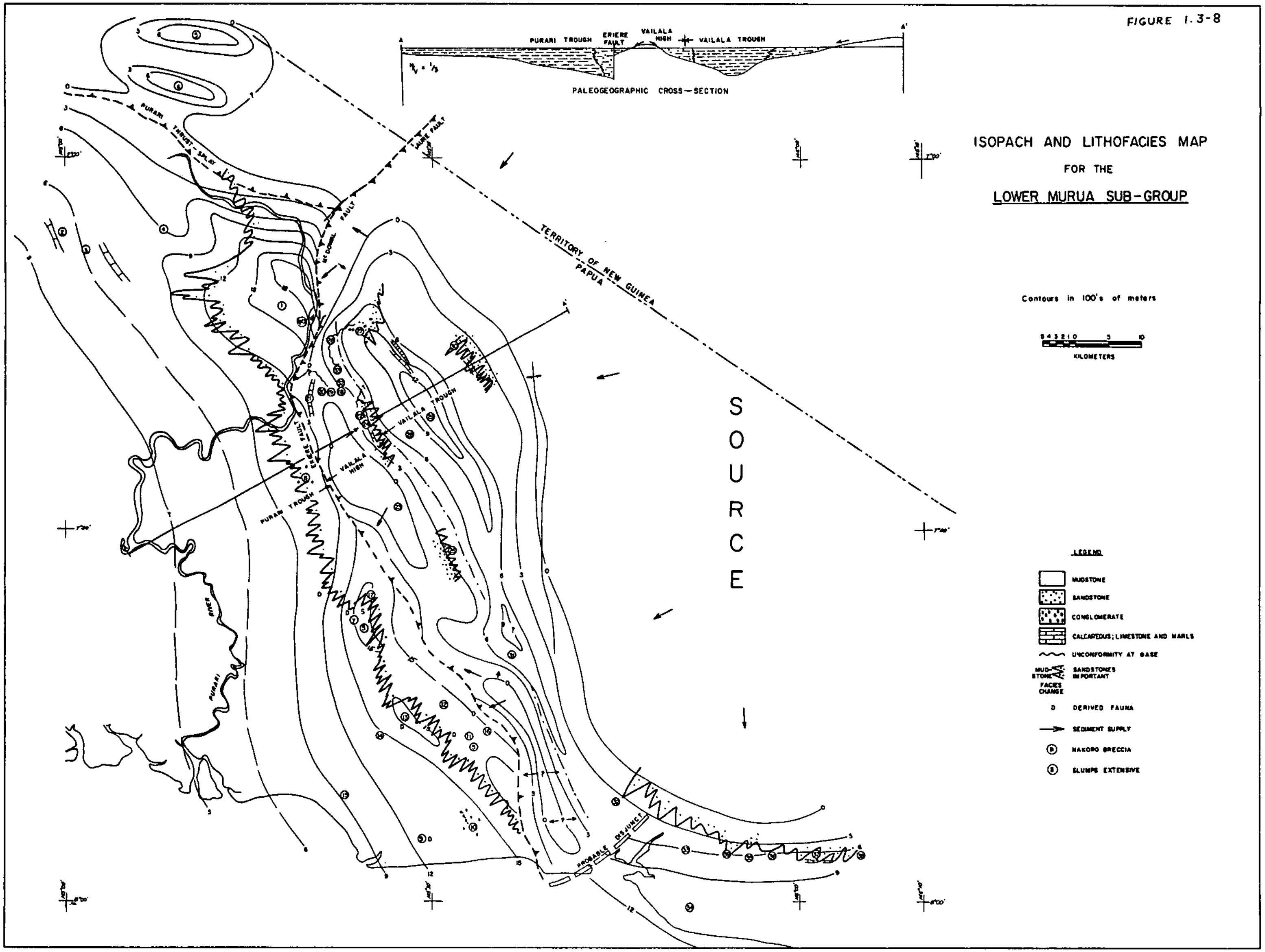


FIGURE 1.3-8

ISOPACH AND LITHOFACIES MAP FOR THE LOWER MURUA SUB-GROUP

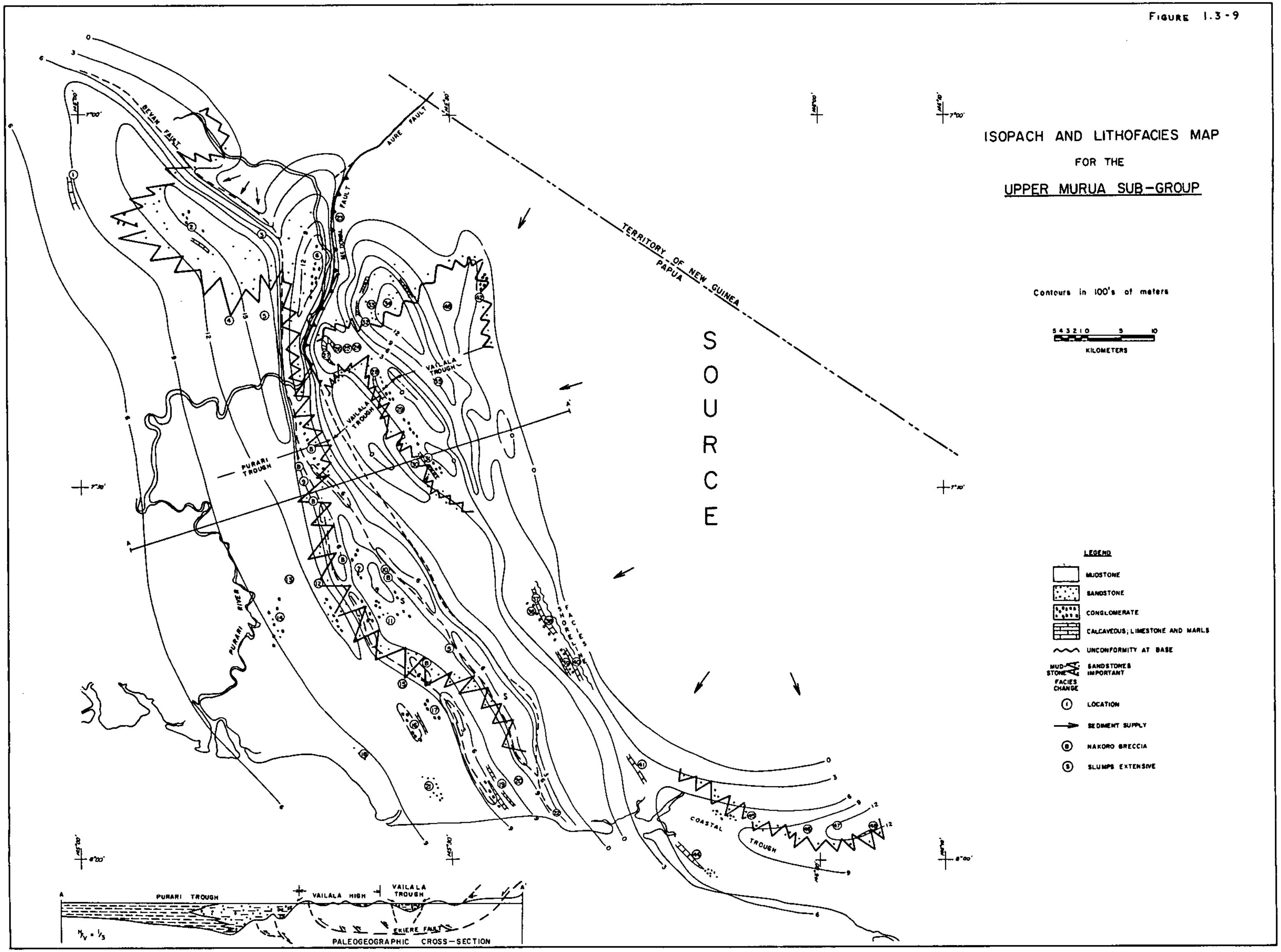


Figure 1.3-9
ISOPACH AND LITHOFACIES MAP
FOR THE
UPPER MURUA SUB-GROUP
Contours in 100's of meters
KILOMETERS
LEGEND
MUDSTONE
SANDSTONE
CONGLOMERATE
CALCAREOUS; LIMESTONE AND MARLS
UNCONFORMITY AT BASE
MUDSTONE
SANDSTONES IMPORTANT
FACIES CHANGE
LOCATION
SEDIMENT SUPPLY
NAKORO BRECCIA
SLUMPS EXTENSIVE
SOURCE
TERRITORY OF NEW GUINEA
PAPUA
BEVAN FAULT
AURE FAULT
PURARI TROUGH
VAILALA TROUGH
PURARI RIVER
SHORELINE FACIES
COASTAL TROUGH
VAILALA HIGH
EKIERE FAULT
PALEOGEOGRAPHIC CROSS-SECTION

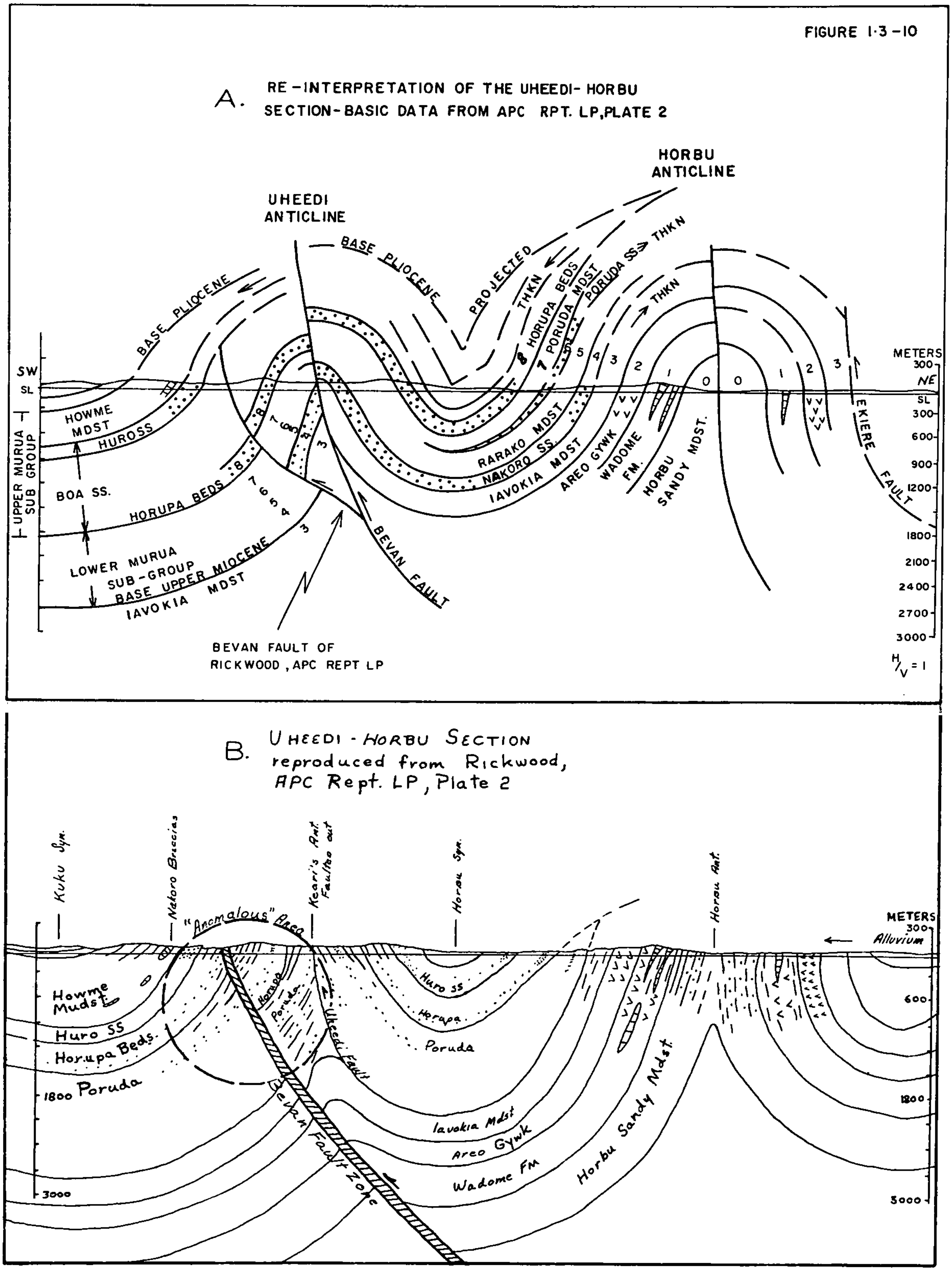


FIGURE 1·3-10
A. RE-INTERPRETATION OF THE UHEEDI-HORBU SECTION-BASIC DATA FROM APC RPT. LP, PLATE 2
HORBU ANTICLINE
UHEEDI ANTICLINE
BASE PLIOCENE
PROJECTED
THKN
HORUPA BEDS
PORUDA MDST
PORUDA SS
SW
SL
NE
METERS
HOWME MDST
HUROSS
UPPER MURUA SUB GROUP
BOA SS.
HORUPA BEDS
LOWER MURUA SUB-GROUP
BASE UPPER MIOCENE
IAVOKIA MDST
RARAKO MDST
NAKORO SS
IAVOKIA MDST
AREO GYWK
WADOME FM.
HORBU SANDY MDST.
EKIERE FAULT
BEVAN FAULT
BEVAN FAULT OF RICKWOOD, APC REPT LP
300
600
900
1200
1800
2100
2400
2700
3000
H/V = 1
B. UHEEDI - HORBU SECTION reproduced from Rickwood, APC Rept. LP, Plate 2
Kuku Syn.
Nakoro Breccias
"Anomalous" Area
Keari's Ant. Faulted out
Horbu Syn.
Horbu Ant.
METERS
Alluvium
Howme Mdst
Huro SS
Horupa Beds
Poruda
Huro SS
Horupa
Poruda
Uheedi Fault
Bevan Fault Zone
Iavokia Mdst
Areo Gywk
Wadome FM
Horbu Sandy Mdst
300
600
1800
3000

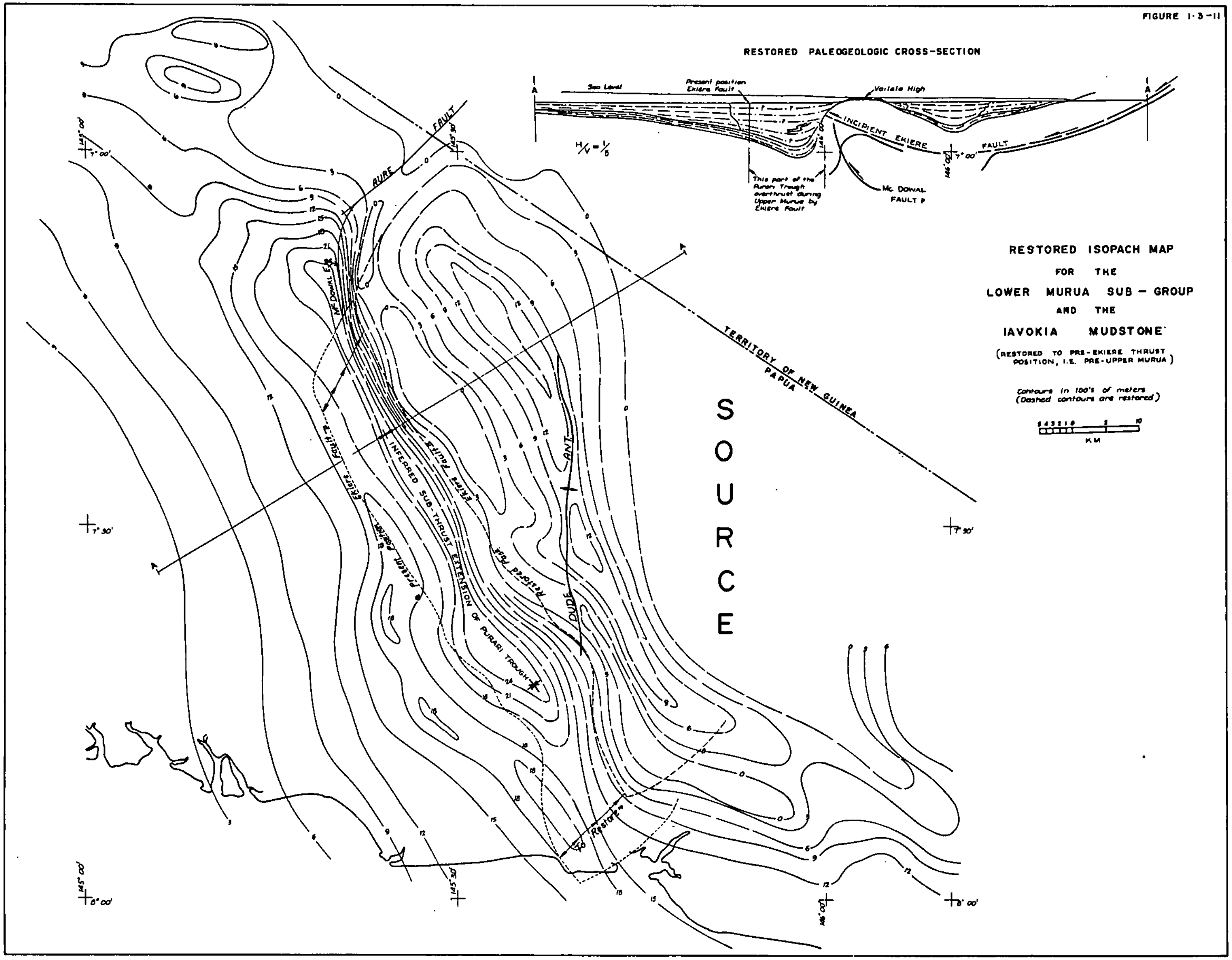
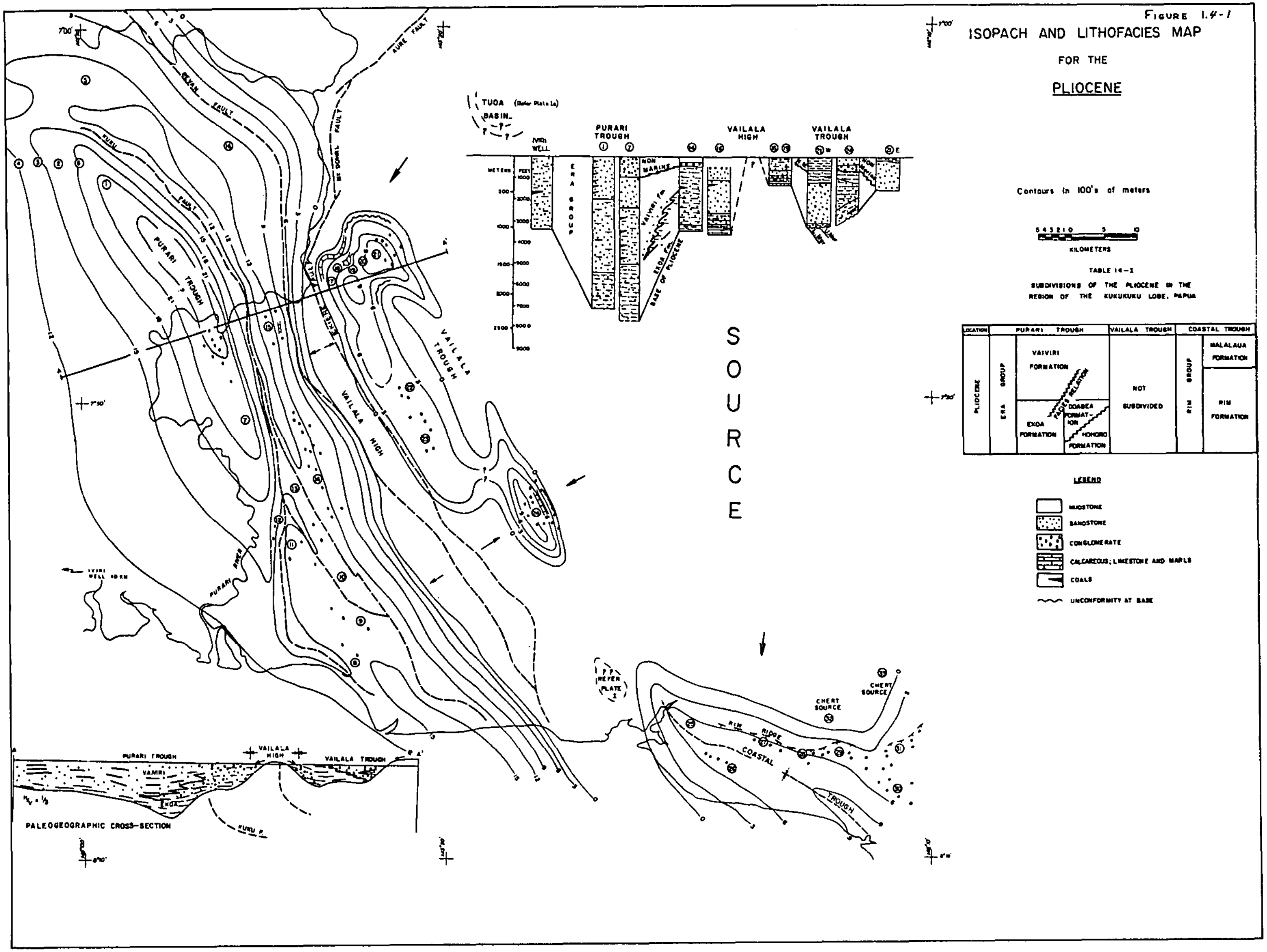


FIGURE 1-3-11
RESTORED PALEOGEOLOGIC CROSS-SECTION
Sea Level
Present position Ekiere Fault
Vailala High
INCIPIENT EKIERE FAULT
H/V = 1/5
This part of the Purari Trough overthrust during Upper Murua by Ekiere Fault
Mc DOWAL FAULT ?
RESTORED ISOPACH MAP
FOR THE
LOWER MURUA SUB – GROUP
AND THE
IAVOKIA MUDSTONE
(RESTORED TO PRE-EKIERE THRUST POSITION, I.E. PRE-UPPER MURUA)
Contours in 100's of meters
(Dashed contours are restored)
KM
AURE FAULT
Mc DOWAL
TERRITORY OF NEW GUINEA
PAPUA
SOURCE
INFERRED SUB-THRUST EXTENSION OF PURARI TROUGH
Ekiere Fault
Restored Fault
Present Contact
ANT.
DUDE
Restored
7° 00'
7° 30'
8° 00'
145° 00'
145° 30'
146° 00'



LOCATION		PURARI TROUGH		VAILALA TROUGH	COASTAL TROUGH	
PLIOCENE	ERA GROUP	VAIVIRI FORMATION	FACIES RELATION	NOT SUBDIVIDED	RIM GROUP	MALALAUA FORMATION
		EKOA FORMATION	OOABEA FORMATION / HOHORO FORMATION			RIM FORMATION

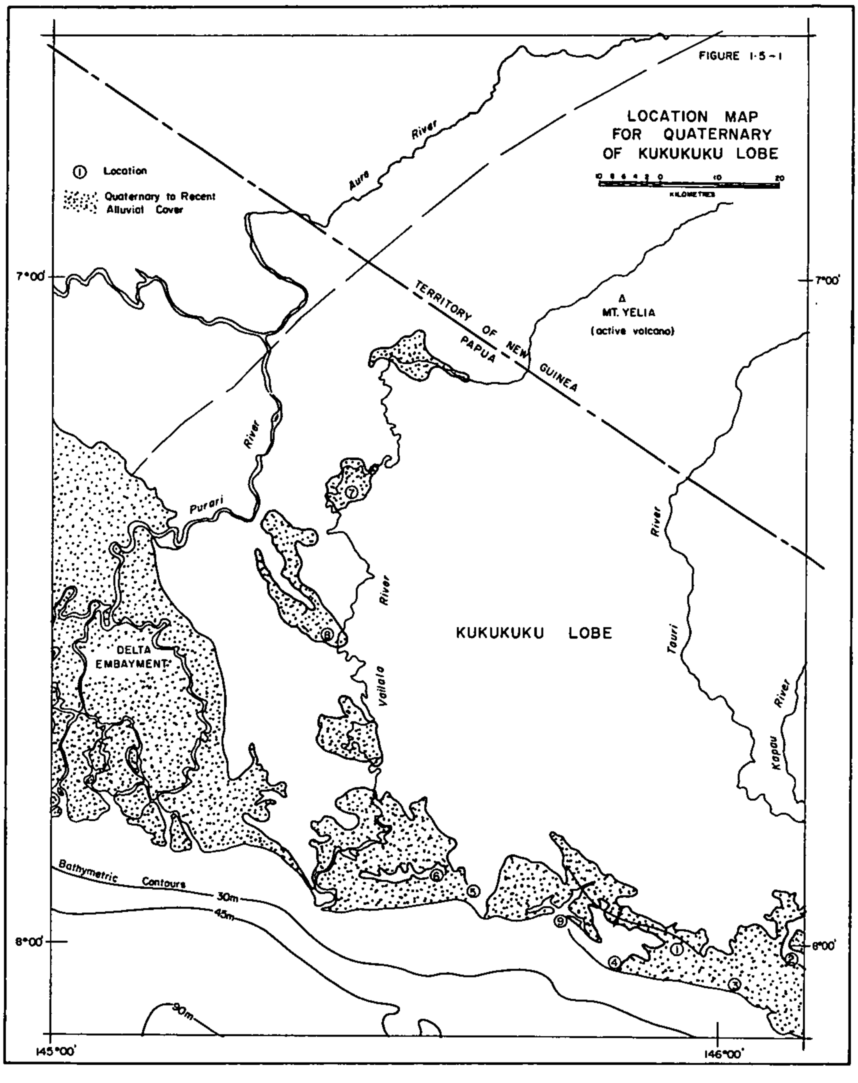


FIGURE 1·5–1
LOCATION MAP
FOR QUATERNARY
OF KUKUKUKU LOBE
KILOMETRES
① Location
Quaternary to Recent
Alluvial Cover
Aure River
TERRITORY OF NEW GUINEA
PAPUA
MT. YELIA
(active volcano)
Purari
River
River
Vailala
KUKUKUKU LOBE
DELTA
EMBAYMENT
Tauri
River
Kapau
River
Bathymetric Contours
30m
45m
90m
7°00'
7°00'
8°00'
8°00'
145°00'
146°00'

2. STRUCTURAL ANALYSIS

INTRODUCTION

The preceding stratigraphic analysis, in addition to examining the nature and distribution of the sediments and depositional troughs of the Kukukuku Lobe, was designed to illustrate the inadequacy of the previously held assumption that the deformation of the Kukukuku Lobe, as a whole, can be accounted for simply by invoking a late Pliocene or post-Pliocene 'orogeny'. In marked contrast to this, I now intend to demonstrate that the deformation of the Kukukuku Lobe has been essentially continuous at least since the beginning of the Lower Miocene. The oldest of the individual structural units within the Kukukuku Lobe occupies the eastern part of the Lobe, with structural units becoming progressively younger toward the west. This corresponds to the westward spread of uplift and the westward shift of depositional axes across the Lobe through time.

The main problems of this structural analysis therefore, are firstly, to delineate the nature, extent and age of the individual structural units and secondly, to illustrate the temporal, spatial and genetic relationships between these units.

In many cases, the structural units have exerted a control on subsequent depositional troughs and conversely, some of the structural units appear to conform to, and be controlled by the pre-existing depositional ~~ional~~ framework. This interdependence between depositional framework and structural configuration was introduced in the preceding chapter and will be further examined in this chapter.

In the structural configuration of the Kukukuku Lobe, two main classes and a sub-class of structures, or structural units, can be recognized. The first class consists of the narrow, folded and faulted uplifts, such as the Dude-Murua and Tauri Anticlinoria, which form the core of the Kukukuku Lobe. These units are the primary result of vertical uplift of the earth's crust and are distinguished by this uplift. Associated with this class of structures, we have a sub-class of structures which have developed as a secondary result of vertical uplift. These structures are the result of gravitational gliding down the regional gradient and are best developed and typified in the broad belt of folds and thrusts in the western half of the Kukukuku Lobe. These structures are relegated to a sub-class and are regarded as secondary because the driving-force which has produced these structures is dependent on the uplift which has produced the regional gradient.

The second major class of structures is formed of structures which have developed as a result of simple shear deformation about a vertical Intermediate Stress Axis, *e.g.* the Aure Fault, Purari Faulted-Anticlinorium, Er Trend and the Coastal Trend. Simple shear stresses have resulted in transcurrent, or wrench, faults, with associated oblique folding, and in the bending and rotation of structures of the first class. Regionally, this seems to be the most important class of structures firstly, in the aforementioned effect on structures of the first class and secondly, because the simple shear stress system relating to these structures is held to be responsible for the deformation of the Kukukuku Lobe as a whole. The uplift responsible for the first class of structures is, also, thought to be a result of this simple shear stress system. This stress system and its regional application are subjects of Chapter Three of this thesis.

The general plan of this chapter is to examine firstly the units of uplift in the core of the Kukukuku Lobe and then, to demonstrate the relationship of these units to the resultant secondary structures. Lastly, I will examine the simple shear deformation and illustrate the effect of this deformation on the structures of the first class and its subsidiary sub-class.

2.1 P R I M A R Y U P L I F T S O F T H E K U K U K U K U L O B E

2.1.1 <u>DUDE - MURUA ANTICLINORIUM; KAROVA SYNCLINE; ALBERT FAULT</u>

A. DESCRIPTION

The Dude-Murua Anticlinorium is the most conspicuous structural unit of the thesis area in that it is dominantly a <u>north-south</u> trending feature. Toward the south, the anticlinorium swings smoothly from the north-south trend into a northwest trend. The anticlinorium can be recognized over a distance in excess of 120 kilometers, although the character of the northern portion of the anticlinorium is somewhat different from the character of the southern portion (refer later). The width of the anticlinorium is fairly constant, being about ~~eleven~~ 11 to 16 sixteen kilometers between bounding structures.

To the north of New Years Creek, the Dude-Murua Anticlinorium is bounded on the west by the Dude Anticline. To the south, the Yanne Fault and Yanne'ia Anticline form the western boundary of the anticlinorium. The eastern boundary of the anticlinorium is formed by the Murua Anticline in the north, by the Yave'ia Anticline and the Yave'ia Fault in the vicinity of the Ivori and Murua Rivers and, again, by the Murua Anticline f~~u~~arther to the south (refer Plate I). A more generalized eastern boundary for the anticlinorium might be taken as the trough of the Karova Syncline.

The Dude-Murua Anticlinorium consists of a series of sub-parallel anticlines and synclines. Anticlinal axes are regularly spaced at a distance of three to five kilometers. The most persistent of these anticlines are the Dude and Murua Anticlines, which can be traced along the entire length of the anticlinorium and from which the name of the anticlinorium is derived. The structures between these anticlines can be traced from the southern end of the anticlinorium northward to Fault 'A', a distance of about 90 ninety kilometers.

In the southern part of the anticlinorium, the anticlines are steeply pinched in the axial regions, with the limbs flattening-out rapidly into broad, shallow synclines. Stanley (APC Rept. LH-1) has termed this a belt of <u>catenary folds</u>, which gives an apt description of their shape. According to McWhae (APC Rept. LR), the catenary style of folding very rapidly gives way to more open and gentle folding toward the north, in the Yoai and New Years Creek sections. Farther north in the eastern part of the M'bwei River section, however, the beds are steeply folded. In detail, the folds of the anticlinorium are irregular in trend and variable in plunge, but regionally these folds are remarkably continuous and parallel. The anticlines are generally asymmetrical, ~~the~~ the west or southwest flank being the steeper. Crestal faulting is frequently important, the northeast flank being upthrown as a rule. Locally, however, the southwest flank of the anticline is upthrown, *e.g.* the Urai'ia Anticline and, probably, the Haue'ia Anticline in the vicinity of the Lohiki River. The anticlines are occasionally overturned toward the west or southwest, *e.g.* the Dude Anticline to the south of the Lohiki River and the Haue'ia Anticline immediately to the north of the Lohiki River. Local overturning of both flanks has been suggested along the Yave'ia Anticline and Yave'ia Fault (APC Rept. LH-2). Local longitudinal faulting usually accompanies the overturning, and the adjacent syncline to the southwest is often tightly pinched or/and faulted, *e.g.* the Kevoro and Muruwaie Synclines respectively in the vicinity of the Lohiki River and to the south. In general, local transverse faulting has not been mapped, but a study of the aerial photographs suggests that minor transverse faulting is usually present (refer Plate I).

The Dude-Murua Anticlinorium has a generally consistent southerly plunge along its length; exposures in the north being mainly in Lower Miocene rocks and exposures in the south being mainly in Middle Miocene rocks. The southeasterly plunge of the Dude-Murua Anticlinorium is marked by the unconformity at the base of the Iavokia Mudstone, and all post-Aure Group beds swing smoothly around the plunge of the anticlinorium.

The Dude-Murua Anticlinorium appears to have been a major source area from the deposition of the Iavokia Mudstone onwards, and all post-Aure Group beds thicken away from, and become unconformable towards the anticlinorium. This indicates that the folding was accomplished prior to Toa Group deposition. Across the southeasterly-plunging end of the anticlinorium, the Toa Group is tilted away from the anticlinorium, generally at an angle of about 30^{o} but sometimes up to ~~about~~ 60^{o}. This is taken to be a reflection of post-Aure Group uplift of the anticlinorium. At the south end of the anticlinorium the Iavokia Mudstone is possibly folded into the Kevoro Syncline, which would suggest a rather late development of such marginal structures.

Directly opposed to the relationship shown by post-Aure Group rocks, the Aure Group thickens rapidly toward, and from west to east across the anticlinorium. Sections have been measured across several structures at the southern end of the anticlinorium (refer Section 1.3-1), and these show no appreciable variation on opposed limbs of these structures. This indicates that folding generally had not been initiated prior to, nor was it developing during, the deposition of the Aure Group. This very narrowly brackets the initiation of the major folding of the Dude-Murua Anticlinorium to the time represented by the unconformity at the base of the Toa Group. The folding of the anticlinorium is, therefore, coincident with the intial uplift and emergence of the anticlinorium, both features marking the incipient inversion of a pre-existing, strongly negative area. The order of this inversion can best be visualized by the fact that about 3.5 kilometers of marine section belonging to the Aure Group is now exposed in the Murua River section, the lowest beds being exposed at an elevation of about one kilometer. With the knowledge that the lowest beds exposed were deposited well below wave-base, these figures represent a minimum post-depositional uplift of about five kilometers.

The exact structural configuration of the Dude-Murua anticlinorium to the north of the Ivori River is still uncertain. Dip information from three traverses is available, *e.g.* the M'bwei River traverse (APC Repts. LI, LR), New Year Creek traverse (APC Rept. LR), and the Ivori River traverse (N. Pratt and Whittle ? 1940). Details of the Ivori River traverse, other than dip information, have not been recorded in a report. Of the other two traverses, only one sample from beds to the east of the Dude Anticline has yielded an age, this being taken from beds occurring some 700 meters above the lowest exposures in the Haue'ia Anticline in the M'bwei River section. The age of this sample was determined as early Lower Miocene (APC Rept. LR, Paleo. Append.). The problems involved are two-fold. Firstly, the proper connection and continuation of structures occurring to the south of the Ivori River with those to the north is open to question. This problem becomes even more pronounced when trying to continue structures to the north of the M'bwei River, because there are no field traverses in this area with which to control photogeology.

The second problem involves relating the depth of exposure in these northern traverses with ~~those~~ that in southern traverses. The only non-inferential control available, here, is the single definitive paleontological sample of early Lower Miocene beds in the M'bwei River and the occurrence of Lepidocyclina grits of late Lower Miocene and Middle Miocene age on the west and east flanks of the Dude Anticline to the south of the Ivori River.

Stanley (1960), has suggested that the structures developed to the south of the Ivori River are photogeologically continuous with structures developed in the M'bwei River in the manner shown in Plate I. In this interpretation, the Haue'ia Anticline is continuous with "Evari's Anticline" of McWhae (APC Rept. LR-1). McWhae, however, suggests that structures in this area are not continuous, but are developed en echelon, with minor cross-faulting, as illustrated in figure 2-1 (from APC Rept. LR-1). I regard Stanley's solution as most generally true, because of the continuity of structures to either side of the Haue'ia Anticline, and because the structures, so continued, appear to remain the major structures to the north of the M'bwei River. By observing McWhae's map (figure 2-1), however, it is evident that new structures are developed in the M'bwei River which are not present to the south.

I have studied the photographs of the area to the north of the M'bwei ~~Sa~~ River (Armit Range photo-sheet) with the results shown on the photo-geological map (Plate Ia). This represents the only data we have on this area to date. The area to the east of the Dude Anticline is perplexing, and I am not entirely satisfied with the results. Five things appear fairly certain, however. These are (see Plate Ia):

1) The trend of the Dude Anticline is continuous to the north of the M'bwei River as a large, apparently unfaulted, anticline.

2) The trend of the Murua Anticline can be continued, generally, to the north of the M'bwei River. The configuration of this structure is by no means certain in exact detail, but the general line of uplift is definitely present. At the northern end of the map, the Murua Anticline appears to be represented mainly by a fault.

3) The region between the Dude and Murua Anticlines appears to be occupied mainly by pre-Middle Miocene beds. Younger beds are perhaps unconformable over these beds in the south-central portion of this area.

4) Most of the structures of the Dude-Murua Anticlinorium, as developed in the M'bwei section, are not continuous through this area, and most of these structures seem to disappear to the north of the Tuoa Fault. This

fault may, or may not, affect the Murua Anticline as shown on the geological map. Another important cross-fault, Fault E, parallel in trend to the Tuoa Fault, appears to strongly affect the northern part of the area.

5) On the west flank of the Tuoa Anticline, the Aure Group (? early Lower Miocene) appears to overlie older beds with angular unconformity. There is possibly an unconformity within the Aure Group, f~~u~~arther out on the west flank of this structure, at the base of what is probably the equivalent of the Oboru Sandstone, *i.e.* say at the base of the Ewe Gr~~e~~aywacke.

Aside from these generalizations, all else is considered speculative. The rocks exposed to the east of the Murua Anticline are possibly volcanics, or perhaps mudstones, as they yield a very different aspect in the photographs, than do the rocks to the west. Crystalline basement may be exposed in the core of the Tuoa Anticline. The aspect of the beds exposed on this anticline to the north of the Tuoa River appears remarkably like that of Mt. Yelia volcanics f~~u~~arther to the northeast, but must be older as the volcanic mantle of Mt. Yelia overlies the rocks of the Tuoa Anticline.

The cross-sections of figures 2-2 and 2-3 reveal the Dude-Murua Anticlinorium to be a flat-topped, block-like uplift, with essentially the same beds exposed in the cores of the bounding structures and across the anticlinorium. This structural unit, as outlined, is anticlinorial in aspect, in that the beds brought-up in this unit are consistently older than the beds exposed in the Vailala Synclinorium to the west and the Karova Syncline to the east. The Dude-Murua Anticlinorium is not strictly an anticlinorium, however, because the oldest beds exposed appear to be those exposed in the bounding structures, rather than along the axis of the anticlinorium. The anticlinorium is <u>not,</u> therefore, a broad and gentle upwarp, but a steeply bounded uplift of block-like character. This suggests that the fundamental nature of the anticlinorium is that of an uplifted horst. The western boundary of the anticlinorium is faulted in part, with the east side upthrown, along the Yanne Fault, the Yanne'ia Anticline and the Dude Anticline. The basic character of this boundary, however, is anti-clinal and appears unfaulted to the north of the junction of the Yanne Fault and the Dude Anticline, and in the southern parts of the Yanne'ia Anticline. Similarly, the eastern boundary of the anticlinorium is mainly anticlinal. Where formed by the Murua Anticline, the boundary appears generally unfaulted. To the north of Tuoa Creek, the Murua Anticline appears to have a steep eastern flank and a relatively shallow western flank, *i.e.* the anticline has an <u>easterly</u> facing. It is not likely that the anticline is faulted in this position, as it is thought that the turnover can be followed (photogeologically) in this area. F~~u~~arther to the north (refer Plate Ia) the Murua Anticline appears to be represented by a fault, which dips westerly and is probably upthrown on the west side. This sense of movement would be compatible with the easterly facing of this anticline f~~u~~arther to the south.

The Yave'ia Fault, although the extent of this fault along strike is not certain, partially forms the eastern boundary of the anticlinorium and is upthrown on the <u>west side</u>. The throw of this fault is probably of the order of 700 meters. The exact structural and stratigraphic relations of the Yave'ia Fault and the Yave'ia Anticline are not clear (Stanley, 1960, p.70-71), but it is certain that this fault must be upthrown to the west, and that it faults out much of the western limb of the Karova Syncline in the area between the Murua River and Ivori River. In the region of study in general, faulting which is upthrown on the west or southwest side is rare. Such faulting indicates that the main uplift of the anticlinorium is to the west of the Yave'ia Fault.

The Yave'ia Fault, is a precursor to the <u>Albert Fault</u>, which is, also, upthrown on the west side and which delimits the eastern limb of the Karova Syncline in the south. It will be beneficial at this point to examine both the Karova Syncline and the Albert Fault.

The Karova Syncline is the major flanking structure on the eastern side of the Dude-Murua Anticlinorium. It can be traced along the entire length of the area covered by this thesis before it loses expression beneath the unconformity at the base of the Toa Group, at the southern end of the area. Regionally, the width of the Karova Syncline is fairly constant, at about fifteen 15 kilometers, between bounding structures, *i.e.* between the Murua Anticline and the Aiweriba Anticline in the north, and between the Murua Anticline and the Albert Fault in the south. Where the Yave'ia Fault and associated structures occur between the Murua Anticline and the Karova Syncline, the western limb of the syncline is greatly narrowed (refer Plate I). Pitt (1966) suggests the existence of similar structures between the Karova Syncline and the Albert Fault System on the eastern limb of the syncline.

On a regional scale, the Karova Syncline is of a size comparable ~~size to~~ with the Dude-Murua Anticlinorium. The Karova Syncline occupies the same position, but symmetrically disposed, with respect to the Dude-Murua Anticlinorium as does the Vailala Synclinorium to the west. The latter, however, is wider and more intricately deformed than the Karova Syncline (refer Section 2.2.1). The Karova Syncline is a broad, gently folded structure in its normal and fullest development. In the M'bwei River region, it is estimated that approximately three km. of section is exposed on the limbs of this syncline. About 3.6 km. of section is exposed on the southwest limb of this structure in the Karova Creek region. These figures are comparable ~~to~~ with the amount of section exposed on either limb of the Vailala Synclinorium, say in the Maropo and M'bwei sections. These observations illustrate that the Karova Syncline is a much more important structure than the internal structures of the Dude-Murua Anticlinorium, and that it does not find a ready analogy in these structures, *e.g.* the Kevoro Syncline et cetera. The best comparison, on a regional scale, is with the Vailala Synclinorium or with the Dude-Murua Anticlinorium as a whole.

In a manner similar to the Vailala Synclinorium, but again symmetrically ~~ally~~ disposed, the eastern limb of the Karova Syncline is fault-bounded ~~bounded~~ in the southern part of the region (refer Plate I). The Albert Fault (and Albert Fault System, Pitt 1966) delimits the eastern limb of the Karova Syncline, and the west side of this fault is upthrown. Sadler (in Stanley APC Rept. LH-2), estimates that the stratigraphic throw of this fault is of the order of 2.7 kilometers in the vicinity of Yuiani and Enna Creeks.

It is pertinent to observe, that the important up-to-the-west movement on the Albert Fault in the north, is replaced by the opposite sense of movement on the Obira Thrust to the south. The trace of the Albert Fault is apparently unaffected by the irregular topography it crosses, and the fault gives rise to steep to vertical dips where it crops out. For these reasons, this fault is assumed to be vertical to near-vertical at the surface. The sense of movement, together with the attitude of the beds to either side of this fault in the Enna Creek area, suggests that this fault is a steep thrust fault, possibly dipping to the southwest.

Neither the Albert Fault nor the Obira Thrust disrupt the unconformity at the top of the Aure Group, although what are probably the highest beds in the Aure Group are cut by the Obira Thrust, and as well the Albert Fault involves the Morai River Formation along its known length. This narrowly brackets the age of these faults to the time-interval represented by the unconformity at the top of the Aure Group, which is the same age as the main uplift of the Dude-Murua Anticlinorium.

Cross-Faults

Photogeology suggests that important cross-faulting affects the Dude-Murua Anticlinorium and adjacent synclinal structures.

With regard~~s~~ to correlation and stratigraphic interpretation in this area, the Piyai'ia Fault is the most important. This fault has previously been discussed (refer section 1.3.1., see Plate I).

Of the other faults, Faults A and E seem to be the most important. Each of these faults appears to have an important vertical component and, as well, both faults appear to involve a substantial transcurrent element (refer Plate Ia). Because of the effect of these faults on the longitudinal structures, it appears that the major development of these faults has been post-folding. Fault E and the Tuoa Fault involve mainly older rocks, and this, in turn, suggests that these faults are confined to the deeper part of the column, *i.e.* that they are true basement faults.

B. INTERPRETATION

As nearly as can be surmized, the uplift and folding of the Dude-Murua Anticlinorium began just prior to, and initiated the characteristic style of deposition of post-Aure Group sediments. A good deal of the uplift and internal deformation of this unit must have occurred during the latter part of the Middle Miocene, because of the generally unconformable relations of post-Aure Group sediments toward and around the anticlinorium. Toward the boundaries of the anticlinorium, the Toa Group is involved in structures belonging to the anticlinorium, *e.g.* the Kevoro Syncline and the southerly dip around the southern plunge of the anticlinorium, indicating that uplift and, to some extent, folding continued throughout Toa Group time.

It is evident, from almost any point of view, that the Dude-Murua Anticlinorium has acted as a rather independent structural unit. While thrusting toward the west and southwest is important on the west side of the Dude-Murua Anticlinorium, the Albert Fault, the Yave'ia Fault and local faulting along the Urai'ia and ? Haue'ia Anticlines all have a sense of movement which is upthrown on the west side. This clearly demonstrates the fact that a simple compression from the east or northeast, as is commonly supposed for this area, is not adequate to explain all the features of this unit.

The anticlinorium derives its principal character from the fact that it forms a narrow and linear, generally north-south-trending uplift of older rocks, and I suggest that vertical uplift has been the prime deformative agent of this unit.

Prior to the uplift, the area of the anticlinorium was the site of the very strongly negative Karova Trough, which forms the axial region of the broad feature known as the Aure Trough. This area marks the probable position of the maximum cumulative thickness of the Aure Group. ~~viz. the Karova Trough.~~ The Dude-Murua Anticlinorium is, therefore, the expression of a profound and, for the most part, very rapid inversion of this part of the Aure Trough.

The western and eastern boundaries of the anticlinorium are generally anticlinal in aspect and are importantly faulted in part, but are unfaulted over large distances along strike. This makes it clear that the total uplift of the anticlinorium cannot be accounted for in terms of these structures alone. The amount of uplift is essentially constant across the strike of the anticlinorium, yet this uplift has no specific structural expression within the anticlinorium, *i.e.* the required amount of uplift (at least five kilometers) cannot be directly attributed to specific structures within the anticlinorium per se.

To either side of the Dude-Murua Anticlinorium is a very broad synclinal structure, *viz.* the Vailala Synclinorium to the west and the Karova Syncline to the east. The west and east limb of these 'synclines' respectively are strongly thrust away from the centralized uplift of the anticlinorium. It is suggested that a major part of the uplift of the Dude-Murua Anticlinorium is to be found in these and similar flanking structures rather than in the anticlinorium per se. This interpretation envisages a sequence, as shown in figure 2-4, whereby the narrow and rapid initial uplift gave early expression to the Dude-Murua Anticlinorium as an integral feature, but where later vertical movement beneath the Anticlinorium was accommodated mainly by outward movements, toward the west on the McDowal (?Ekiere) ~~Ekiere (McDowal~~) Bevan and Kuku faults in turn, and toward the east on the Yave'ia and Albert faults.

This, in turn, accommodated and broadened the continued regional uplift, as shown in figure 2-4b.

Finally, it is important to observe that the Karova Syncline, while broadly similar, differs from the Vailala Synclinorium in some important aspects. Firstly, the Karova Syncline is only about one-third to one-half the width of the Vailala Synclinorium. Secondly, it is not internally deformed as is the Vailala Synclinorium and thirdly, the Vailala Synclinorium is younger and has had a longer structural development than the Karova Syncline which, along with the Albert Fault, is unconformably transgressed by the Iavokia Mudstone. I suggest that the reason for these differences probably lies in the various forms of asymmetry in this region (refer figure 2-4~~b~~c). Two important facts suggest and illustrate this hypothesis.

The first form of asymmetry is the strong westerly-and southwesterly-facing of the structures of this area. Even the Urai'ia Anticline and the Haue'ia Anticline, which locally have an upfaulted western limb, have a westerly facing. Further, the large-scale, southwesterly-overturning of the Dude Anticline to the south of the Lohiki River has no opposed counterpart on the eastern side of the anticlinorium. Comparing an equal area ~~to~~ on either side of the Dude-Murua Anticlinorium, it is immediately obvious that there is a gross asymmetry of this region, simply in the amount of deformation present to either side of the anticlinorium. There is, therefore, a profound southwesterly and westerly asymmetry in the structural form of this region.

The second asymmetry lies in the fact that the western side of the Dude-Murua Anticlinorium was adjacent to a structurally low area during both the uplift of the anticlinorium and the folding of the Vailala Synclinorium. Conversely, the area to the east of the anticlinorium, ~~i.e.~~ viz. the Tauri Anticlinorium, appears to have been a structural high during this time, with the lower part of the Aure Group forming an exposed source-area to the east of the Idigue Anticline during most of the Middle Miocene. The Tauri Anticlinorium, for the most part, must have remained a high area to the present, as the Toa Group and the Rim Group do not appear to have ever covered this area. Whereas outward spreading and gliding toward the west ~~was~~ were unrestricted and accommodated by the regional gradient, therefore, movement toward the east must have been retarded by the regional gradient. Consequently, the stresses developed in this area found easiest relief toward the west, and the major part of the deformation was directed down the regional gradient.

The cause of the folding within the Dude-Murua Anticlinorium presents somewhat of an enigma. A structural cross-section constructed by the Busk Method, assuming a concentric form of the folds, very accurately predicts the known position of stratigraphic markers across the southern end of the anticlinorium (see figure 2-2). This should be expected because the stratigraphic section involved is formed by a series of alternating sandstones and mudstones of varied textures, composition and bedding characteristics, *i.e.* the section is inhomogeneous, and large viscosity differences in a direction parallel to bedding are present. Large viscosity differences were undoubtedly present during folding, because these rocks, in large part, were folded only very shortly after deposition and were probably soft sediments at the time of folding. This condition should lead to a concentric-type of folding, where slip or flow parallel to bedding is the dominant fold mechanism. In support of this, no pervasive cleavage or jointing systems have been reported in these rocks. In the sections which I viewed in the field in the Murua River area, jointing systems perpendicular to sub-perpendicular and parallel to bedding are dominant, and joint-spacing is strongly dependent on lithology. Locally, joint or cleavage systems at a low angle to bedding (about 30°) are present but, again, are strongly dependent on lithology and are confined to particular beds (usually mudstones) within local sections. Many beds appear perfectly massive, without jointing systems of any kind. All of these features are characteristic of concentric folds.

From these considerations, I regard it as most probable that the folds of the Dude-Murua Anticlinorium are primarily concentric in style. This implies that, in some manner, these folds die-out at depth. Pursuing this reasoning further, it will be noted that very nearly the same stratigraphic interval is exposed in the core of the various folds in each section (see figures 2-2 and 2-3). This can be taken to mean that the folding of any one section was initiated at nearly a constant stratigraphic level and, possibly, is indicative of a general decollement beneath these folds. The structures of the Vailala Synclinorium and the M'bwei River section, however, indicate that folding has been somewhat disharmonic and that various structures die-out at different stratigraphic levels (refer section 2.2.1). This consideration suggests that the prediction of a single decollement interval beneath these folds could be in serious error. Thickness variations and depth of exposure in a direction parallel to the Dude-Murua Anticlinorium must, also, be considered. It is evident for instance, that a decollement prediction of figure 2-2c could only very improbably extend to the depth of the beds which are <u>presently exposed</u> in the M'bwei River section (figure 2-2a). If only lithology and thickness of the section involved are taken into account, however, irrespective of age, it can be seen that hypothetical decollements for both would fall at a similar distance below an arbitrary datum at the top of the Aure Group. This suggests that, mechanically, a <u>single decollement</u> may not be improbabale, but, if present, this decollement <u>does not</u> follow a constant <u>stratigraphic interval</u>.

A good example of structural disharmony in this area can be seen by recalling the argument presented in my stratigraphic analysis regarding the relationship of the Morai River Formation to the Swanson Syncline, Haue'ia Anticline, Lohiki Syncline, Urai'ia Anticline, Kevoro Syncline, and the Murua Anticline. The first four of these structures die-out suddenly, shortly above the base and below the coarsest phase of the Morai River Formation. At the interval in which these structures die-out, there is a good deal of minor deformation and prominent occurrences of quickstones, or mudstone breccias. Both of these features have been related to a detachment at this interval, above which the coarse phase of the Morai River Formation did not participate in the aforementioned folds. A similar situation is here suggested for the Rakavo Syncline and the

Yave'ia Anticline where they plunge-out beneath the base of the Morai River Formation on the southwest limb of the Karova Syncline (refer Plate I). This latter relationship, however, is most probably somewhat altered by additional faulting in this area, *i.e.* the Yave'ia Fault possibly extends through this area but may, also, die-out beneath the Morai River Formation. The fact that the Morai River Formation is strongly folded in the Kevoro and Karova synclines and in the Murua Anticline reveals that the theoretical relationship is not fully realized. Where the lithological character of the section was favourable, however, as below the coarse phase of the Morai River Formation, a detachment-zone is a realized fact.

It is proposed that the internal folding of the Dude-Murua Anticlinorium, being generally concentric in form, is discontinuous in section and dies-out at depth. This is shown generally by the fact that as older rocks become exposed toward the north, folding within the anticlinorium, becomes very gentle in large part. This is especially noticeable to the north of the Ivori River.* If this folding were caused directly by folding or faulting within the 'basement', exactly the opposite should be expected, and both folding and faulting should be expected to increase in importance with depth. In fact, both faulting and folding become less important as older beds become exposed toward the north, *e.g.* compare figures 2-2 and 2-3. Accepting that the main local movements associated with the Dude-Murua Anticlinorium are uplift and concomitant outward movement away from the uplift, and accepting that the folds within the anticlinorium do not continue ad infinitum with depth, suggests that these folds, too, were caused by bedding-plane slippage off the uplifted area. As the facing of these

* Were more information available, it would probably be possible to consider the area to the north of the Ivori River as a separate entity. With the information at hand, however, it is best to consider the Dude-Murua Anticlinorium as an integral feature.

structures is toward the southwest, gliding toward the southwest is indicated.

The west flank of the Urai'ia (?) and Haue'ia Anticlines are locally up-faulted, however, suggesting that possibly some movement toward the east or northeast has occurred. A striking feature concerning this point can be seen from the geological map (Plate I). By comparing the flank-width of each of these anticlines along strike, it can be seen that the upthrown west flank of these structures is very limited in extent; ~~area;~~ this phenomenon being largely restricted to the area in which the Dude Anticline is strongly overturned. Rather than movement toward the northeast, I suggest that these faults, where upthrown on the west side, are primarily tensional faults which were generated as a result of the locally increased southwesterly movement due to, and expressed by, the overturning of the Dude Anticline (see figure 2-5).

Bucher (1963), has recently produced an experimental model of folding caused firstly, by relative uplift and secondly, by the resultant outward gravitational flow. Bucher's figure 10 (opposite p.807) is reproduced as figure 2-6 of this thesis. The broad similarity between this model and the cross-sectional configuration of the Dude-Murua Anticlinorium and adjacent 'synclinal' structures is readily apparent - even the asymmetry of this region is somewhat mimicked by the built-in asymmetry of Bucher's model. This model qualitatively demonstrates and reproduces, to a striking degree, the rough surficial structure of the Dude-Murua Anticlinorium and associated features (see figure 2-30). The major and probably the most important feature not explained by this model is the cause of the major uplift and downwarps, represented in this context by the Dude-Murua Anticlinorium, the Vailala Synclinorium and the Karova Syncline. This relationship is discussed in a later section (2.1.3).

2.1.2 TAURI ANTICLINORIUM

The area between the Idigue Anticline and Eruki Fault to the west and the Kapau Anticline or the outcrop of the Kapau Limestone to the east is somewhat broadly defined here as the <u>Tauri Anticlinorium</u> (refer Plate I). The eastern boundary of the anticlinorium probably extends southward ~~of~~ from the Kapau Limestone beneath the unconformable cover of Middle Miocene and younger rocks of the Lakekamu Embayment. Much of the rationale behind delineating this unit is dependent on stratigraphic arguments, to which the reader should refer (section 1.3.1).

The eastern boundary of the Tauri Anticlinorium to the north of the Kapau Limestone presents a problem. The area to the west of the Kapau Limestone seems to be occupied mainly, by rocks older than the Kapau Limestone, *i.e.* by early Lower Miocene and possibly pre-Miocene (?Cretaceous) rocks. The early Lower Miocene rocks (Yuyebba Creek Beds), that are exposed just to the west of the Kapau Limestone, strike directly into the beds underlying the Kapau Limestone (the lower part of the Hell's Gate Sub-Group) to the north of Yuyebba Creek. It has been proposed that the Yuyebba Creek Beds are unconformably overlain by the Hell's Gate Sub-group in this region, but this particular contact may be either a fault or an unconformity. Pitt (1966) has photogeologically mapped the "Obagewa Fault" in this position. If this fault is present, it would necessarily be upthrown on the <u>west</u> side, and as such would form the natural eastern boundary of the Tauri Anticlinorium.

The only field traverse extending entirely across the Tauri Anticlinorium is that of the Tauri Expedition (APC Rept. LH-2), which crossed the anticlinorium at about 7° 40' S. latitude. Three field surveys have examined the southern end of the Tauri Anticlinorium in the Hell's Gate - Saw Mountains area. The major part of the structure of the anticlinorium has been delineated photogeologically, firstly by A.P.C. geologists and secondly by Pitt (1966). Pitt has revised and extended the A.P.C. map of this area northward to about 7° 30' S. latitude. To the north of this, the geology has not been investigated, except for the widely spaced traverses of Fisher (1935) in the upper Kapau and Langimar River region. I have collaborated with Pitt on several specific aspects of his photo interpretation, particularly in the Saw Mountains and Kapau River areas, but the map of this area presented with this thesis is mainly due to Pitt's efforts. I have differed with Pitt on some points of interpretation and accordingly have modified the map presented with this thesis to this extent. It should be stressed at this juncture that this is a highly deformed and complex area, and it is doubtful that any but the broadest features can be outlined by photogeology to the complete satisfaction of all.

A. DESCRIPTION

The Tauri Anticlinorium trends north-northwest. It is formed principally of Lower Miocene rocks (in this area) and flanked to either side by thick accumulations of Middle Miocene rocks (and Upper Miocene and Pliocene rocks to the southeast). The oldest rocks, and the only Eocene exposures known in this region are brought up in the Hell's Gate-Saw Mountains area at the southern end of the anticlinorium, and early Lower Miocene beds have been crossed in Yuyebba Creek about 24 km. to the north. Just to the north of 7^{o} 40' S. latitude, early Lower Miocene or older rocks probably occupy the major area of the anticlinorium (Pitt, 1966). To the north of the mapped area, the Tauri Anticlinorium falls on the trend of the Aiweriba Anticline, which exposes beds of early Lower Miocene age or older in its core. The Tauri Anticlinorium is, therefore, most probably continued, at least partially, toward the north in the Aiweriba Anticline. More broadly, the logical northward continuation of the Tauri Anticlinorium is in the "Kratke Metamorphics". Except where stated, however, the term Tauri Anticlinorium will refer only to the mapped area to the south of 7^{o} 30' S. latitude. The south end, and southeast side of the Tauri Anticlinorium is marked by the unconformity at the base of the Muiai Sub-Group (Middle Miocene).

There is a fundamental asymmetry of the Tauri Anticlinorium toward the west and southwest. All important faults of this area are upthrown on the northeast or east side, and most are probably thrust faults with the thrusting directed, therefore, toward the west and southwest. In the area between the Saw Mountains and the Mea (Barrier) Anticline the rocks are very nearly entirely easterly dipping, and overturning toward the west is probable in this area.

The south end of the Tauri Anticlinorium is tightly folded and faulted into a series of markedly sinuous structures which trend generally north-south. Toward the north, say north of 7° 40' S. latitude, these structures appear to open-up into broader and more gently folded structures which trend north-northwest, and which expose older rocks toward the north. The important strike faults in this region appear to be upthrown on the east side, or thrust toward the west, *e.g.* the Idigue and Eruki Faults, the Dala Fault and the Werr Fault.

There is a profusion of confused dips in the area to the west of the Saw Mountains, even though the main structures seem largely traceable. This indicates that many minor structures are present in this area. Osborne (~~1941~~ APC Rept. LE-2) has attributed much of this confusion to syn-depositional slumping. I regard this as a probable solution even though no direct evidence for slumping has been offered, because this area is close to the steep eastern margin of the Lower Miocene depositional trough.

There is a marked southward plunge of the anticlinorium between about 7° 30' and 7° 40' S. latitude. Because Eocene rocks are exposed in the Hell's Gate area and because no Eocene rocks were found in the traverse to the north, there must be a northward plunge of the top of the Eocene to the north of the Hell's Gate area. Somewhat contradictorily, the presence of the Saw Mountains Limestone (and younger beds) swinging smoothly across the southern end of the anticlinorium suggest an overall plunge to the south. The area between 7° 40' S. latitude and Hell's Gate seems to be marked by a high degree of northwest-trending transverse faulting, which possibly accounts for the opposed plunges of the anticlinorium in this area. The area between the opposed plunges should be a structural low, and this is somewhat borne-out by the probable presence of an unconformable 'basin' of (?) Middle Miocene rocks at the south end of the Wagewa Syncline (refer Plate I). The transverse faulting seems invariably to display sinistral transcurrent offset, but may be upthrown to either side.

The Iavokia Mudstone is everywhere tilted away from the older rocks exposed in the anticlinorium at an angle of 15^{o} to 20^{o}, which is probably a reflection of late, gross uplift of the anticlinorium. It is significant that this formation is not tilted nearly as much in this area as it is across the southern plunge of the Dude-Murua Anticlinorium to the west, where this formation frequently dips at an angle of 45^{o} or more. This is probably a reflection of the relatively young age of the Dude-Murua Anticlinorium as compared ~~to~~ with that of the Tauri Anticlinorium, *i.e.* late Middle Miocene versus late Lower Miocene.

The rocks involved in these structures are mainly in a siltstone - mudstone - sandstone facies. None of these rocks are metamorphosed and no pervasive cleavages have been reported. The form of the structures is defined by bedding attitudes, and it is a fair assumption that bedding has played a fundamental role in the mechanism producing these folds. This means that the form of the folds is essentially concentric, and it will be expected that these folds are discontinuous in section. It should be possible to examine this relationship by tracing these folds into the areas of older rocks exposed toward the north. It is unfortunate that there have been no geological traverses across the region to the north. It is difficult to see how all of the structures of the anticlinorium can be continuous to the north, because only the large Aiweriba Anticline was reported in the upper Tauri River Area. The relatively simple Aiweriba Anticline may represent the whole of the Tauri Anticlinorium; the fold trends in the younger rocks either disappearing toward the north, or (and) bending around the older rocks exposed in the core of this anticline. This relationship is somewhat borne-out and suggested by the trend of the Karova Syncline, by the topography and by the few dips recorded in this area. I suggest this as a probable solution. It is depicted semi-diagrammatically in figure 2-7.

B. INTERPRETATION

The deformation of the Tauri Anticlinorium on both local and regional scales, seems to have been spread over a rather long interval of time. The early folding and faulting of the Tauri Anticlinorium, which is probably of late Lower Miocene age, is strikingly revealed by the manner in which structures strike into the unconformity beneath the Saw Mountains Limestone. This marks the main internal folding of the anticlinorium, and this folding was accompanied by strong uplift, as is indicated by the thinning and absence or unconformable relationships of the Middle Miocene rocks across the anticlinorium.

The presence of coarse Middle Miocene conglomerates to either side of the anticlonirium, suspected thinning of the Middle Miocene across the anticlinorium and the present general lack of Middle Miocene rocks on the anticlinorium all indicate that the general uplift of the anticlinorium continued throughout most of the Middle Miocene. The angular unconformity beneath the (?) late Middle Miocene beds at the southern end of the Wagewa Syncline, and probably again to the west of the Saw Mountains, indicates early Middle Miocene folding. This unconformity is, itself, folded (although to a less degree than the underlying rocks), which indicates that folding movements did not stop with the early folding.

Because the "Be Creek Beds" are most likely of basal Middle Miocene age, because they occur in an area of mainly lower Miocene rocks and because this area seems to have been a source area throughout much of the Middle Miocene, I suggest that these beds were probably structurally preserved by early Middle Miocene folding and faulting in this area. Another indication of late Middle Miocene folding comes from the fact that the unconformity at the base of the Muiai Sub-group is folded by the Kapau Anticline.

The unconformity at the base of the Toa Group (Maipora Formation), on the other hand, seems to mark the upper limit of folding within the Tauri Anticlinorium. This unconformity, although faulted in some places, *e.g.* as to the east of Maipora Creek, does not appear to participate in any of the folded structures which can be directly linked to the Tauri Anticlinorium. The Yamuti Anticline and South Yamuti Syncline are possible exceptions to this rule, but these structures are transverse to the main trend of the Tauri Anticlinorium. The Maipora Formation is certainly involved in folding to the south and east of the Tauri Anticlinorium, but these structures are probably younger than the principal development of the anticlinorium, *e.g.* the Muruwaie Syncline and Malalaua Anticline appear to have developed mainly during the Upper Miocene and Pliocene. For the most part, the Maipora Formation wraps smoothly around the south end of the Tauri Anticlinorium. This trend is heralded by a similar behavior of the unconformity beneath the Saw Mountains Limestone (Muiai Sub-group).

The main internal, or 'local' deformation of the Tauri Anticlinorium seems, therefore, to have been largely accomplished during the late Lower Miocene, or less probably earliest Middle Miocene. Subsequent folding and faulting occurred, but to a much less degree, through the early Middle Miocene, and internal deformation of the anticlinorium virtually ceased before the deposition of the Maipora Formation. In terms of local folding and faulting, therefore, we can consider the Tauri Anticlinorium as primarily a late Lower Miocene unit. The main folding of the Tauri Anticlinorium is, therefore, related in time to the uplift that exposed the anticlinorium as a source-area for Middle Miocene sediments (refer 1.3.1). The uplift of the anticlinorium has continued from the late Lower Miocene to the present, except for the minor, and probably local subsidence which permitted (?) late Middle Miocene sediments to accumulate unconformably on the structures of the anticlinorium. Opposed to this, the unconformity at the base of the Muiai Sub-group and, to a more marked degree, the unconformity at the base of the Maipora Formation have remained relatively undeformed across the south end and eastern side of the anticlinorium. The uplift of the anticlinorium has, therefore, proceeded somewhat independently of the folding movements. Because of this, the conclusion drawn is that the uplift has not been dependent on the local uplift which is inherent in folding of this type, and that the reverse is possibly the case, *i.e.* the folding is probably a result of the uplift or of the stresses which caused the uplift.

The regional structural development of the Tauri Anticlinorium and its relation to the sedimentary configuration of this region are more complex problems than is the local development. Broadly, the gross form of the anticlinorium, as we presently see it, was outlined late in the Lower Miocene, but there is evidence of earlier movement.

Firstly, there is possibly an unconformity at the top of the Kapau Limestone, or within the Lower Miocene (lower part of the late Lower Miocene), which would indicate that uplift of the Kapau Limestone occurred during the early part of the Lower Miocene. Secondly, the Hells Gate Sub-Group is probably unconformable on the Eocene and (or) early Lower Miocene in the Hell's Gate area and on the early Lower Miocene (Yuyebba Creek Beds) to the west of the Kapau Limestone. These observations suggest very early uplift, erosion and possibly local deformation near the eastern margin of the Tauri Anticlinorium.

The difficulties in relating the Tauri Anticlinorium to the pre-Middle Miocene paleogeography of this region are apparent when considering the eastern boundary of the Aure Trough during the late Lower Miocene. It is clear from the presence of the limestone-conglomerate facies, unconformities within the section and from the outcrop of Eocene and early Lower Miocene rocks that the eastern margin of the trough is rapidly being approached, or that this margin is actually represented, in the Kapau and Hell's Gate areas. A generally north-south, or even northeasterly, line can be drawn between these areas and broadly called the eastern margin of the Aure Trough for the late Lower Miocene. This line is then generally parallel to the major structural trend in this area and sub-parallel to the Middle Miocene-Lower Miocene unconformity that presently marks the eastern and southern limit of exposure of the Tauri Anticlinorium. This line, also generally parallels the north to northeasterly trend of the western edge of the Owen-Stanley metamorphic rocks. Broadly then, it can be stated that the eastern boundary of the late Lower Miocene uplift of the Tauri Anticlinorium was an inherited feature that had been determined by the depositional framework developed very early in the Lower Miocene, and that the main area of this late Lower Miocene uplift corresponds closely to the main trough of Lower Miocene deposition. In addition, the internal deformation of the anticlinorium seems to be controlled somewhat by the facies distribution of the Lower Miocene. The tight folding and faulting of the anticlinorium effectively stops at the Kapau Limestone, or where the Lower Miocene passes from a sandstone and mudstone facies into a limestone-conglomerate facies.

The aforegoing generalized conclusions are difficult to escape, but in detail, the problem is not so easily solved. Firstly, the Middle Miocene is transgressive over the Tauri Anticlinorium, and there is no reason to believe that the unconformity between the Middle Miocene and Lower Miocene marks the real structural boundary of the anticlinorium. The fact that the structures of the anticlinorium strike directly into this unconformity indicates the opposite, and suggests that the eastern margin of the anticlinorium is to be found to the east of the Hell's Gate area beneath the post-Aure Group cover of the Lakekamu Embayment. As a best approximation, the eastern margin of the anticlinorium and, therefore, of late Lower Miocene folding can be inferred beneath this cover by extending it generally from the Kapau Limestone parallel to the structural trend developed in the anticlinorium to the west. The margin so constructed should also mark the approximate eastern limit of the unconformity between the Middle Miocene and Lower Miocene.

Secondly, the apparently close relationship between the eastern margin of the Lower Miocene depositional trough and the eastern margin of the late Lower Miocene uplift of the Tauri Anticlinorium, although <u>regarded as generally true</u>, is probably in error to the extent that the Lower Miocene trough-margin is misidentified by drawing a generalized north-south line through (and therefore equating) the Kapau and Hell's Gate areas. It seems (refer section 1.3.1) that to find a Lower Miocene section equivalent to that of the Hell's Gate area in the Kapau area we must go to the east of the Kapau Limestone. This implies that sedimentary trends strike north-northeasterly in this region. The real eastern margin of the Lower Miocene trough most likely trends northeasterly and lies to the east of both the Kapau Limestone and Hell's Gate area, but probably somewhat closer to the latter. This trend is probably marked locally, to some extent, by the trend of the North Doorway Anticline and Fault and more broadly by the western edge of the Owen Stanley crystallines which trends north-northeast.

Before proceeding, a brief summary of the principle features of the Tauri Anticlinorium is now warranted. The most outstanding features of the Tauri Anticlinorium are firstly, that the folding is primarily a late Lower Miocene feature, secondly that this folding was accompanied by a gross uplift of the anticlinorium which has continued to the present, thirdly, that the anticlinorium is structurally asymmetrical toward the west and southwest, and finally, that the structural form acquired during the uplift and folding of the anticlinorium was probably pre-determined to a significant extent by the configuration of the Lower Miocene depositional trough.

The importance of southwesterly directed thrusting in this area and, in general across this entire region has led to the generally accepted conclusion that a compressional push <u>from</u> the east or notheast has been responsible for these structures; the push generally assumed to have come from or been generated in the crystalline backbone of the Owen Stanley Ranges. The asymmetry of the anticlinorium may or may not be due to a compression from the east, however, because the westerly dipping regional gradient across this area should have tended to produce the same effect. In this area, a simple compressional push from the east or northeast, *i.e.* from the Owen Stanley Ranges, is difficult to visualize as the cause of the structural configuration of the Tauri Anticlinorium. This is because the large, gently and simply folded Muiai Syncline lies between the Tauri Anticlinorium and the crystalline core of the Owen Stanley Ranges to the east. It is probable that the

Tauri Anticlinorium is primarily the effect of vertical movements and, therefore, that it should be regarded as a unit that is essentially independent of compressional stresses ~~movements~~ in the Owen Stanley Ranges.

Broadly, however, it can be stated that the internal folding of the Tauri Anticlinorium represents either a local or regional east-west to northeast-southwest compression. Whether this compression extends to the basement or whether this compression is merely a secondary result of vertical uplift is indeed the crux of the problem and, in turn, must be related to the primary cause of the uplift. Probably some of this folding may be accounted for in terms of a tendency for the sediments to slip off the uplifted area, as was suggested for the Dude-Murua Anticlinorium.

Finally, we need to examine the Tauri Anticlinorium with respect to secondary flanking deformation. It has been proposed that the Vailala Synclinorium and the Karova Syncline and Albert Fault have developed as a result of the uplift of the Dude-Murua Anticlinorium. We should expect that similar secondary effects accompanied the uplift of the Tauri Anticlinorium. From the structure of this region, as can be determined from the geological map, it is apparent that the uplift of the Tauri Anticlinorium has not caused as extensive secondary deformation simply because there is nothing equivalent to the Vailala Synclinorium to the west of this anticlinorium. It is suggested that the uplift and outward-spreading of the Dude-Murua Anticlinorium resisted and retarded, for the most part, a similar late outward-spreading of the Tauri Anticlinorium toward the west. This relationship is best seen in the structure of the area between the Albert Fault and the Idigue Anticline and Fault (refer Section 2.2.4). The folding of the latter area is believed to be due to the local compression caused by the eastward spreading of the Dude-Murua Anticlinorium uplift and the westward spreading of the Tauri Anticlinorium uplift. The Obira Thrust and the strong south-westerly asymmetry and overturning at the southern end of this area are, therefore, regarded as a secondary result of the late lateral spread of the Tauri Anticlinorium where relatively unresisted by the easterly-directed movements generated in the Dude-Murua Anticlinorium. Similar secondary structures might be expected on the eastern side of the Tauri Anticlinorium, but it would be expected that lateral spreading in this direction would, again, have been retarded by the rise in the regional gradient toward the Owen Stanley Ranges; a situation similar to that on the east side of the Dude-Murua Anticlinorium.

The Tauri Anticlinorium <u>as a whole</u> must be regarded as a basement structure, *i.e.* as generally a large anticline, which probably is horst-like, in the basement. This is seen firstly in the age of the rocks involved in the anticlinorium and secondly in the fact that the anticlinorium is probably a continuation of the trend of the "Kratke Metamorphics" exposed to the north. The internal structure and surface folding of the anticlinorium ~~is a~~ are different matters, however. It has been suggested that the internal folding of the anticlinorium is discontinuous at depth, because these folds probably bend around the older rocks exposed to the north and die-out to some extent toward these older rocks. This statement is perhaps not rigorously correct, but is regarded as correct to the first approximation. The problem of geometrically relating these folds to the vertical uplift of the anticlinorium, is therefore, effectively the same as that discussed for the Dude-Murua Anticlinorium and a similar solution might be advocated, *viz.* slippage off the uplift. The problem is not exactly the same, however, because older rocks are involved. Further, this area has not undergone the severe Middle Miocene subsidence that affected the area of the Dude-Murua Anticlinorium. It is not likely, therefore, that the Tauri Anticlinorium can strictly be taken as a model for the structure of the Dude-Murua Anticlinorium at depth, although this relationship might be partially realized.

2.1.3 <u>THE ORIGIN OF UPLIFT OF THE DUDE-MURUA AND TAURI ANTICLINORIA</u>

It should now be clear that a simple late Pliocene, or post-Pliocene compressional push from the crystalline backbone of the Owen Stanley

Ranges is not an adequate explanation for the deformation of the Kukukuku Lobe as has thus far been reviewed. This will become even more evident as the fold and thrust belts to the west and east of the Dude-Murua Anticlinorium are examined in subsequent sections. Neither the age-relationships nor the structural configuration of these anticlinoria can be explained by this hypothesis.

In previous attempts to relate the deformation of the Kukukuku Lobe to the Owen Stanley Ranges, there has been a tacit assumption that the deformation of the Owen Stanleys is temporally related to the deformation of the Kukukuku Lobe. The latest regional metamorphism and related deformation of the Owen Stanleys is a Cretaceous feature (refer Section 3.2.1), and the deformation of the Kukukuku Lobe is clearly not related to this phenomenon. On the other hand, Lower Miocene to Recent conglomerates surround the crystalline massif of the Owen Stanley Ranges, and the deformation of the Kukukuku Lobe may be indirectly related to the Lower Miocene to Recent uplift of the Owen Stanleys that is implied by the existence of these conglomerates. It appears, however, that the Dude-Murua and Tauri Anticlinoria are best considered as integral structural units which are independent of the Owen Stanley Ranges. The best solution, therefore, seems to be to regard these units as a series of independent structural entities, which have resulted from a common stress field. In this view, the Owen Stanley Ranges can broadly be considered simply as the easternmost largest and oldest in this series of uplifts.

Whatever stresses have affected this area, the response or strain, in relation to these anticlinoria, has been primarily vertical uplift. In addition, the uplift of the Owen Stanley Ranges predates the uplift of the Tauri Anticlinorium which predates that of the Dude-Murua Anticlinorium. It will be seen later, that structures become progressively younger as we proceed westward from the Dude-Murua Anticlinorium. It is not a single event, or 'orogeny' for which we must seek a cause, therefore, but a series of events or a continuum, which is marked by a westward progression of uplift through time.

The Dude-Murua Anticlinorium marks the axis of a strong positive Bouguer Anomaly (the 'Kukukuku maximum', see figure 3-6) which trends north-south down the axis of the anticlinorium. This is a startling fact, both because this is a mountainous region and because this trend marks what is probably the maximum cumulative section of the Aure Group (ten kilometers ±). The presence of this positive Bouguer Anomaly makes it untenable to suggest that the uplift of the Dude-Murua Anticlinorium was caused solely by isostatic adjustment or density inversion mechanisms, although each of these mechanisms has probably played its part (refer Section 3.4.5). I suggest, therefore, that a compressional stress has forced relatively dense, sub-sialic material upward beneath this area, thereby causing both the uplift and the positive Bouguer Anomaly which marks the uplift. Extending this reasoning, I suggest an upthrust belt of basic and ultrabasic rocks, broadly similar to the Papuan Basic and Ultrabasic Belt (refer 3.2.1), probably underlies the 'Kukukuku maximum'.

Because the 'Lakekamu minimum' (flanking the Tauri Anticlinorium and 'Kukukuku maximum' to the east see figure 3-6) is probably related to the thick Middle Miocene to Recent sediments (ten kilometers ±) of the Muiai Syncline and Lakekamu Embayment, I regard it as probable that the Tauri Anticlinorium is more closely related to the crustal structure causing the 'Kukukuku maximum'. I suggest, therefore, that the uplift of the Tauri Anticlinorium is, also, a result of compressional stresses.

The compressional stress envisaged is oriented in an east-northeasterly direction at about 75^{o} - 255^{o}, and is believed to be due to regional simple shear stresses. This problem and the mechanism which produced the westward migration of uplift are discussed in Chapter Three.

2.2 SECONDARY DEFORMATION RESULTING FROM THE UPLIFT OF THE KUKUKUKU LOBE

2.2.1 VAILALA SYNCLINORIUM

A. DESCRIPTION

The Vailala Synclinorium is named ~~after~~ for the Vailala River, which forms the major drainage system of this area. The north and west boundaries of the Vailala Synclinorium are formed by the Aure, McDowal and Ekiere Faults. The eastern boundary is formed by the Dude Anticline which, also, forms the western boundary of the Dude-Murua Anticlinorium in this area.

The top of the early Lower Miocene occurs at an elevation of about one kilometer on the Aure Scarp (more correctly, as used in this thesis, the scarp of the McDowal Fault) and at about 500 meters on the west flank of the Dude Anticline. In the APC Kariava No. 1 well, near the axis of the synclinorium, the top of the early Lower Miocene occurs at about 2.8 kilometers below sea-level. The amplitude of the Vailala Synclinorium is, therefore, of the order of three kilometers.

For the purpose of this discussion, and because of a different form of structural behavior to the south of the Er Fault, the Er Fault is taken as a provisional southern boundary for the Vailala Synclinorium (to be amended later; refer section 2.2.2). As defined, the Vailala Synclinorium is approximately 40 km. wide at its broadest point and 110 km. long along the eastern boundary.

Deformation within the synclinorium, as expressed at the surface, has been mainly by folding, some fourteen anticlines having been mapped by field traverse and photogeology. Crestal faulting does not appear to be important in these anticlines but, where present, the northeast side is upthrown, *e.g.* the Suniyana and Hadina Anticlines are possibly faulted in this manner. The axial regions of the anticlines are usually steeply dipping to vertical, dips flattening rapidly into broadly folded, rather gentle intervening synclines. If an asymmetry is present in the anticlines, the facing is, except locally, toward the southwest. At least one important longitudinal fault, the "Haha Fault", is present. The Yanne Fault, a combination longitudinal-cross-fault, occurs near the eastern border of the synclinorium. This fault is complex, and the description of it is left to a special section (refer section 2.2.2). One large cross-fault, <u>Fault A</u>, has been delineated photogeologically. Detailed mapping has revealed that minor local cross-faults are associated with the Kariava Anticline, and more mapping on this scale would probably reveal a similar picture on other anticlines.

The structures of this area are sinuous in plan, but have a strong and dominant north-northwesterly trend (about 340°). Near the Dude Anticline (eastern boundary), structures, including the Dude Anticline, trend more northerly.

In the north, the Vailala Synclinorium and individual component structures plunge strongly to the southeast, away from the Aure Fault, to as far south as the approximate latitude of the M'bwei River. In the southeastern part of the synclinorium, several folds show a strong northerly plunge. In the south-central and southwesterly portion of the synclinorium, a series of brachy-anticlines ~~are~~ is developed, partly in an en echelon pattern, ~~and plunge at both ends~~.

<u>Northern and Western Boundaries</u>

The Aure Fault (refer section 2.4.1) forms the northwestern boundary of the Vailala Synclinorium. This fault is fundamentally a steep, dextral, transcurrent fault but, also, possesses a strong component of vertical movement, the southeast side being upthrown. Upthrow~~n~~ on this fault is probably responsible for the southeasterly plunge of the Vailala Synclinorium.

The western boundary of the synclinorium is formed by the Ekiere and McDowal Faults. An imposing fault-line scarp, rising from an elevation of about 80 meters at the Purari River to above 1,300 meters near the junction of the Purari and Aure Rivers, marks the presence of the McDowal Fault. This scarp is then continuous to the northeast with that of the Aure Fault, which forms an important transverse divide across Papua and New Guinea. Together these scarps have been called the Aure Scarp *(see cover)*.

The McDowal Fault has a very strong thrust component, throwing Eocene beds on the east side over beds as high as the Upper Murua Sub-Group, representing a stratigraphic throw of the order of six kilometers. It is most probable that the McDowal Fault, also, has a component of dextral transcurrent movement. This is indicated by the manner in which the So-oi, Whi-ho and Ouha Anticlines are intersected by the fault (figure 2-8). My suggestion is, because of a close analogy with the Bevan and Kuku Faults (refer section 2.2.3) that the McDowal Fault is primarily a low-angle overthrust fault. The transcurrent movement and, most probably, some part of the excessive throw of this fault, I suggest, are due to secondary movements caused by major transcurrent movements on the Aure Fault (refer section 2.4.1). The Ekiere Fault marks the toe of an allochthonous thrust sheet which has slid off the Dude-Murua Anticlinorium and overriden the McDowal Fault (refer 1.3.2 and, B of this section).

None of the structures of the Vailala Synclinorium are continuous, nor can they be matched, across the combined trend of the Aure, McDowal and Ekiere Faults. At least twelve (possibly fourteen) major structures of the Vailala Synclinorium are either truncated by, or die-out on, these faults, indicating that folding has developed independently to either side of these faults.

Eastern Boundary

The eastern flank of the Vailala Synclinorium is formed by the Dude Anticline which trends nearly north-south. This flank is like the north and western flank in that the <u>bounding structure trends differently</u> from the structures developed within the synclinorium. In this particular discussion, the Dude Anticline will be examined only as far south as the Ivori River.

The Dude Anticline has been crossed in the M'bwei River, New Years Creek and Yoai Creek. The existence of this fold to the north of the M'bwei is dependent on aerial-photo interpretation, but the situation is relatively clear.

From the M'bwei River to between five and six kilometers to the south, the Dude Anticline is a strongly asymmetrical structure facing to the west. The west flank of the anticline dips steeply, with dips of 70^{o} - 80^{o} being the rule, whereas dips on the east flank are shallow (20^{o} - 25^{o}). Along this section, the anticline appears to be largely unfaulted. Early Lower Miocene beds are exposed in the core of the anticline in the M'bwei section, and exposures to the east of this axis are mainly in early Lower Miocene beds. From photogeological observations, these relations appear to hold true northward to Fault A.

About five to six kilometers to the south of the M'bwei River, the steep western flank of the Dude Anticline becomes progressively replaced by the Dude crestal fault and the Yanne Fault (refer section 2.2.2). Both faults are upthrown on the eastern side. In Yoai Creek, the Dude Fault lies <u>behind</u> the Dude axis (to the east) and faults-out most of the late Lower Miocene, having a throw of the order of two kilometers (APC Rept. LR).

In the area of Yoai Creek, the Dude Anticline is a very broad, gently rounded and symmetrical structure. Dips on the flanks are of the order of 20^{o} and <u>flatten</u> to 4^{o} to 5^{o} over the crest of the anticline. This is entirely out of character with the general form of the anticlines of the Dude-Murua Anticlinorium, which consistently steepen sharply in the crestal region. From the Dude Fault eastward to the Murua Anticline exposures are in early and late Lower Miocene beds. To the west of the Dude Fault, and Dude Anticline in general, exposures are in Middle Miocene and, possibly, the upper part of the late Lower Miocene. The Dude Anticline, therefore, retains its function as the eastern boundary of the Vailala Synclinorium (and the western boundary of the Dude-Murua Anticlinorium) in this area.

About three kilometers to the south of Yoai Creek, the Dude Fault again merges with the axial trace of the Dude Anticline and becomes the crestal fault of this structure. The throw of this fault most likely diminishes southward, as the throw of the Dude crestal fault is negligible in Tokwaine and Dude Creeks, three and eight kilometers south of the Ivori River, respectively.

B. STRUCTURE AT DEPTH

The Aure and McDowal Faults bring-up Eocene, and most probably Cretaceous beds on the upthrown side. This effectively reveals a picture of the intersecting structures at depth. The M'bwei Anticline, a structure which can be traced for approximately 48 km., affords the best model and will here be described.

To the south of the M'bwei River, the M'bwei Anticline is strongly and sharply folded, has a pinched core and exposes about 1500 meters of section on its flanks. The width of the anticline, <u>here</u>, is about three to five kilometers between adjacent synclinal troughs. Toward the north, about five kilometers to the northwest of the Vailala River - Tuoa Creek junction, the anticline rapidly changes character to become a more gently folded, broadly plunging structure. Judging from approximate elevations and photogeological markers, the plunge is of the order of 10° (to the southeast). Here, the width between bounding synclines has increased to between six and eight kilometers. Farther to the northwest, just behind the Aure Fault, the width of the anticline between bounding synclines increases to nearly 15 kilometers. In the same direction, that is up-plunge and down section, the axial region of the fold becomes progressively more gentle, beds tracing across the axis with less and less bending and becoming essentially parallel in strike to the Aure Fault. By the time the top of the

Eocene limestone is reached (a very distinctive photo-marker), the fold is very small (refer Plate I) with little noticeable bowing in the (?) Cretaceous and lowest Eocene exposures adjacent to the Aure Fault. This location has not been examined in the field, but a study of the aerial photographs suggests that minor repetitive faulting occurs here.

This description then, indicates that the amplitude and general intensity of the M'bwei Anticline decrease with depth and as the Aure Fault is approached. Were this anticline merely truncated by the Aure Fault and persistent to a much greater depth, we should not expect a fold of such diminutive size adjacent to this fault, unless the strike of the folded beds was strongly divergent to the strike of the fault. This is definitely not the case, the exact opposite in fact being true. The indication from this particular fold example is, therefore, that the fold actually dies-out at depth, probably a short stratigraphic distance below the Eocene. This fold, also, diminishes toward the Aure Fault and, if not purely a reflection of depth of exposure, is a further indication that this fold is confined to the upthrown side of the Aure Fault, *i.e.* this fold has no continuation across the Aure Fault.

Two additional points need be made concerning this structure before we proceed with the general analysis. Firstly, if the M'bwei Anticline were caused directly by a true basement fault, *i.e.* a fault involving pre-sedimentary crystalline rocks (at random, see Plate II, Geol. Soc. Aust. Journ. Vol. No. 8), the amplitude and intensity would be expected to increase as depth is attained. This is directly opposite to what is observed and, therefore, basement faulting is ruled-out as a direct cause of this fold. Any shortening implied by the M'bwei Anticline, therefore, will apply only to the section above the lowest beds involved in the fold, *i.e.* most likely the beds above some interval within the Cretaceous.

The second point, concerns the rapid change in the character of this fold in the vicinity of the Vailala River-Tuoa Creek junction. The stratigraphic position where this marked decrease in sharpness and amplitude occurs is very near the Middle Miocene-Lower Miocene boundary (refer Plate Ia). This can be taken to indicate some degree of disharmony in this fold. Other data (refer later, this section), suggest that this same (approximate) stratigraphic 'horizon' forms a detachment, or decollement, -zone of some importance in this area. It is very important to stress, however, as similar evidence is lacking for the area between the Aure Fault and the Hell's Gate area, that the M'bwei Anticline affects rocks at least as deep in the section as the Eocene and most probably affects Cretaceous beds as well.

Similarly to the case of the M'bwei Anticline, beds trace around the Whi-ho Anticline with progressively less amplitude as the McDowal Fault is approached. Here, however, the lowest beds exposed are early Lower Miocene and the trends of the anticline and bedding are more strongly transected by this fault. Because of the decrease in amplitude and the known involvement of beds as low as early Lower Miocene, I suggest that the Whi-ho Anticline is generally similar to the M'bwei Anticline at depth, *i.e.* implying that this fold does not extend below some interval within the Cretaceous.

Both the Ouha Anticline and the So-oi Anticline have their origin in minor thrust-splays off the McDowal and ~~the~~ Ekiere Faults respectively. The thrust-splays, the Ouha Fault and the So-oi Fault,* join these major faults at an acute angle, curving into the fault from the axial

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* The So-oi Fault has been introduced photogeologically. This is done, aside from general aspect, because a very clear marker-bed, occurring some 1100 m. below the top of the Aure Group, can be traced from the Whi-ho Syncline (Maropo section), to, and along the axis of the So-oi Anticline. A similar thickness of beds could not be present below the top of the Aure Group on the southwest flank of the So-oi Anticline, even if the dips were vertical. Recorded dips average only about 20° half-way up this flank. Further, this structure is plunging, but beds cannot be traced around the plunge as the Ekiere Fault is approached. It is, therefore, with confidence that this fault is introduced. This interpretation may be somewhat affected by a probable unconformity at the top of the Aure Group on the southwest flank of this structure, but the proposed faulting appears to be essentially correct.

regions of the Ouha and So-oi Anticlines. Both faults are upthrown on the northeast side. In both cases, the faults die-out <u>up-section</u>, and beds can be traced smoothly bending around the plunge of the anticlines.

In the case of the Ouha Anticline, the Ouha Fault throws Eocene beds over early Lower Miocene beds in the core of the anticline, but the top of the early Lower Miocene (or a horizon very near stratigraphically) appears to trace continuously around the plunge. This anticline is, therfore, less 'pinched' and unfaulted up-section.

A semi-diagrammatic cross-section (figure 2-9) constructed parallel to the trace of the Aure, McDowal and Ekiere Faults, and looking down the plunge of the 'intersected' structures, ~~graphically~~ illustrates the aforegoing series of discussions.

<u>Evidence Suggestive of a Detachment, or Decollement, -Zone at the Approximate Horizon of the Middle Miocene-Lower Miocene Boundary</u>

The "Haha Fault", Iova Syncline, Iala Anticline and Isa Syncline, in the central portion of the Vailala Synclinorium, now draw our attention. Each of these structures dies-out in a very nearly constant, and narrow stratigraphic interval on the southwest flank of the M'bwei Anticline (refer figure 2-10). The interval at which these structures vanish closely approximates the Middle Miocene/Lower Miocene boundary, which traces straight down the flank of the M'bwei Anticline striking almost perpendicularly to the trend of the aforementioned structures. As there are no signs of a fault intersecting bedding, and many clear photogeological marker-beds which argue against such a fault, it can only be concluded that there is a strong structural disharmony, *i.e.* a decollement zone, within this stratigraphic interval. It will be remembered, that a structural disharmony at this same stratigraphic interval is suggested by the manner in which the M'bwei Anticline sharply increases in intensity at this interval.

The So-oi Anticline falls almost directly in line with the Keka-Kariava anticlinal trend and is a possible continuation of this trend. There is evidence from the APC Kariava No. 1 Well to suggest that the Kariava Anticline vanishes or, at least, greatly reduces amplitude on a decollement near the Middle Miocene-Lower Miocene boundary. This, if correct, would favor an interpretation of a decollement beneath the So-oi Anticline within the same interval (refer preceding paragraphs). It will, therefore, be helpful to examine the Kariava Anticline at this point.

Kariava Anticline: (Feet are used as the unit of length here in order to avoid confusion with the original well data):

The Kariava Anticline was drilled to a depth of 12,621 feet in the APC Kariava No. 1 Well (1946-1948, 1941-1942). The dips and stratigraphic boundaries recorded in this well are presented in Table 2-I. Stanley (1960, p.125), to explain the steep dips below 8,264 feet, has suggested that the well passed into the steep southwest flank at this depth. Dip orientations recorded in a report (APC Rept. LKF) not available to Stanley show that this is probably not the case, as all dips are northeasterly.*

A concentric reconstruction of the Kariava Anticline at depth, using surface dips and the "marker O horizon" as a guide to form, suggests that a decollement zone (ill-defined) is probable between 1,500 and 4,500 feet stratigraphically below the "marker O horizon", or 3,000 to 6,000 feet stratigraphically below the top of the Middle Miocene (figure 2-11). It is interesting to note that this construction predicts that the well would not have passed through the sub-surface axial-surface as Stanley suggested. An important point is that the

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* These orientations are possibly open to doubt, as attitudes determined by this same method (unknown) near the surface are known to be spurious. This, however, is the only and, therefore, the best information available.

T A B L E 2-1

WELL DATA FROM A.P.C. KARIAVA No. 1 WELL

(From Graphic Well-log LKE)

R.T.E. = 560 Feet
STARTING HORIZON : 900 Feet Below Top of Aure Group
300 Feet Below "marker o horizon"

CALCITE and/or GYPSUM VEINING : ····

DEPTH	DIP - ALL NE	STRATIGRAPHIC BOUNDARY
917	16 Degrees	
1275	26	
1383	23	
1527	24	
2275	4	
2280	4	
2345	5	
	Cont. Low dip	
3012	4	
3185	16	
3230	18.5	
3311	10	
3382	18	
3960	12.5	
4038	12.5	
4073	12	
4085	10	Base Middle Miocene between 4084 - 4232
4630	10±	
4809		
····		
4839		
4845	3.5	
4875	4±	
4949	5±	
5104	3±	
5152	3±	
5181	3	
5760		
····		
5880		
6050····		5900 - Formation Pressure 4500 lbs/sq. in.
6132		
····		
6280		
····		
6340		
6346	45	
6362	35	6362 - 8037 : 11 deg. avg. dip
6373	10	
6381	15	

TABLE 2-1 (Contd.)

DEPTH	DIP	STRATIGRAPHIC BOUNDARY
6540		
····		
6580		
(6440)	25	
(6464)	30 ?	
6799	10	
6921	13	
6940	8	
7048	Low Dip	
7078	" "	
7099	8	
7108	9	
7125	9	7200 - Formation Pressure 4450 lbs/sq. in.
7390	20 ?	
7439	7	
7450	7	
7156	10	
7467	8	
7483	10	
7487	7	
7515	6	
7837	5	
7885	5	
8037	14	8037 - 8960 : 31 deg. avg. dip
8264	40	
8285	28	
8295	25	
8306	25	
		8385 - Base late Lower Miocene
8482	35	
8960	30	8960 - T.D. : 49 deg. avg. dip
9094	60 ?	9094 - 10773 : Some 'cleavage' orientations,here, dip at a lower angle than bedding. Therefore, possible overturning.
9100	48	
9119	57	
9644	48	
9645	54	
9648	51	
10178	45	
10183	42	
10184	48	
10185	42	
10773	42	
11557	48	
11577	50	
12198	52	
12621	TOTAL DEPTH	

irregular dips recorded clearly indicate that this anticline has formed with some degree of disharmony, *e.g.* the dips both increase and decrease with apparent irregularity throughout the course of the well, rather than increasing or decreasing with regularity. This could possibly affect a concentric construction, but in this case the irregularities above 8,264 feet are reasonably accurately predicted by the construction presented.

At approximately 6,350 feet in the well, (or about 7,600 feet in stratigraphic thickness below the top of the Middle Miocene), relatively high dips of 45^{o} and 35^{o} were met below a zone of sub-horizontal dips (3^{o} - 5^{o}) measured in sandstones at approximately 5,200 feet. The high dips correspond to the base of a 700 foot mudstone unit, which extends upward to 5,400 feet. It is probable that the high dips continue to the top of the mudstone unit. A flow of gas and saltwater was found in the 'high-dipping' mudstone unit with an abnormally high formation pressure, *viz.* 4,500 lbs./in^2 versus 4,450 lbs.in^2 recorded 1,300 feet lower in the well at 7,200 feet. Below the high dips, a zone of low dips (averaging 11^{o} with a questionable high dip of 30^{o}) was met in dominantly sandstone beds to 8,037 feet.

Occurrences of a fauna recorded as "Marginopora and Sorites" are listed at 5,000 - 5,200 feet, 5,375 feet, and at 6,200 feet, as well as consistently being recorded above the Middle Miocene-Lower Miocene boundary. Marginopora has been generally regarded as a Middle Miocene index fossil in this region (refer, also, Eames et al, 1962), yet each of these specified occurrences is below the basal Middle Miocene boundary and below zones containing a definitive Lower Miocene foraminiferal assemblage. It is possible, therefore, that these occurrences are to be explained by fault repetition in this general interval (see figure 1.3-3b). According to this interpretation, the Middle Miocene-Lower Miocene boundary was met three times in the well interval between 4,200 feet and 6,200 feet. The low, 3^{o} to 5^{o} dips in the upper-half of this interval suggest that faulting, if here present, is sub-horizontal.

Calcite veining is common in this interval (refer Table 2-I), but is nowhere recorded above 4,809 feet and does not occur again below 6,580 feet until high dips are again met at about 8,400 feet. Calcite veining is a common feature of fault zones throughout this region (and I know of no report of calcite veining that is not connected with faulting and structural disturbance). This very strong correlation between the zone of calcite veining and the interval of suspected fault repetition, therefore, lends support to the faulting hypothesis.

The suggested repetition of strata (figure 1.3-3b) is of the order of 1,500 - 2,000 feet. It is pertinent to note, that closure on the "marker O horizon" (the marker on which the geometric construction of figure 2-11 is based) is estimated to be approximately 1,000 feet in the vicinity of Kariava No. 1 Well (Stanley, 1960, p.120). The closure on this horizon could, therefore, be well accounted for by the proposed repetition in the decollement zone. This suggests, in turn, that the Kariava Anticline per se does not exist below this zone, *i.e.* say below 6,200 feet in the well.

In summary, I suggest the following interpretation:

1) The zone between 4,200 feet and 6,200 feet in the well corresponds to the decollement zone predicted by the concentric construction of figure 2-11. The actual decollement occurs at about 6,200 feet, and the interval above this to 4,200 feet is repeated section. The true thickness of the late Lower Miocene stage is regarded as about 2,050 feet.

2) This zone occurs at approximately 6,000 feet stratigraphically below the top of the Middle Miocene, or approximately 400 feet below the top of the late Lower Miocene. In other words, this zone occurs approximately at the Middle Miocene-Lower Miocene boundary.

(a) This interpretation supports, and is supported by, conclusions reached earlier concerning the "Haha Fault", Iova Syncline, Iala Anticline, Isa Syncline, to a lesser extent the M'bwei Anticline and possibly the So-oi Anticline, *viz.* that a detachment, or decollement, -zone exists approximately at the Middle Miocene-Lower Miocene boundary.

3) This decollement zone is most probably the sub-surface continuation ~~ion~~ of the Ekiere Fault.

If the dip orientations discussed earlier (Table 2-I) are accepted as correct, then any interpretation of the Kariava Anticline meets a difficult problem in the zone of steep northeasterly dips below 8,264 feet. Two interpretations have been proposed. These are firstly, that the well stayed on the northeast flank of the anticline and secondly, that a major, sub-horizontal overthrust was met in the well at between 8,000 feet and 8,200 feet (APC Rept. LKF).

The first of these solutions offers a geometrically unlikely and, judging from the form of known anticlines (at random, see de Sitter, 1956), a naturally improbable configuration (APC Rept. LKE-5 Plate I).

The second solution (*ibid*) suggests a more likely picture. This solution proposes that a sub-horizontal overthrust was met in the well at about 8,200 feet. This fault was interpreted to connect to the surface trace of the Ekiere Fault. The steep northeasterly dips below the proposed thrust were explained as being part of the Ivori Junction Anticline, the crest of this anticline having been offset, about 2 miles, above the thrust i~~s~~n an up-thrust (southwesterly) direction.

A unique solution to this problem cannot be given from the information at hand, but the data available can be outlined and possibilities offered. Several possibilities are depicted in figures 2-13 and 2-14.

My suggestion is that the steep dips low in the well are related to the McDowal Fault which has been overridden by the more surficial Ekiere Fault as shown in figure 2-13b.

An additional factor to be considered, in the interpretation of the Kariava Anticline, is the type of section involved. As discussed in Section 1.3.1, the early Lower Miocene beds, or the major part of the interval involving high dips in the Kariava No. 1 Well, are mainly mudstones, fine-sandstone and thin limestones. These beds are overlain by a section which consists mainly of sandstones and, presumably, are underlain by Eocene limestones. The broad picture is, thus, of a thick, potentially 'incompetent' unit situated between 'competent' units. In such a section, one would expect deformation to be more intense in the 'incompetent' unit and possibly of a nature different from the deformation expressed by the 'competent' unit (figure 2-14). The same type of situation occurs in the M'bwei River section, where the early Lower Miocene beds are mainly interbedded sandstones and mudstones while the late Lower Miocene is represented by a thick, massive sandstone unit. Of this latter section, Carey (APC Rept. LI) observed that the style of deformation in the early Lower Miocene beds is different from that of the overlying, massive sandstones, *i.e.* the early Lower Miocene beds are more tightly and closely folded. This difference in style of deformation led Carey to suggest that an unconformity possibly exists between the late Lower Miocene and early Lower Miocene beds in this section. On the scale of an individual fold, descriptively similar situations are common in nature when 'competent' and 'incompetent' beds are folded together. The type of situation envisaged (see figure 2-14) is one in which the 'competent' beds, *viz.* frequently sandstones, within a fold have deformed in a concentric manner while the 'incompetent' beds, *viz.* frequently mudstones, have deformed in an irregular manner. Steeper dips might, therefore, be expected in an 'incompetent' unit, in the core of a fold, than in the surrounding 'competent' units. This kind of interpretation for the steep dips, occurring below 8,037 feet in the Kariava No. 1 Well would not necessarily invalidate a disharmony at the suggested decollement level, but would disallow the view that the Kariava Anticline, per se, dies-out on this decollement.

Structural Disharmony Above The Middle Miocene-Lower Miocene Boundary

The Suniyana Anticline and Suniyana Syncline bear a similar relationship to the Iala Anticline, as the Iala Anticline bears to the M'bwei Anticline. In the case of these structures, however, the stratigraphic interval below which these structures no longer exist is well up in the Middle Miocene succession.

The M'bwei Syncline and Yoai Anticline provide another example of structural disharmony above the Middle Miocene-Lower Miocene boundary. A prominent photogeological marker, occurring approximately 400 meters below the base of the Upper Miocene in the M'bwei River section, can be traced around the M'bwei Anticline, M'bwei Syncline and Yoai Anticline in the manner depicted in figure 2-15. This indicates that the M'bwei Syncline and the Yoai Anticline do not extend upwards in section above this marker.

Figure 2-15 suggests that the M'bwei Syncline and Yoai Anticline are minor structures relative to the M'bwei Anticline. An analogy between the relationship of these structures to the M'bwei Anticline and the relationship of the Iala Anticline (and associated structures) to the M'bwei Anticline may not be far out of order, as the Iala Anticline, also, dies-out on the flank (SW) of the M'bwei Anticline. Pursuing the analogy, this would suggest that the M'bwei Syncline and Yoai Anticline do not persist to a depth below the Middle Miocene-Lower Miocene boundary.

C. CROSS-FAULTING

From a study of the aerial photographs of this area, I suggest that an important cross-fault, Fault A, cuts this area in the manner shown on the geological map (Plate Ia).

Judging from the position of the base of the Middle Miocene, Fault A has a substantial (amount unknown) vertical component, the south side being upthrown. Suggested offsets of axial trends across this fault are indicative of a component of sinistral transcurrent movement. It appears, that both the vertical and transcurrent components of movement increase toward the northeast.

The manner in which Fault A curves into the trend of the Dude Anticline is strikingly similar to the trend of the Yanne Fault in the area to the south. This suggests that Fault A is perhaps basically a tear fault arising from, or accommodating, differential movements above either the Ekiere Fault or McDowal Fault (refer later this section).

Aligned plunges and marked curvature of the Whi-ho Anticline, Ouha Anticline, Iova Syncline and Suniyana Anticline, together with the great thickness of Upper Miocene beds (two kilometers) to the south, are strongly suggestive of normal faulting at depth with a trend parallel to that of Fault A. A possible explanation of this feature and Fault A, relating them (as secondary tensional faults) to dextral movement on the Aure Fault, is presented in figure 2-16.

The Er Fault, appears to be an important cross-fault which, to this point in the discussion, marks the southern boundary of the Vailala Synclinorium. To the north of the Er Fault, deformation (as expressed at the surface) has been mainly by folding, whereas deformation has been mainly by imbricate thrust-faulting to the south of this fault. The Er Fault is discussed in detail in a subsequent section (refer section 2.4.4).

D. INTERPRETATION

From the stratigraphy of this area and from structural discussion, we learned that all post-Aure Group stratigraphic units were deposited marginally to an uplifted area, the western border of which approximates the position of the Dude Anticline. As well as presently being a structural synclinorium, the Vailala Synclinorium was a depositional basin, or structural low, during the deposition of post-Aure Group sediments. In general, a structural high existed on the western limb of the synclinorium during this time (the Vailala High), in a position corresponding approximately to the area between the Ekiere Fault and the Kariava Anticline. To the west of the Ekiere Fault, post-Aure Group sediments attain maximum thickness in the vicinity of the Purari River (the Purari Trough) before, again, thinning-out across the shelf area to the west.

Along the western limb of the Vailala Synclinorium, the thickest accumulation of the Lower Murua Sub-Group is adjacent to, and over-ridden by the overthrust west limb of the synclinorium, *viz.* the McDowal Fault. By the end of Lower Murua deposition, structural relief across the Vailala Synclinorium was, at least, equal to the maximum thickness of the Lower Murua Sub-Group, *e.g.* about 1200 m. in the south and 1800 m. in the area of the McDowal Syncline. The actual structural relief was probably greater than this as the Iavokia Mudstone has not been considered, and because the eastern area was emergent while the western area was submerged and not particularly shallow.

Using the present position of the bounding structures of the Vailala Synclinorium, the regional northeasterly rise on the top of the Middle Miocene at the end of Lower Murua deposition must have been of the order of 1:20 in the north and 1:10 across the Imbricate Belt (refer section 2.2.2). The actual gradient is likely to have been greater, as the thickness of the Lower Murua Sub-Group beneath the McDowal Fault is probably greater than the observable thickness. By the end of Upper Murua deposition these regional gradients must have been essentially doubled. Across, and along the entire length of the Vailala Synclinorium then, tectonic transport was away from the structurally high area and toward the structurally low area, or, <u>down the regional gradient</u>. This strongly suggests that gravitational gliding has probably played a prime role in forming the structures of the Vailala Synclinorium.

In detail, it can be seen that the eastern limit of sedimentation (in the area of the Paun Basin) moved westward throughout post-Aure Group time (refer figure 2-17). This is taken to reflect progressive emergence, or uplift, of the Dude-Murua Anticlinorium throughout this time. Corresponding to this westward shift, the axis of the Vailala Trough moved progressively westward across the Vailala Synclinorium for each age-group, *e.g.* the Lower Murua "trough" was on the eastern limb of the Paun Basin, the Upper Murua "trough" corresponds approximately to the trough of the Paun Basin and the Pliocene "trough" corresponds approximately ~~with~~ to the So-oi Syncline and Keke's Basin (see figure 2-17). At the same time, a westward shift of the Vailala High can be detected, the high moving from the general position of the Kariava Anticline during Lower Murua deposition, becoming larger and more pronounced during Upper Murua deposition and being situated near the present site of the Ekiere Fault during Pliocene deposition. Post-Aure Group time, therefore, corresponds to a time of strong deformation within the Vailala Synclinorium. Localized folding movements, during this time, are revealed by unconformities and (or) stratigraphic character on the Iori, Ivori Junction, Kariava, So-oi and Whi-ho Anticlines, the Isa and (?) Suniyana Synclines and on the Ekiere Fault.

I have suggested (also, refer <u>Imbricate Belt</u>) that the McDowal Fault is primarily a low-angle overthrust fault, which flattens with depth to become a decollement just below the base of the Eocene, presumably within Cretaceous beds. I have projected the McDowal Fault at depth to pass beneath folds at least as far east as the M'bwei Anticline.

I now suggest, that the primary features of the sedimentational and structural history of this area find a reasonable explanation in the following manner:

1) Uplift occurred along, and to the east of, the Dude Anticline, *i.e.* uplift of the Dude-Murua Anticlinorium, initiating the characteristic post-Aure Group sedimentary pattern of deposition peripheral to a rising land mass.

2) Continued emergence intiated and propagated gliding toward the southwest, away from the emerging area and into the structural low of the Purari Trough.

3) The gliding was accommodated initially on a sub-Eocene decollement - the McDowal Fault - probably during Lower Murua ~~Miocene~~ or Iavokia time.

4) The gliding induced faulting and folding in the moving, allochthonous slab.

5) The gradual southwesterly gliding produced an actively rising high, above the 'toe' of the moving slab, which migrated to the southwest as the slab advanced, leaving a structural low, or "trough", behind the migrating high.

6) Early in Upper Murua time, a thrust sheet involving principally the Middle Miocene part of the section slid off the Dude-Murua Anticlinorium - the Ekiere Fault - and over~~t~~rode the McDowal Fault. This sheet of sediment was folded and faulted as it slid westward over the Purari Trough (refer, also, 1.3.2).

7) The pre-existing Aure Fault, formed a natural structural boundary along which the differential movements, required by the gliding and the internal deformation of the gliding slab, could be accommodated. This permitted the Vailala Synclinorium to deform independently of the area to the northwest of the Aure Fault.

8) Both contemporaneous and subsequent movements on the Aure Fault have altered the structures produced by the aforementioned factors. It is highly probable that, while the Vailala Synclinorium developed, it was simultaneously being deformed by transcurrent movement on the Aure Fault. These movements will be discussed more fully in the following chapter.

9) Subsequent uplift, which is most likely a continuation of the emergence that began in the Dude-Murua Anticlinorium to the east during Toa Group deposition, has raised the entire synclinorium to its present position. Raised, Pleistocene boulder-terraces occur in this area and indicate that active uplift is presently occurring (refer section 1.5).

2.2.2 THE IMBRICATE BELT

A. DESCRIPTION

Somewhat arbitrarily (refer later), the area between the Yanne'ia Anticline and the Ekiere Fault can be defined and described as an integral structural unit. This unit, the Imbricate Belt, is bounded on the north by the Er Fault, and by the Kerema Estuary and the present coastline to the south. The Imbricate Belt, is, thus, about 16 km. wide by 50 km. long.

The first important observation to make, concerning this unit, is that deformation has been almost entirely by faulting, with only relatively minor and discontinuous folds being present. The area as a whole, and particularly the southern half, forms a belt of north-easterly-dipping beds. There is no evidence to suggest that these faults developed from anticlines ~~that later became faulted as their development progressed~~, and the general north-easterly dip and lack of overturning deny it. These structures are baiscally faults, as they appear to be.

The second observation is that the Imbricate Belt occurs between the areas of more gentle folding to either side (although these areas, also, contain important faults). A broad and generlized "compression from the northeast", as is commonly supposed for this region, will not satisfactorily explain this relationship.

A third generalization is that the eastern side of the Imbricate Belt coincides approximately with a 'line' across which Middle Miocene beds rapidly shelve toward the southwest (refer figure 1.3-4). Similarly, the Imbricate Belt coincides approximately with an area which is probably underlain by relatively thin, shelf-like late Lower Miocene and early Lower Miocene beds (refer figures 1.3-1 and 1.3-2). The Imbricate Belt, thus, occurs in an area of relatively thin Aure Group sediments.

The overall trend of the Imbricate Belt is north-northwest (330^{o} - 340^{o}), but all of the component structures are markedly sinuous in plan (refer figure 2-18). With the exception of the Haha Fault, the faults of the Imbricate Belt are upthrown on the northeast side, *i.e.* thrust toward the southwest. The stratigraphic throw of the major faults, *e.g.* the Ekiere, Auivera and Ope-Kouru Faults, is of the order of 1.6 to three kilometers. At least one important cross-fault, the Marupi Fault, crosses the Imbricate Belt. The nature of this fault is, for the most part, unknown (refer later).

In the crestal region of the Yanne'ia Anticline, about 300 m. to 600 m. of late Lower Miocene beds are brought to the surface; these beds contain the only late Lower Miocene faunal (foraminifera) assemblages known in the area, and are probably the oldest beds exposed in the Imbricate Belt. The area between the Yanne'ia Anticline and the Ekiere Fault, *viz.* the Imbricate Belt, exposes mainly Middle Miocene beds of the Aure Group. To the west of the Ekiere Fault, exposures are dominantly in Upper Miocene and Pliocene beds. The gross structure of the Imbricate Belt, therefore, is that of an asymmetrical, strongly faulted synclinorium, and the overall structure is very like that of the Vailala Synclinorium in that the western boundary is strongly overthrust and the eastern boundary anticlinal. It is suggested that the Imbricate Belt is the proper southerly continuation of the Vailala Synclinorium.

It will be helpful to later discussion to compare the form, in plan, of the Yanne'ia Anticline ~~and~~ with that of the imbricate thrusts to the west. Figure

2-18 shows that the sinuosity of the thrusts is directly opposed to that of the Yanne'ia Anticline, the opposed trends forming a near mirror image. The strong southwestward bulges in the plan of the thrusts occur directly opposite faulted culminations of the Yanne'ia Anticline. This is interpreted as indicating that the southwestward bulges are a direct response to increased uplift along the Yanne'ia axis, *i.e.* increased uplift yielded increased southwestward thrusting.

Faulting of the Imbricate Belt

The principal thrust faults of the Imbricate Belt are the best known, *e.g.* the Ekiere, Auivera, Ope-Kouru and Pipo Faults. From west to east, there is a decrease in the stratigraphic throw of these faults, from about three km. on the Ekiere Fault to about 1.2 km. on the Pipo Fault. Each of these faults (and perhaps the Pasia Fault), despite the general decrease in stratigraphic throw toward the east, consistently brings-up beds from a very nearly constant stratigraphic interval (beds near the top of the "Lower Arenaceous Subdivision") on the upthrown side. Neither of these facts can be satisfactorily explained if these faults are regarded as steep, deep-seated reverse faults. Were this the case, it would be necessary to postulate that faulting and, therefore, uplift dies-out progressively toward the east. This is exactly opposite to what is found, as the Dude-Murua anticlinorial area occurs to the east and indicates a structural rise in this direction. Further, it would have to be regarded as fortuitous that the same stratigraphic interval is brought up on the upthrown side of these faults. These relations would perhaps be tenable if the Aure Group were thinning eastward across the Imbricate Belt but, again, all indications are that it is rapidly thickening toward the east. These considerations, therefore, lead me to suggest that these faults were initiated within a very nearly constant stratigraphic interval, *i.e.* that they are thrusts arising from a sole-thrust, or decollement occurring within the "Lower Arenaceous Subdivision". This interpretation makes it unlikely that any of the minor structures associated with these fault slices extend, in section, below the fault surface of the associated fault, and certainly not below the stratigraphic interval from which these faults arise.

The Ekiere Fault is the most important thrust of the Imbricate Belt in that it is the most continuous fault, its stratigraphic throw is greatest and it forms the western boundary of the Imbricate Belt and Vailala Synclinorium. This fault, therefore, probably represents the emergence of the decollement per se. This implies that the whole of the Imbricate Belt is part of a discrete thrust sheet which has moved southwestward on a decollement represented by the Ekiere Fault (refer 2.2.1 and 1.3.2).

Haha Fault

The Haha Fault is sub-parallel to the trend of the Ekiere, Ope-Kouru and Pipo Faults, but is different from these, and all other faults of the Imbricate Belt, in that the southwest side of this fault is upthrown. In the vicinity of the Pawro Basin, the Lower Murua Mudstone on the northeast side of the fault is in juxtaposition with Middle Miocene beds on the southwest upthrown side. It is probable that the Haha Fault as drawn in figure 2-19 should be redrawn to the position shown in figure 2-18. I suggest that the so-called "Haha Fault", occurring to the north of the Er Fault, is probably not the continuation of the Haha Fault to the south of the Er Fault as previously believed. The "Haha Fault" to the north of the Er Fault has a strong thrust component, with the northeast side upthrown. The Haha Fault proper probably does not have a surface (? or subsurface ?) continuation to the north of the Er Fault.

The Haha Fault forms the southwestern boundary of the Pawro Basin, and this basin is strongly asymmetrical toward the Haha Fault. The asymmetry is expressed by the thickness of both the Upper Murua Mudstone and Pliocene beds, which thicken across the basin toward the Haha Fault, and by the fact that the Upper Murua Mudstone (Pawro Facies) which becomes strongly unconformable toward the northeastern side of the basin, onlapping the Lower Murua Mudstone and the Aure Group in turn.

At present, only a small ~~inlier~~ outlier of the Lower Murua Mudstone occurs on the upthrown (southwest) side of the Haha Fault, and it seems probable that the Lower Murua Mudstone was never as thick on the upthrown side of this fault as on the downthrown side. This view is somewhat inferential, but is argued principally because of the relatively shallow-water, sandy character of the Lower Murua Mudstone present in the Auivera fault-slice, because of the absence of the Lower Murua Mudstone over this area and because the Lower Murua structural high - the Vailala High - trends directly into the supposed high on the upthrown side of the Haha Fault (refer Section 1.3.2 and figure 2-17).

Stanley (1960, p.107) suggests that the stratigraphic throw of the Haha Fault varies from about 150 m. in the south to about 1200 m. in the north. These movements were deduced assuming that a constant stratigraphic interval was deposited across this fault, an assumption which I regard as unlikely for reasons enumerated above. The 150 m. throw near the south end of the Pawro Basin is not likely to represent the physiographic throw of this fault which must, by my interpretation, be regarded as the important factor. The physiographic throw is likely to be of the order of 1200 m. or the approximate thickness of the Upper Miocene beds in this area.

From the discussion of the preceding paragraphs, a logical interpretation of the Haha Fault and Pawro Basin is that these structures represent a tensional gap, or stretching near the heel of the allochthonous slab as it glided southwestward on the Ekiere Fault. The fact that the Haha Fault is essentially parallel to the thrust trend to the west is taken to indicate that it is actually a part of the allochthonous slab, and that it was generated by the southwestward movement of the slab.

Structures East of the Haha Fault and North of The Pawro Basin

Three well-developed structures, the Hadina Anticline, "Isa" Syncline and Urahara Anticline, occur in this area. There is a strong possibility that minor faulting occurs on the southwest flank of the Urahara

Anticline (refer Plate I). Each of these structures plunges-out rapidly beneath the Upper Miocene and Pliocene beds of the Pawro Basin and the continuation of these structures to the south of the Pawro Basin poses a problem.

These structures, in that they are well-developed folds with faulting seemingly not important, have closer affinities ~~to~~ with the structures of the Vailala Synclinorium to the north of the Er Fault than ~~to~~ with those of the Imbricate Belt. These structures, therefore, can be regarded as transitional in style of deformation, between the folding to the north and faulting to the south. With this in mind, it might be expected that these structural lines are expressed somewhat differently to the south of the Pawro Basin.

The "Isa" Syncline finds continuation to the south of the Pawro Basin in the fault-bounded Pawro Syncline. The Pawro Syncline has formerly been continued northward along the trough of the Pawro Basin (refer figure 2-19). In view of the unconformity at the base of the Upper Murua Mudstone in this area, and in consideration of the relatively independent depositional and deformational history of the Pawro Basin, I regard it as highly improbable that the supposed connection of the trough of the Pawro Basin (which is delineated primarily by dips in Pliocene beds) with that of the Pawro Syncline has any structural significance. From a study of the aerial photographs, I suggest this connection per se is more apparent than real (see figure 2-18), and that the apparent connection is due mainly to the effect of deposition in a pre-existing, or contemporaneously forming syncline. This is graphically illustrated by the manner in which the Isa Syncline and Urahara Anticline lose expression in the Upper Murua Mudstone and Pliocene beds at the north end, and on the west limb of the Pawro Basin (refer Plate I).

Accepting the proposed connection of the "Isa" Syncline and the Pawro Syncline, it is probable that the Hadina Anticline finds a southern continuation in the Pasia Fault. The Urahara Anticline finds continuation in either the unnamed fault on the east limb of the Pawro Syncline, or in the Yanne'ia Anticline. The former suggestion is most likely the case (refer later).

Yanne'ia Anticline

Sections at both the north and south ends of the Yanne'ia Anticline have revealed that late Lower Miocene beds are exposed in the core of this structure. Nowhere to the west of the Yanne'ia axis have definitive, in-situ, late Lower Miocene faunas been found; all recorded faunas being younger or non-definitive.

The Yanne'ia Anticline has a sinuous north-northwesterly trend. The sinuosity of the Yanne'ia Anticline, however, is directly opposed in sense to the fault trends to the west (see figure 2-18). The anticline has a variable plunge, with culminations occurring in the areas of maximum curvature (in plan) of the axial trend. The crest of the Yanne'ia Anticline is certainly faulted, the northeast flank being upthrown, but the amount of throw is variable and uncertain. The manner in which photogeological horizons close around the south-easterly-plunging noses of this structure (refer APC map sheets LZ-10, LZ-22) indicates that the anticline is not greatly faulted in these regions. Faulting becomes apparent, however, toward the culminations of the anticline. Glasessner's correlations (APC Rept. LH-24), suggest a crestal fault with a throw of 1200 m. in the Iabu'ia Creek sections (northern culmination). A reasonable lithological correlation is possible, however, which would call for crestal faulting of the order of only 150 m. (APC Rept. LH-24; see figure 2-19).

In the Pawro Basin, a strong photogeological linear, a mapped fault and an anomalous hip dip all fall on the trend of the Yanne'ia anticlinal axis and suggest the continuation of this faulted axis through, but probably mainly beneath, the Pawro Basin (refer figure 2-18).

The Upper Murua Mudstone (Pawro Facies) is strongly unconformable on the Aure Group at the northern end and on both flanks of the Yanne'ia Anticline. This unconformity, in conjunction with the marine character of the Upper Murua Mudstone, attests to oscillatory movements along the Yanne'ia Anticline during the Upper Miocene. Both Upper Murua and Pliocene rocks have been proved to thin across the Pawro Basin toward the Yanne'ia Anticline and a Pliocene coral-reef is developed almost on the axis of the anticline. At the same time, the non-marine part of the Pliocene section thickens and coarsens toward this anticline and, probably, overlaps the Upper Murua Mudstone at the southern end of the Pawro Basin, just to the west of the Yanne'ia axis (refer figure 2-18).

In the most general case, these data indicate that the Yanne'ia axis was a structural high prior to the deposition of the Upper Murua Mudstone, that it remained a structural high during the deposition of this unit and the Pliocene beds, and that it may have been a source area during the early part of Upper Murua and (or) Pliocene deposition. The facts that the Pawro Basin is folded, and that the Yanne'ia crestal fault marks a line of faulting through the Pawro Basin, indicate that this structure remained active after the deposition of these beds.

Yanne Fault (Formerly "Sawri Fault")

The Yanne Fault is the major part of a fault formerly called the Sawri Fault. I regard the Yanne Fault as a direct structural connection between the Dude and the Yanne'ia Anticlines, and the name suggested for this fault is derived from the name of the latter anticline. The "Sawri Fault", as previously interpreted, includes both the Yanne Fault and the Sawri Fault of this thesis (refer Plate I). The geological map accompanying this thesis depicts my interpretation of this structure, along with the suggested configuration of the Yanne Fault. It is proposed that the term Sawri Fault be restricted to the synclinal fault as shown on the geological map.

The Sawri Fault was first recognized in Sawri Creek, where it is marked by numerous faults in a general fault-zone. The fault is synclinal in aspect, and prior to the recognition of the fault this structure was believed to be a simple syncline.

The fact that the Sawri Fault is basically synclinal makes this fault a unique feature in this region. Coupled to this, the southwest flank of the adjacent Dude Anticline, or upthrown side of the Sawri Fault,is overturned along the eastern side of the Imbricate Belt. The amount and extent of overturning of the Dude Anticline is, also, a unique feature of this region. A detailed cross-section across the Sawri Fault and Dude Anticline, along Doroi'ia and Numbiai Creeks (refer figure 2-20), shows that the stratigraphic throw of the fault is not great, and that the throw is distributed in a broad fracture zone in the crushed trough of this synclinal structure.

The aspect of the Sawri Fault remains synclinal and the strike essentially parallel to the longitudinal axis of the Dude Anticline northward to the Lohiki River. The overturned southwest limb of the Dude Anticline briefly reverts to normal between Wabada and Pi'ia Creeks. At this point, the trace of the Sawri Fault swings sharply toward the axis of the Dude Anticline, which would be expected if the faulting were controlled simply by the overturning of the anticline. North of Pi'ia Creek, the Dude Anticline again becomes overturned, and the trace of the fault swings away from the anticlinal axis. The Dude Anticline remains overturned almost to the Lohiki River, to the north of which the anticline is never again overturned. Just to the north of the Lohiki River, the southwest limb of the Dude Anticline can be smoothly traced (photogeoloically) from normal westerly dips to overturned easterly dips (my photo interpretation; refer Plate I). In this position, I suggest that the fault formerly known as the "Goddiapa Fault" is the proper continuation of the Sawri Fault. Where the overturned dips revert to normal, the syncline adjacent to the Dude Anticline, known in this area as the Habbdai'ia Syncline, becomes a more gently folded structure with only very slight faulting along the trough. Synclinal faulting is apparently absent further to the north.

For these reasons, I suggest that the Sawri Fault, as here outlined, is a relatively shallow feature which was formed by crushing and squeezing in the syncline as a direct consequence of the overturning of the Dude Anticline.

A study of the aerial photographs covering the Sawri Fault in the area to the south of Yanne'ia Creek has resulted in the interpretation presented on the accompanying geological map. This interpretation should be compared to the previous interpretation which is presented in figure 2-19.

The Yanne Fault was formerly regarded as the northern continuation of the Sawri Fault. ~~(refer figures 2-18 and 2-19).~~ I regard it as probable that the Yanne Fault continues southward as the crestal fault of the Yanne'ia Anticline (refer Plate I).

Broadly, the Yanne Fault is concordant with the gross northerly structural grain of this area. In detail, however, this fault is strongly discordant, separating an area of northwesterly-trending structures to the west from structures with northerly trends to the east. At least seven separate structures, and the flank of two additional structures, are truncated on the downthrown (west) side of this fault. In contrast, only three structures are truncated on the upthrown (east) side of this fault, and the fault trend is parallel, in general, to the combined trend of the M'bwei and Habbdai'ia Synclines. The structures on the downthrown block are, therefore, either overridden by the fault, or have developed somewhat independently of those on the upthrown block.

In the north, the Yanne Fault swings through a northeasterly trend to merge with the crestal fault of the Dude Anticline. This northeasterly section of the Yanne Fault is believed to have a strong transcurrent component, sinistrally offsetting the trends of the Yoai Anticline and Oboru Syncline by about 1.6 km., and the M'bwei Syncline about 800 meters. The amount and sense of transcurrent movement is somewhat uncertain, however, due to two factors. Firstly, I have recognized the Yoai Syncline, Oboru's Anticline and a probable fault in the M'bwei Sa section to the north. At present, I have no means of tracing these structures southward. If these structures do, in fact, extend southward to the Yanne Fault, the supposed offsets might be somewhat altered, *i.e.* supposed matching features are possibly misidentified across this fault. Secondly, the extent to which structures have developed independently across this fault will obviously affect the interpretation of offsets across this fault.

The stratigraphic throw of the Yanne Fault is variable, but has been estimated at about two km. in the area north of the Pawro Basin (APC Rept. LR). This can be regarded as only a rough estimate however, because the stratigraphy of this area is not well known.

The aforegoing observations demonstrate that the Yanne Fault is a more important fault than the Sawri Fault, and that it has a very different character. Coupled to this, the Yanne Fault is generally anticlinal, or sometimes homoclinal, in aspect but is rarely synclinal. These features strongly suggest that the Yanne Fault does not find logical continuation in the Sawri Fault, as formerly suggested (see figure 2-19).

The Yanne Fault, on the other hand, is similar to the Yanne'ia Anticline in that both of these structures follow, or form a more or less definite boundary between important structural units, *e.g.* the Vailala Synclinorium to the west and the Dude-Murua Anticlinorium to the east. From this, I suggest that the Yanne Fault forms a direct structural link between the Dude Anticline and the Yanne'ia Anticline, which respectively form the eastern boundary of the Vailala Synclinorium to the north and the Imbricate Belt to the south.

The exact nature of the Yanne Fault is difficult to determine. The same considerations discussed with respect to the Dude and Yanne'ia Anticlines will apply, in general, to this fault. If the suggested transcurrent offsets along this fault can be accepted (refer above), then it is difficult to visualize that the Yanne Fault could be a thrust fault. The offsets would suggest downward movement of the downthrown side as opposed to overthrusting of the upthrown side. This suggests the possibility that the Yanne Fault is a normal fault, and that it may represent either the emergence of a decollement (the Ekiere Fault?) from beneath the Vailala Synclinorium, or that it is a tensional fault due to the westward glide above the decollement. The former alternative offers great promise in providing a ready explanation for the difference in folding to either side of the Yanne Fault, whereas the local nature of the latter alternative would not explain this relationship. Nor can this difference be explained by overriding of a thrust sheet, if the suggested transcurrent offsets are correct. If the suggested offsets are not accepted as correct, then the most simple assumption to make would be that the Yanne Fault is a thrust that has overriden the structures on the downthrown block and that they are now present beneath the fault.

Relationship Between the Yanne'ia Anticline and Dude Anticline

To the north, the Dude Anticline forms the east boundary of the Vailala Synclinorium, while to the south, the Yanne'ia Anticline seems to serve this structural function. This involves a close structural differentiation and, perhaps a closer one than is warranted from the amount and uncertainty of stratigraphic data available. This transference of structural function may be real, or it may be only apparent. I favor somewhat the former interpretation.

The case for a real transference of structural function between these anticlines can be summarized in the following observations:

1. The oldest recorded faunas, in the area of the Imbricate Belt, are brought up on the northeast limb of the Yanne'ia Anticline, and to the east equivalent beds are exposed more deeply and with regularity (refer 2.1.1). This situation is similar to the section across the Dude Anticline in the M'bwei River.

2. There is a very close relationship between the trend of uplift along the Yanne'ia Anticline and thrusting of the Imbricate Belt, whereas the trend of the Dude Anticline

(in this same area) does not bear this relationship to the trend of the thrusting.

3. There is a strong change in the character of the Dude Anticline to the south of the Ivori River. This is, perhaps, related to a change in the fundamental character of this anticline which, in turn, may be related to the transference of major uplift from this anticline to the Yanne'ia Anticline.

4. As nearly as can be surmized, the Yanne'ia Anticline marks an older structural line across which Middle Miocene beds of the Aure Group thicken rapidly toward the east. As equivalent time-horizons are exposed to both the east and west of this anticline, the anticline must mark a zone of strongly reversed movement and major uplift.

5. There is probably a direct structural connection between the Dude Anticline and the Yanne'ia Anticline via the Yanne Fault, which has accommodated the transference of structural function.

Cross-Faulting

Aside from the Er Fault (refer section 2.4.4) , a study of the aerial photographs in conjunction with field data (recorded on the APC 1: 40,000 map series) suggests that important cross-faulting affects the southern part of the Imbricate Belt. Strong photo-linears suggest the possibility of cross-faulting in the area to the west of the Pawro Basin (refer Plate I). I have not studied the photos of the area between the Pawro Basin and the area shown in figure 2-18. Figure 2-18 depects my photo interpretation of cross-faults in the southern part of the Imbricate Belt.

Marupi Fault

This fault, particularly on the eastern side of the Imbricate Belt, forms a well-marked photogeological linear and is probably the most important cross-fault recognized. In the east, this fault separates primarily northwest-striking beds to the north from nearly east-west strikes to the south. This fault corresponds to a mapped fault of limited extent, and with a mapped "zone of irregular dips" (map sheet LZ-22) occurring just to the north of Irahabra Creek. The photo-linear traces westward through opposed dips in Opau (Karabure) Creek and thence through a zone of irregular dips in lower Haha Creek. Westward from Haha Creek there are no field data, but the photo-linear continues in the manner shown in figure 2-18.

The Marupi Fault does not appear to form a break in the dip-slope marking the Ekiere Fault. The fault is continued westward to the Vailala River (as a dotted line), however, because it falls directly on the trend of a large, positive, residual gravity anomaly which trends east-west (refer figure 2-23). The Marupi Fault, also, passes through opposed dips in Hihia Creek. Structures which trend east-west, corresponding to the trend of the gravity anomaly and the Marupi Fault, have not been mapped in this, largely alluvial-covered, area but have been mapped to the southwest. It seems unlikely that the apparent continuation of the Marupi Fault and this anomaly is merely fortuitous, and this fault should be expected at depth even if surface features such as the Ekiere Fault are not offset.

The gravity data in the Vailala River area suggest that the Marupi Fault has a substantial vertical component of displacement. The residual gravity values along this trend are of the order of 2.0 to 3.5 milligals, which is two to three times larger than the normal residual anomaly in this region (usually 0.5 to 1.5 milligals; refer figure 2-23).

The most conspicuous flanking residual low is to the north of the Marupi Fault, while values fall off more evenly and slowly to the south. These data, together, suggest that the Marupi Fault is deep-seated and that the south side may be upthrown. Stratigraphic information is sorely lacking in the area where the Marupi Fault crosses the Imbricate Belt, and the stratigraphic throw of this fault is unknown.

B. INTERPRETATION

In broad form, the Imbricate Belt is a strongly faulted synclinorium. The general character of the Imbricate Belt is similar to that of the Vailala Synclinorium in that the western limb is formed by the strongly thrust Ekiere Fault and the eastern limb is anticlinal. As such, it is the logical southward continuation of the Vailala Synclinorium.

Stratigraphic considerations have yielded isopach and lithofacies maps, which indicate that the area to the east of the Imbricate Belt (the Dude-Murua Anticlinorium) began rising late in the Middle Miocene. Sediments deposited thereafter (post-Aure Group), were deposited peripherally to this emerging anticlinorial area. Coincident with this uplift, or shortly thereafter, we get our first evidence of deformation within the Imbricate Belt. From this, it can be inferred that the uplift to the east and the deformation within the Imbricate Belt are genetically related, and I suggest the latter is probably a result of the former. These relationships are similar to those displayed in the northern part of the Vailala Synclinorium. For this reason, I suggest that the genetic development of the Imbricate Belt has been similar to that given earlier for the northern part of the Vailala Synclinorium, *viz.* the deformation is due to gravitational gliding away from the uplifted Dude-Murua Anticlinorium.

The pertinent question to now ask, is why the Imbricate Belt has deformed by faulting whereas the northern part of the Vailala Synclinorium has deformed mainly by folding. There are two reasonable answers to this question. Firstly, the deformation of the Imbricate

Belt probably occurred at a more rapid rate than the deformation to the north, as is indicated by the amount of faulting present. This could possibly mean that the uplift of the Dude-Murua Anticlinorium was more rapid opposite the Imbricate Belt than further to the north. The second possibility is that westward gliding in the area of the Imbricate Belt may have met a barrier, thereby causing the gliding sheet to pile-up in a series of imbricate thrusts.

We can examine this second possibility further by considering the width of the Imbricate Belt as compared ~~to~~ with the width of the Vailala Synclinorium to the north of Er Fault. The maximum width of the Imbricate Belt is about 16 km., whereas the maximum width of the Vailala Synclinorium to the north of the Er Fault is about 40 kilometers. Assuming now, the hypothesis that the Ekiere Fault passes beneath the Vailala Synclinorium and that it was generated in the uplifted area of the Dude-Murua Anticlinorium, it can be suggested that the allochthonous slab was allowed to glide farther in the north before it met the 'resistance' which caused the decollement to emerge as the Ekiere~~-Aure~~ Fault. In the north, where gliding advanced farther, the allochthonous slab stretched and sagged, thereby producing the Paun Basin with its thick accumulation of Upper Miocene sediments. In the south, where gliding met resistance, the allochtonous slab piled-up against the rising toe (the Ekiere Fault) forming a series of imbricate thrust faults (figure 2-20-1).

2.2.3 THE THRUST AND FOLD BELT SOUTHWEST OF THE PURARI THRUST - SPLAY AND THE EKIERE FAULT

The northern boundary of this structural unit is formed by the Purari Fault and Purari Thrust-Splay, the eastern boundary by the McDowal and Ekiere Faults, and the southern and western boundary is formed by the Delta Homocline.

The major structures of this belt are the Bevan and Kuku Faults (refer Plate I). Between the Bevan and Kuku Faults, the structure is broadly synclinal and the varying plunge along this synclinal trend has produced a series of elongated basins. Near the Aure Lineament, where a sharp bend in the trend of this unit occurs, the structure is complex. This bend itself is an integral tectonic element and, as such, these complexities can best be discussed in a separate section (refer section 2.4.1).

A. BEVAN FAULT

The Bevan Fault is the northeasternmost structure in Papua which is continuous across the Aure Lineament. This fault has been mapped over a distance of approximately 130 kilometers. To the northwest, the Bevan Fault merges with, or is transected by the Purari Fault; to the southeast this fault merges with, or is transected by, the Ekiere Fault.

In outcrop, the Bevan Fault is typical of the major faults of this area. The fault-zone is up to several hundred feet wide and is marked by steep, chaotic dips and numerous pug-zones in which beds are frequently shattered and calcite-veined. The steep dips and the linear trace which the fault makes along its entire length indicate that the fault is essentially vertical at the surface. Beds consistently dip away from the fault, thereby imparting a generally anticlinal aspect to the fault.

The northeast side of the Bevan Fault is upthrown. The stratigraphic throw of this fault is variable, but is generally of the order of 1.5 to three kilometers. From the northwest end of this fault to as far south as Bevan Rapids (where the fault crosses the Purari River), the fault throws rocks very low in the Middle Miocene over beds fairly high in the Lower Murua Sub-Group. The throw of this fault is maximal where it crosses the Aure Lineament, ~~and it is possible that Lower Miocene beds are brought up at this location (refer section 1.3.1)~~.

To the south of Bevan Rapids, the throw of the Bevan Fault is neither as great, as constant, nor are exposures along the fault as deep as to the north of Bevan Rapids. In places, however, the Bevan Fault attains a throw of the order of two km., *e.g.* between the Nakoro and Pemani Anticlines. In the following pages, I use the term Bevan-Pemani Fault when referring specifically to the section of the Bevan Fault to the south of Bevan Rapids, but have retained the term Bevan Fault as a name for the entire structural feature. I have altered the extension of this fault to the south of Bevan Rapids, and the detail of this alteration is presented later in this section.

B. KUKU FAULT

The Kuku Fault is parallel in trend and broadly similar in surface aspect to the Bevan Fault. The fault has been mapped from a position near the mouth of the Vailala River northwest to a position near the junction of Puri Creek and the Era River, a distance of about 120 kilometers. The northeast side of the fault is upthrown, throwing Upper Murua rocks over Pliocene rocks along most of its length. Where the Kuku Fault crosses the Aure Lineament and, again, from the Piamorra Structure to the southeast, Lower Murua beds are brought to the surface by this fault. The stratigraphic throw of the fault is variable along strike, but is generally of the order of 1.5 kilometers.

To the southeast of the intersection of the Kuku Fault and the Aure Lineament, beds dip away from the fault imparting an anticlinal aspect to the fault. Dips are steep to vertical near the fault, and the fault trace is linear, indicating that the Kuku Fault is essentially vertical at the surface.

C. PLIO-MIOCENE SYNCLINAL BASINS

From northwest to southeast, the Pide Basin, Mena Basin, Kuku Basin, Goigi Basin and Vara's Basin are part of a broad synclinal structure developed between the Bevan and Kuku Faults. The basins per se are formed by the variable plunge of this synclinal structure. The basins are generally symmetrical, having steeply dipping limbs (vertical in the case of Vara's Basin) which shallow-out rapidly to sub-horizontal dips in the troughs of the basins. The plunges, in at least two cases, are caused by transverse structures, *e.g.* the Mena Fault-Wira Anticline trend causes the opposed plunges between the Pide and Mena Basins, and the Mena Anticline causes the opposed plunges between the Mena and Kuku Basins. From an analysis of the structural plan of this area (refer later, section 2.4.4), it is suggested that faulting at depth is likely to be the cause of the opposed plunges between the Kuku and Goigi Basins and between Goigi and Vara's Basins.

The parallelism of this broad synclinal trend with the trend of the Bevan and Kuku Faults genetically relates these features. Stratigraphic evidence (refer later) indicates that the line of the Bevan Fault began activity during the early part of Upper Murua deposition, and that the line of the Kuku Fault commenced activity early in the Pliocene. For these reasons, the synclinal zone must have begun formation at this time, *i.e.* the northeastern limb near the beginning of Upper Murua deposition and the southwestern limb near the beginning of the Pliocene. By this analysis, ~~this analysis,~~ this synclinal zone must have been, in some measure, a structural low and depositional trough during most of the Pliocene.

The transverse Mena Anticline, between the Mena and Kuku Basins, is particularly interesting because it suggests a sequence of development of these structures. The fact that a sequence exists, again shows that the deformation of this area is the result of a series of 'events' and not merely a single, episodic event.

The Mena Anticline trends at very nearly a right angle to the synclinal-basin trend. The basins plunge away from the anticlinal axis, and the anticlinal axis plunges toward the synclinal axis connecting these basins. This suggests that these structures are essentially contemporaneous. It will be noted, however, that a cross-fault truncates and offsets the trough of the Mena Basin but does not offset the axis of the Mena Anticline. This suggests that the Mena Anticline may be a younger structure than the Mena Basin. The easterly plunge of the Mena Anticline to the east of this cross-fault may be a result of the cross-fault, rather than a result of folding on the Mena-Kuku synclinal trend. The sequence of deformation envisaged is as follows:

1) Folding along the Mena-Kuku synclinal trend;
2) Formation of the cross-fault, truncating and offsetting the synclinal trend;
3) Folding of the westerly plunging Mena Anticline, resulting in the opposed plunges between the Mena and Kuku Basins;
4) Vertical offset on the cross-fault, the northwest side being upthrown, causing the easterly plunge of the Mena Anticline.

D. PURI ANTICLINE

Only the eastern end of the Puri Anticline falls in my thesis area, but a brief description of this anticline will offer help in interpreting the Kuku Fault.

The Puri Anticline is the most deeply exposed structure between the Bevan and Kuku Faults, beinging up Lower Miocene limestones (the Puri Limestone) in its western culmination at about 145° E. longitude. To the west, the Puri Anticline is essentially an east-west-trending structure, but in this area the anticline is strongly sinuous in plan. Grossly, the trend of the Puri Anticline is in sympathy with that of the Bevan and Kuku Faults, but the bend in the Puri Anticline is more exaggerated. Where the bend in the anticlinal axis is sharpest (north of the Suai Basin), the anticline is strongly faulted by many minor longitudinal and transverse faults which are not present further to the west (APC Repts. LI, LT). To the southeast of the bend, the axis of the anticline is dextrally offset, about 1.5km., by a transverse fault which trends northeasterly. Immediately to the north of this, the synclinal axis between the Pide and Mena Basins is dextrally offset, about three km.,by a northerly-trending transverse fault.

The concentrated faulting at the bend of this anticlinal axis, together with the dextral offset of the axis, suggests that this anticline was bent, probably subsequent to its formation, by a dextrally acting stress couple. In addition to this, the Puri Anticline has a slight southwestward-facing asymmetry at the surface, and a strong southwestward-facing in the sub-surface in the vicinity of the western culmination. This is as would be expected in view of the southwesterly-directed movements on the Kuku and Bevan Faults. Seismic work, however, suggests a northeastward-facing of this anticline in the area of the strong bend of the anticlinal axis (Puri West, 1:40000 Map Sheet). This anomalous facing could well be explained in terms of a subsequent reversal of the normal southwestward facing, as a result of the same dextral stress couple which has bent the anticline.

The Puri Anticline is of particular interest because the APC bore, Puri No. 1 (1a and 1b) yielded clues to the internal structure of the anticline. As an aside, the Puri No. 1 Well has been the most successful well in Papua to date. This well,

> ".....produced oil at a maximum rate of 1610 bbl/day declining over nine days to 34 bbl/day" (1961, Bur. Min. Res., Publication 6, p.37).

At 2261 meters (7425 feet), the drill passed from Lower Cretaceous mudstones (Tubu Shales) into Lower Miocene limestones (Puri Limestone), thus proving the existence of a major thrust at this depth. The deviated wells, Puri No. 1a and No. 1b, encountered the thrust at essentially the same depth, thereby proving that the thrust encountered is a sub-horizontal overthrust (Stanley, 1960, p.201). Even apart from the discovery of this overthrust, the internal structure of Puri Anticline is complex and not completely worked-out. Of the Lower Cretaceous mudstones encountered above the main thrust it is stated,

> "Emphasis must be placed on the remarkably contorted nature of the Cretaceous mudstone, particularly above the thrust. The degree of slickensiding was intense, and the extent of fracturing indicates that the beds are, in all probability, a jumbled mass ...." (1961, Aust. Bur. Min. Res., Pub. No. 6, p.17).

A spurious thickness of Eocene and the probable occurrence of Eocene beds within a Cretaceous interval below the main thrust, suggest that thrusting involving repetition is present in this interval (*ibid,* p.18).

The above-quoted publication suggests that the overthrust encountered in the Puri well is the sub-surface continuation of the Era Fault (*ibid,* p.19). Stanley, however, suggests that this thrust is to be continued as the Kuku Fault at the surface (1960, p.198). The APC Maps (Puri West, 1:40000 Map Sheet) show that the south side of the Era Fault is upthrown, which is opposite to the sense of movement required by the overthrust in the Puri Well. For this reason, I agree with Stanley's suggestion that this thrust is most likely represented by the Kuku Fault at the surface.

The Puri Seismic Survey (1961, Bur. Min. Res., Pub. No. 21), furnishes data which is most helpful in constructing a cross-section of the Puri Anticline. Figure 2-21a is a cross-section of the Puri Anticline reproduced from this publication (from figure KAF-8). It is evident from figure 2-21 that this publication has followed Publication No. 6, or vice-versa, in their interpretation of the structure of this area. I have based my interpretation of this area, which is presented in figure 2-21b, on the data presented in figure 2-21a in conjunction with the map data from the APC 1:40000, Puri West, Map Sheet.

It has often been proposed that both the Bevan and Kuku faults possibly have a strong transcurrent component, thus explaining the variable throw and the lack of matchable structures across these faults. I suggest, however, that the general (not perfect) parallelism of these faults with associated fold trends is more indicative of faulting movements similar to those involved in the folding, *i.e.* movements essentially perpendicular to the fold axes or fault traces. The consistent anticlinal aspect of these faults indicates that this is so, and the sub-horizontal configuration of the Kuku Fault at depth demands it.

In that the Bevan Fault is remarkably parallel to the Kuku Fault in both trend and history (refer later), I suggest that the Bevan Fault is similar at depth to the Kuku Fault, *i.e.* suggesting that the Bevan Fault flattens rapidly down-dip to become a sub-horizontal overthrust fault.

This view does not completely disallow transcurrent movements on the Kuku and Bevan Faults, but suggests that, if present, transcurrent movements are subsidiary to the main thrusting movements. I have, in fact, already suggested that transcurrent movement on the Bevan and Kuku Faults is likely to have occurred as a secondary result of the bending of these structures along the Aure Lineament. This late movement, plus the observation that most of the folding to either side of these faults seems to have developed independently, most probably accounts for the lack of matchable structures across these faults.

The fact that the Kuku and Bevan Faults are anticlinal in aspect suggests that the faults developed first and primarily as anticlines, as several authors before have noted. Continued <u>local</u> compression then yielded faulted-anticlines, which became faulted to such a degree as to eventually lose their primary nature as anticlines. I subscribe~~d~~ to this view and accept this as the course of development followed by these faults. That these faults remain essentially anticlines in places, *e.g.* the Bevan Fault in the Horbu area, adds support to the suggested growth sequence, but indicates that the sequence has developed to varying degrees along the length of these faults.

E. HOHORO ANTICLINE

Three wells and seven shallow scout bores have been drilled on the Hohoro Anticline. The N.G.O.C. No. 1 well (1926-1928) drilled to 413 meters (1,353 feet), the APC Hohoro No. 1 well (1949-1950) drilled to 1440 meters (4,721 feet) and the APC Hohoro No. 2 well (1951-1952) drilled to a total depth of 3242 meters (10,642 feet; Stanley, 1960, p.217-224). An analysis of this anticline, using the data from these wells, is pertinent to the understanding of the regional structure of this area.

Surface Geology

The axial trace of the Hohoro Anticline curves from a west-northwest trend at its western end, to a north-northwest trend at the eastern end, forming part of a regional northwesterly trend which Carey (APC Rept. LI) has termed the "coastal trend" (refer section 2.4.5).

The axial trace of the Hohoro Anticline has been interpreted as bending sharply northward at its western end, through an angle of 90°, to continue northward as part of the Pairi-Mekori Anticlinal trend. This bend cannot be proven in the field due to alluvial cover in the critical area. Northerly strikes in Upper Miocene beds at Hebe Hill, at the west end of the Hohoro Anticline, and a sympathetic ~~similar~~ but more gentle bend in the trend of the Parimamu Syncline support this supposed connection.

The Hohoro Fault parallels the anticline, cutting the south flank of this structure. The northeast side of the fault is upthrown, the stratigraphic throw being of the order of 150 m. at the southeast end of the anticline and possibly increasing toward the northwest.

In cross-section, the Hohoro Anticline is strongly cuspate and slightly asymmetrical to the southwest. It has a narrow and pinched core, with near-vertical to overturned dips being the rule in the beds exposed at the crest of the structure. Away from the crestal region, dips shallow rapidly. At the base of the Pliocene (Era Group), about 500 m. to the north of the anticlinal axis, the average dip is about 40°, decreasing rapidly to sub-horizontal dips in the trough of the Parimamu Syncline about five kilometers to the north.

The northern flank of the Hohoro Anticline exposes approximately 1430 m. (4700 feet) of Pliocene sediments to the trough of the Parimamu Syncline. An additional 425 m. (1400 feet) of Upper Miocene (Upper Murua) beds are exposed in the crest of this structure.

The upper part of the exposed Upper Miocene section is usually normally-bedded, whereas the lower part of the section is generally chaotic, forming a belt of "plastic", or running mudstones in outcrop. The running mudstones have highly irregular attitudes and are generally vertical to overturned. These mudstones are intensely slickensided and brecciated. Mud volcanoes and gas blows are frequently associated with the running mudstones.

The outcrop width of both the normally-bedded mudstones and the running mudstones is variable, which has led Rickwood to state,

> "......the soft mud occurrences do not conform to a definite horizon in the Upper Murua....." (1947, LHB, p.9-13).

Another interpretation is that the running mudstones are diapiric with respect to the normally bedded mudstones, which still admits the possibility that the running mudstones are confined to a "definite horizon".

The cause of the running mudstones has been variously attributed to faulting, bentonitic content of the mudstones and to diapirism, which possibly encompasses both of the former causes. The best evidence that the running mudstones are directly due to faulting is that these mudstones are confined to the narrow zone of the Hohoro Fault at the southeastern end of the anticline. The zone of running mudstones widens to nearly one kilometer toward the northwest, however, and cannot be directly related to important faulting. From this, it seems more probable that the Hohoro Fault has been localized along the zone of running mudstones rather than vice-versa. It is pertinent, also, that the zone of running mudstones widens up-plunge on the anticline. This would be expected if the running mudstones, generally, represent a stratigraphically controlled interval, below the normally-bedded mudstones. The uncertainty behind this reasoning is due to the fact that the zone of running mudstones then narrows to the northwest, and a concomitant northwesterly plunge, though possible (Stanley, 1960, p.215), has not been proven.

The migration of fluids along a brecciated fault surface offers a possible explanation for the running mudstones (Gray and Bouchier, 1929-30; Rickwood, APC Rept. LHB) but, again, a direct relation to important faulting is difficult to prove.

The wells drilled on this anticline have shown that the zones of running mudstones are not merely a surface phenomenon. The extent and variation of these zones, both at the surface and at depth, would call for an extremely complex fault system - this again suggests diapirism. Carey (APC Rept. LJ) has suggested that the form of this anticline (as well as that of the Pairi, Huromoipa and Mekori Anticlines), both in cross-section and plan, likens it to diapiric structures. De Verteuil and Rickwood (APC Rept. LHB) came to the conclusion that some degree of diapirism and piercement of Pliocene beds was important in the early development of the anticline. Because of the fact that no beds older than the Upper Murua Sub-Group are exposed in the crest of this anticline and because the Pliocene-Miocene contact is normal, Stanley observes that this anticline is not

> ".....due to piercement from a much greater depth in the manner of a true diapir". (1960, p.213).

This is a valid observation. My conclusion regarding this structure, to be argued in detail in subsequent paragraphs, is that the anticline began development as a normal concentric fold, but that diapirism developed within the Upper Murua Sub-Group as the fold developed. The running mudstones are believed to be a secondary result of faulting and brecciation and probably abnormally high water pressures at depth; these mudstones in turn causing a tendency toward diapirism in the core of this structure.

From considerations of regional stratigraphy (refer section 1.3.2), it was expected, prior to the drilling of Hohoro No. 2, that the entire Upper Miocene section would be of the order of 1.8 kilometers (6000 feet) thick at Hohoro. The Upper Murua Sub-Group was expected to be about one kilometer (3,300 feet) thick. Because of the position of Hohoro relative to the shelf area to the west, the Upper Miocene section was expected to be thinning across this area, the preceding thicknesses being given as maximal estimates. Contrary to these estimates, the Hohoro Well No. 2 drilled an estimated 2160 meters (7,100 feet) of Upper Murua beds and was still in Upper Miocene beds when the well bottomed at 3242 meters (10,642 feet). This is an excess of 1160 meters (3800 feet), or more than twice the thickness expected for the Upper Murua section in this area. This extraordinary thickness suggests that a re-appraisal of the section encountered by the bore is wanting. This is undertaken in the subsequent paragraphs.

Geometry of The Hohoro Anticline and Theoretical Prediction of a Decollement Zone

A geometrical construction of the Hohoro Anticline, based on a revised version of DeVerteuil and Rickwood's cross-section of this anticline (APC Rept. LHB) and incorporating well data, is presented in figure 2-22. This construction (following Carey, 1962) suggests that a decollement zone theoretically exists beneath this anticline, in an interval between about 425 meters (1,400 feet) and 790 m. (2,600 feet) stratigraphically below the base of the Pliocene. This construction involves the assumption of pure concentric folding which, in view of the nature of the mudstones exposed (and drilled) in the core of this structure, can at best be regarded as only a reasonable approximation. The construction presented, however, uses the base of the Pliocene as a guide to the form of the fold. As Pliocene beds are not involved in zones of running mudstones, nor pierced to any great extent by these zones, a decollement prediction with respect to the base of the Pliocene should yield reasonable results.

Well Data and Discussion (Information from Stanley, 1960, p.209-224, except where noted; feet are used as the unit of length to avoid confusing original data)

In the N.G.O.C. Hohoro No. 1 Well, which spudded-in near the top of the Upper Murua Sub-Group, dips go from 48° at 1,007 feet to "very high" at 1,050 feet. At 1,353 feet, the well was discontinued because of "heaving shale", which some two months later had refilled the hole to 1,132 feet. There can be little doubt that the "heaving shales" are similar to the running mudstones exposed at the crest of this structure.

The APC Hohoro No. 1 Well passed from dips of 15° at 3,433 feet, to vertical dips at 3,923 feet. Below 3,923 feet, to bottom at 4,721 feet, questionable dips of 50° and 65° are recorded. Cores below 3,415 feet yielded "material unsuitable for detailed examination" (APC Rept. LHC-1). "Heaving shales", again, caused drilling difficulties and, for this reason, the well was abandoned at 4,721 feet. The base of the Pliocene was met at 1,046 feet, or 2,000-3,000 feet above the zone of steep dips and running mudstones.

The APC Hohoro No. 2 Well met the base of the Pliocene at 2,064 feet, which was 650 feet higher than expected. At 3,647 feet, or 1,583 feet below the base of the Pliocene, running mudstones were met. The only cores taken from this well were from the Lower Murua Sub-Group, in the interval between 9,982-10,042 feet. Core requests from 7,764 feet, 8,124 feet, 8,306 feet and 9,292 feet were disallowed for "operational reasons", presumably because of running mudstones. Very little dip information was taken from this well, opposed dips of 16° and 20° being recorded from the interval between 1,300-1,500 feet. A statement from Stanley (p.224) concerning this well, is apropos,

> "The operational difficulty of drilling in the Upper Murua Group is almost insuperable".

In Hohoro No. 2 a 7,282 foot interval, from 2,064-9,346 feet, was assigned to the Upper Murua Sub-Group. A <u>stratigraphic</u> thickness of approximately 7,100 feet has been suggested for this interval (APC Rept. LHE-1,2). This obviously <u>assumes</u> a dip of 15° for this interval, but this can be <u>no more than a guess</u> owing to the lack of dip information. As previously noted, this is 3,800 feet in excess of the 3,300 feet expected for the Upper Murua Sub-Group in this area.

Considerations of the Pliocene stratigraphy of this area show the Pliocene section to thin from 4,700 feet on the south limb of the Parimamu Syncline, to 4,200 feet on the north limb, representing a convergence rate of about 165 feet per mile. In the light of this, the occurrence of the base of the Pliocene 650 feet higher than expected in Hohoro No. 2 illustrates an important fact. The expected position of the base of the Pliocene in Hohoro No. 2, was calculated from surface dips and from the position of this horizon in Hohoro No. 1, some 3,800 feet to the southwest. To explain the anomalous occurrence of this horizon in Hohoro No. 2 by thinning toward the northeast, requires a thinning rate of about 850 feet per mile, or more than five times the known thinning rate. Thinning, therefore, does not seem a likely explanation for this anomalous occurrence. A logical explanation lies simply in the suggestion that the syncline flattens-out more rapidly than concentric constructions based on surface, or near-surface, dips would predict. This suggestion implies, that the folding has not so much down-buckled the syncline, but rather uplifted the anticline.

The convergence rate of the Pliocene, toward the northeast can be taken to represent a structural fall of the base of the Pliocene at a similar rate toward the southwest. Removing folding, this represents a regional dip of about 2° to the southwest. If this dip were maintained from the trough of the Parimamu Syncline to the position of Hohoro No. 2, a distance of two miles, any horizon below the base of the Pliocene should have been at least 330 feet lower at the well-site than at the trough of the syncline prior to folding. Assuming now, that the thickness of Pliocene beds beneath the trough of the Parimamu Syncline is 4,500 feet, and assuming the surface beds to be at sea-level, places the base of the Pliocene at 4,500 feet below sea-level at this location. Further, assuming the expected thickness of 3,300 feet for the Upper Murua Sub-Group, places the base of this group at 7,800 feet below sea-level. With the suggested regional dip, and prior to folding, the base of the Upper Murua Sub-Group would be expected at about 8,130 feet below sea-level beneath Hohoro No. 2. The actual position of this horizon in Hohoro No. 2 was placed at 9,185 feet below sea-level, or about 1,000 feet lower than a pre-folding analysis predicts, yet the well was drilled on an anticline. Folding should have raised this horizon well above the 'predicted level' if this horizon was involved in the folding. A regional dip of 10°, or an Upper Murua section, 4,300 feet thick, would yield the base of the Upper Murua Sub-Group unfolded, *i.e.* implying that this horizon was not involved in the folding of the Hohoro Anticline. This, in turn, implies that the Hohoro Anticline dies-out above the base of the Upper Murua Sub-Group, and that a decollement zone exists between this horizon and the base of the Pliocene. A 10° regional dip is not considered excessive, as the 2° dip is based on an unfolded Pliocene section and post-folding uplift to the north has certainly occurred.

The most important, and as yet most assailable, assumption of the preceding discussion is that the Upper Murua Sub-Group is of the order of 3,300 feet thick in this area. The necessary corollary to this assumption is that the supposed 7,100 feet of Upper Murua Sub-Group encountered by the Hohoro No. 2 Well represents a tectonically thickened section. Judging from known examples of decollement-folds, *e.g.* the Appalachian foreland folds of West Virginia and Pennsylvania, U.S.A., such thickening might be expected if a decollement zone exists within the Upper Murua Sub-Group beneath the Hohoro Anticline. It will be beneficial at this point to examine more closely the sections drilled at Hohoro.

The entire Upper Miocene section encountered at Hohoro consists of mudstones, with only very minor intercalations of coarser material. Lithologically, the section is constant and monotonous and furnishes no lithological marker-horizons. It has elsewhere been noted that while a twice-normal thickness of the Upper Murua Sub-Group has been postulated for this area, there are no noticeable facies or faunal differences between this and sections of 'normal' thickness. The faunal subdivisions of the Upper Murua Sub-Group, recognized in areas to the north, have been recognized in Hohoro No. 1 and No. 2 Wells. The subdivisions recognized in these wells can be compared as follows: (information from LHC and LHE well-logs)

	Thickness	
Subdivision	Hohoro No. 1	Hohoro No. 2 (15° dip)
Howme Mudstones	1650 feet	2300 feet
Huro Sandstones	1900 feet	2700 feet
Horupa Mudstones	Top at 4600 feet	Top at 7100 feet

As these wells are 3,800 feet apart across strike, this suggests northeastward thickening at a rate of about 1,000 feet per mile in each unit. This is not realistic, and the lack of concomitant changes in facies and faunas denies it. If accepted, however, and extrapolated through the entire supposed thickness of the Upper Murua Sub-Group, these data suggest that this group attains a thickness of about 13,000 feet in the trough of the Parimamu Syncline, two miles to the north-east, which is beyond reason. It will be noted, that dips have not been taken into account for Hohoro No. 1, while a 15^{o} dip has been assumed for Hohoro No. 2. In that Hohoro No. 1 is situated closer to the anticlinal axis and, therefore, in an area of generally steeper dips (recorded dips average about 30^{o}), dip consideration in Hohoro No. 1 will only increase this disparity. The significance of these subdivisions in these wells is, therefore, open to serious doubt. Further doubt exists in that it can be argued, on the basis of stratigraphic position, that the Howme Mudstones and the Huro Sandstones are essentially time equivalent facies units in the Nakoro-Horbu area. There is no reason to suspect that this is not the case at Hohoro, and the significance of the subdivisions as recognized here remains uncertain.

The point of the preceding discussion is to question whether the paleontological data provide proof either that the Hohoro No. 1 section is normal, or that it is interpreted correctly. From this discussion, the answer to these questions must be no. The data, as interpreted, demand highly improbable conclusions, and the significance of the data is uncertain. My evaluation of the significance of these data as presented is that they probably, but not certainly, represent only broad superposition within the Upper Murua Sub-Group.

A final point is that, accepting the suggested paleontological boundaries as valid, the top of the Horupa Mudstones must have an average dip of 34^{o} between Hohoro No. 1 and No. 2 wells. This would suggest that the beds below 7,100 feet in Hohoro No. 2 are dipping at more than twice the amount (15^{o}) used to calculate the stratigraphic thickness. This would reduce the previously suggested thickness of

3,380 feet, for this interval, to 3,010 feet.

The average dip at the top of the Howme Mudstones and the top of the Huro Sandstone is $\underline{10^{\circ}}$ and $\underline{12^{\circ}}$, respectively, between these wells. An angular discrepancy exists, therefore, between these horizons and the top of the Horupa Mudstones.

Interpretation

My interpretation of the Hohoro Anticline is that it is basically a concentric fold which is grounded in a decollement zone within the Upper Murua Sub-Group. I suggest that the Hohoro No. 2 well drilled through this decollement zone and through an anomalous, tectonically thickened section of the Upper Murua Sub-Group. The tectonic thickening is most probably a result of imbricate thrusting arising from the decollement zone.

The case for a decollement interpretation of a fold, or folded belt, lies in proving that the fold does not exist below the decollement zone. From the available information, this cannot be conclusively proven for the Hohoro Anticline. With reasonable assumptions, however, a case has been argued to this effect. The anomalous thickness of the Upper Murua Sub-Group and the spurious paleontological results then find explanation in terms of a tectonically disturbed and thickened zone above the decollement zone.

I regard the fact that beds or fault-slices of the Lower Murua Sub-Group are not included in this thickened zone, as an indication that the decollement occurs above the top of this group, or within the Upper Murua Sub-Group. Additional, but negative, evidence favoring this hypothesis is that cores were taken ~~allowed~~ from below the Upper Murua Sub-Group in Hohoro No. 2. This is possibly an indication that drilling became easier within this interval and, perhaps, that the main tectonic disturbance had been passed.

That the Hohoro Anticline is not basically a diapiric fold is suggested by the fact that the base of the Pliocene and upper part of the Upper Murua Sub-Group are bent-up with the fold, *i.e.* they are not (strongly) pierced. The available paleontological data suggest that superposition within the Upper Murua Sub-Group is broadly maintained. Many things, however, suggest that some degree of diapirism has occurred. The steep to vertical dips in the core region of this and related folds indicate that vertical movements have been important in this region. Both limbs of the closely related Mekori Anticline (refer later) are locally overturned. This is a characteristic of diapirs and a further indication that vertical movements have dominated in the core regions of these folds.

The first recorded occurrences of running mudstones in N.G.O.C. No. 1, Hohoro No. 1 and Hohoro No. 2 are at about 245 meters (800 feet), 610 meters (2,000 feet) and 499 meters (1,600 feet) stratigraphically below the base of the Pliocene respectively. In surface exposures, the zone of running mudstones commonly occurs as little as 61 meters (200 feet) below the base of the Pliocene. These data show that the first occurrence of running mudstones is essentially stratiform (somewhat reversed) between Hohoro No. 2 and No. 1 wells, but that running mudstones occur progressively closer to the base of the Pliocene as the crest of the anticline is approached. This perhaps, suggests that a 'zone' of running mudstones is transgressing, or piercing, overlying formations as the axis of the fold is approached, *i.e.* implying diapirism within the Upper Murua Sub-Group.

A general argument favoring the probability of diapirism, can be advanced on the density contrast between the Upper Miocene mudstones and the overlying Pliocene beds. As seen, the Pliocene section in this area consists of a large portion of sandstone, making this section, on the whole, more dense than the Upper Miocene mudstone section. Geophysical studies centered in this area have assumed densities of 2.2 for the Pliocene section and 2.0 for the Upper Miocene section. It should be expected, therefore, that the Upper Miocene beds will tend toward diapirism with respect to the Pliocene section.

As noted, gas blows and mud volcanoes are common features of the zones of running mudstones exposed at the crest of the anticline. A substantial brine flow and gas flows were found in association with the running mudstones met at 1,080 meters (3,647 feet) in Hohoro No. 2 well, proving that fluids are available at depth and active is producing the running mudstones. The suggestion is, that the faulting and brecciation associated with the decollement zone beneath this anticline have yielded a migration channel for fluids. This has resulted in high water pressures and increased mobility (running mudstones) within the Upper Murua Sub-Group and, in turn, has led to incipient diapirism in the crestal regions of the anticline.

<u>Geophysical Evidence for the Structure of the Hohoro Anticline</u>

The results of a gravity survey in this region (APC Rept. LU) indicate that a <u>negative</u> residual gravity anomaly occurs about 460 meters south of, and parallel to, the surface axis of the Hohoro Anticline (see figure 2-23). Nearly symmetrically flanking, and parallel to, the Hohoro axis are <u>positive</u> residual anomalies, the north-flank anomaly passing over the location of Hohoro No. 2. The trough of the Parimamu Syncline is paralleled by a negative residual anomaly.

The suggestion has been made (*ibid*), that the north-flank positive anomaly is over the sub-surface crest of the Hohoro Anticline. This interpretation would be plausible, if it could be proven that this fold incorporates beds older and more dense than the Upper Murua Sub-Group. The aforegoing discussions suggest that this is probably not the case~~.~~ and, as well, there is no reason to assume that the axial surface of this anticline dips at an angle of 50^{o} as required by this hypothesis.

On the other hand, there is the suggestion that the mudstones of the Upper Murua Sub-Group are tectonically thickened by at least twice the normal thickness in the Hohoro No. 2 well and, probably, by a much greater amount in the core of the anticline. It has been noted that the Upper Murua Sub-Group is generally less dense (2.0) than the overlying Pliocene section (2.2). If the structure of this fold is as I suggest, then a negative gravity anomaly should be expected over the tectonically thickened core of this structure. The symmetrically flanking positive anomalies could then be explained, at least partially, in terms of a closer approach to a more normal section.

If this explanation of the gravity picture is feasible, then the fact that the flanking positive anomalies are nearly symmetrical with respect to the anticlinal axis suggests that the axial surface of this anticline is nearly vertical. This is suggested by the steep to vertical dips in the core of this structure, by the indications that diapirism has played a part in the development of this structure and by geometrical construction.

A corollary of this reasoning is that the axial trend of the Hohoro Anticline might plausibly be extended beneath the alluvial cover along one of the gravity lows shown in figure 2-23.

Related Structures

The Mekori-Pairi anticlinal trend is essentially continuous with the Hohoro Anticline. The Huromoipa Anticline is broadly similar in plan to this connected trend and merges with it. Both the Mekori-Pairi anticlinal trend and the Huromoipa Anticline are closely similar, in cross-section and in depth of exposure, to the Hohoro Anticline (refer Plate I). For these reasons, I suggest that all of these structures are genetically related, and that they are founded in a decollement zone within the Upper Murua Sub-Group.

The Parimamu Syncline is regarded as a residual low formed between these rising anticlinal structures. It is pertinent to note that this syncline plunges in sympathy with the widening of the Upper Murua outcrop in the core of the Hohoro Anticline, but plunges in the opposite direction. This is possibly indicative of removal of material from beneath the syncline toward the tectonically thickened core of the anticline. This couplet, *i.e.* a localized basinal low adjacent to an anticlinal culmination, can be seen in the decollement folds of West Virginia, U.S.A., or more generally, in residual sinks around salt diapirs.

Summary of Interpretation

1) The previously suggested stratigraphic thickness of 2,160 meters (7,100 feet) for the Upper Murua Sub-Group encountered in Hohoro No. 2 well is regarded as an anomalous, tectonically thickened section. The thickness of a normal section for this area is suggested to be of the order of 1,000 meters (3,300 ± feet).

2) It is suggested that the Hohoro Anticline, the Mekori-Pairi anticlinal trend and the Huromipa Anticline are basically concentric folds which are grounded in, or arise from, a decollement zone within the Upper Murua Sub-Group. The decollement zone probably occurs about 610 meters (2,000 feet), stratigraphically, below the base of the Pliocene. Tectonically thickened zones should be expected, above the decollement zone, in each of these structures.

3) Faulting and brecciation associated with the decollement zone has tended to channel fluids along this zone. This, coupled to the relatively low density of the Upper Murua Sub-Group, has resulted in incipient diapirism within this group in anticlinal regions.

4) The rise of the anticlinal structures above the decollement zone, leaving the synclines as residual lows, characterizes the nature of these folds. This is stated as a contrast to folding which bends the synclines downward as well as bending the anticlines upward. Removal of material away from the synclinal areas toward the anticlinal areas is possibly illustrated by the plunge relationship of the Hohoro Anticline and the Parimamu Syncline.

5) The negative residual gravity anomaly paralleling the Hohoro anticlinal axis is taken to reflect a tectonically thickened section of the, relatively light, Upper Murua Sub-Group in the core of this structure.

F. REGIONAL STRUCTURE SOUTHWEST OF THE EKIERE FAULT TO THE SOUTH OF BEVAN RAPIDS

The structure of this area is dominated by the Bevan-Pemani and Kuku Faults although several large structures have been mapped in the area. Upper Miocene and Pliocene rocks form the main outcrop of this area, but toward the east narrow bands of Middle Miocene rocks are brought to the surface in fault slices and anticlinal cores.

The faults of this area invariably have the northeast side upthrown, but the stratigraphic throw of these faults is ~~generally~~ variable along strike, owing in part to the fact that large structures are intersected obliquely by the faults. The stratigraphic throw of any one fault may vary from hundreds of meters to the order of 1.5 kilometers.

These faults are steep to vertical at the surface, as indicated by dips near the faults, and by the linear trace of these faults through irregular topography, but the attitude of the fault surfaces at depth is unknown, except in the case of the Upoia Fault. This fault has been shown by the drill (APC Upoia No. 1) to have a northerly component of dip of about 55°. The anticlines of this area face to the southwest, and in as much as the faults and folds of this area have subparallel trends and because the faults are directly related to anticlinal structures in many cases, *e.g.* the Eako-Keari Fault, these faults are taken to be northeasterly-dipping thrust faults.

The usual interpretation, based largely on the characteristic linear trace, is that these faults are fundamentally steep thrust faults involving basement (*e.g.* see Geol. Soc. Aust. Journ. Vol. No. 8, plate II). Aforegoing discussions of the Puri No. 1 and the Hohoro No. 2 wells show that this cannot be considered a general rule. ~~is not generally the case.~~ The following discussion will argue that these faults flatten rapidly down-dip to become sub-horizontal over-thrusts.

A strong pattern is developed in the structural plan of this area (see figures 2-24 and 2-25). This pattern is developed in two major structural units, here called the Kuku-Hoho ~~Horo~~ Unit and the Pemani-Keari Unit. Each of these units consists of a sub-rectilinear, northwesterly-trending (320°) major fault, *e.g.* the Kuku and Bevan-Pemani Faults, with an associated zone of sinuous structures to the southwest. This zone of sinuous trends is bounded on the southwest by a faulted anticlinal trend which merges to the northward (and southward?) with the major northwesterly fault. Each of these units will be analysed in detail.

I have slightly altered the structural trends in the southern part of this area. These changes are based on the results of a detailed gravity survey of this area, taken in conjunction with stratigraphic considerations. The rationale behind these alterations must be briefly discussed before the broader structure of this area can be attempted.

Figure 2-23 is a partial reproduction of a residual gravity anomaly map produced by Richards (APC Repts. LU, LU-2). The trends of the anomalies (dashed lines) correspond well with geologically established structures, and these trends can be accepted with some degree of confidence as a likely indicator of structural trends. The heavy lines on figure 2-23 indicate my interpretation of these data.

The most important feature to note, is the suggested continuation of the Kuku Fault. The position of this fault is based on the position of a strong gravity gradient, the range of which varies between 0.2 and 1.5 milligals. The northwest side of the gradient is always the positive side, corresponding to the upthrown side of the Kuku Fault.

Considerations of the stratigraphy of the Beleppa area (refer section 1.3.2) led to the conclusion that a faulted anticlinal structure must be present in the Beleppa area, with a trend essentially parallel to the strike of the section (east-southeast). The gravity data and the stratigraphic arguments, therefore, find mutual support, and it is with confidence that this suggestion is offered.

The fact that a strong gradient exists across this fault indicates that rocks of density higher than that of the downthrown Upper Miocene mudstones are involved on the upthrown side of this fault. The relatively dense ~~sandstones of the~~ Aure Group is ~~are~~, therefore, probably involved on the upthrown side of this fault. The relatively low gradient, at the position where the Kuku Fault crosses the Vailala River, is most likely due to the presence of relatively dense Pliocene sandstones on the downthrown block, thereby offsetting to some extent the density contrast.

Another important feature of figure 2-23 is the strong, nearly east-west trend. Quoting Richards,

> "This trend is a big feature and we find a good flanking low to the north paralleling the transverse fault which limits the Upoia Anticline to the south (the Upoia Fault-AK).... it seems obvious that we are dealing with deeper features than in the alluvial areas to the south" (*ibid*, p.8).

This feature, here called <u>the Marupi Fault</u>, finds logical continuation in a zone of irregular dips and structural discordance which transversely crosses the Imbricate Belt (refer section 2.2.2).

The southern extension of the Eako-Keari Fault finds support in a gravity high extending along the supposed continuation of this structure. Similarly, the Orevi Fault finds a logical continuation along a gravity high which falls on the trend of this fault. This trend falls very close to a zone of high and irregular dips on Agapihu Creek and, as such, the fault has been redrawn through the gravity high and this zone of structural disturbance. Because of a general parallelism to other structures of this area, the Bevan-Pemani Fault has been redrawn to parallel a gravity low in this area. This makes the "Agapihu Fault", formerly regarded as the southern extension of the Orevi Fault, more likely a continuation of the Bevan-Pemani Fault.

The Hohoro Anticline (refer previous section) and the Parimamu Syncline find logical continuation along gravity lows occurring to the south of the Kuku Fault.

Kuku-Hohoro Unit

The Kuku Fault marks the western and southern outcrop limit of the Lower Murua Sub-Group in this area, and generally throws Upper Murua and Lower Murua beds over Pliocene and Upper Murua beds respectively. The stratigraphic throw on this fault is variable, but in the area of the Piamorra Anticline, where near-basal Lower Murua beds are thrown against Pliocene beds, the throw must be at least of the order of two kilometers. The general aspect of this fault has been discussed previously.

For 40 kilometers of its 50 kilometer extent (in this area) the fault trace is a straight, linear feature trending at 320° - 140°. Along the southeastern-most 16 kilometers, the trace becomes markedly sinuous, in a manner paralleling the trend of the Hohoro Anticline and Hohoro Fault.

Along most of the length of the Kuku Fault, beds consistently dip away from the fault imparting an anticlinal aspect to the fault. Beds are overturned (toward the south) against the fault in the Beleppa area at the southeastern end of the fault.

Immediately behind the Kuku Fault to the northeast, the broad structure is synclinal; Vara's Basin and the Dowa Syncline generally paralleling the Kuku Fault. This synclinal trend is broken by the transverse Piamorra Anticline which trends north-northeast.

The area between the Kuku Fault and the Hohoro-Pairi-Mekori anticlinal trend is largely a broad structural basin, being broken only by the narrow, pinched and, probably, semi-diapiric Huromoipa Anticline. I have argued that this area is underlain by a decollement within the Upper Murua Sub-Group.

The western limit of the Kuku-Hohoro unit is formed by the Hohoro-Pairi-Mekori anticlinal trend. These anticlines are steep, narrow structures which are crestally faulted and probably semi-diapiric in nature. This trend merges gently toward the north with the Kuku Fault.

Stratigraphic evidence suggests that folding movements within the Kuku-Hohoro unit began either late in the Upper Miocene or early in the Pliocene. During this time, this area was structurally low and was receiving thick sediments which were derived in part from an adjacent high to the northeast. As Pliocene rocks are involved in these structures, these movements must have continued through the Pliocene.

Pemani-Keari Unit

This unit is similar in overall configuration to the Kuku-Hohoro Unit, but is much more complex.

In its northern extremites the "Pemani Fault", as previously interpreted, dies-out or becomes unrecognizable in the Upper Murua Sub-Group on the northeast limb of the Uheedi Anticline. It has been argued that the Bevan Fault, in the area of Goigi Basin, occurs along the axis of the Uheedi Anticline as the crestal-fault of this structure (refer section 1.3.2). Because of the overall similarity in plan between the Kuku-Hohoro Unit and the Pemani-Keari Unit, I suggest that the "Pemani Fault" merges with the crestal-fault of the Uheedi Anticline. This implies that the main extension of the Bevan Fault, to the south of Bevan Rapids, is what was previously known as the "Pemani Fault". I suggest, therefore, that the term Bevan-Pemani

Fault should be used for that part of the Bevan Fault which extends south of Bevan Rapids.

The fault previously called the "Bevan Fault" (in this area) is more likely to bear the same relation to the Bevan-Pemani Fault as does the Hohoro-Pairi-Mekori anticlinal trend to the Kuku Fault. For this reason, I suggest that the fault previously called the "Bevan Fault" (in this area) be renamed the Eako-Keari Fault, after two prominent anticlines, the Eako and Keari Anticlines, which are adjacent to this fault. The arguments supporting these alterations will be amplified in subsequent paragraphs.

The Bevan-Pemani Fault separates an outcrop area of mainly Aure Group and Lower Murua Sub-Group to the northeast, from an outcrop area of mainly Upper Murua Sub-Group and, to a less extent, Lower Murua Sub-Group to the southwest. Small outcrops of the Aure Group do occur to the southwest of this fault, but only to a very limited extent on the Orevi, Upoia and Eako-Keari faults (refer Plate I). As with the Kuku Fault, the stratigraphic throw of the Bevan-Pemani Fault is variable. Near the northern end of the Pemani Anticline, where near-basal beds of the Lower Murua Sub-Group are thrown over beds high in the Upper Murua Sub-Group, the throw of this fault must be of the order of two kilometers. Along its entire length of about 50 kilometers, the Bevan-Pemani Fault has a rectilinear trace which trends northwesterly at 320 degrees. In the south, I have continued the Bevan-Pemani Fault along the crestal fault of the Iavokia Anticline and then the Agapihu Fault.

Stratigraphic evidence suggests that activity along the Bevan-Pamani Fault began during the early part of Upper Murua deposition in the Goigi Basin area. The stratigraphy of the area of the Nakoro Anticline suggests that folding movements in this area began during the early phases of Upper Murua deposition or perhaps, during the latter part of Lower Murua deposition. At this time, this area was a structural low and was receiving sediments derived, at least in part, from a rising area to the east of the Horbu Anticline and Ekiere Fault. During

Pliocene deposition, this area seems to have been a structural high which was supplying sediments to basinal areas to both the southwest and northeast.

The area between the Bevan-Pemani Fault and the Eako-Keari Fault is structurally complex. It is essentially basinal in that Upper Murua rocks occupy much of the central portions of the area, while older beds crop out near its borders and at either end. The basinal form is interrupted by the Nakoro, Uheedi and Upoia Anticlines and by the Hewa, Orevi and Upoia faults. All of these structures are sinuous and irregular in plan.

The southwestern boundary of the Pemani-Keari unit is formed by the Eako-Keari Fault (formerly the Bevan Fault). This fault has an anticlinal character over its entire length of about 60 kilometers. The Keari and Eako Anticlines trend generally parallel to the fault, for approximately 13 and six kilometers respectively, before the fault truncates these structures. The Eako Anticline is overturned toward the southwest against the fault. The Hewa and Orevi Fault, together, form a feature which is similar in plan to the Eako-Keari Fault, but is more accentuated. The Uheedi Anticline is overturned toward the southwest against the Hewa Fault.

The only fault of the Pemani-Keari Unit (and of this entire region) for which dip information is available at depth is the Upoia Fault. The Upoia Fault was intersected by the APC Upoia No. 1 Well at a depth of 855-955 meters (2,800-3,130 feet). The well was drilled on the upthrown (north) side of the Upoia Fault, about 610 meters (2,000 feet) from the surface trace of the fault. The fault is believed to be steep to vertical at the surface. Combining this information, it can be said that the Upoia Fault is concave upwards, and that it dips northward at an average of about 55^{o} between the surface trace and the well-site. This is essentially the same (slightly steeper) as the dip of the beds immediately overlying the fault in the well. The Upoia Fault, therefore, most likely passes into bedding a short stratigraphic distance below the lowest horizon intersected in this well. The stratigraphic throw of the Upoia Fault is about 1.2 kilometers (Stanley, 1960, p.154). As with the Puri Well, then, the Upoia Well revealed that at least some faults of this region shallow rapidly down dip.

At the northern end of this area, the Eako-Keari Fault merges gently with the crestal-fault of the Uheedi Anticline, and, therefore, with the Bevan-Pemani Fault. The configuration at the southern end of the Pemani-Keari Unit is more uncertain, owing to the extensive alluvial cover. Two possibilities are given in figures 2-24 and 2-26 for the southern extension of the structures within this unit. The south end of the Bevan-Pemani Fault merges with the trend of the Ekiere Fault.

<u>Interpretation</u>

Both the Kuku-Hohoro and Pemani-Keari Units are situated in what was the general area of thickest Toa Group deposition. In both cases, folding and faulting movements began <u>during the depositional history</u>, as the sediments involved appear to have been influenced by these structures. The Pemani-Keari Unit seems to have begun development during the early part of Upper Murua deposition or late part of Lower Murua deposition, whereas the Kuku-Hohoro Unit seems to have begun development during late Upper Murua or early Pliocene deposition. The <u>Pemani-Keari Unit is</u>, therefore, somewhat <u>older than</u> the <u>Kuku-Hohoro Unit</u>. The Pemani-Keari unit is, also, more complex, a fact which is probably due to the longer history of development of this unit.

Both the Kuku-Hohoro and Pemani-Keari Units developed on the southwest flank of an uplifted area which was supplying sediments to the down-dropped basinal areas in which these structural units occur. In each case, the sense of tectonic transport is away from the uplifted area and toward the low, basinal area. It might be <u>assumed</u>, therefore, that the deformation of these units is genetically related to the uplift of the respective high areas to the northeast.

From this point, the factors involved become more numerous and the reasoning more complex. The contemporaneous uplift to the northeast of the Pemani-Keari Unit was to some extent the result of localized folding and faulting movement. Superposed on these localized movements was the broad uplift of the entire region, which spread westward across the region through time. Either the localized uplift movements, say the McDowal Fault, or the more regional uplift could have given rise to the Pemani-Keari Unit, and the problem is to which of these movements does this structural unit relate. The nature of the uplift to which the Kuku-Hohoro Unit is coupled must involve the same factors, as localized movements are evident in the Pemani-Keari unit, and the Upper Miocene and Pliocene column of this area shows a tendency toward a shallowing depositional environment upward through the section.

In resolving this problem, there is yet another important feature to be noted. This is, that the maximum southwestward-convexity of both the Hohoro-Pairi Mekori anticlinal trend and the Eako-Keari Fault is essentially opposite the position of maximum throw of the Kuku and Bevan-Pemani Faults respectively. In the case of the Kuku-Hohoro Unit, both the Hohoro and Huromoipa Anticlines have their maximum development in this position. In the Pemani-Keari Unit, the Nakoro Anticline has its culmination in this position. This strongly suggests that the southwestward-convexity of these structures is genetically related to movements on the Kuku and Bevan-Pemani faults.

Judging from the analysis of the Hohoro Anticline and the picture presented by the Upoia Fault, it seems that the frontal structures of the Kuku-Hohoro and Pemani-Keari structural units are relatively shallow features, determined by faulting which flattens rapidly down-dip. In the case of the Hohoro Anticline, a decollement zone within the Upper Murua Sub-Group is involved. By analogy, a similar feature is probably involved underlying the area between the Eako-Keari Fault and the Bevan-Pemani Fault, but in this case any proposed decollement zone must fall within the Aure Group. Judging, again, from the Upoia Fault, this decollement zone would probably fall between about 1,000 m. and 1,200 m. below the top of the Aure Group.

The Kuku and Bevan-Pemani faults, on the other hand, appear to be more fundamental features both in their relation to configuration of the depositional basin, and in that they now separate broad areas of older rocks to the northeast from broad areas of younger rocks to the southwest. Nowhere to the northeast of the Bevan-Pemani Fault are Upper Murua beds present to the extent, or with as great thickness, as to the southwest of this fault. An exception to this statement is the area of the Paun Basin, but this is far removed from the area in question. With this exception, this statement holds true for the entire length of the combined Bevan, Bevan-Pemani Fault. To the northeast of the Bevan-Pemani Fault, the Upper Murua Sub-Group is characteristically developed in the thin, shallow-water Pawro Facies and is generally unconformable on underlying beds. Similarly, nowhere to the northeast of the Kuku Fault are Pliocene beds developed to the extent, nor in as great thickness, as in the area to the southwest of this fault. I have argued that these variations are not simply the result of erosion but they reflect primary depositional variations (refer sections 1.3.2 and 1.4).

For the above reasons, I suggest that the faulting associated with the Hohoro-Pairi-Mekori anticlinal trend and with the Eako-Keari Fault is subsidiary to the Kuku Fault and the Bevan-Pemani Fault respectively. The manner in which the frontal structures merge in plan with the Kuku and Bevan-Pemani Faults, and the association of maximum convexity of the frontal trends with maximum displacement of these faults, suggests that the frontal structures merge with these faults at depth, *i.e.* as opposed to being cut by these faults. The frontal structures, most likely, have arisen from and been initiated by movement on the Kuku and Bevan-Pemani Faults.

From the beginning of Toa Group deposition to the present, there has been a broad regional gradient rising to the northeast across this area. As the sense of tectonic transport is down this regional gradient, it is likely that gravitationally induced movements have been responsible for these structures. I suggest, that local uplift along the Kuku and Bevan-Pemani faults, followed by outward gliding down the regional gradient in a direction perpendicular to the trend of these faults, has been the genesis of the Kuku-Hohoro and Pemani-Keari structural units. The position of maximum movement on the Kuku and Bevan-Pemani faults should then be correlative with the maximum outward gliding. This appears to be the case, as seen by comparing the maximum southwestward-convexity of the frontal belts with the maximum displacement on the Kuku and Bevan-Pemani faults. The more northerly oriented structures have probably involved a large amount of tearing, as well as thrusting, (refer figure 2-2~~4~~5).

By this analysis, the nature of the Kuku and Bevan-Pemani faults is a more fundamental problem. This becomes even more obvious on a regional scale (refer Plate I). These faults are different from all of the other fault and fold trends of this area in their rectilinearity, and because all other structures either merge with, or are cut by these faults. These points indicate that the Kuku and Bevan-Pemani faults are probably of deeper origin than these other structures and, possibly, that they are of a different nature.

Because these faults are downthrown in the direction that, for the time interval involved, was toward rapidly thickening sediment accumulation, *viz.* the southwest side, and because these faults appear to have affected sedimentation by control of the configuration of the sedimentary basin, it is possible that these faults are mainly tensional in character. Opposed to this, the fact that these faults are largely anticlinal in aspect suggests a thrust origin. The interpretation of the Kuku Fault, from both the Puri Well and seismic surveys in the Puri area, indicates that the Kuku Fault becomes a sub-horizontal thrust at depth. If this interpretation is correct, then it is likely that the Kuku Fault and, by analogy, the Bevan-Pemani Fault flatten rapidly down-dip to become sub-horizontal thrust faults, and I have accepted this alternative.

The formation of both the Kuku and Bevan-Pemani faults seems closely related to a contemporaneous uplift of the Kukukuku Lobe to the northeast of these faults, *i.e.* they formed on the flank of actively rising areas, and are explicable either as a result, or as an agent of this uplift. As well, these faults were thrust over adjacent structural lows toward the southwest.

In summary:

1) The structures between the Hohoro-Pairi-Mekori anticlinal trend and the Kuku Fault are subsidiary to the Kuku Fault and, probably, owe their origin to the Kuku Fault. These structures are, most likely, grounded in a decollement zone within the Upper Murua Sub-Group.

2) The structures between the Eako-Keari Fault and the Bevan-Pemani Fault are subsidiary to the Bevan-Pemani Fault and, probably owe their origin to movement on this fault. These structures are ~~possibly~~ probably grounded in a decollement zone occurring at about 1000 m. to 1200 m. below the top of the Aure Group.

3) The Kuku and Bevan-Pemani Faults are, therefore, the major faults of this area. As a best approximation, these faults probably flatten down dip to become sub-horizontal thrusts. These faults were probably generated in areas of contemporaneous uplift to the northeast.

4) The Bevan-Pemani Fault is probably an older structure than the Kuku Fault. The Bevan-Pemani Fault marks the northeast boundary of thick Upper Murua sediments, and the Kuku Fault marks the northeast boundary of thick Pliocene sediments.

G. DELTA HOMOCLINE

The Delta Homocline is the most southwesterly, and probably the youngest, major structural unit developed in the region under consideration.

As the name implies, the Delta Homocline is a generally homoclinal, southwesterly-dipping structure which forms the north and east boundary of the Delta Embayment. The southwesterly dip is a result of beds dipping away from the Kuku Fault in the northwest, and away from the Mekori-Pairi anticlinal trend to the south of the Orloli Anticline (refer Plate I). The homocline is formed almost entirely of Pliocene beds at the surface, the sandstones of this unit forming a minor belt of foothills preceding the high mountains to the north and east.

The homoclinal dip is general, but is not perfect. The regional homoclinal dip is disrupted by the Era Fault and Era Syncline to the northwest, and by the Orloli Anticline to the south.

The Orloli Anticline is strongly asymmetrical, facing ~~to the~~ southwest. The trend of this structure is complex, one section trending almost north-south, another section trending west-northwest. The exact manner in which these trends join is still uncertain, although three detailed surveys have been made of this anticline (APC Repts. LOA, LOB and PAP/22/60). In general, the crest-line bifurcates and a reversal of pitch occurs at the change in trend (Stanley, 1960, p.232; refer Plate I). At any rate, it is apparent that the gross anticlinal trend bends sharply through an angle of nearly 90°, recalling a similar situation with the Mekori-Pari-Hohoro anticlinal trend.

The northerly-trending part of the Orloli Anticline plunges beneath alluvium before reaching the Purari River. This section of the fold has a nearly horizontal eastern limb and a vertical to overturned western limb (APC Rept. LOA). This form suggests the possibility that this structure is faulted at depth, but crestal faulting is absent at the surface.

The west-northwest-trending section of this anticline is more nearly symmetrical and more cuspate in section than the northerly-trending sector. This part of the fold is accompanied by a parallel fault on the northeast flank, which is upthrown on the southwest side. The anticlinal axis merges with the Kuku Fault, the anticline tending to lose its character as the fault is approached.

Basically because of the similarity in plan but, also, because of a general similarity in section and depth of exposure, to the Mekori-Pairi-Hohoro anticlinal trend, I suggest that the Orloli Anticline is grounded in a decollement zone within the Upper Murua Sub-Group, and that the Orloli Anticline is related to the Kuku Fault in the same manner as proposed for the former trend. The difference in cross section between the separate parts of the Orloli Anticline indicates that each part has undergone somewhat different deformation. I suggest that this difference is probably due to general thrusting movements perpendicular to the section with the northerly trend, but accompanied by transcurrent movements beneath the section which trends west-northwest (refer figure 2-25).

The Delta Homocline occurs in the area that was the site of maximum Pliocene deposition. The constancy of facies throughout the great thickness of Pliocene sediments present (approximately ~~2425~~ 2135 m.), indicates that this area was actively subsiding during the deposition of these beds. Evidence from the Wana and Kuru bores (Geol. Soc. Aust. Journ., Vol. 8, p.78-80; Smith, 1964), and, to a less extent slim indications from stratigraphic considerations indicate that Upper Miocene beds thin, in general, across this area. All the evidence in hand (refer Chapter I) suggests that this general area acted as a relatively stable shelf during pre-Upper Miocene, Tertiary deposition as well. The general picture, then, is one of the shelf environment gradually being transgressed from the north and east by a trough environment, the trough environment having reached as far as the general area of the Delta Homocline by the Pliocene.

This brief stratigraphic review, has been included at this point to indicate that there is probably a structural or, as yet undefined, stratigraphic significance in the fact that a marked negative Bouguer gravity anomaly (-40 milligals) occurs in this region. The minimal axis occurs well to the southwest of the Delta Homocline and thickest Pliocene accumulation (refer figure 3-6). A discussion of this feature can best be included in the next chapter, but it is mentioned here as another structural element of this area.

A final observation concerning this region comes from seven bores drilled along the Purari River, to the west of the Mekori Anticline. The deepest of these bores, P.O.D. Conrad No. 6, was drilled to about 780 m. (2,551 feet) and was still in (?)Pliocene beds at bottom. The exact age of these beds is uncertain, as the Pliocene and Quaternary were not differentiated in these wells. Fair correlations between wells, indicates that the beds drilled are essentially horizontal, but occasional dips up to 20° were encountered (Gray, 1946, p.4). At any rate, there appears to be no major near-surface folding in the area immediately to the west of the Pairi-Mekori anticlinal trend.

The Delta Homocline, therefore, forms the western and southern limit of large-scale Tertiary deformation, its form being controlled by the Kuku Fault and related structures. It has been shown that much of the post-Aure Group deformation occurring to the east of the Delta Homocline can be related, either directly or indirectly, to gliding movement down a contemporaneous regional gradient toward the southwest. It is significant that this deformation should cease where this contemporaneous gradient reversed at approximately the position of the Delta Homocline, *e.g.* the Toa Group probably thins and shelves in character to the south and west across the homocline which implies that the regional gradient rose across this area during that time. Moreover, both the Eocene and the Aure Group are probably in a thin, shelf facies across this area, which suggests that the regional gradient rose toward this area (from the north and east) throughout most of the Tertiary. This strongly suggests that the deformation in this region has been controlled to some extent by the configuration of the regional gradient during deformation. In turn, this suggests that much of this deformation has been <u>passive</u>, in that it has merely accommodated itself to the form of the regional gradient.

A logical conclusion, which has been reached earlier on separate grounds, is that gravitational gliding has been extremely important in the deformation of this region. ~~It will be noted, however, that such deformation can only be a secondary effect of vertical movement which is the primary feature to be explained.~~

2.2.4 FOLDED AREA BETWEEN THE ALBERT FAULT AND THE IDIGUE ANTICLINE

I will now examine the structural configuration to the east of the Dude-Murua Anticlinorium, between the Albert Fault and the Idigue Anticline (refer Plate I). From west to east, the Albert Syncline, Enna Anticline, Chauma Syncline, Meoue Anticline and Yage Syncline are the chief structural features between the Albert Fault and the Idigue Anticline. There has been only one field traverse across these structures, that being the Enna Creek - Idigue Creek Traverse (APC Rept. LH-2). Two photogeological interpretations (Sadler, APC Rept. LH-2, Plate LH-18, and Pitt, 1966) have extended the structures crossed in this traverse. I have accepted, with modifications, the interpretation offered by Pitt (1966) for inclusion in the geological map accompanying this thesis.

None of the abovementioned structures were recorded in Carey's (APC Rept. LI) upper M'bwei River traverse. It must be assumed, therefore, that these structures either die-out, or that they are faulted-out by the Eruki Fault toward the north.

There is a strong regional rise toward the northeast across this area. The lowest beds exposed (in the Enna Creek-Idigue Creek section) on the southwest flank of the Idigue Anticline are probably about 1,200 m.

stratigraphically lower than the lowest beds exposed in the core of the Enna Anticline and about 2,400 m. lower than the highest beds exposed on the downthrown side of the Albert Fault.

Taking beds exposed at an equivalent elevation on the southwest flank of the Enna and Indigue Anticlines, the regional rise is of the order of 1:3 toward the east.

The rocks of this area are tightly folded, and dips of less than 50^{o} are rare. The northeast flank of the Enna Anticline provides an exception to this rule. A dip of 15^{o} is recorded on this flank and dips appear, from photogeology, to remain shallow to the trough of the Chauma Syncline. The crest-to-crest distance, or wave-length of folding, is about 2.7 km. in this area.

The Enna Anticline has a strong southwesterly-facing, but the Meoue and Idigue Anticlines face to the northeast. Each of these anticlines is crestally faulted. Sadler (APC Rept. LH-2) suggested that the northeast flanks of both the Enna and Meoue Anticlines are upthrown about 120 m. and 180 m. respectively. Pitt (1966), on the other hand, suggests that the southwest flanks of these anticlines are upthrown. I am more inclined toward Sadler's interpretation.

Sadler (*ibid*) regarded the Idigue Anticline as unfaulted, but this necessitates interpreting some northeasterly dips, which were regarded as normal in the field, as being overturned toward the southwest. Overturning toward the southwest does not seem an entirely satisfactory explanation because this anticline faces to the northeast. Assuming that the axis of this anticline occurs between the opposed dips requires that the northeast flank of this anticline is upthrown at least 450 m. by Sadler's correlation (~~APC Rept~~ ibid, Plate. LH-25). This is not unlikely, because an interval of strongly tuffaceous and slightly conglomeratic beds was found on the southwest flank of this anticline, but an equivalent lithology was not found on the northeast flank. It should be noted, however, that no direct evidence of faulting was observed in the field. A related, but somewhat independent argument has led me to suggest that the Idigue Anticline must be crestally faulted with the northeast flank upthrown at least 670 m. (refer section 1.3.1). Furthermore, it seems probable that the area to the east of the Idigue axis was a structural high and formed source-area during most of the Middle Miocene. For these reasons I suggest that major crestal faulting is present along the axis of the Idigue Anticline, and that the northeast flank of this anticline is upthrown. Photogeological evidence does not oppose this view and strongly favors it for the most part, *i.e.* especially in the area of Idigue Creek. I suggest that the Idigue crestal-fault is most probably continuous with the Eruki Fault toward the north (see Plate I).

Pitt (1966), however, suggests that the main continuation of the Eruki Fault is the Mea Anticline and Mea Fault, and that the "Idigue Fault" is not a crestal fault but occurs on the northeast flank of the Idigue Anticline, throwing the southwest flank up. These local differences in interpretation could be satisfactorily resolved only by field work in this area.

Regionally, both Pitt's picture and my own are broadly consistent in that <u>a major line of faulting occurs in this area and separates an area of relatively older rocks to the east from an area of younger rocks to the west</u>. This line of faulting, which I suggest is marked by the Eruki Fault and the Idigue crestal-fault, probably formed the eastern boundary of the Karova Trough during the Middle Miocene. ~~Toward the north, the area to the east of the Eruki Fault was probably a structural high earlier in the Miocene, as the early Lower Miocene appears to be unconformable on older rocks on the flanks of the Tuoa (? and Aiweriba) Anticline.~~

Southward from the Enna Creek section, the structure of this area undergoes a marked change. About six to eight kilometers to the north of the unconformity at the base of the Iavokia Mudstone, the Albert Syncline and the Enna Anticline become overturned toward the southwest. In this area the Obira Thrust, which is thrust toward the southwest, replaces and (or) displaces the Albert Fault as the major fault. To the east, the Meoue Anticline is largely replaced by the Meoue Fault and the Yage Syncline becomes completely faulted-out.

Beneath the unconformity at the base of the Iavokia Mudstone, there is probably an unconformity within the Aure Group around the southeastern end of these structures (refer Plate I and section 1.3.1). Unlike the younger unconformity at the base of the Iavokia Mudstone, this unconformity appears to have been strongly folded and faulted.

A. INTERPRETATION

These structures must be largely of late Middle Miocene age, because the youngest beds of the Aure Group are involved in these structures, and the Iavokia Mudstone is unconformable across the south end of these structures. This unconformity has not been folded into these folds. The Iavokia Mudstone dips southward at an average dip of about 20° to 30°, which is probably mainly a result of the gross ~~regional~~ uplift of the older beds to the north of the unconformity.

The probable unconformity within the Aure Group at the southern end of this area indicates that folding movements here began during the final phase of deposition of the Aure Group. These folds must, therefore, be regarded as virtually contemporaneous with the initial uplift and folding of the Dude-Murua Anticlinorium, *i.e.* <u>late Middle Miocene</u>. The eastern boundary of this unit was probably defined, in some manner, during the <u>early part</u> of the Middle Miocene along the line represented by the Idigue Fault and the Eruki Fault. The regional rise toward the east across this area is, therefore, a relatively old feature, and it has not been reversed by the subsequent deformation.

The Idigue crestal-fault and the Eruki Fault appear to be thrust faults in their present configuration. It must be remembered, however, that the area to the west of these faults was strongly downwarped, or downfaulted, during the early history of the faults, *i.e.* Middle Miocene sediments of the order of three to five kilometers thick accumulated to the west of the Idigue crestal-fault while the area to the east was undergoing erosion. It is not probable, therefore, that simple thrusting movements adequately explain these relationships.

The latest discernable movement on this fault-line is that which resulted in the folding and faulting of the Idigue Anticline, indicating that movements along this structural line continued, at least, until the late Middle Miocene. I regard it as probable, that the thrust aspect of the Idigue crestal-fault is a relatively late feature of this fault, because the folding to the west of the fault appears to be primarily a late Middle Miocene feature. This folding, and the folding and thrusting of the Idigue Anticline, cannot be linked easily or directly to the folding of the Tauri Anticlinorium to the east, because the folding of that area appears to be primarily a late Lower Miocene feature.

The great thickness of Middle Miocene rocks to the west of the Idigue crestal-fault, together with the rapid decrease in thickness and unconformable relations displayed by the Middle Miocene rocks to the east of this fault, suggests that early Middle Miocene normal faulting to the west of, or along the Idigue crestal-fault was probably important. As an alternative to a simple compressional origin of the Idigue crestal-fault, I suggest that this fault may have originated as a steep normal fault, downthrown to the west, but that it subsequently overturned toward the structurally low area to the west and thereby became a fault with a late, and near-surface thrust aspect.

Two basic explanations can be offered to explain the folding and faulting that is at present between the Albert Fault and the Idigue Anticline.

The first is that it is the result of easterly-directed movement which was generated in the uplift of the Dude-Murua Anticlinorium. The second is that it is the result of westerly-directed movement which was generated in the uplift of the Tauri Anticlinorium. A combination of these explanations, *i.e.* that these structures represent the deformation of an area which was situated <u>between</u> these opposed movements, presents a third possible explanation and is the one I think most likely.

The first explanation is strongly favored by Pitt's (1966) photo and stratigraphic interpretation of this area. This solution has many attractive points, the main one being that this area would then form a close analogy (although opposed in sense) with the area to the west of the Dude-Murua Anticlinorium. The 'Idigue Fault' (as drawn by Pitt) could then be regarded as the eastern limit of the area directly affected by the uplift of the Dude-Murua Anticlinorium, rather than the Albert Fault as I have suggested. The slight northeasterly-facing of the Meoue and Idigue Anticlines in the Enna Creek area favor this interpretation, but the strong southwesterly-facing of the Enna Anticline opposes it to a greater degree because this anticline, being closer to the Dude-Murua Anticlinorium, would be expected to show a pronounced northeasterly-facing. This interpretation would, also, require that the very strong southwesterly-facing of these structures at the southern end of this region is a subsequent feature, superposed on an original northeasterly-facing set of structures.

The second explanation, *viz.* that these structures are the result of westerly-directed movements, is attractive because a reasonable analogy can be drawn with the area of folding and thrusting to the west of the Dude-Murua Anticlinorium. In other words, the Middle Miocene rocks and structures of this area ~~are~~ could be grossly related to the Tauri Anticlinorium as the post-Aure Group rocks and structures of the Vailala Synclinorium are related to the Dude-Murua Anticlinorium. Further, strong southwestward thrusting seems to be demanded by the marked southwesterly asymmetry present in the structures at the southern end of this region.

The most pertinent observation with regard~~s~~ to this explanation is that the deformation of the area to the west of the Idigue Anticline is more closely related, in time, to the deformation of the Dude-Murua Anticlinorium than it is to the deformation of the Tauri Anticlinorium. The close temporal relationship between the deformation of the Dude-Murua Anticlinorium and the deformation of the area to the west of the Idigue Anticline is not satisfactorily accounted for by this second explanation alone. Again, the asymmetry present in the Enna Creek area appears to be disposed in exactly the opposite manner to what should be expected if only westerly-directed thrusting movement is responsible for these structures.

The third explanation appears to offer the most complete solution. I propose that the area between the Albert Fault and the Idigue Anticline has been deformed as a result of the local compression~~s~~ caused principally by the opposed movements revealed by these faults.

The key to this hypothesis lies in the overall configuration of the Albert Fault. I have suggested that the Albert Fault is most probably a secondary result of the uplift of the Dude-Murua Anticlinorium. This fault is the major structure of the Enna Creek area, but the stratigraphic throw diminishes toward the south (refer Plate I). At the very southern end of the region, the Obira Thrust replaces the Albert Fault as the major structure of the area. The Obira Thrust is upthrown on the east side, or in the opposite sense to that of the Albert Fault. This indicates that the secondary effects of the uplift of the Dude-Murua Anticlinorium die-out as the uplift itself dies-out and plunges southward. As the Albert Fault approaches the Obira Thrust, the eastward thrusting on the Albert Fault rapidly becomes subordinate to the westward thrusting of the Obira Thrust. In this same area, the Albert Syncline and Enna Anticline become overturned toward the southwest.

This reasoning suggests that did the Albert Fault continue undiminished toward the south, these structures would not have become overturned, and the Obira Thrust would not have developed so strongly. This is further suggested by the fact that the throw of the Obira Thrust diminishes very rapidly to the north of its intersection with the Albert Fault, *i.e.* the throw of the Obira Thrust decreases rapidly where the throw of the Albert Fault increases rapidly. This demonstrates that there has probably been an interaction between the movement on the Albert Fault and the structures developed to the east of this fault and, in turn, implies a relationship between the development of the Dude-Murua Anticlinorium and the development of the structures to the east of the Albert Fault.

Similarly, toward the north in the Enna Creek area, where the throw of the Albert Fault is great, a northeasterly-facing is partially developed in the structures between the Albert Fault and the Idigue Anticline, yet crestal faulting along the Enna and Meoue Anticlines upthrows the northeast flank. This suggests that these structures have not developed freely or singularly from either easterly-directed or westerly-directed movements, and possibly indicates an interaction between these movements. To this extent then, the structural configuration between the Albert Fault and the Idigue Anticline has been dependent on the easterly movement of the Albert Fault and, therefore, indirectly dependent on the uplift of the Dude-Murua Anticlinorium.

The relationship between the Albert Fault and the Obira Thrust suggests that, for the most part, the 'local' movements associated with the Dude-Murua Anticlinorium, where developed, have acted as a barrier and a buttress to more pervasive westerly-directed movement. This is further indicated by the fact that the south end of the Murua Anticline, which forms the eastern boundary of the Dude-Murua Anticlinorium, is associated with <u>southwesterly-directed</u> thrusting, *i.e.* implying that the independence of this unit is lost as the uplift diminishes down the southern plunge of the Anticlinorium. Presumably, this permitted the more pervasive westerly-directed movement to be expressed.

By this interpretation then, the strong southwesterly-facing at the southern end of this area is a feature which is contemporaneous with the main folding of the area and is not a superposed feature as the first offered explanation implies. The cause of the westerly-directed movements is most probably related to late Middle Miocene uplift of the Tauri Anticlinorium as a secondary ~~level~~ result, *viz.* lateral spreading toward the structurally low area of the Karova Trough. This problem is the subject of the following section.

2.3 THE RELATIONSHIP BETWEEN UPLIFT AND RESULTANT SECONDARY STRUCTURES OF THE KUKUKUKU LOBE

In considering the genesis of the thrust and fold belt that occurs to the west of the Dude-Murua Anticlinorium, two factors stand-out. Firstly, this deformation occurred adjacent to a contemporaneously rising area and secondly, the asymmetry and sense of thrusting are directed away from the uplifted area and down the regional gradient. From this, I have inferred that gravitational gliding down the regional gradient has been an extremely important factor in the genesis of these structures. In this section, I will examine the relationship, in cross-section, or at depth, between these 'secondary' structures and the 'primary' uplift (see figure 2-30).

There are two basic solutions to this kind of problem, each of which lies at the extreme end of a continuum. The first and generally standard solution is that the gravitational gliding planes emerge on the flanks of the uplift (refer figure 2-27a-1). This type of solution has been proposed by Van Bemmelen (1949, 1954) for orogenesis in general, and more specifically, for orogenesis in the East Indies and New Guinea. A variation of this solution may be likened to a land slide (figure 2-27a-2).

The second solution is that of Carey (1962). This solution (figure 2-27b; after Carey, 1962, figure 44) demonstrates that what are essentially gravitational gliding planes need not emerge, but may turn downward into the heart of the rising area.

Both of the above solutions recognize that vertical uplift is the prime cause of the outward, gravitational gliding movements. Carey's solution recognizes in addition, that the vertical uplift and consequent outward gliding, or flow, may be dynamically balanced to the point that further vertical movements in the heart of the rising area produce only an outward spreading. Both of these solutions are verified by observed geological phenomena, and the principles involved are valid, regardless of the origin of the vertical movements, *i.e.* whether by fundamental vertical movement or by vertical movement induced by compression (see de Sitter, 1956, p.290).

The factor which relates these two 'end-member' solutions is time in relation to the viscosity of the material being deformed (in near-surface conditions). Rapid and narrow uplifts of relatively viscous material will tend to produce the type of solution shown in figure 2-27a. Broad and slow uplifts will tend to produce a pattern like figure 2-27b. Given time, and/or size and/or depth, figure 2-27a should evolve toward figure 2-27b. It is theoretically probable, therefore, that in an orogen we should get a combination of figure 2-27a and 2-27b as the age and area of exposure (uplift) increases.

The aforegoing considerations are directly applicable to a discussion of the origin and depth-configuration of the secondary structures occurring to the west of the Dude-Murua Anticlinorium.

The atypical character and general form of the Dude Anticline to the north, the distinctive pattern of the opposed sinuosities of the Yanne'ia Anticline and the imbricate thrust trends, and the Yanne Fault suggest a configuration at depth similar to figure 2-27a. The very rapid reversal of movement and uplift of the Dude-Murua Anticlinorium and my interpretation of the Ekiere Fault further suggest that movements as depicted in figure 2-27a may have been important.

Judging both from the amount of uplift required and from the amount of outward gliding required however, it is difficult to see how the entire thrusting movements can be accounted for by the known throws of the Dude and Yanne'ia crestal-faults and Yanne Fault, and this implication does not seem satisfactorily explained. This same consideration must be taken into account, and is just as damning, for configurations which involve only steep thrusting along these anticlines.

It, therefore, seems probable that additional thrusting movements are required which are not directly manifested in the crestal-faults of these anticlines. It will be remembered, also, that the sense of movement on the Yanne'ia axis was strongly <u>reversed</u>, which implies that the total vertical uplift to the east of this axis is probably not expressed by the anticline or faulting along the anticline. These factors point toward a solution with the same general character as figure 2-27b. I regard it as probable that both types of solution have been important in the final configuration of the fold and thrust belt. Ideally, a configuration such as shown in figure 2-28, which involves a transition from the first solution at the surface (figure 2-27a) to the second solution at depth (figure 2-27b), may not be unreasonable. For this reason, I have adopted the general configuration of figure 2-28 for the regional cross-sections of figure 2-30.

A related question that should briefly be considered here is why do the Kuku, Bevan and the McDowal Faults suddenly rise through the section after remaining essentially parallel to bedding beneath the Vailala Synclinorium? The answer to this question necessarily involves speculation. In that the fault very nearly follows a constant stratigraphic interval, we can assume that the faulting has been localized along a relatively weak zone. One logical explanation for a sudden emergence of such faults is that the weak zone loses its character and ability to accommodate movement, thereby forcing the thrust slab to cut across bedding if further thrusting movements are to occur. In this case, a facies-change within the weak zone, or within the beds below and above the weak zone (if water pressures are important), would be a possible reason for the emergence. It has been suggested that the Lower Miocene part of the Aure Group is relatively thin and developed in a shelf, or near-shelf facies on the west side of the Imbricate Belt. If the proposed decollement of the Imbricate Belt occurs just below the Middle Miocene-Lower Miocene boundary as suggested, then it might be reasonable to expect that the emergence of the Ekiere Fault has been caused by the proposed facies change within the late Lower Miocene in this area.

A second possible explanation for a sudden emergence could be that the weak zone, while retaining its character, is structurally disturbed. Two basic possibilities, each with a probable variation, are presented diagrammatically in figure 2-29. As facies-changes are commonly associated with structural breaks, it is not improbable that a combination of these two factors would produce the sudden emergence of a 'bedding plane' fault. The fact that the thickest development of the Lower Murua Sub-Group, the Upper Murua Sub-Group and the Pliocene (Era Group) occur on the downthrown side of the McDowal, Bevan and Kuku Faults respectively, suggests that a general configuration like that presented in No. 1 of figure 2-29 is not improbable. This solution would provide a ready mechanism for both the emergence of the faults and the subsidence required on the downthrown side of these faults.

The aforegoing interpretation of depth relationships has two important implications on questions previously discussed (refer Section 2. 1, figure 2-4). Firstly, the Kuku, Bevan, and McDowal Faults, which are considered to be basically gravitationally-induced, sub-horizontal overthrusts, are considered to <u>turn down</u> beneath the rising area represented primarily by the Dude-Murua Anticlinorium. A rationale for the more westerly faults involving beds lower in the column directly follows from this in that they are younger faults, *i.e.* as older beds are brought higher by the continued uplift, younger faults turn down progressively into older beds.

A second point is that the Kuku, Bevan and McDowal Faults are a reflection of more fundamental, potentially vertically-directed movements. During the Upper Miocene and later structural development of this area, however, the primary vertically-directed stresses found easiest relief in outward movements, or lateral spreading, before much of the potential vertical movement could be realized. A natural corollary to this reasoning is that the movements displayed in these secondary flanking-structures, together with those of the Dude-Murua Anticlinorium, represent the total amount of upward movement which has occurred at depth beneath this area. The Kuku, Bevan and McDowal Faults, therefore, can be considered as both fundamental agents and effects of the regional uplift of the Kukukuku Lobe.

2.4 SIMPLE SHEAR DEFORMATION

The structural units thus far examined have formed as the result of uplift and secondary gliding and spreading outward from the uplift. This deformation may be described in terms of Maximum and Minimum Principal Stress axes which are oriented about a sub-horizontal Intermediate Principal Stress axis. In this section, I will describe deformation that is the result of simple shear stresses oriented about a vertical Intermediate Principal Stress axis.

This deformation has the same general status as do the primary compressional uplifts, in that both classes of deformation are directly related to a common simple shear stress system (refer section 3.4.6). The simple shear deformation appears more important, however, because the structural units of this category have deformed both the uplifts and the related secondary structures. Moreover, these structural units identify the stress system which has controlled the overall tectonic development of the Kukukuku Lobe (refer section 3.4.6).

2.4.1 THE PURARI OROCLINE AND THE AURE LINEAMENT

The Purari Orocline can be described, simply, as the structural bend which occurs near the Purari River-Aure River junction in central Papua (refer Plate I). This bend, however, is the most complex and the most fundamental tectonic zone in the region covered by this thesis. Further, the density of geological data in this and immediately adjacent areas is greater than for any other area involved in this study. The key to my tectonic interpretation of this region lies in my interpretation of the structures of this zone.

The Aure Lineament (refer later) is the most important single structural element of the Purari Orocline. Carey (1938, 1941) referred to this lineament as the "Purari Bending Axis". Along its trend, this lineament separates wholly different regional structural and sedimentary patterns. On the northwest side of the lineament structural trends are more westerly than on the southeast side, where trends are northerly. The Aure Lineament, therefore, forms the axis of the Purari Orocline and, as such, must be related to this tectonic element either as a causal ~~casual~~ or a resultant feature. I suggest that the Aure Lineament is a causal ~~casual~~, or controlling structure of the Purari Orocline (refer section 3.4.6).

To the northwest of the Aure Lineament, the gross structural grain is west-northwest, at approximately 300°, for a distance of at least 400 kilometers, from the western border of Papua to about 144° 00' E. longitude (refer Plate II). From here to the Aure Lineament, a distance of 150 kilometers, trends swing into a more westerly strike of about 280°. At the Aure Lineament, a marked bend in the structural trends - the Purari Orocline - occurs. To the southeast of the Aure Lineament structural trends vary from north-northwest to north-south. In gross aspect, though not in detail, there is a zone of transitional trends; the structures to the west of the Dude-Murua Anticlinorium trend at about 340° while the Dude-Murua Anticlinorium trends nearly north-south.

The bend of the main cordillera of Papua and New Guinea mimics this bend in the structural grain, and the bend of the main cordillera, therefore, is not merely a superficial feature but is structurally founded. The bend in the main cordillera is marked by a structural low, with both the crystalline core of the Bismarck Range to the west and the crystalline core of the Owen Stanley Ranges to the east plunging beneath the thick Tertiary sediments which occupy the structural low.

The bend in the structural trends at the Aure Lineament was recognized long ago by Carey, who used the term "Purari Bend" to describe this feature (APC Rept. LI). Most importantly, Carey recognized that this bend, is itself, a tectonic feature impressed on structures of less magnitude. More recently Carey has defined the term <u>orocline</u> as

> "....an orogenic belt with a change in trend which is interpreted as an impressed strain" (1958, p.191; see also, Carey, 1955).

The term orocline accurately describes the change of trend in this area and, as such, this feature has since been renamed the <u>Purari Orocline</u> by Carey (1957, figure 40b).

The structure of the Purari Orocline, as an integral unit, and its regional relationship to the geology of Papua and the Territory of New Guinea will be discussed in the following chapter (refer section 3.4.6). The <u>detailed</u> structure of the Purari Orocline in the area of the main bend of the Purari River will here be discussed.

The complexity of major structural trends in this area is evident from the geological map. It should be noted at this juncture, that the detailed geology of this area is even more complex. Hundreds of dip measurements recorded show the area to be almost wholly steeply-dipping to vertical, but bedding attitudes are chaotic in many cases (APC Rept. LI, Plate LI-8). In spite of this complexity, it seems that major structures and stratigraphic units can be reasonably traced through this area. The rocks cropping out in this area are dominantly mudstones, and much of the complex detail has been ascribed to a general 'incompetent' collapse of these mudstones in response to the complex tectonic stresses that have deformed the area (*e.g.* Carey, APC Rept. LI; refer later this section). The confused dips suggest that many minor structures are present in this area, and these have been mapped in several places (APC Rept. LI, Plate LI-8).

The feature previously recognized as the "Aure Fault" is a combination of three separate structures - the Aure Fault, McDowal Fault and the Ekiere Fault of this thesis. From the junction of the Purari and Aure Rivers, the Aure Fault extends as a nearly rectilinear, northeasterly-trending feature for about 90 km. to the northeast (refer Plates I and II). At this river junction, the feature previously called the "Aure Fault" makes a sharp southward bend, and the fault trace becomes somewhat erratic. I have restricted the name Aure Fault to the northeast-southwest section of the "Aure Fault". The irregular northwest to north-south trending section forms the Ekiere Fault and McDowal Fault of this thesis.

From Fisher's traverse of the Lamari River (1935, Plate I), the Aure Fault can reasonably be extended for at least 30 km. to the northeast of the farthest point traced by photogeology; here, metamorphics are in probable fault-contact with sediments. As a tectonic feature, the lineament of the Aure Fault can be extended at least 25 km. to the southwest of its southernmost outcrop near the junction of the Purari and Aure Rivers. The Soho (anticlinal) Nose and the unnamed fault that cuts the southeastern end of the Mena Basin, fall directly on the trend of the Aure Fault. The Aure Fault is such an important structure and the northeasterly trend so rare in this region, that a genetic relation between the Aure Fault and these structures which trend northeast is imminently probable. I suggest that the Soho Nose and the unnamed fault are the surface expression of the Aure Fault passing beneath. Hence, the Aure Fault together with this southwesterly extension are regarded as an integral structural element which is here referred to as the Aure Lineament.

Previously presented facies and isopach data for the Lower Miocene rocks of this area suggest that substantial dextral transcurrent movement has probably occurred on the Aure Lineament (refer figures 1.3-1 and 1.3-2), and I suggest this, *viz.* a dextral transcurrent fault, is the essential nature of the Aure Lineament. The argument can be expanded to include additional stratigraphic and structural data not covered by the aforementioned figures.

Figure 3-7 illustrates the northern limit of shelf deposition for the subdivisions of the Tertiary recognizable in this region. To the southeast of the Aure Lineament, inferences must be made from a relatively limited amount of data. The basis for such inferences are discussed in a previous section (refer section 1.3.1).

To either side of the Aure Lineament, there is a consistent regression of the shelf toward the southwest and south through time. The detail of this regression, as expressed by restored facies and isopach trends, is in disharmony at the Aure Lineament. As seen, the early Lower Miocene trends show a greater disjunct than do late Lower Miocene trends which, in turn, show a greater disjunct than trends of the Middle Miocene. Middle Miocene isopach trends suggest continuity across the Aure Lineament. Basing judgment on Upper Miocene and Pliocene structural trends, however, I suggest that the continuity of the Middle Miocene trends, while more complete than for earlier trends, is only apparent. This can best be seen by comparing the facies trends of conglomeratic Middle Miocene beds to either side of the Aure Lineament.

The amount of offset of Miocene isopach and facies trends at the Aure Lineament is not equivalent for features of different ages, but appears greater for older features. This is indicative of secular movement, as opposed to a single spasmodic movement, along this lineament. The isopach and facies offsets suggest that movement along this lineament began, at least, as early as the Lower Miocene, and relationships shown by the Kuku Fault indicate~~s~~ Pliocene movement. The cross-fault which cuts the Mena Basin and marks the presence of the Aure Lineament, appears to be the latest structure in the structural complex south of the Mena Basin (refer section 2.2.3), and there is no reason to suggest that movement on the Aure Lineament is not occurring ~~ing~~ at present. For reasons to be developed later, I suggest that this movement began during, or shortly after, the Eocene (refer Chapter 3). At any rate, this analysis suggests that offset of Middle Miocene sedimentary trends is probable across this Aure Lineament as much later movement on this lineament is indicated.

The Kuku and Bevan Faults provide further insight to this problem. Figure 2-31 shows the Kuku and Bevan Faults in relation to the Aure Lineament. The case has been argued that the Bevan Fault is an older structure than the Kuku Fault, and it is instructive to examine the spatial relationship between the traces of these two faults.

It is readily observable that the bend in the trace of the older (Bevan) fault is greater than that of the younger (Kuku) fault. I suggest that this relationship is explicable in terms of an impressed bending of these features due to secular, dextral transcurrent movement on the Aure Lineament. If the Aure Lineament were active prior to the formation of the Bevan Fault and remained active during the formation of the Kuku Fault, which I suggest is the case, the older (Bevan) fault should be bent more than the younger (Kuku) fault - which it is. It is important to stress, that this particular spatial relationship cannot be explained by movements which were entirely post-Kuku Fault.

It is now necessary to examine the overall relationships of the McDowal Fault and the Purari Thrust-Splay. The McDowal Fault has been examined in some detail previously, and the detail of the Purari Thrust-Splay is presented later (refer section 2.4.3).

It has been shown that, by and large, the McDowal Fault marks the eastern limit of the main Lower Murua depositional basin, and that this fault is strongly thrust over the eastern flank of this basin.

The McDowal Fault has been interpreted, in general, to be a thrust fault which flattens rapidly down-dip to become a sub-horizontal thrust, and is believed to be a major structure beneath the Vailala Synclinorium and the Imbricate Belt.

The Purari Thrust-Splay is similar to the McDowal Fault in that it effectively marks the, northern in this case, limit of thick Lower Murua outcrop and, most probably, deposition. The site of maximum Lower Murua deposition occurs in the cuspate area between the Purari Thrust-Splay and McDowal Fault. Further, the Purari Thrust-Splay is similar to the McDowal Fault in that it is the next major fault mountainward of the Bevan Fault.

The combined trend of the Purari Thrust-Splay and McDowal Fault is much like the trend of the Bevan Fault, but is more exaggerated. Because of this similarity, the analogous features between the Purari Thrust-Splay and McDowal Fault and in view of the preceding analysis, I suggest that the McDowal Fault and the Purari Thrust-Splay were once continuous and have since been rotated and offset into their present position by dextral movement on the Aure Lineament. Carey (APC Rept. LI) has previously argued this ~~case,~~ for the original continuity of these faults, largely on the similar disposition of these faults with respect to the Soho Nose.

Judging from the relationship of the combined Purari-McDowal fault trend to Lower Murua beds, it can be suggested that this trend pre-dates the Bevan Fault. This is indicated and supported by a comparison between these structures in their relationship to the Aure Lineament. Whereas the <u>younger</u> Kuku Fault is <u>bent less</u> than the older Bevan Fault, the <u>still older</u> Purari-McDowal fault trend has been bent more than the Bevan Fault. This offers further testimony to the secular nature and importance of transcurrent movement on the Aure Lineament.

The amount of offset along the Aure Lineament, either total or incremental, is difficult to ascertain due to the uncertainty of identifying matching features to either side of the lineament. Cumulative offset is probably of the order of at least 90 km. (refer Chapter 3).

It is important to stress, that actual offset is only part of the movement associated with the Aure Lineament. The structures discussed above indicate that substantial rotation had taken place prior to fracturing and offset. Projecting the Kuku, Bevan and ?McDowal Faults along the normal 320^{o} trend, from the Vailala River area to the intersection of these features with the Aure Lineament, suggests rotations of these faults (about a vertical axis) of 10, 15 and 15 km. respectively (see figure 2-31). The latter distance is regarded as a conservative estimate, as the concealed extension of the McDowal Fault beneath the Ekiere Fault is not well known.

Substantial vertical movement is another feature of the Aure Lineament, as is shown by the fact that Eocene beds, ?Cretaceous beds and ? "Metamorphics" are thrown against beds of the Aure Group along the Aure Fault. In these instances, the southeast side of the fault is upthrown. The configuration of the Upper Murua beds against the unnamed fault, which marks the surface expression of the Aure Lineament at the southeast end of the Mena Basin, indicates that the northwest side of this fault is upthrown, as well as being dextrally offset. The southeasterly-facing asymmetry of the Soho Nose is possibly another indication of this sense of vertical movement.

The fact that each of the Lower Murua, Upper Murua and Pliocene sections attains maximum thickness adjacent to the Aure Lineament is, again, possibly indicative of vertical movement on the lineament. This particular feature, however, may be more closely related to localized movements on the Purari Thrust-Splay, McDowal, Bevan and Kuku Faults, all of which attain maximum displacement and depth of exposure in the area where they cross the Aure Lineament. This observation leads, in turn, to another point. In view of the 'late' deformation of these faults as a result of movement on the Aure Lineament, it seems probable that the original throw of these ~~lesser~~ faults may have been somewhat accentuated by the later transcurrent movements.

Finally, it need be stressed that a directional development through time is expressed by the structural and sedimentary patterns of this area in their relationship to the Aure Lineament, because both structures and sedimentary basins decrease in age toward the southwest along this lineament. This is an extremely important point, and it will receive more attention in Chapter Three.

2.4.2 THE AURE - TSOMA - ANUNA GRABEN

This unit is a fault-bounded, roughly triangular graben. In the graben, structures trend north to north-northwest (refer Plate II). The structure of this area has been delineated largely by photogeology, as field traverses have covered only the northern and western edges of the area.

The Hou-Toila Fault Zone forms the western boundary of this unit and trends north-south. This is a complex zone of disturbance consisting of the Hou, Toila and Tsoma Faults and the Tsoma Anticline. The western side of the fault-zone is relatively upthrown. To the west of this fault-zone, structures trend west-northwest. This trend is truncated by the Hou-Toila Fault-Zone, and structures to the east of the fault-zone trend north-south to north-northwest in harmony with the trend of the fault-zone. The abrupt truncation of the northwesterly-trending structures suggests the possibility of transcurrent movements (? dextral) on this fault zone.

Rickwood (APC Rept. LW) argued that the Hou-Toila Fault-Zone - he applied the term Gono-Panoroa Line to this feature - marked the eastern edge of the early Lower Miocene shelf. This conclusion is uncertain, however, due to the fact that early Lower Miocene beds have not been examined to the east of the fault-zone in the area to the south of the Anuna Fault. The character of the early Lower Miocene beds examined to the east of the Hou-Toila Fault-Zone and north of the Anuna Fault indicates that the early Lower Miocene shelf may have extended some distance to the eastward of the Hou-Toila Fault-Zone (refer section 1.3.1). The implication of Rickwood's conclusion, *i.e.* that the Hou-Toila Fault-Zone is the result of the rejuvenation of an older basement fault remains a possibility but needs further proof.

At the south end of the Hou-Toila Fault-Zone, the fault-zone is interpreted as partly truncating and partly merging with the Purari Faulted-Anticlinorium (see figure 2-36).

The Aure-Tsoma-Anuna Graben is bounded on the southeast by the Aure Fault which trends northeast. In the Aure River area this fault throws Eocene or older beds on the southeast, against beds of the Aure Group on the northwest.

The triangular-shaped graben between the Hou-Toila Fault Zone and the Aure Fault is occupied by structures which trend north-northwest to north-south. The anticlines of this area have narrow and pinched crests, but do not appear to be faulted to any great extent. In contrast, the synclines are gentle, broad-bottomed structures. Rickwood (APC Rept. LW ~~LW, 1956~~) draws an analogy between the morphology of these synclines and the line of Plio-Miocene synclinal basins in the Purari River area to the south. He suggests that the synclines acted as essentially stable, unmoving areas between rising anticlines during folding movements.

To the north, the structures within the Aure-Tsoma-Anuna Graben are truncated at a right angle by the Anuna Fault, which trends east-west. The south side of the Anuna Fault is downthrown. Owing to the fact that Lower Miocene sections are thicker and more volcanic to the north of the Anuna Fault than in any section measured to the south of this fault, Rickwood (APC Rept. LW) suggests that this fault was originally a normal fault, downthrown to the north, on which the sense of movement has since been reversed. He also, suggests that this fault has a transcurrent element because of the abrupt manner in which it intersects the structures of the Aure-Tsoma-Anuna Graben. These structures have no continuation to the north of the Anuna Fault, where structures again trend west-northwest. Rickwood suggests that the Aba Fault truncates the Anuna Fault at its eastern end, because the Gorga Syncline is continuous around the eastern end of the Anuna Fault (see Plate III). To the west, the Anuna Fault does not offset the trend of the Hou-Toila Fault-Zone, and it is improbable, therefore, that the Anuna Fault extends to the west of this fault zone.

To the west of the Aba Fault, Middle Miocene rocks form the main outcrops within the Aure-Tsoma-Anuna Graben. To the east of this fault, Lower Miocene rocks are believed to form the main outcrops. Lower Miocene, and perhaps Eocene, rocks crop out in the southern part of this area.

The time and mode of origin of the Aure-Tsoma-Anuna Graben are difficult problems. Apart from Rickwood's assumption that the Hou-Toila Fault-Zone marks the edge of the early Lower Miocene shelf, there are no facies indications that this graben had any effect on Miocene sedimentation. Facies and isopach lines appear to trend northwesterly across this area. The structures associated with this graben involve beds as young as Middle Miocene. Deformation of this area must, therefore, be post-Middle Miocene, at least in part. The possibility that the gross structure of the Aure-Tsoma-Anuna Graben was blocked-out by older basement faults, *e.g.* the Hou-Toila Fault-Zone and the Anuna Fault, cannot be neglected. Rickwood has suggested that the general line of the Aba Fault has a syn-depositional influence during the Middle Miocene, and in addition I have suggested that the Aure Fault was an active structural line from early Miocene and perhaps from the beginning of the Tertiary, to the present. Both of these lines of evidence add weight to the hypothesis that the broad form of the graben was blocked out early in the Tertiary.

It is difficult to visualize a match between any of the structures within the Aure-Tsoma-Anuna Graben and those without, because the structures within the graben find no logical continuation beyond the faulted boundaries of the graben. It is probable, therefore, that there is no match, and that the structures within the graben have developed independently. The structures within the graben were probably developed as a result of the downdrop of the graben floor and gravitational gliding toward this structural low (see figure 2-32). If this were the case, then the age of the graben is most probably post-Middle Miocene.

The occurrence of the triangular Aure-Tsoma-Anuna Graben situated apically to the convex side of the Purari Orocline is an association too distinctive to overlook. Carey (1955), has found such an association to be typical of oroclines. He explains these grabens ("sphenochasms") as tensional openings, which are complementary to the rotational movements involved in the bending of the orocline. That a graben such as the Aure-Tsoma-Anuna Graben, might be present in this position is predicted by Carey's orocline concept. The origin of the Aure-Tsoma-Anuna Graben as a tensional opening, due to the bending of the Purari Orocline, is strongly suggested. This mode of origin is depicted diagrammatically in figure 2-33, following Carey's (APC Rept. LI) proposed origin of the Purari Orocline (also, see Smith, 1964).

A problem of this interpretation arises from the fact that the Aure-Tsoma-Anuna Graben occurs as an interior structure of the Purari Orocline. This can best be described graphically, as in figure 2-34. The Gorga Syncline and structures to the north are continuous around the Anuna Fault and must mean that the Aure-Tsoma-Anuna Graben is only of local import. This, in turn, can only mean that the Purari-Orocline has formed by differential movements within the whole, and that a simple bending as depicted in figure 2-33 is not sufficient to explain the entire picture. In addition, I have suggested that the Aure Lineament shows evidence of being a major transcurrent fault and, in fact, a controlling structure of the Purari Orocline. In other words, in this area we have the interaction of dextral movement, *viz.*

the Aure Lineament, and sinistral movement, *viz.* the Aure-Tsoma-Anuna Graben and the Purari Faulted-Anticlinorium (refer next section). The exact relationship between the Aure-Tsoma-Anuna Graben and the Aure Lineament is a very difficult problem, to which an entirely satisfying solution cannot as yet be given, but this example furnishes another indication that the simple bending as illustrated in figure 2-33 is not an entirely satisfactory explanation.

Finally, it is pertinent to ask how much rotation has been involved in the formation of the Aure-Isoma-Anuna Graben. The fact that this graben is bounded on the north by the Anuna Fault, which is possibly a transcurrent fault, suggests that some rotation has been involved. An answer to this question cannot be given either directly or entirely. Any explanation involves uncertainties and relationships which are difficult to explain. Three possible solutions are given diagrammatically in figure 2-35 along with brief explanatory notes.

2.4.3 THE PURARI FAULTED-ANTICLINORIUM

A. DESCRIPTION

The Purari Faulted-Anticlinorium is a major structural element of Papua, but only the southeastward-plunging end of it falls in the area encompassed by this study.

The Purari Faulted-Anticlinorium exposes a complex core of Cretaceous rocks with infaulted and infolded Eocene and Miocene beds. The anticlinorium is bounded by major faults which trend west-northwest, but the folded and faulted structures between the faulted boundaries trend more northwesterly and are intersected obliquely by the boundary faults (refer figure 2-36).

The Purari Fault and Purari Thrust-Splay form the southern boundary of the anticlinorium. Near the junction of the Purari and Aure Rivers, the Purari Thrust-Splay throws Lower Miocene rocks on the north, over Middle Miocene rocks to the south. Some 30 kilometers to the west, Cretaceous beds are brought up on the Purari Fault. The eastern end of the Purari Thrust-Splay is truncated by the Aure Fault near the junction of the Purari and Aure Rivers.

The northern boundary of the Purari Faulted-Anticlinorium is less well-defined. This boundary is most likely formed by the Ih Fault. The Ih Fault is a major fault, which trends west-northwest and parallels the trace of the Purari Fault. The south side of the Ih Fault is upthrown, throwing Cretaceous, Eocene and Lower Miocene rocks against Middle Miocene rocks. At the east end, the Ih Fault ends against the Hou-Toila Fault-Zone. To the west the Ih Fault has not been mapped farther west than Paw Creek, but a possible westward continuation may be suggested, as shown in figure 2-36.

To both the north and south of the Purari Faulted-Anticlinorium, the structure is more simple than that of the anticlinorium. In these areas the structural grain is generally parallel to the north-west trend of the Pio Fault to the north, or the Bevan Fault to the south.

Rickwood (APC Rept. LW) has drawn a line, trending sub-parallel to the Pio River, which he suggests marked the northern edge of shelf deposition during the late Lower Miocene and the Middle Miocene (refer figures 1.3-2 and 1.3-4). On the basis of the occurrence of derived 'basement', Cretaceous, Eocene and Miocene pebbles and faunas and frequent slump structures in (often conglomeratic) Eocene to Middle Miocene sections along the Pio River, Rickwood has suggested that the area to the south of this line was an actively rising erosional area from the Upper Eocene through the Middle Miocene. This line marks the faulted, northern edge of a feature which Rickwood termed the Wana Swell.

Nowhere to the north of the Purari Fault have thick Upper Miocene beds been found, and it is doubtful that the Lower Murua Sub-Group was ever extensive, or that Upper Murua beds were deposited at all, to the north of this fault. This suggests that the area immediately to the north of the Purari River, ~~i.e.~~ viz. the Purari Faulted-Anticlinorium and the northern edge of the Wana Swell, remained an actively rising area during the Upper Miocene.

Similarly, Pliocene sediments (excluding volcanics) are not present to the north of the Purari Fault. Rickwood argued that the area between the Pio and Purari Rivers was a high area during the active Plio-Pleistocene volcanic phase of Mt. Karimui, as the mantle of this volcano does not extend south of the Pio River. These data taken together strongly indicate that this part of the anticlinorium continued its emergence into the Pleistocene.

With geomorphological arguments, Rickwood suggests that this area (known physiographically as the Purari Dividing Range) is actively rising at present, *e.g.* well-marked erosional benches and short, torrential, bounder-choked tributaries with many waterfalls are the rule to the south of the Pio River, whereas benches are lacking, waterfalls rare and tributaries are better graded and separated by dissected hills on the north side of the Pio River.

B. INTERPRETATION

The nature and genesis of the Purari Faulted-Anticlinorium and associated structures is problematic. The ~~related~~ bounding faults have linear traces through areas of irregular topography, and beds near the faults are generally steep to overturned. Both of these facts indicate that the faults are steep to vertical at the surface. For this reason, most workers have taken these faults to be steep reverse faults. Owing to the fact that the Puri Well proved the existence of sub-horizontal thrust faults in this region, however, Stanley (1960, p.236) acting on an earlier suggestion of Carey, suggests that these faults, too, flatten down-dip to become sub-horizontal overthrusts. The problem is not clear-cut, however.

The structural plan of the Purari Faulted-Anticlinorium is depicted in figure 2-36. The striking character of this plan is strongly suggestive of sinistral transcurrent movement on the Purari and ~~the~~ Ih Faults.

This would mean that the Purari and Ih Faults are essentially vertical faults, *i.e.* as opposed to being primarily sub-horizontal overthrusts. This implies a very different tectonic significance than do sub-horizontal overthrusts. My solution to this problem, which generally follows the original idea of Carey (1938) and later of Smith (1964) is as follows:

1) The gross trend of the Purari Faulted-Anticlinorium, and the Purari and Ih boundary faults, is more westerly than either the regional structural grain or the structural grain within the Purari Faulted-Anticlinorium. The <u>simple shear stress system</u> depicted in figure 2-36 can adequately account for all of the features of the Purari Faulted-Anticlinorium.

2) The Purari and Ih Faults, which trend obliquely to and intersect regional folding trends, can be contrasted to faults such as the Pio, Bevan and Kuku Faults, which parallel both regional and local fold trends. This suggests that the 'Purari-type' of fault is different in nature to the 'Kuku-type' of fault. The Kuku Fault has been proven, by the Puri Well, to flatten down-dip to become a sub-horizontal overthrust. Therefore, the Purari-type of fault is not likely to be this kind of fault.

3) Rickwood's work has shown that the general area of the Purari Faulted-Anticlinorium has had a history of tectonic activity ranging through nearly the entire Tertiary to the present. This involves tectonic activity along this structural line over a period of sixty 60 to seventy 70 million years, which is at least an order of time greater than movements involving sub-horizontal overthrusting. On the other hand, secular movement on large transcurrent faults, is usually the case, *e.g.* the Aure Lineament in this area, or the San Andreas Fault of California.

4) For these reasons, I suggest that the Purari and Ih Faults are primarily transcurrent faults and are the controlling structures of the Purari Faulted-Anticlinorium. Ramifications of this suggestion are as follows:

(a) The folding and faulting trends within the Purari Faulted-Anticlinorium can be explained either as part of the more northwesterly regional folding trend which has been cut by the Purari and Ih faults, or, as a direct result of movement on the Purari and Ih faults and the stress sytem which has produced these faults. In figure 2-36, some <u>15 structures</u> are shown to occur between the Purari and Ih faults, and these are <u>confined</u> to the area <u>between these faults</u>. This suggests then, that these structures have developed because of movements on the Purari and Ih Faults.

(b) From the preceding discussion, it is not illogical to suggest that the Ih Fault per se marks the northern edge of the Wana Swell, and that the Purari Faulted-Anticlinorium is, in fact, the 'Wana Swell'. The Purari Faulted-Anticlinorium could readily have yielded local uplifts throughout its development by means of various structures of the anticlinorium developing at different rates and in different places through time. It must be remembered, also, that the vertical displacements on the Purari and Ih Faults are quite substantial. These movements, as well, have provided uplifted areas of erosion. The fact that the main part of the Upper Miocene is confined to the area south of the Purari Fault, as opposed to earlier Miocene beds being relatively thick across this area, suggests that most of the vertical displacement on these faults occurred from the end of the Middle Miocene onwards.

(c) Formerly, the Purari Fault and the Purari Thrust-Splay have been regarded as a single feature, both being referred to as the "Purari Fault". My suggestion that the Purari Thrust-Splay and the McDowal Fault were once continuous (refer 2.4.1) should, therefore, be examined. This suggestion requires, by analogy with the suggested interpretation of the McDowal Fault, that the Purari Thrust-Splay is basically a sub-horizontal thrust fault, whereas I regard the Purari Fault as primarily a transcurrent fault.

I think this apparent discrepancy can be rationalized by regarding the Purari Thrust-Splay as a thrust-splay of the main Purari Fault. This is not illogical, for three reasons:

1. The part of the former "Purari Fault", here called the <u>Purari Thrust-Splay</u>, trends more northwesterly than the Purari Fault and is, therefore, more closely related to the structural grain developed to both the north and south of the Purari Faulted-Anticlinorium.

2. The Purari Thrust-Splay does not make a smooth join with the Purari Fault, but joins it through a series of small faults. The intersection of the Purari Thrust-Splay with the more westerly-trending Purari Fault is analogous in plan to the intersection of the Bevan Fault with the Purari Fault. The Bevan Fault, by its generally anticlinal aspect and seemingly close analogy with the Kuku Fault, appears to be essentially a sub-horizontal overthrust fault at depth. The Purari Thrust-Splay, which parallels the Bevan Fault, will therefore, be expected to possess the essential character of the Bevan Fault.

3. For the reason that the Purari Thrust-Splay intersects fold trends in the same manner, though not to the same degree, as the Purari Fault, I suggest it is likely that this fault is a thrust-splay of the main Purari Fault, rather than being an entirely different fault.

(d) An observation can be made with regard to the position of the Purari Faulted-Anticlinorium and, in particular, the position of the Ih Fault. It is clear, that the position of the Purari Faulted-Anticlinorium is closely related to a line of marked thickness and facies change in both late Lower Miocene and Middle Miocene beds. The area immediately to the north must have been actively down-faulted during these stages, and it is not unlikely that the Ih Fault was initiated as a normal fault.

Shearing movements, such as displayed by the Purari Faulted-Anticlinorium, would have a high tendency to occur along such a pre-existing line of weakness. It is, therefore, pertinent to query whether the shearing movements have simply taken advantage of a pre-existing line of weakness, or whether the shearing itself was the cause of this line of weakness. Because of the long tectonic history of the anticlinorium and because of its actively rising character throughout its history, I suggest that the latter suggestion is the more probable solution.

2.4.4 ER FAULT - ER TREND

A fault mapped in Er Creek has been extended by Stanley (1960, p.106) and named ~~given~~ the ~~name~~ Napima Fault (refer Plate I). The existence of the Napima Fault is not unlikely, but it is also possible that the relationships accounted for by this fault may well be accounted for in terms of the known unconformable relationships of the Pliocene and Upper Miocene beds in this area. If the Napima Fault exists, however, I regard it as more likely that this fault either ends against, or is truncated by the fault mapped in Er Creek which is here called the Er Fault. The Er Fault is continued westward (as a dotted line), and this entire feature is called the Er Trend. The Er Trend appears to be a more fundamental structural line than does the Napima Fault. My interpretation is compared to Stanley's in figures 2-37 and 2-38.

As shown in ~~the~~ preceding discussions, a line coinciding approximately with the Er Trend separates the northern, folded part of the Vailala Synclinorium from the southern, faulted part (the Imbricate Belt). The Er Trend, also, corresponds closely to the Aure Group facies and isopach trends, with a supposed general thinning and shelving ~~character~~ occurring southward across this trend. Both of these features suggest that the Er Trend is of major importance.

The exact nature of the Er Trend is uncertain. The relative position of the Lower Murua Sub-Group to either side of the Er Fault and the position of the Upper Murua Sub-Group to the north of this fault, suggest that the Er Fault and, therefore, the Er Trend is upthrown on the south side.

The relationship of fold axes to the Er Trend suggests that sinistral transcurrent movements have occurred along the trend (figure 2-38). Stanley's matching-up of structures across this trend, however, shows very slight dextral offsets across this fault. It has previously been shown (refer section 2.2.2) that the supposed matching of the Haha Fault across the Er Fault is most likely in error, which places the other supposed connections across this fault in doubt. This, in addition to the grossly different structural pattern on either side of this trend, has led me to suggest that structures have developed somewhat independently across the Er Trend. It has been pointed-out, however, that there is a narrow zone of, more or less, transitional development between the faulting of the Imbricate Belt and the folding to the north. It is, therefore, a difficult task to decide just which structures should, or should not be matched across this fault. I regard it as probable that no great transcurrent offsets occur on the Er Fault, at least in the exposed section. I do suggest, however, that there has been gross differential movement, in a sinistral sense, between the area to the north of the Er Trend and the area to the south.

There are two basic interpretations possible for the Er Trend. These are firstly, that the Er Trend represents 'basement' faulting, and secondly, that the Er Fault is confined to the allochthonous slab above the decollement (the Ekiere Fault) which underlies this area.

My interpretation of the Vailala Synclinorium advocates that the folded area to the north of the Er Trend has, in fact, glided farther toward the southwest than has the area to the south. This, then, provides a built-in mechanism for relative sinistral transcurrent movement on the Er Trend.

The problem is not so simply solved, however, as the questions of why the block to the north was allowed to glide farther and why this change should be so distinctly marked at the Er Trend must be asked. The answer to both of these questions, as previously suggested, must lie in either the structural configuration or the lithological character of the pre-Middle Miocene part of the Aure Group, or perhaps in a combination of these factors.

The first factor to consider, is that the line of the Er Trend marks opposed plunges between the Goigi Basin and Vara's Basin. This suggests that the effects of the Er Trend are felt outside of the Ekiere thrust sheet and indicates that the Er Trend, if this extension is valid, is not confined to this thrust sheet. For clarity, I will stress, here, that I do not propose that the Er Trend cuts the surface beds between the Goigi and Vara's Basins, but merely that it is present as a basement feature which affects these structures.

The second factor is that a conglomerate, which occurs near the base of the Middle Miocene section, is exposed at the intersection of the Er Fault and the Yanne Fault and contains blocks of Lower Miocene limestone up to 15 feet in diameter. There is no apparent source for these blocks to the north or east, and they must have been derived from the north-west, west or southwest. Blocks of such size imply steep slopes and possibly faulting.

As thick limestone beds occur in the Lower Miocene of Kariava well, this forms a possible source area, but such blocks were not found in the sequence drilled at Kariava. It is most probable, therefore, that these blocks were derived from the southwest. For these two reasons, which unfortunately furnish the only clues available aside from the general trends of isopachs and lithofacies, I suggest that the Er Trend probably marks a line of basement fracture to the south of which the Lower Miocene is developed in a shelf or near-shelf facies. In short, it is suggested that the Er Trend is a line of Lower Miocene, and probably early Lower Miocene, 'basement' (?) fracture, across which

Lower Miocene beds rapidly thin and change to a predominantly calcareous, shelf-like facies toward the south, and along which subsequent sinistral movements have occurred.

In present structural form and in its early depositional history, the Er Trend is probably closely analogous to the northern margin of the Purari Faulted-Anticlinorium.

From the relationships described above, it can be seen that the Er Trend most probably is an important structural feature in this area, but is one which, for the most part, is presently concealed beneath the sedimentary cover. On the evidence of the aligned reversed plunges of structures occurring to both sides of the Ekiere and Yanne Faults, four additional "basement faults" parallel to the Er Trend can be inferred (refer figure 2-39). Faults parallel to this trend have been mapped, photogeologically, across the Dude-Murua Anticlinorium to the east (refer Plate I).

An important feature to note, is that the area over which such 'faults' can be inferred is very limited (15 to 20 km. wide), and that such strongly expressed features do not occur elsewhere along the entire length of the Vailala Synclinorium. Another feature is that the relationship of all of these 'faults' to the folding of this area suggests a sinistral component of movement.

The overall pattern, as outlined in figures 2-39 and 2-40 is very similar in size and aspect to that developed in the Purari Faulted-Anticlinorium. An important point in this respect is that this trend occurs in an area of a much thicker Miocene section than does the Purari Faulted-Anticlinorium. The question that follows, is to what extent a feature such as the Purari Faulted-Anticlinorium may be present beneath this area, but largely masked by the sedimentary cover?

2.4.5 COASTAL TREND

Carey (APC Rept. LJ) recognized a structural feature which he termed the Coastal Trend. As the coast is approached from the north, nearly all the structures of this region swing from more northerly trends to more westerly trends toward the coast. The validity and importance of this feature can best be seen by referring to the geological map (Plate I). The swing in trend is especially noticeable in the trend of the Hohoro Anticline, Kuku Fault and Dude-Murua Anticlinorium. The Muruwaie Syncline, which trends at about $115^{\circ} - 120^{\circ}$, is transverse to the major structural trends in this region and is probably a direct expression of the Coastal Trend.

Although well-defined regionally, the Coastal Trend is not a sharply defined lineament, but influences the structural trends over a broad belt some 15 to 20 km. inland from the coast. The Coastal Trend is expressed differently and to a varying degree by the structures of this region, as can be observed from the geological map. The fact that all major structures and structural units seem to be affected to some degree by the Coastal Trend suggests firstly, that the Coastal Trend is a real and fundamental structural element of this region, secondly that the Coastal Trend is probably a deep-seated feature, and thirdly that the Coastal Trend is either a very late feature, or that it is of secular nature. The proof of the first of these suggestions, other than from the aspect of the geological maps, must lie in the validity of the second and third suggestions.

A discussion of the third suggestion is the most instructive and furnishes a good introduction to the problem. The Coastal Trend affects all of the major structural units of this region. This means that the Coastal Trend must be either the latest tectonic element of the region or, more probably, that the Coastal Trend is of a secular nature. This is because the major structural units of this region are of different ages, having developed from the late Lower Miocene through the Pliocene.

I now suggest that the Coastal Trend has been a controlling element in the tectonic development of this area from, at least, the late Middle Miocene onward. This can be seen, generally, from the fact that the post-Aure Group isopach and lithofacies maps of this area generally conform to and mark the Coastal Trend.

The post-Aure Group rocks of this area essentially mark the southern plunge of the broad feature known as the Kukukuku Lobe. The distribution and character of these rocks are not a simple reflection of the plunge of the Kukukuku Lobe, however. This is seen firstly in the fact that marine sediments of the order of 3,000 m. thick have accumulated in this area. This indicates that subsidence has been active during the deposition of these sediments, and this subsidence is probably proceeding at present (refer section 1.5).

Secondly, it has been shown that the Kukukuku Lobe is a complex feature consisting of independent major structural units of different ages, *i.e.* the Dude-Murua Anticlinorium of late Middle Miocene age and the Tauri Anticlinorium of late Lower Miocene age. If the post-Aure Group depositional configuration in this area were a lag feature, controlled simply by the dying-out of the uplift which occurred to the north, it would be expected that all Middle Miocene sediments, as well as post-Aure Group sediments, would thicken around the southern plunge of the Tauri Anticlinorium. The reverse is seen to be the case, as the southern end of the Tauri Anticlinorium seems to have been a structurally high area during the Middle Miocene and, probably, during the Lower Miocene as well. Even if the early Middle Miocene depositional ~~ional~~ configuration did conform to the post-Aure Group configuration (and it may partially, refer following paragraphs), a major basement feature could be expected in this area because of the close spatial relationship between the southerly plunges of the non-contemporaneous Dude-Murua and Tauri Anticlinoria.

The plunge of the Dude-Murua Anticlinorium can be examined further and the incipient development of the Coastal Trend dated more closely. It has been suggested that the extremely coarse conglomerates of the Morai River Formation partially pre-determined the plunge of the Dude-Murua Anticlinorium, before the uplift and folding of the anticlinorium occurred, largely because the conglomerates resisted folding movements. Extending from this, it was suggested that faulting, upthrown to the south, has almost certainly been responsible for the production of these remarkably coarse conglomerates.

The proposed late Middle Miocene faulting that gave rise to these conglomerates can, in turn, be regarded as a fundamental cause of the plunge of the Dude-Murua Anticlinorium in this area. This, then, means that the southerly plunge of the Dude-Murua Anticlinorium is, itself, an independently controlled feature, *i.e.* it is not merely a lag-feature. This faulting probably indicates the incipient development of the Coastal Trend.

The southerly plunge of the Tauri Anticlinorium, as presently seen in this area and with respect to the post-Aure Group depositional configuration, was most likely determined at this time, also. This implies that the Tauri Anticlinorium most probably continued well to the south of its present surface extension, and that the plunge* is a superposed, independent structural feature.

Between the deposition of the Morai River Formation and possibly the deposition of the overlying calcareous beds but certainly before the deposition of the Toa Group, the nature of the Coastal Trend reversed. Subsequent to the deposition of the Morai River Formation the area of the Coastal Trend became an area of strong subsidence and has remained

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* The term plunge is not really correct in this usage with respect to the structure of this anticlinorium per se. The anticlinorium does plunge to the south with respect to the post-Aure Group rocks of this area, but the structure of the anticlinorium is strongly discordant beneath the unconformities present in this area, and the presence of Eocene rocks in the Hell's Gate area indicates a northerly plunge of the anticlinorium per se.

so to the present. The subsidence of this area was most probably accentuated by the late Middle Miocene and later uplift of the Dude-Murua Anticlinorium, or of the Kukukuku Lobe as a whole. The Coastal Trend, as can be seen in the area of the Muruwaie Syncline, represents a strongly downwarped or down-faulted area that received thick sediments from the late Middle Miocene onwards. Because the Coastal Trend most probably affects the structural trend of even the latest structures in this area, *e.g.* the Hohoro Anticline and Kuku Fault, this trend must be regarded as essentially a secular feature which has developed from, at least, the late Middle Miocene to the Recent.

The second suggestion, *viz.* that the Coastal Trend represents a basement feature, aside from the marked effect of the Coastal Trend on the major structural units of this region, is most strongly indicated by the character of the conglomerates of the Morai River Formation. The abundance of 'granitic basement' material in these conglomerates, together with their coarseness, has been taken to indicate that faulting, which exposed basement to the south, has been responsible for these conglomerates. This faulting is related to the Coastal Trend as in the aforegoing paragraphs. The first suggestion, *viz.* that the Coastal Trend is a major structural element of this region, follows naturally from this and the preceding discussions.

Just what is the Coastal Trend, and what is its exact 'trend'? Firstly, the Coastal Trend has developed secularly, imposing its presence on all the major structures of the coastal region. This can be shown by an analysis of the coastal region (refer figure 2-41).

Beginning with structures to the west, we can note that the Hohoro Anticline assumes a sharp sinuosity in trend at the coast. Probably a great deal of the sinuosity of this anticline is primary, as my interpretation of this area advocates (refer section 2.2.3), but the major structure of this area, the Kuku Fault, after remaining nearly rectilinear over a distance in excess of 45 km. to the north, makes a sharp southward, then southeastward bend in trend about 15 km. north of the coast. The bend in the trend of the Kuku Fault is broadly paralleled by the southward concavity in the trend of the Hohoro Anticline and Parimamu Syncline. This bend (s) is either primary or imposed. Because the normal pattern of the Kuku Fault is rectilinear, and for supporting reasons to follow, I suggest that the bend is an imposed feature reflecting the Coastal Trend.

Moving eastward through a distance of 15 km., the Dowa Syncline Eako-Keari Fault, Orevi Fault, Bevan-Pemani Fault and the Ekiere Fault, each a major structure, all make an analogous southward bend, that of the Ekiere Fault being the most marked. Much of the sinuosity of trend in this area is, again, probably primary but the sudden bend in the, essentially rectilinear Beven-Pemani and Ekiere Faults suggests an imposed bending. In this area, the supposed sub-surface continuation of the Marupi Fault strongly suggests 'basement' faulting with a general east-west trend.

To this point then, there is a strong suggestion of an imposed bending and perhaps transverse basement faulting, but it is pertinent to note that none of these structures or structural units are greatly disrupted, nor has their development been retarded. These structures developed mainly during the Upper Miocene and Pliocene.

Farther eastward in the older rocks exposed in the Imbricate Belt, the presence of strong, transverse faulting which trends generally east-west is difficult to escape at the southern end of the Imbricate Belt. While transverse faulting seems important in this area, the gross form of the Imbricate Belt has not been greatly disrupted and there is no suggestion that the Imbricate Belt was hindered or retarded in its development. The Imbricate Belt is probably mainly an early Upper Miocene feature.

Moving eastward to the Dude-Murua Anticlinorium, it has been shown that the southern plunge of this unit was probably determined by the Coastal Trend, but in a developmental rather than an imposed sense, *i.e.* the

Coastal Trend hindered or retarded a more southerly development of the anticlinorium. The Dude-Murua Anticlinorium is principally a late Middle Miocene feature.

In the area still farther to the east, it is suggested that the southern 'plunge' of the late Lower Miocene Tauri Anticlinorium is a discordant, superposed feature that has been caused by the Coastal Trend.

Summarizing, it can be seen that there is a progressively increased expression of the Coastal Trend in proceeding from the younger rocks and, more importantly, younger structural units to the west, to the older rocks and older structural units to the east. To enumerate, the progressive increase in the influence of the Coastal Trend toward the east is expressed, firstly by bending in the Hohoro area, secondly by local faulting in the Imbricate Belt, thirdly by retardation of development of the Dude-Murua Anticlinorium and finally by disruption of a major tectonic element, the Tauri Anticlinorium. The overall result of these movements has been the gross bend in the structural configuration of this area. This sequence is broadly indicative of ~~either a decrease in the effect of the Coastal Trend to the west and (or) through time, or more probably of~~ a secular development of the Coastal Trend. ~~as previously suggested.~~

The analysis shows, also, that local folding and faulting have developed at a greater rate than the Coastal Trend, and that the Coastal Trend has developed at the expense of the local folding and faulting movements. Viewed from a slightly different aspect, where structures are young we can see their full and proper development, relatively unaffected by the Coastal Trend. As structures increase in age, the influence of the Coastal Trend gains in import to the extent of disrupting major structural elements.

Basing judgment firstly, on the secular nature of the Coastal Trend secondly on the gross structural pattern of the coastal region, thirdly on the probability of faulting being associated with the Coastal

Trend, and finally on an analogy with the Purari Faulted Anticlinorium and Er Trend, it is suggested that the Coastal Trend represents a major zone of sinistral transcurrent shearing at depth. The pattern suggested is depicted in figure 2-41. The suggested trend of this shearing is approximately 105° - 115°, which is based principally on the trends of the Muruwaie Syncline, the Er Trend and the Purari Faulted-Anticlinorium.

In summary, the westerly swing in strike as the coastal region is approached is, therefore, regarded as an impressed bend, and the bend is held to be the result of important sinistral transcurrent shearing at depth. This shearing is mainly a basement feature and is only broadly, although definitely, expressed in the overlying sedimentary cover. The bending and shearing have not been suddenly imposed but have developed over a protracted interval of time, probably beginning late in the Middle Miocene. From either a structural or stratigraphic viewpoint, the tectonic development of the coastal region has been strongly interwoven with this zone of shearing.

Further observations can be made regarding the nature of the shearing associated with the Coastal Trend. The Muruwaie Syncline is considered to mark the main zone of shearing. This syncline is either a compressional downwarp, *i.e.* mainly a fold, or a tensional sag. The trend of this syncline is transverse to all major folding in this area, and it seems unlikely that the syncline would, therefore, represent even a local compression. Coupled to this, the area of the syncline has been a site of strong subsidence throughout post-Aure Group time and possibly somewhat earlier. It is regarded as most probable, therefore, that the Muruwaie Syncline is basically a tensional sag, due primarily to the proposed shearing at depth. It is probable that tensional faulting is associated with the zone of maximum sag of the syncline. The shearing associated with the Coastal Trend must possess, therefore, a tensional component as well as a transcurrent component. This imposes another boundary condition on the tectonic interpretation of this feature.

The Cupola Structure, Koaru ? Anticline and the Malalaua Anticline have as yet been unexplained. I suggest that these structures may have developed as a result of the proposed sinistral shear couple of the Coastal Trend (refer figure 2-41). The Cupola Structure could possibly be related to the outward spreading effect of the Dude-Murua Anticlinorium, but the other two structures, because of their position, trend and age, meet difficulty in such an explanation and must be ascribed to some sort of local compression or uplift. The sinistral stress couple suggested for the Coastal Trend would inherently supply the local compression required.

Finally a possible analogy between the southern plunge of the Dude-Murua Anticlinorium at the Coastal Trend and both the Ivori River plunge of this anticlinorium and the 7° 40' S. latitude plunge of the Tauri Anticlinorium should be mentioned. Both of these latter plunges seem to be associated with possible, or probable, zones of transverse shearing which is generally parallel to the Coastal Trend, *e.g.* the Er Trend and associated linears is closely associated with the Ivori River plunge of the Dude-Murua Anticlinorium (figure 2-39). It is possible, therefore, that these plunges are associated with a tectonic development similar to that of the Coastal Trend (see figure 2-42). This would, in turn, imply a secular development of these plunges and a probable influence on the original depositional configuration of the Aure Group. Each of these plunges is final and profound in that the older rocks exposed to the north never again reappear to the south. As shown elsewhere, the thickest development of the Middle Miocene is probably confined to the area south of the Ivori River plunge, and the unconformable Middle Miocene on the Tauri Anticlinorium is probably confined to the area south of the 7° 40' S. latitude plunge. Each of these suggestions shows a probable general relationship between the development of these plunges and the depositional configuration of the Aure Group, and indicates that the suggested analogy to the development of the Coastal Trend may be valid.

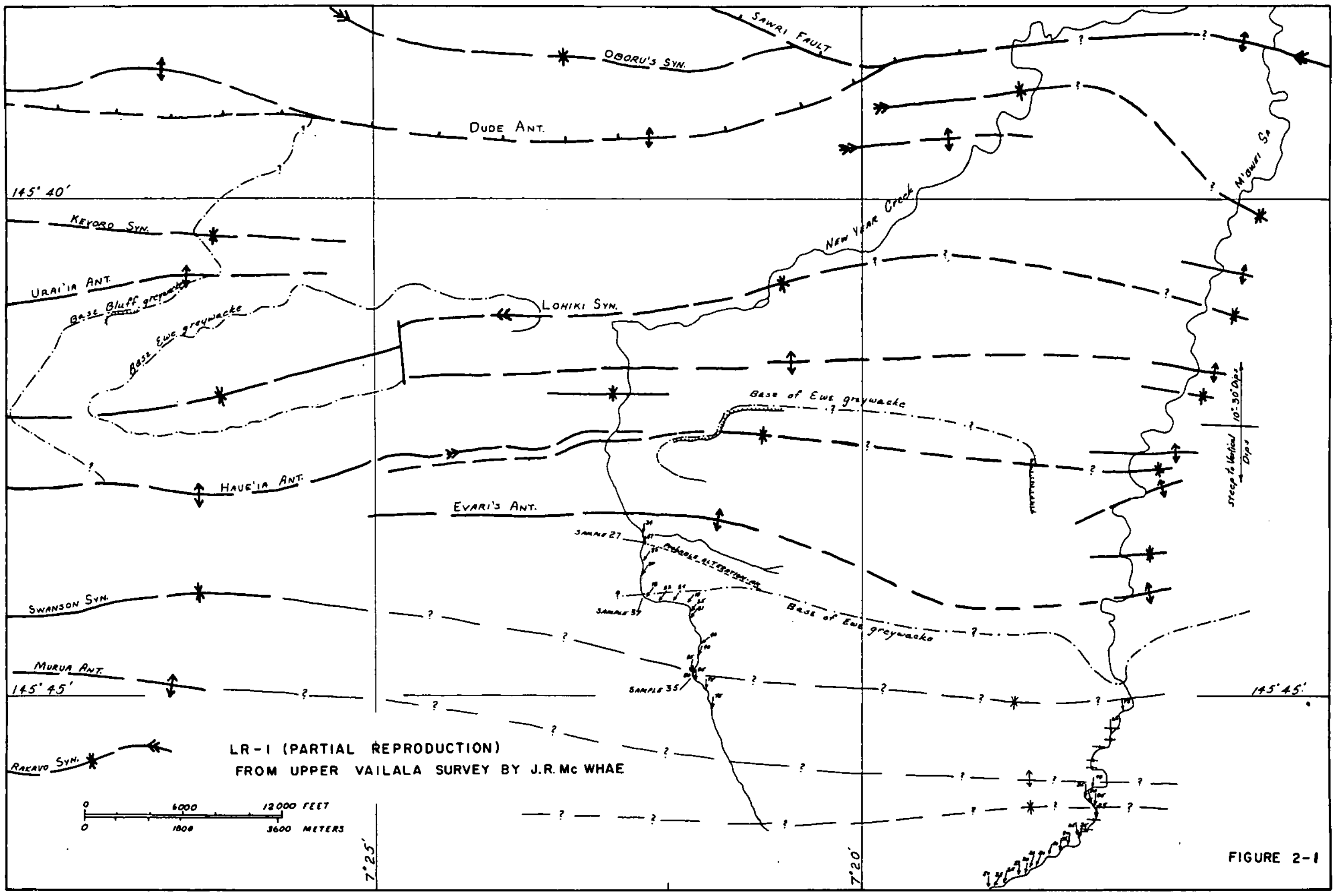


FIGURE 2-1

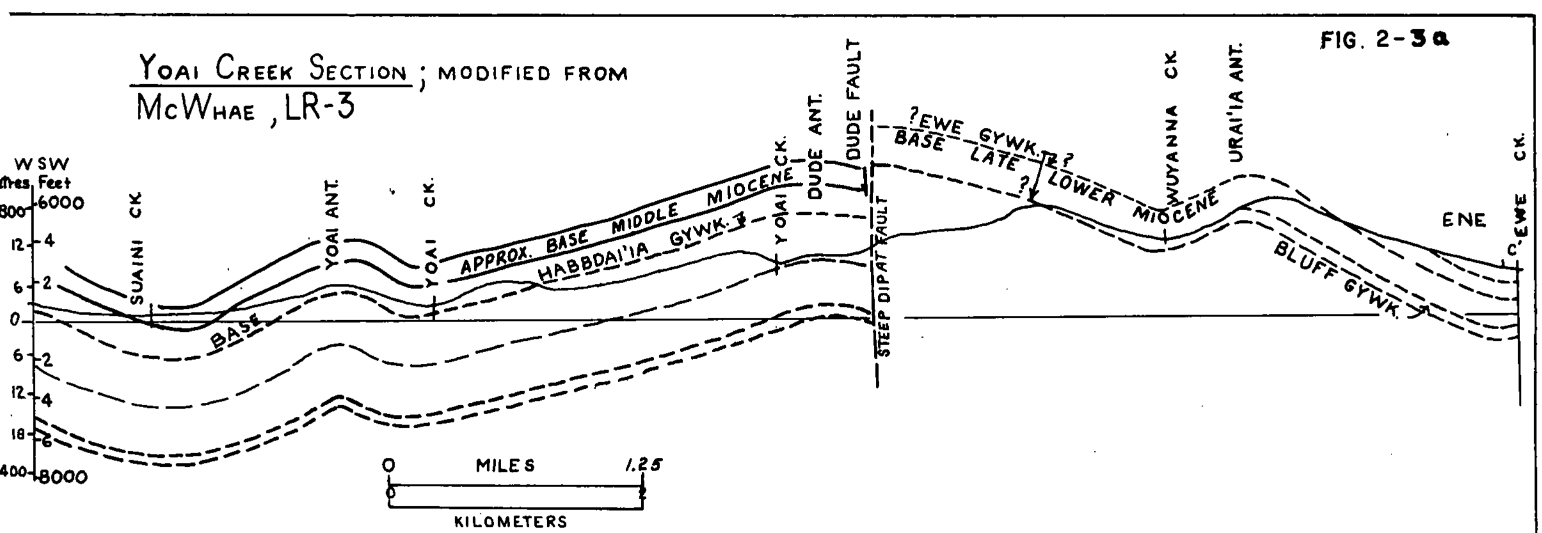


FIG. 2-3a

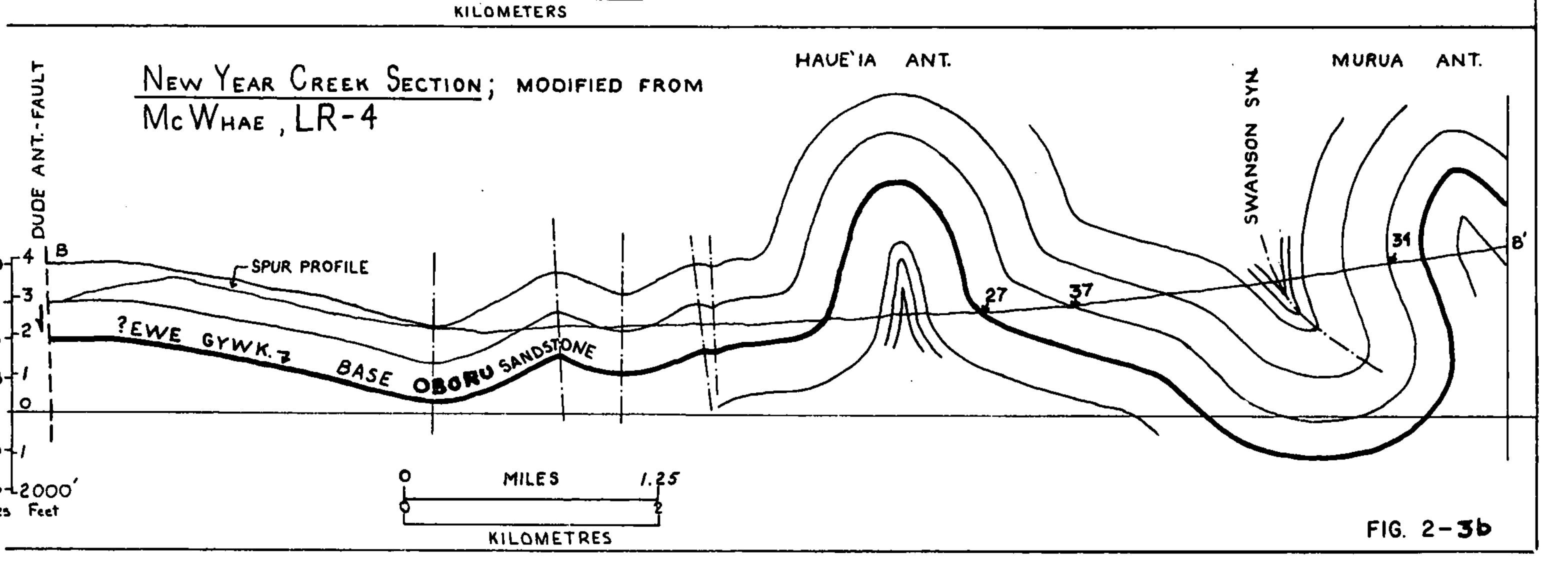
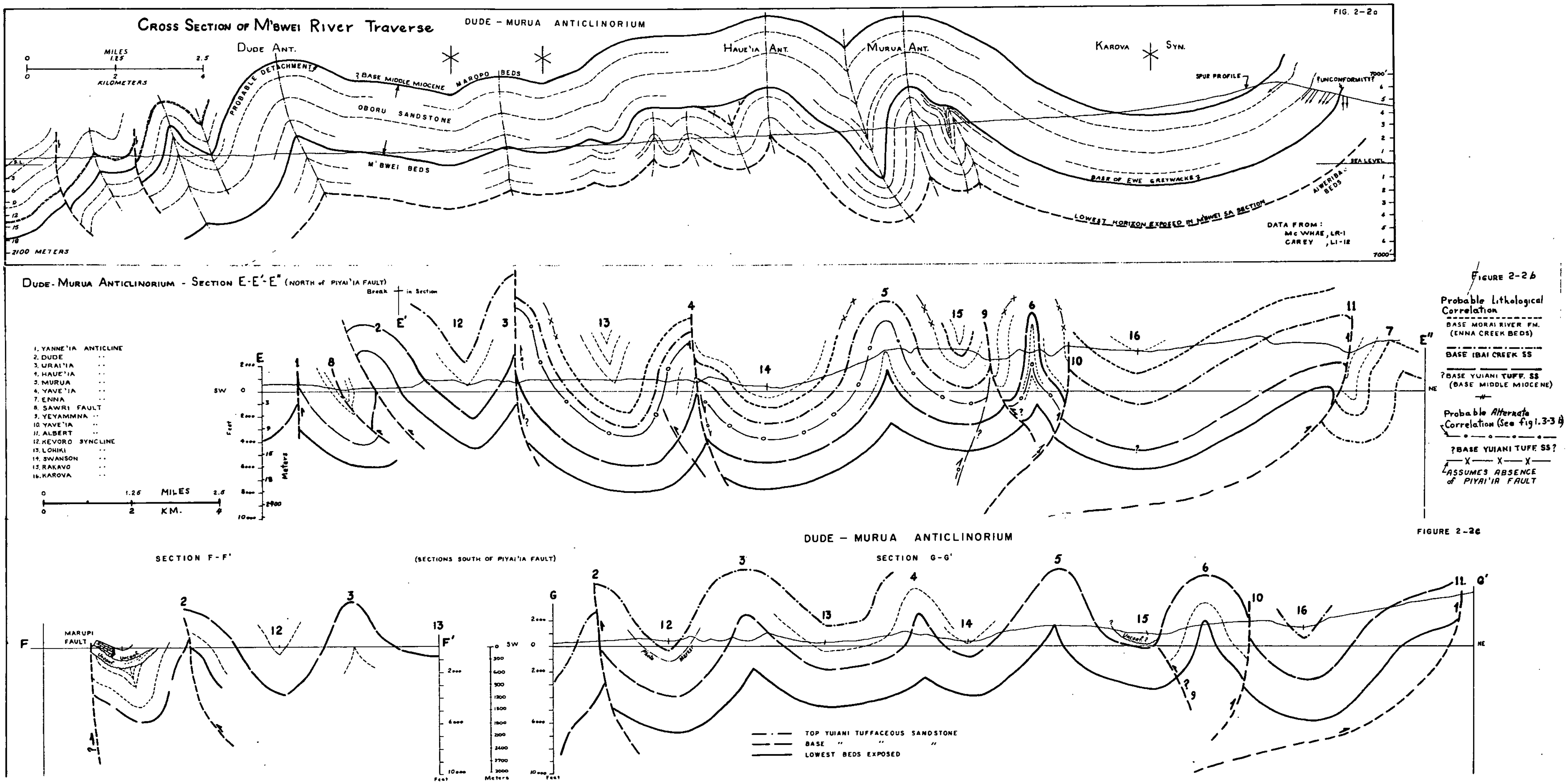


FIG. 2-3b



Cross Section of M'bwei River Traverse
DUDE - MURUA ANTICLINORIUM
FIG. 2-2a
MILES
0
1.25
2.5
2
4
KILOMETERS
Dude Ant.
Haue'ia Ant.
Murua Ant.
Karova
Syn.
PROBABLE DETACHMENT
? BASE MIDDLE MIOCENE
MAROPO BEDS
OBORU SANDSTONE
M'BWEI BEDS
SPUR PROFILE
? UNCONFORMITY
SEA LEVEL
BASE OF EWE GREYWACKE ?
AIWERIBA BEDS
LOWEST HORIZON EXPOSED IN M'BWEI SA SECTION
DATA FROM:
Mc WHAE, LR-1
CAREY, LI-12
7000'
2100 METERS
Dude-Murua Anticlinorium - Section E-E'-E" (NORTH of PIYAI'IA FAULT)
Break in Section
1. YANNE'IA ANTICLINE
2. DUDE ..
3. URAI'IA ..
4. HAUE'IA ..
5. MURUA ..
6. YAVE'IA ..
7. ENNA ..
8. SAWRI FAULT
9. YEYAMMNA ..
10. YAVE'IA ..
11. ALBERT ..
12. KEVORO SYNCLINE
13. LOHIKI ..
14. SWANSON ..
15. RAKAVO ..
16. KAROVA ..
0
1.26
MILES
2.6
0
2
KM.
4
SW
NE
Feet
Meters
Figure 2-2b
Probable Lithological Correlation
BASE MORAI RIVER FM. (ENNA CREEK BEDS)
BASE IBAI CREEK SS
? BASE YUIANI TUFF. SS (BASE MIDDLE MIOCENE)
Probable Alternate Correlation (See fig 1.3-3 b)
? BASE YUIANI TUFF SS ?
ASSUMES ABSENCE of PIYAI'IA FAULT
FIGURE 2-2c
DUDE - MURUA ANTICLINORIUM
SECTION F-F'
(SECTIONS SOUTH OF PIYAI'IA FAULT)
SECTION G-G'
MARUPI FAULT
Feet
Meters
TOP YUIANI TUFFACEOUS SANDSTONE
BASE " " "
LOWEST BEDS EXPOSED

LATERAL SPREAD OF A VERTICALLY RISING ZONE: TO ILLUSTRATE THE RELATIONSHIP BETWEEN THE DUDE-MURUA ANTICLINORIUM AND FLANKING STRUCTURES

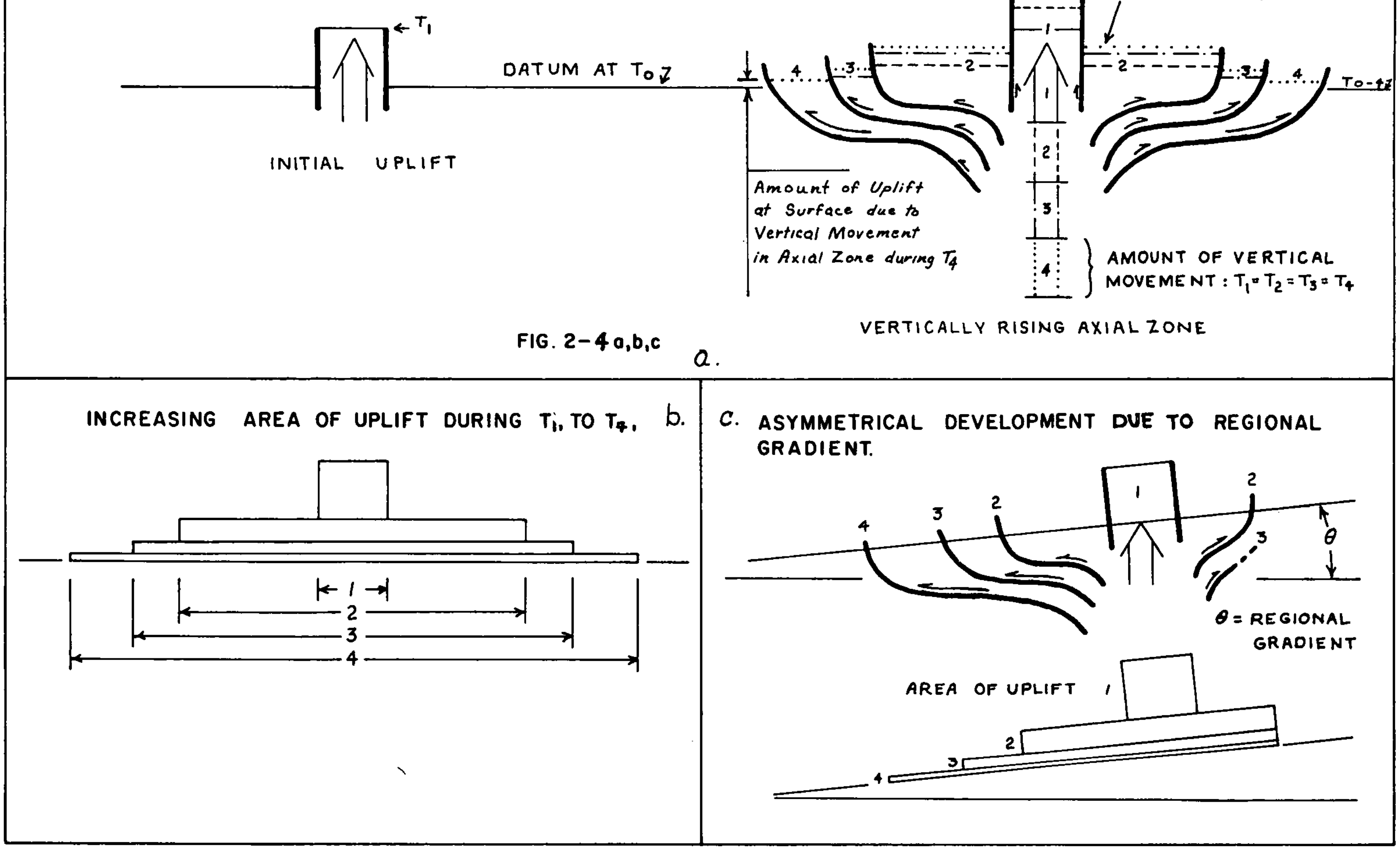


FIG. 2-4 a,b,c

A POSSIBLE GENETIC RELATIONSHIP BETWEEN THE OVERTURN OF THE DUDE ANTICLINE AND FAULTING OF THE URAI'IA AND HAUE'IA ANTICLINES

FIGURE. 2-5

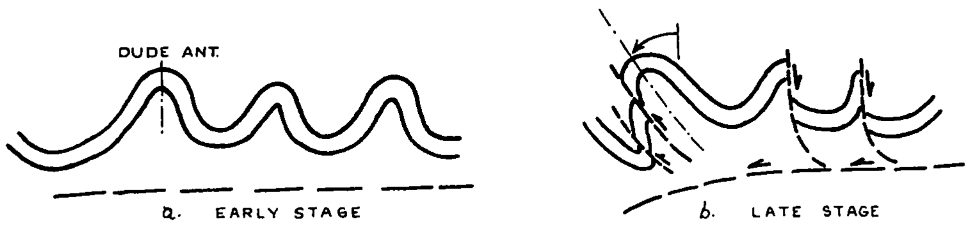
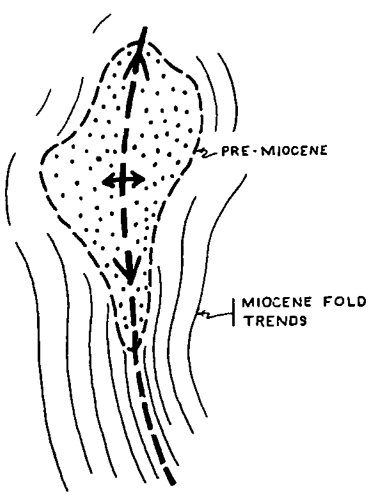


FIG. 2-7



DIAGRAMATIC SKETCH OF PROBABLE RELATIONSHIP BETWEEN MIOCENE FOLD TRENDS AND PRE-MIOCENE BASEMENT TO THE NORTH ALONG THE TAURI ANTICLINORIUM

Figure 2 - 6 Folding model; Reproduced from Bucher, 1963 Figure 10

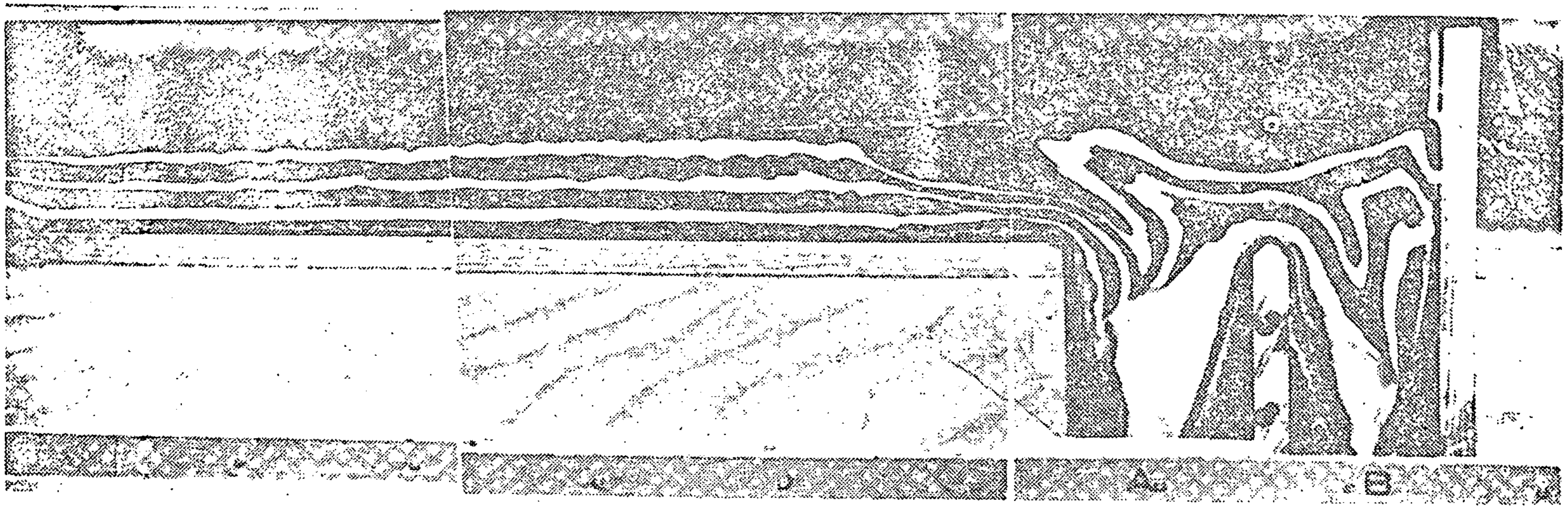
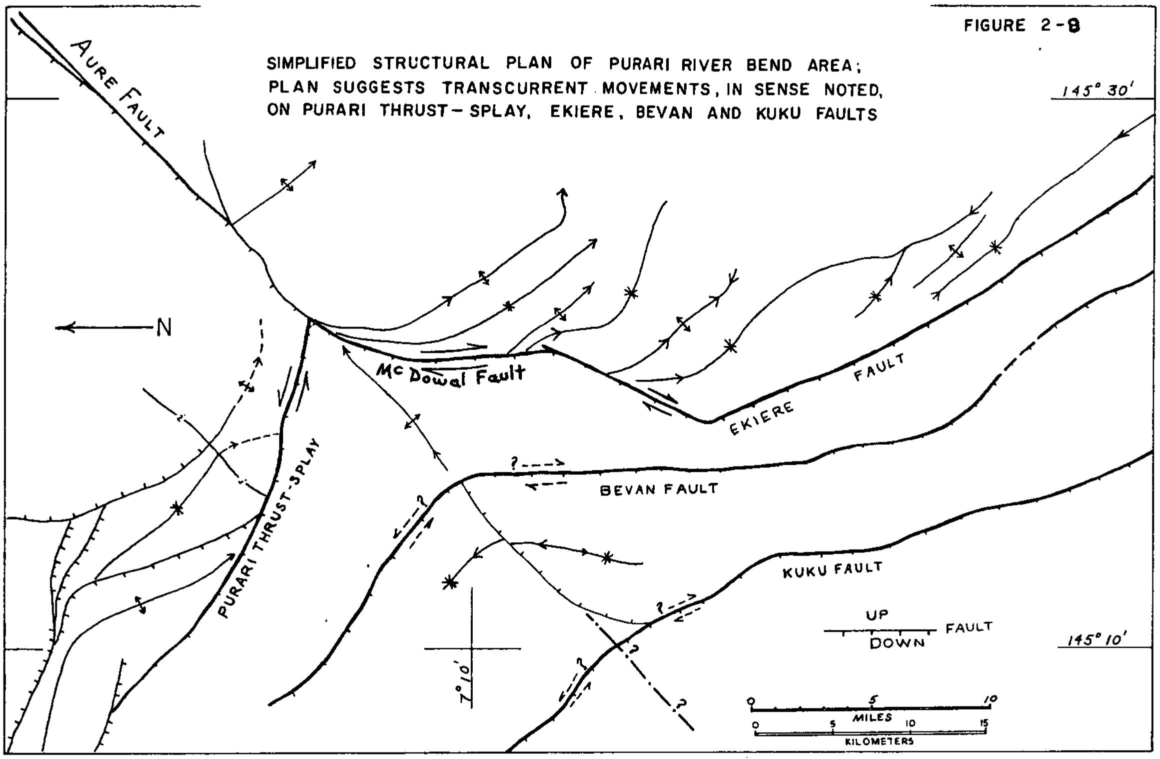
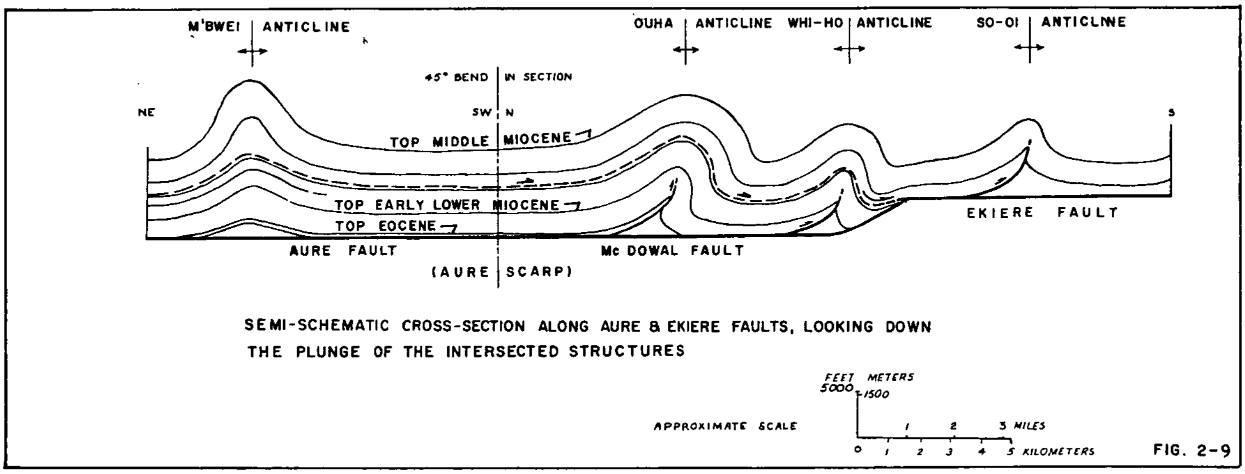


FIGURE 2-9





SEMI-SCHEMATIC CROSS-SECTION ALONG AURE & EKIERE FAULTS, LOOKING DOWN THE PLUNGE OF THE INTERSECTED STRUCTURES

FIG. 2-9

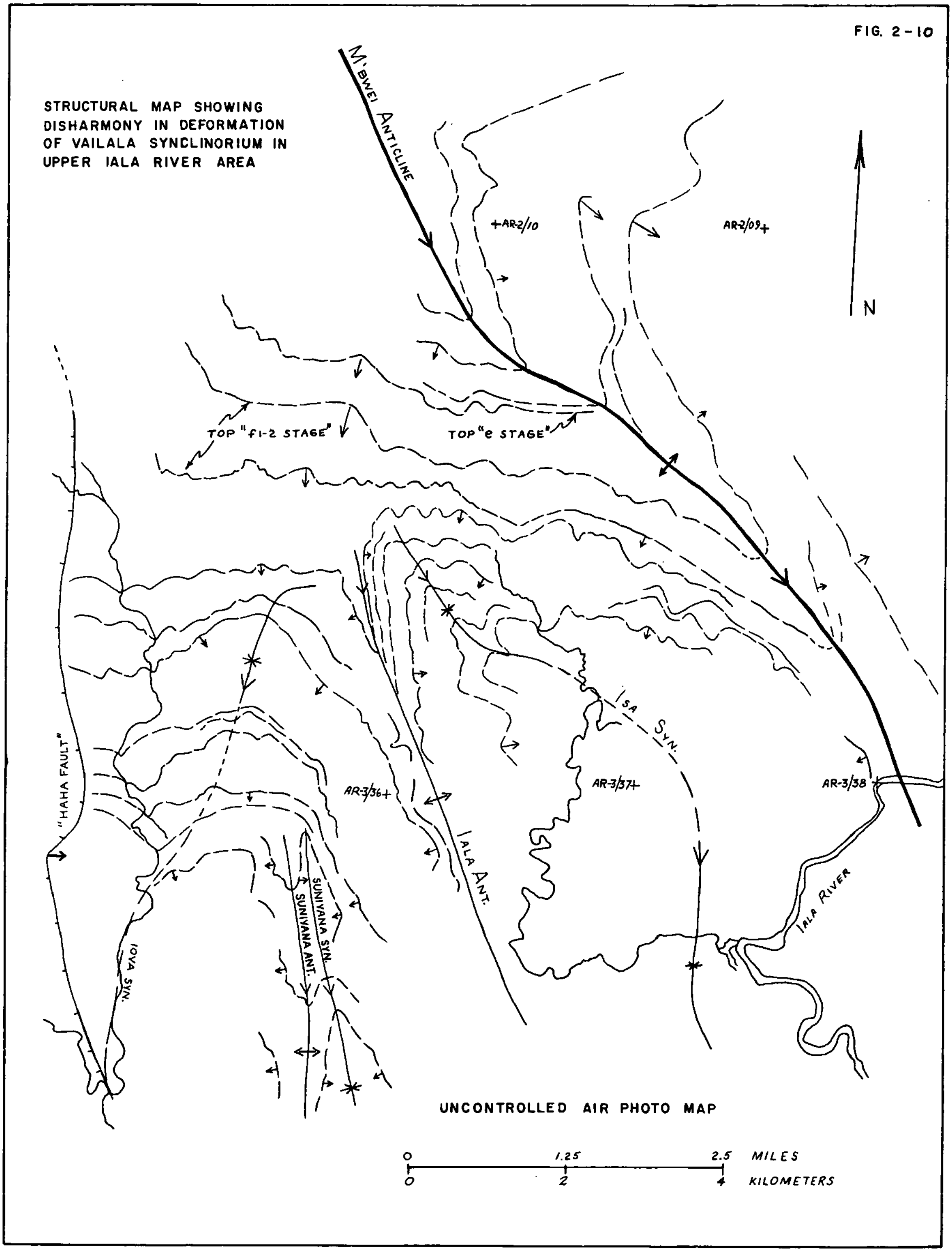


FIG. 2-10
STRUCTURAL MAP SHOWING DISHARMONY IN DEFORMATION OF VAILALA SYNCLINORIUM IN UPPER IALA RIVER AREA
M'BWEI ANTICLINE
AR-2/10
AR-2/09
N
TOP "f1-2 STAGE"
TOP "e STAGE"
ISA SYN.
AR-3/36
AR-3/37
AR-3/38
IALA ANT.
"HAHA FAULT"
IALA RIVER
SUNIYANA SYN.
SUNIYANA ANT.
IOVA SYN.
UNCONTROLLED AIR PHOTO MAP
0 1.25 2.5 MILES
0 2 4 KILOMETERS

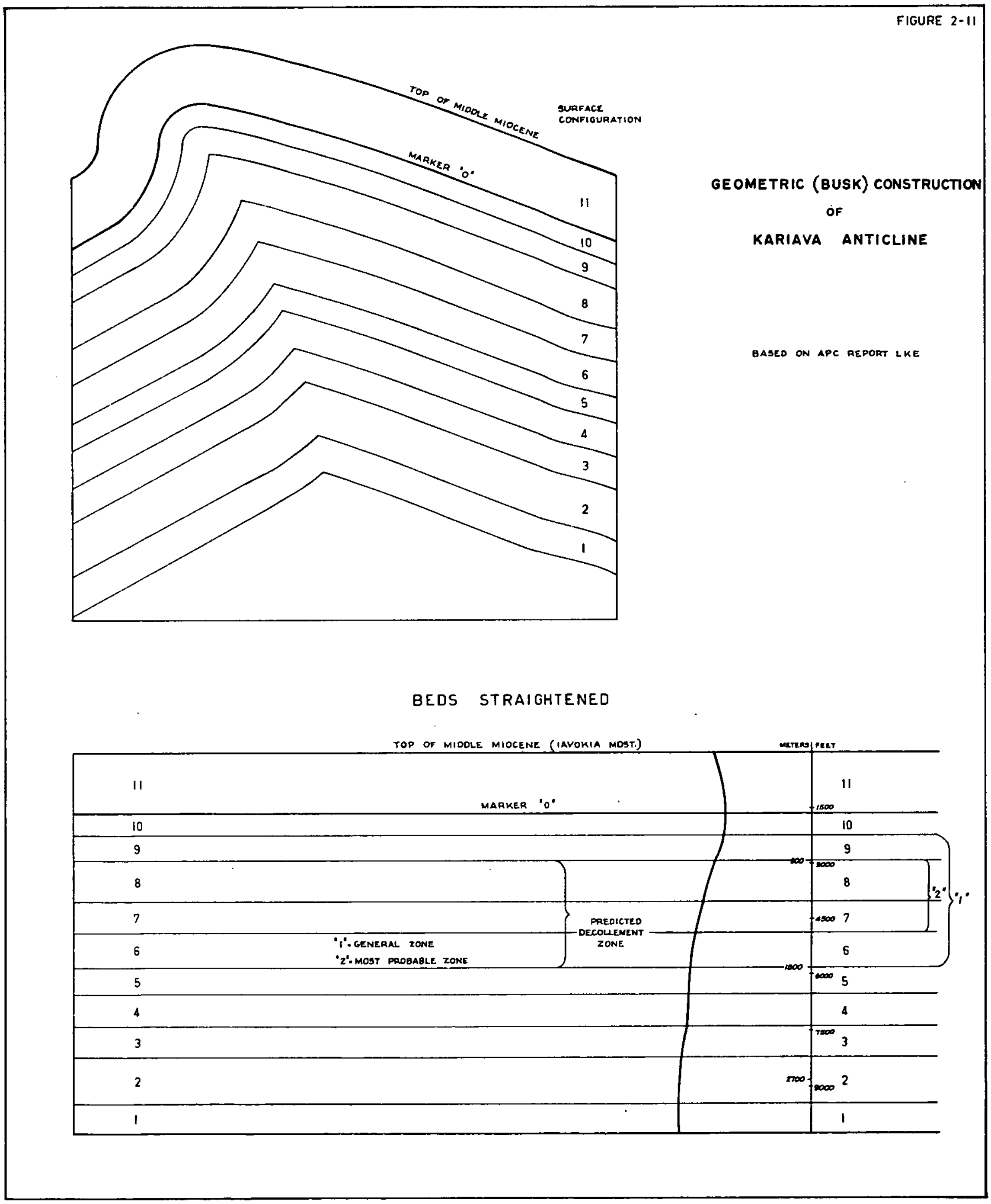
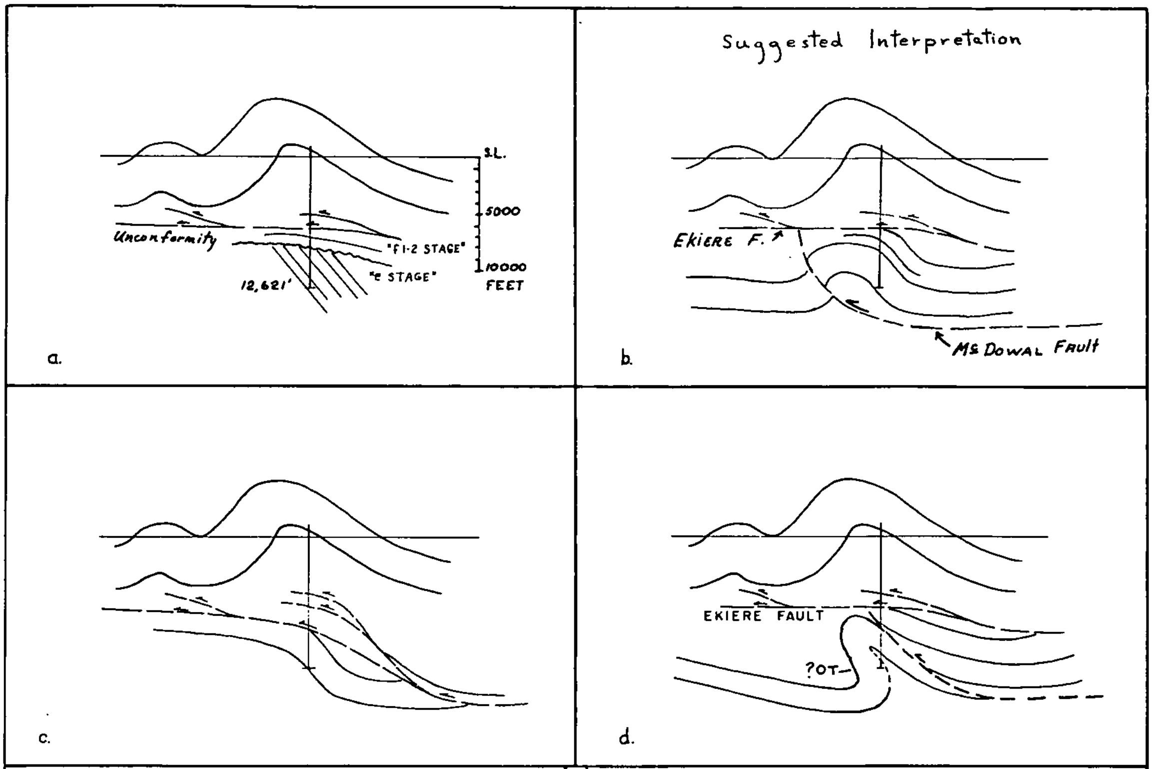


FIGURE 2-11
GEOMETRIC (BUSK) CONSTRUCTION
OF
KARIAVA ANTICLINE
BASED ON APC REPORT LKE
TOP OF MIDDLE MIOCENE
SURFACE CONFIGURATION
MARKER "O"
11
10
9
8
7
6
5
4
3
2
1
BEDS STRAIGHTENED
TOP OF MIDDLE MIOCENE (IAVOKIA MOST.)
METERS
FEET
MARKER "O"
PREDICTED DECOLLEMENT ZONE
"1"- GENERAL ZONE
"2"- MOST PROBABLE ZONE
1500
900
3000
4500
1800
6000
7500
2700
9000
"2"
"1"



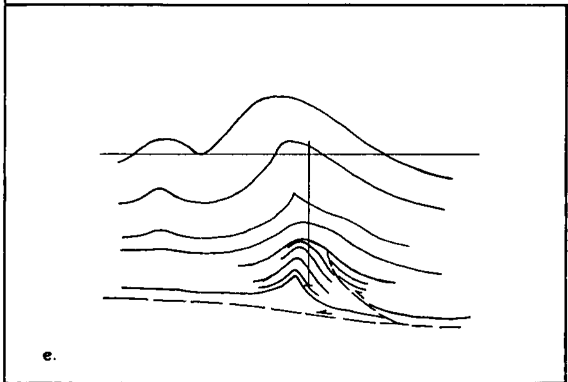


Figure 2-13 a, b, c, d, e

POSSIBLE INTERPRETATIONS OF THE KARIAVA WELL; PRINCIPALLY CONCERNING ZONE BELOW 8264 FEET

Figure 2-14

Concentric Fold : SHOWING DISTURBED CORE AND BASAL DECOLLEMENT

Based on E.S. Hills, figure VIII-24, p. 232, 1963

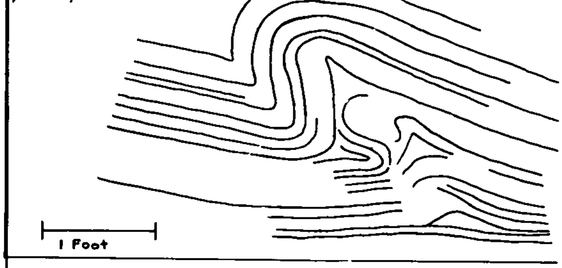
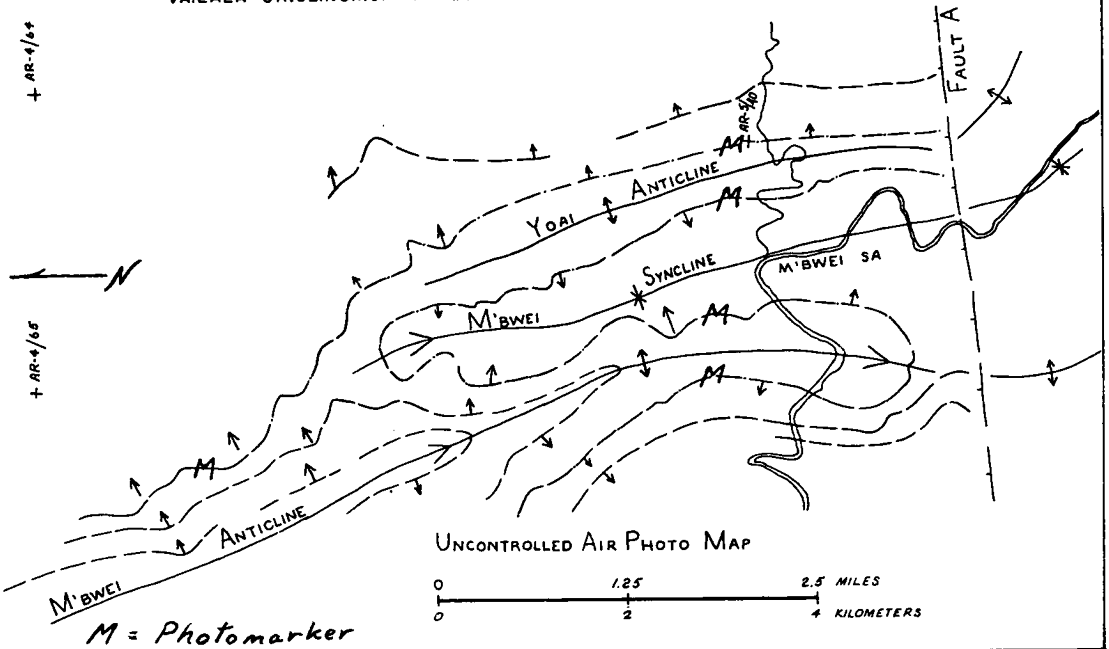
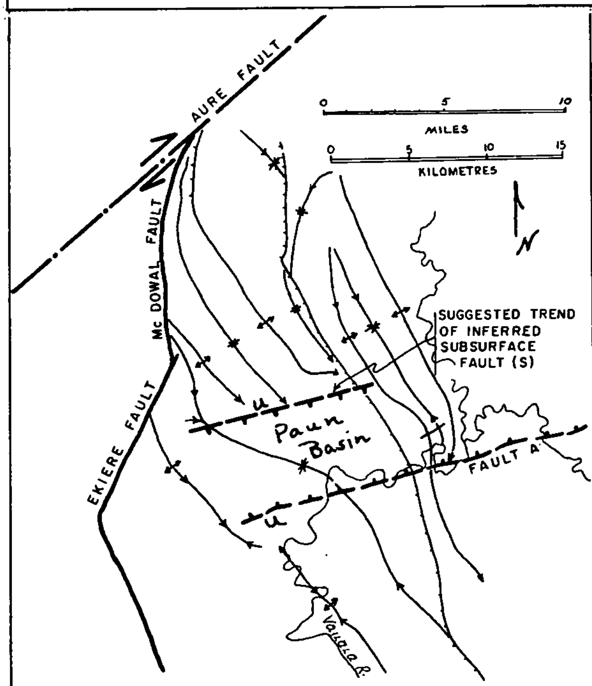


FIG. 2-15

STRUCTURAL PLAN SHOWING DISHARMONY IN DEFORMATION OF VAILALA SYNCLINORIUM IN LOWER M'BWEI RIVER AREA





STRUCTURAL PATTERN OF THE UPPER VAILALA RIVER AREA

FIG. 2-16a

LOCAL SIMPLE SHEAR STRESS SYSTEM AND RESULTANT STRAIN INFERRED FROM FIG. 2-16a

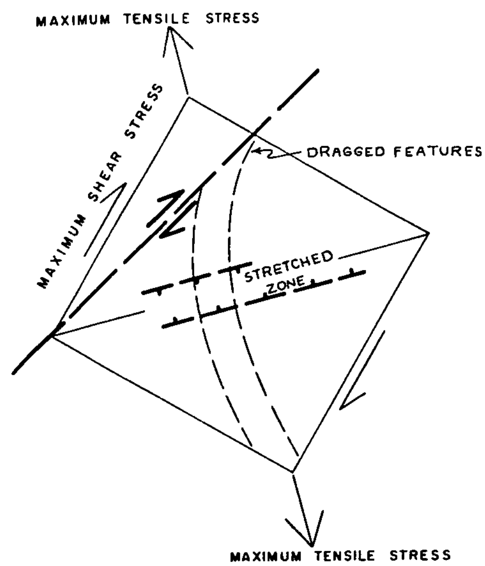


FIG. 2-16b

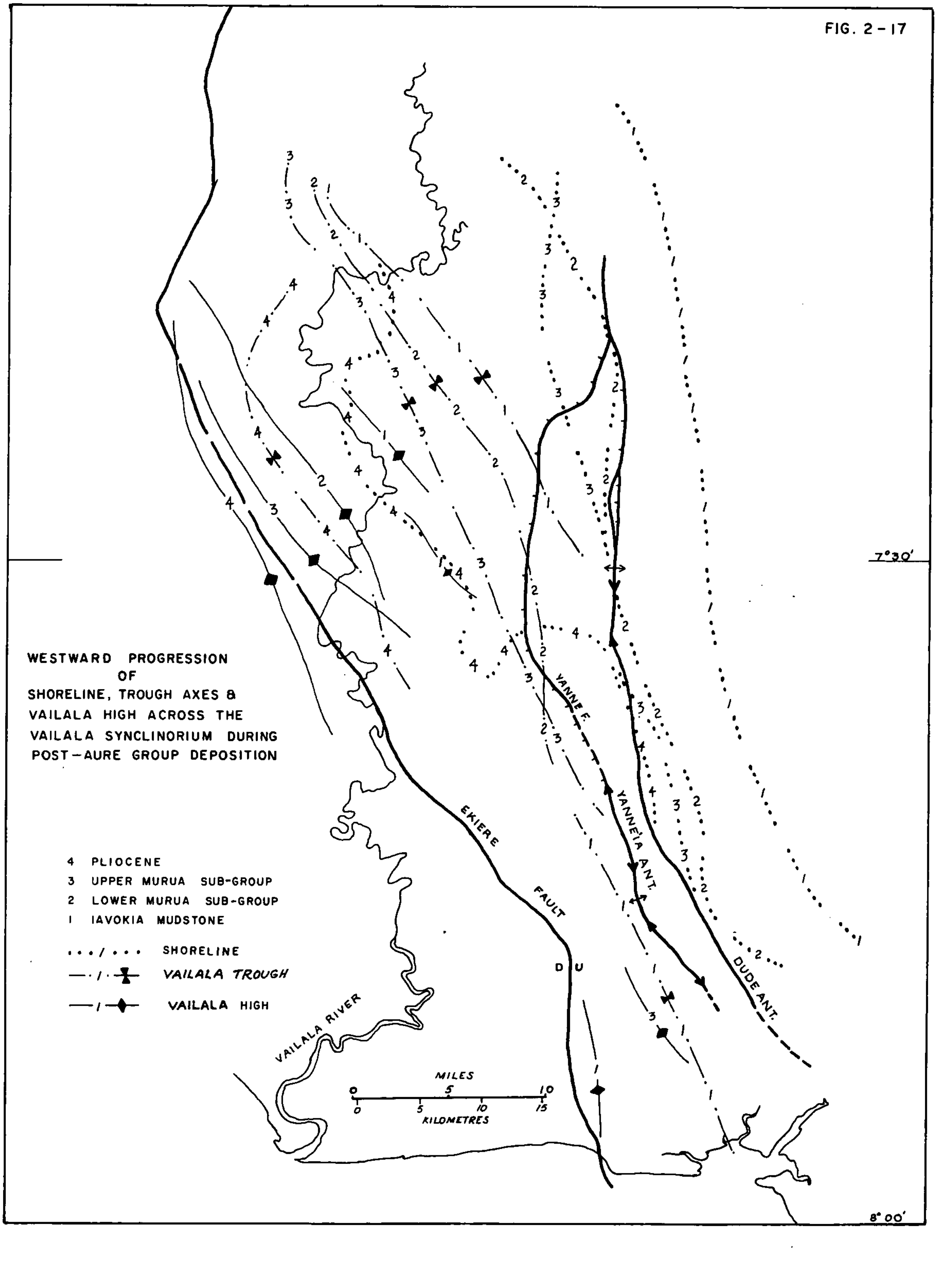


FIG. 2-17
WESTWARD PROGRESSION OF SHORELINE, TROUGH AXES & VAILALA HIGH ACROSS THE VAILALA SYNCLINORIUM DURING POST-AURE GROUP DEPOSITION
4 PLIOCENE
3 UPPER MURUA SUB-GROUP
2 LOWER MURUA SUB-GROUP
1 IAVOKIA MUDSTONE
SHORELINE
VAILALA TROUGH
VAILALA HIGH
EKIERE FAULT
YANNE F.
YANNEIA ANT.
DUDE ANT.
VAILALA RIVER
D U
7°30′
8°00′
MILES
0 5 10
0 5 10 15
KILOMETRES

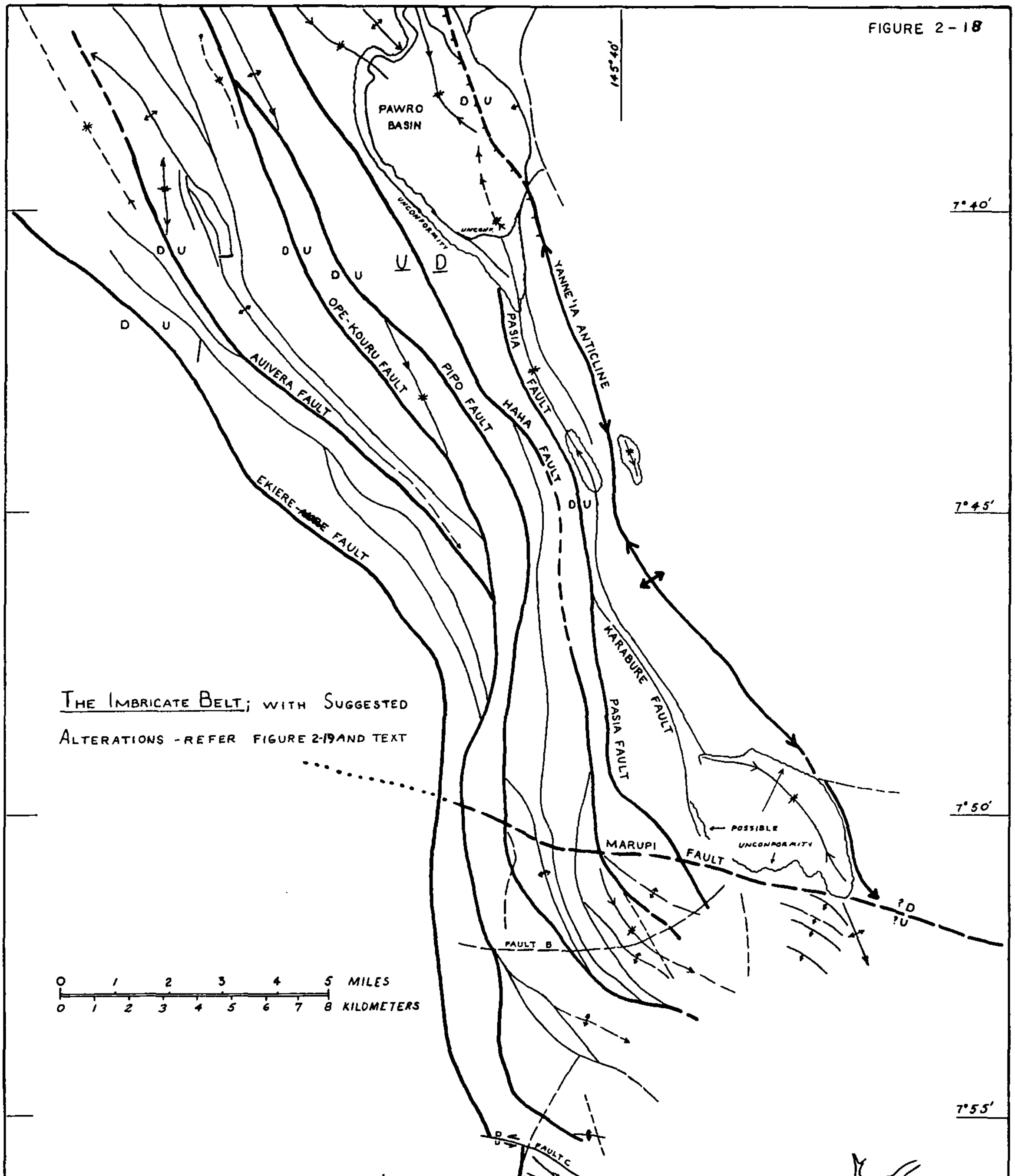


FIGURE 2-18
145°40'
7°40'
7°45'
7°50'
7°55'
PAWRO BASIN
UNCONFORMITY
UNCONF.
YANNE'IA ANTICLINE
PASIA FAULT
HAHA FAULT
PIPO FAULT
OPE-KOURU FAULT
AUIVERA FAULT
EKIERE-~~MIRE~~ FAULT
KARABURE FAULT
PASIA FAULT
POSSIBLE UNCONFORMITY
MARUPI FAULT
?D ?U
FAULT B
FAULT C
FAULT D
KEREMA
0 1 2 3 4 5 MILES
0 1 2 3 4 5 6 7 8 KILOMETERS
THE IMBRICATE BELT; WITH SUGGESTED ALTERATIONS - REFER FIGURE 2-19 AND TEXT

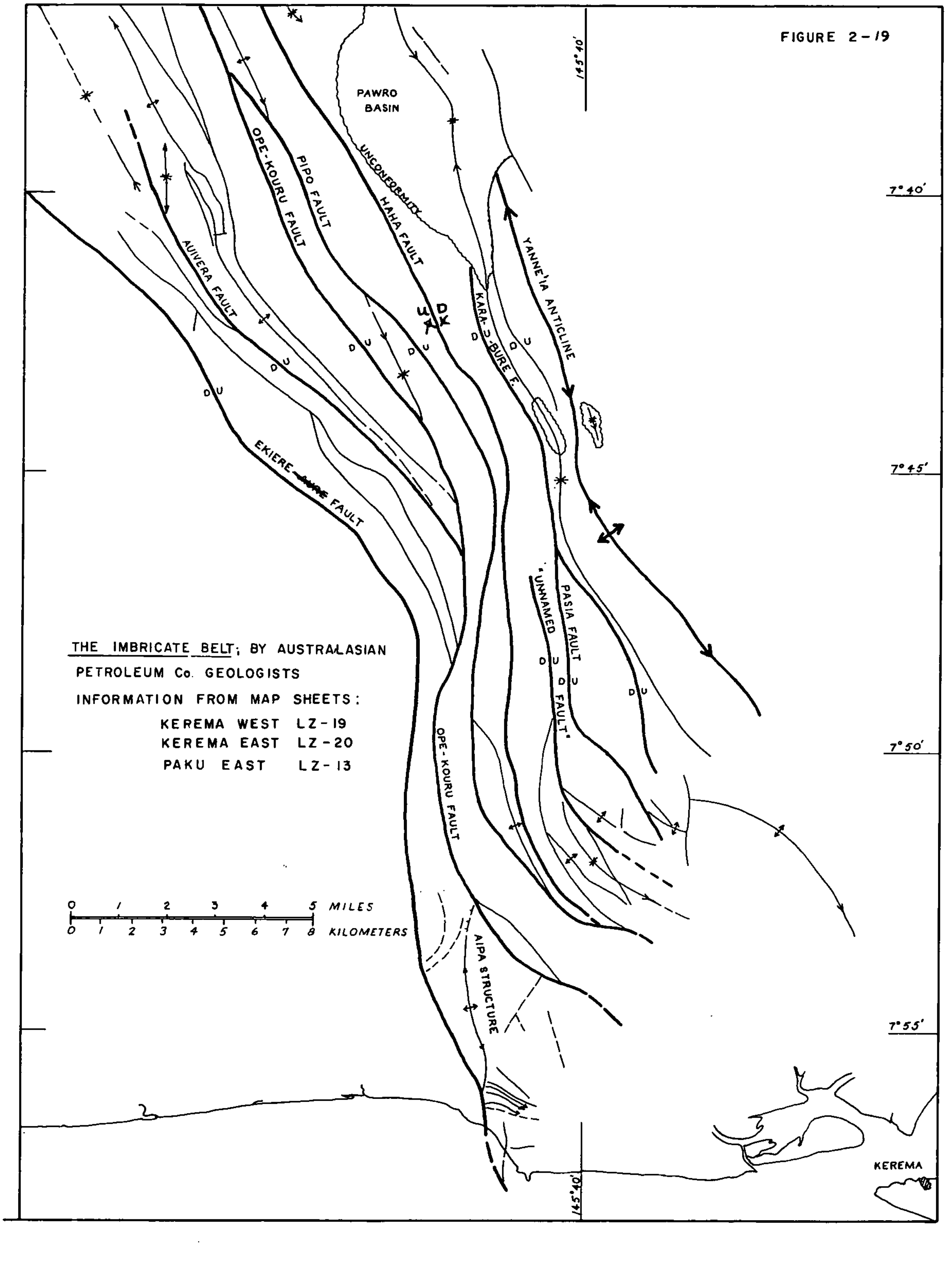


FIGURE 2-19
PAWRO BASIN
UNCONFORMITY
145°40'
7°40'
7°45'
7°50'
7°55'
OPE-KOURU FAULT
PIPO FAULT
HAHA FAULT
YANNE'IA ANTICLINE
KARA-U-BURE F.
AUIVERA FAULT
EKIERE FAULT
PASIA FAULT
"UNNAMED FAULT"
OPE-KOURU FAULT
AIPA STRUCTURE
KEREMA
THE IMBRICATE BELT; BY AUSTRALASIAN PETROLEUM Co. GEOLOGISTS
INFORMATION FROM MAP SHEETS:
KEREMA WEST LZ-19
KEREMA EAST LZ-20
PAKU EAST LZ-13
0 1 2 3 4 5 MILES
0 1 2 3 4 5 6 7 8 KILOMETERS

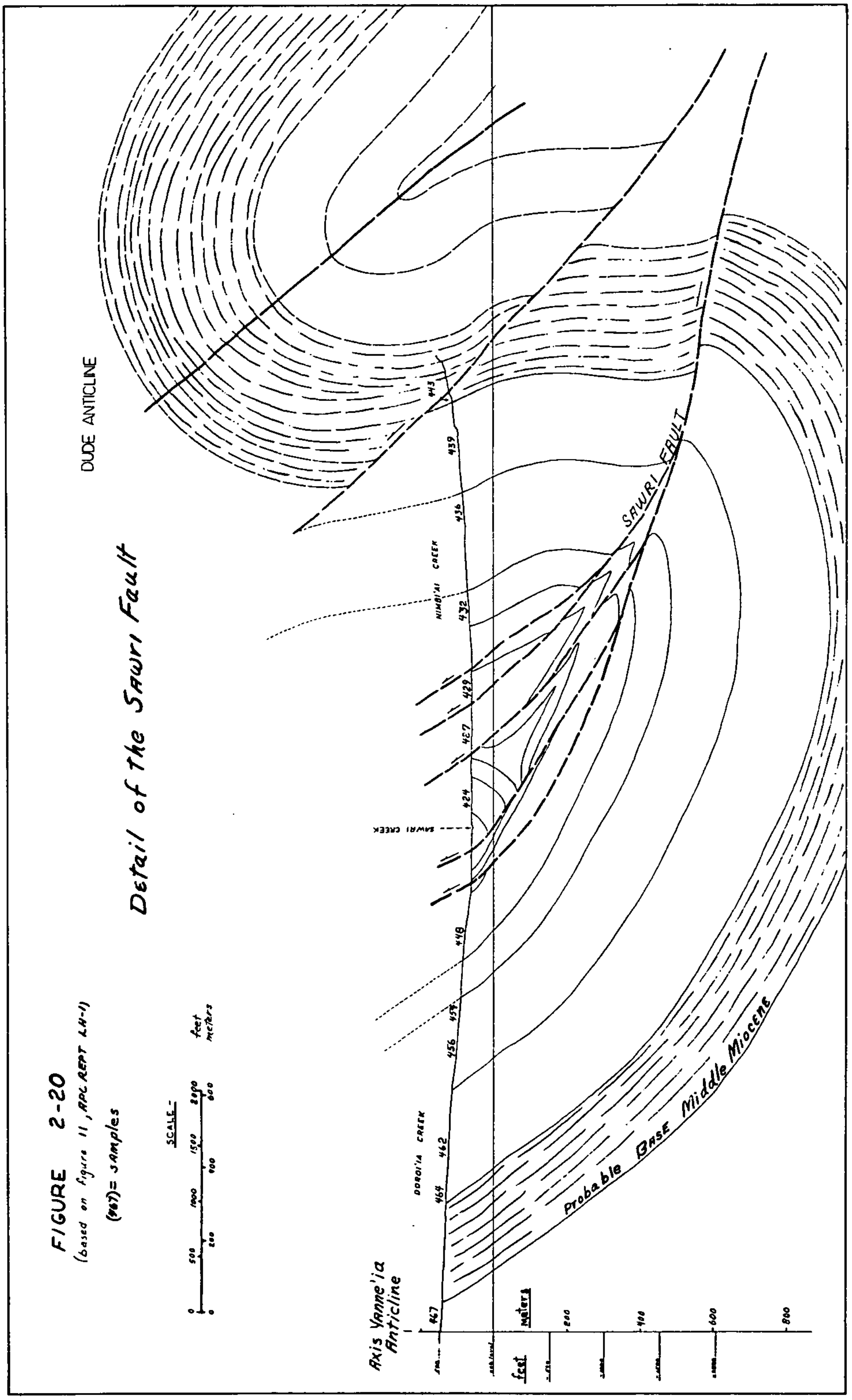


FIGURE 2-20
(based on Figure 11, APC REPT LH-1)
(467)= samples
SCALE-
feet
meters
Detail of the Sawri Fault
DUDE ANTICLINE
SAWRI FAULT
Probable Base Middle Miocene
Axis Yanne'ia Anticline
DOROI'IA CREEK
SAWRI CREEK
feet
Meters
200
400
600
800

Deformation in the Vailala Synclinorium and Imbricate Belt

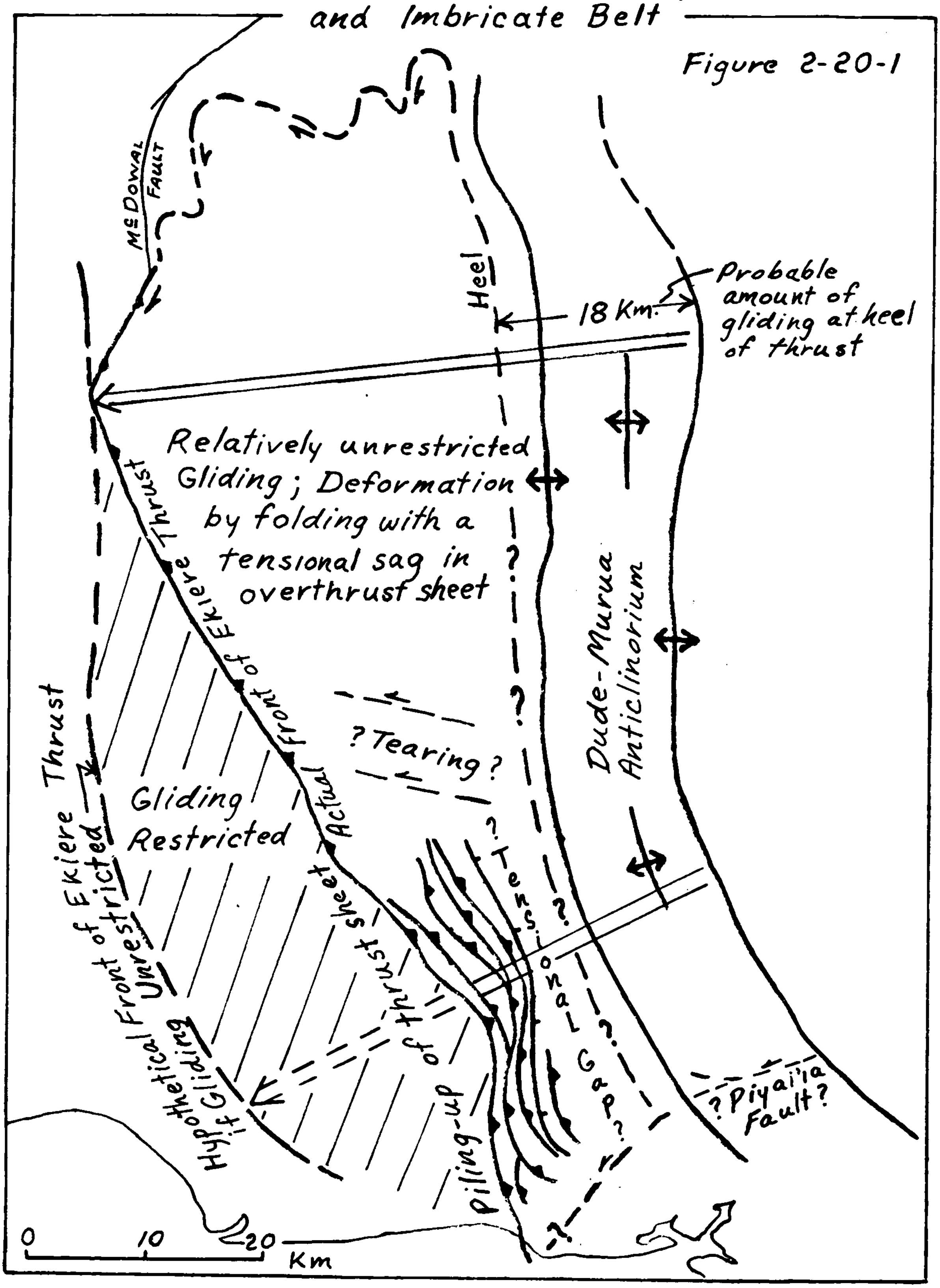


FIG. 2-21 a

CROSS SECTION THROUGH PURI WELL-SITE; REPRODUCED (PARTIALLY) FROM PURI SEISMIC SURVEY
REFERENCE: KAF-8, LINE 6-3

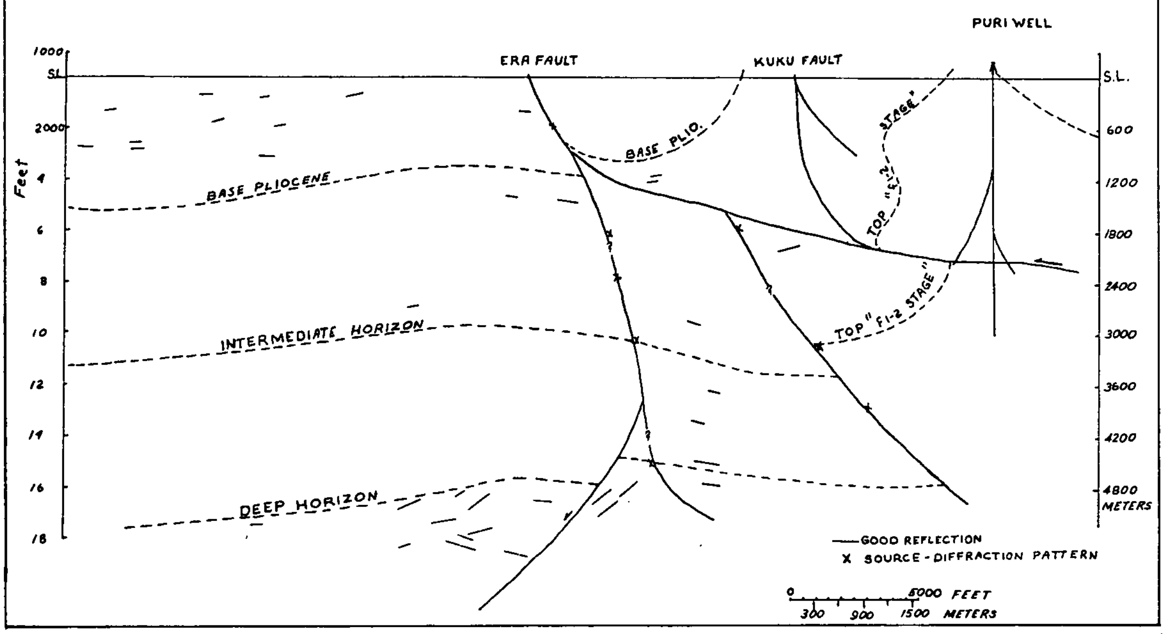
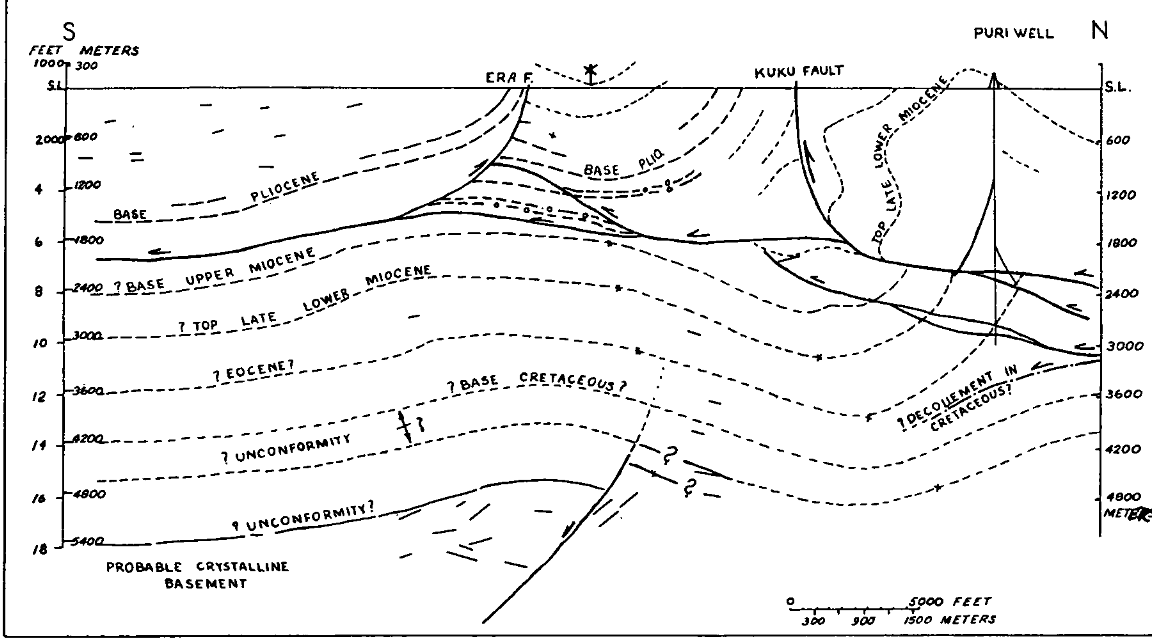


FIG. 2-21 b

CROSS SECTION THROUGH PURI WELL-SITE; RECONSTRUCTED



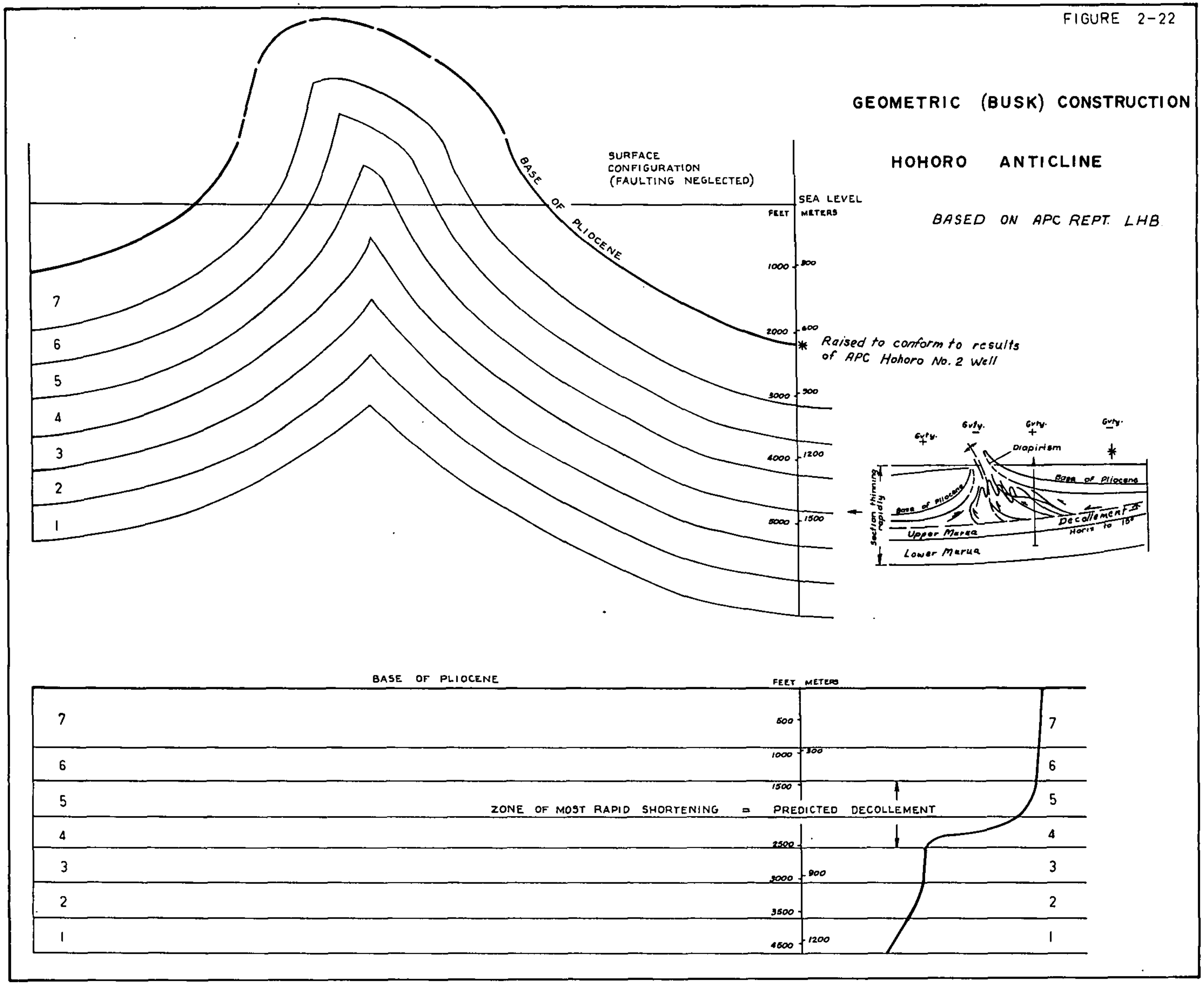
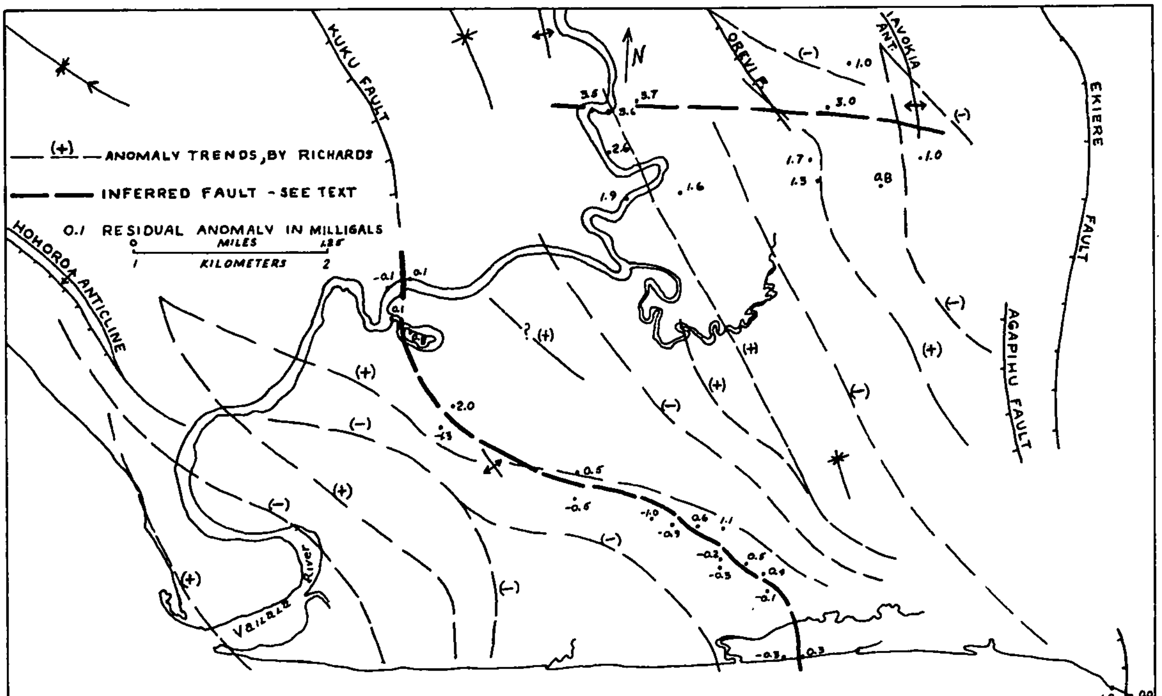


FIGURE 2-22
GEOMETRIC (BUSK) CONSTRUCTION
HOHORO ANTICLINE
BASED ON APC REPT. LHB
SURFACE CONFIGURATION (FAULTING NEGLECTED)
BASE OF PLIOCENE
SEA LEVEL
FEET METERS
1000 300
2000 600
3000 900
4000 1200
5000 1500
Raised to conform to results of APC Hohoro No. 2 Well
7
6
5
4
3
2
1
Gvty.
Diapirism
Base of Pliocene
Decollement
Upper Marua
Lower Marua
Section thinning rapidly
BASE OF PLIOCENE
FEET METERS
500
1000 300
1500
2500
3000 900
3500
4500 1200
ZONE OF MOST RAPID SHORTENING = PREDICTED DECOLLEMENT



RESIDUAL GRAVITY ANOMALY MAP FROM LU-2, 1949 (PARTIAL REPRODUCTION) BY T.C. RICHARDS

FIG. 2-23

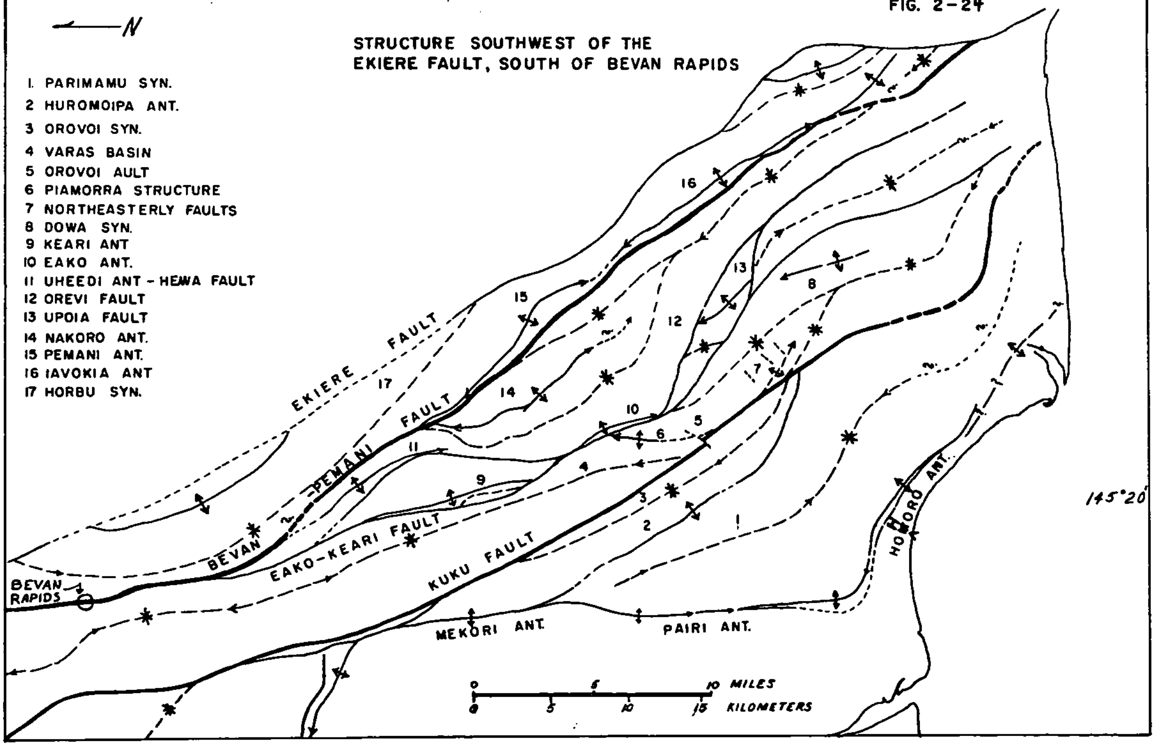


FIG. 2-24

STRUCTURE SOUTHWEST OF THE EKIERE FAULT, SOUTH OF BEVAN RAPIDS

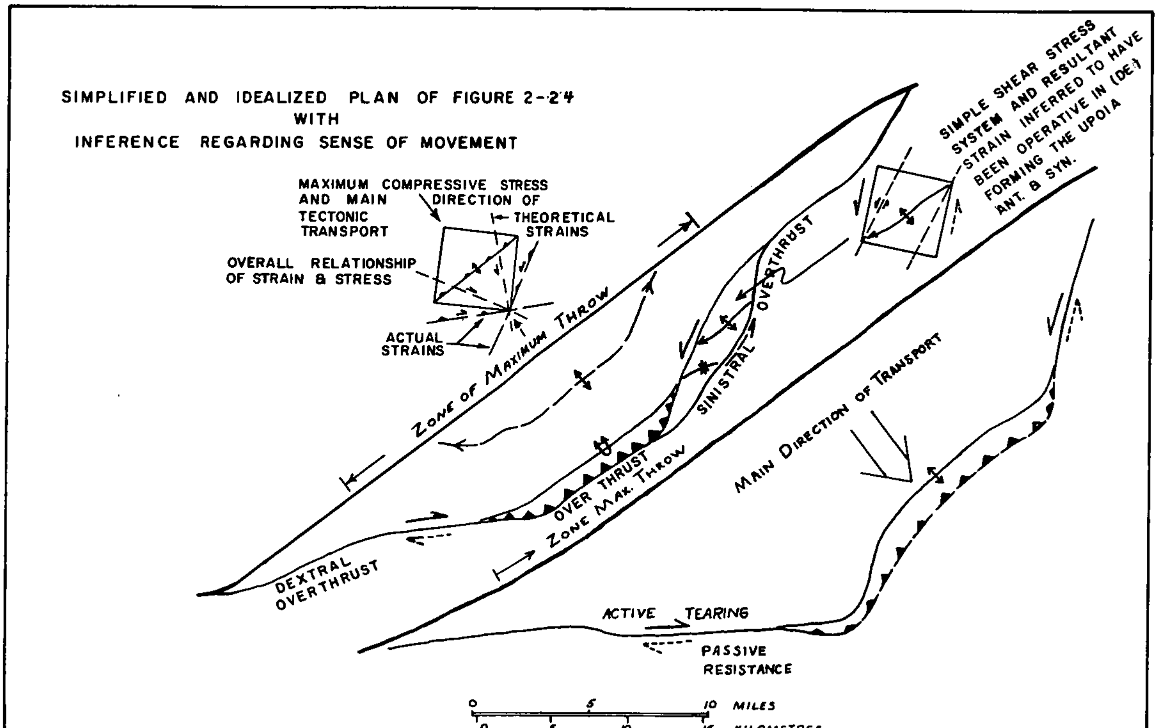
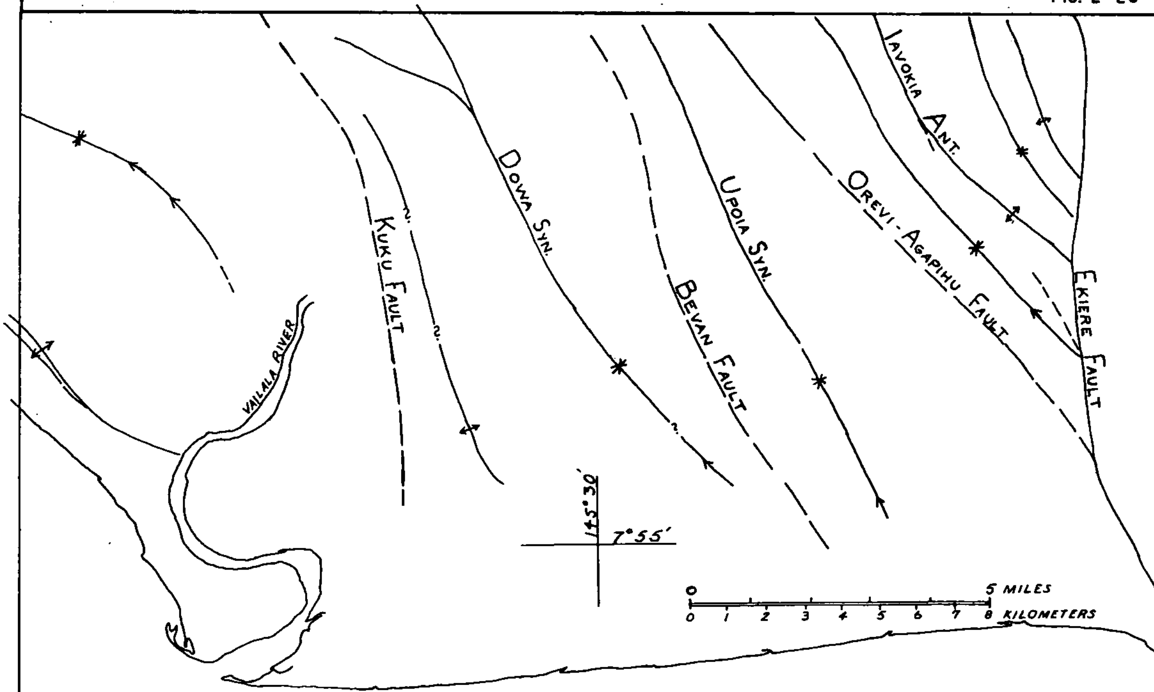
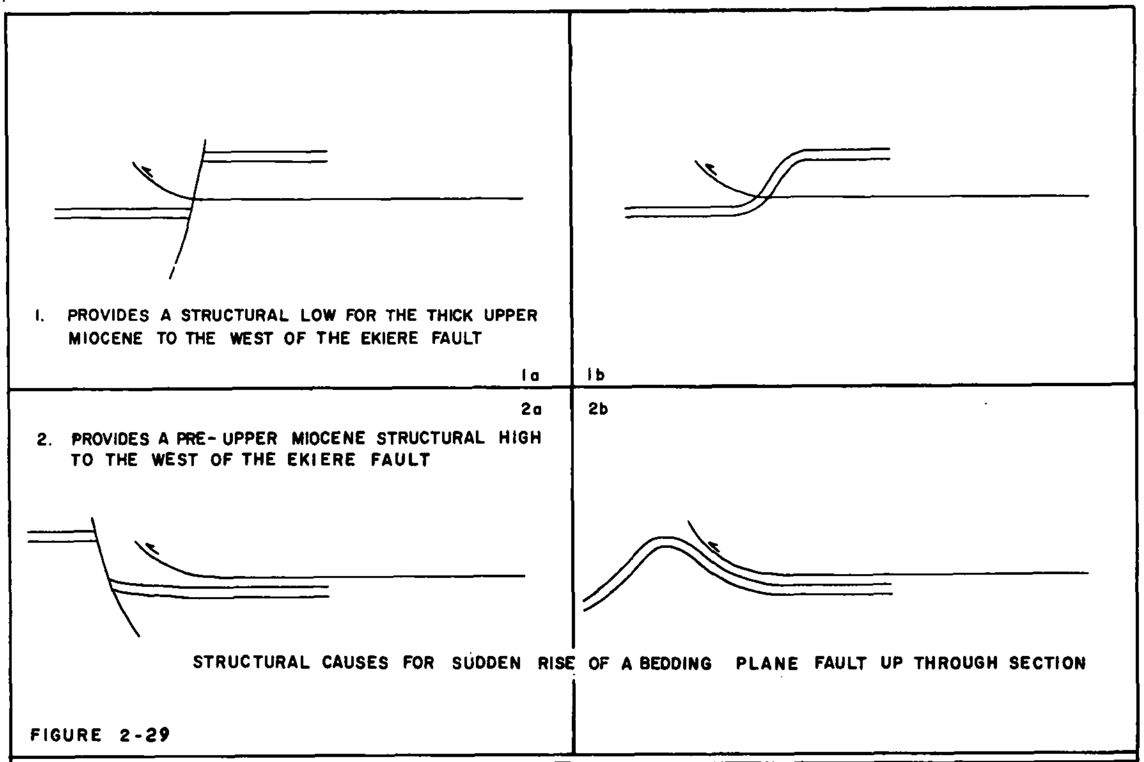


FIG. 2-25



STRUCTURE OF COASTAL REGION WEST OF EKIERE FAULT ACCORDING TO AUST. PETROL Co. MAP SHEETS: VAILALA WEST AND VAILALA EAST

FIG. 2-26



STRUCTURAL CAUSES FOR SUDDEN RISE OF A BEDDING PLANE FAULT UP THROUGH SECTION

FIGURE 2-29

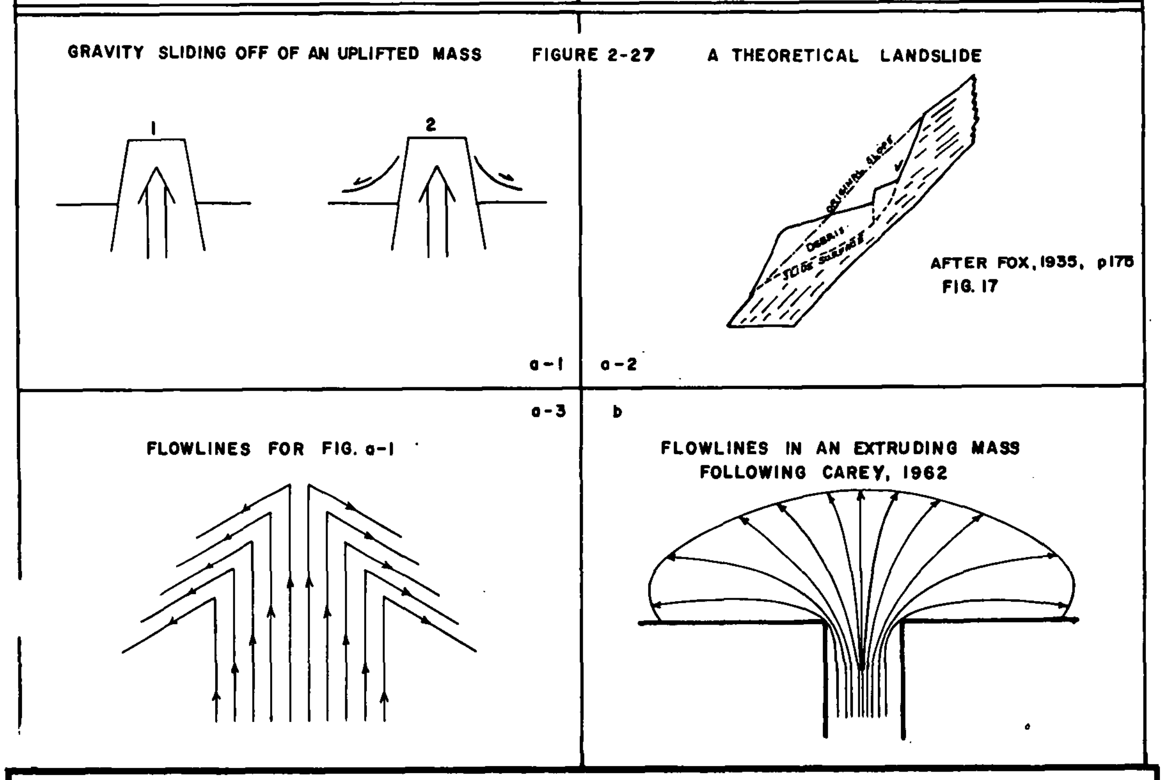


FIGURE 2-27

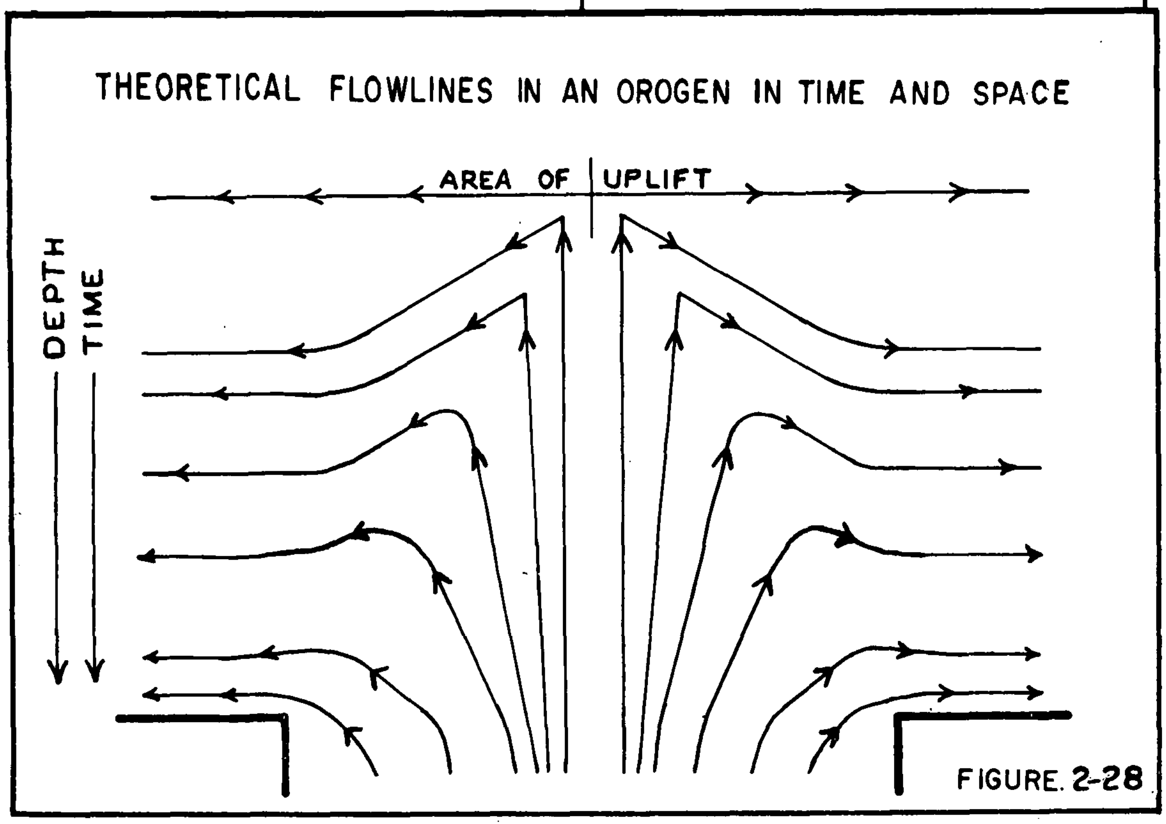
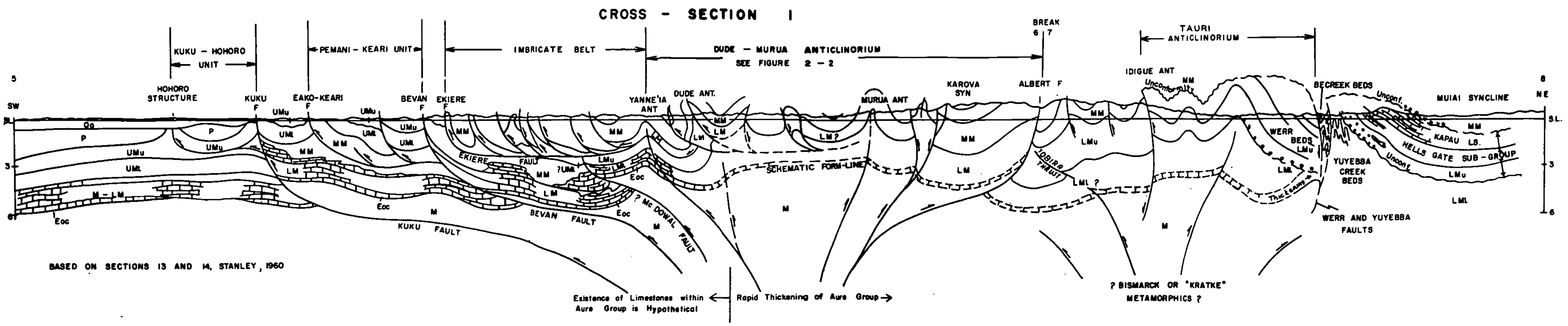


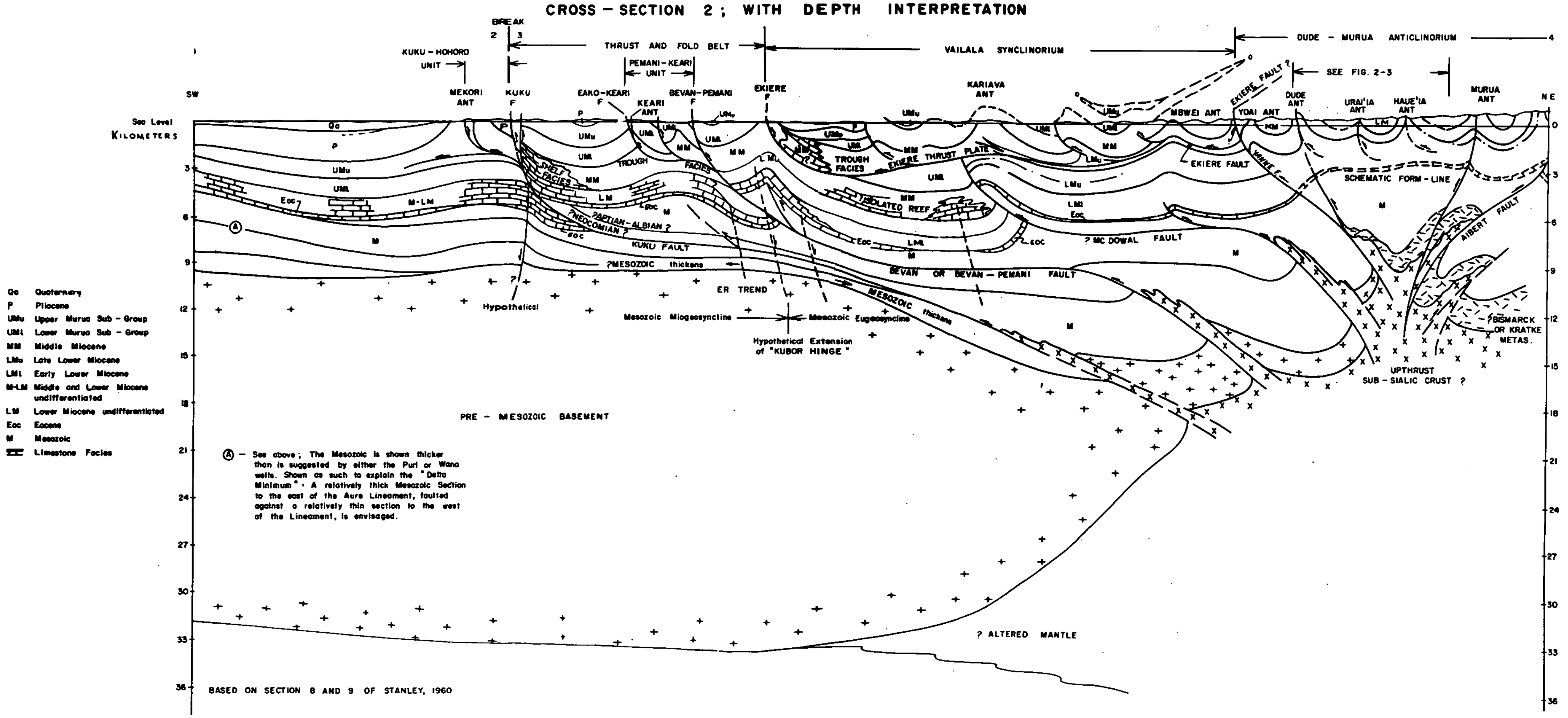
FIGURE. 2-28



COMPOSITE STRUCTURAL CROSS - SECTIONS ACROSS THE KUKUKUKU LOBE

figure 2-30

$H/V = 1$



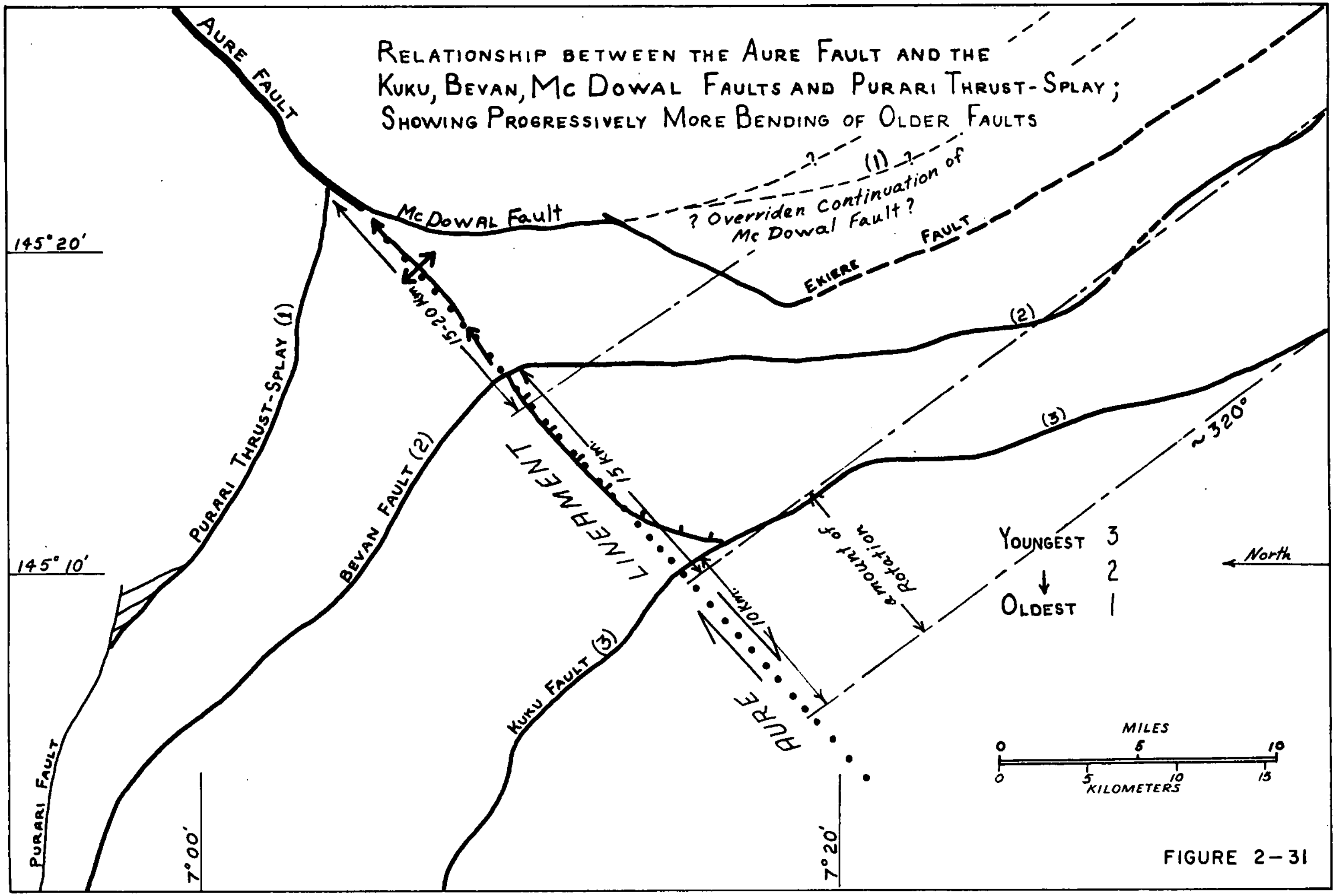

Relationship between the Aure Fault and the
Kuku, Bevan, Mc Dowal Faults and Purari Thrust-Splay;
Showing Progressively More Bending of Older Faults
Aure Fault
Mc Dowal Fault
? Overriden continuation of Mc Dowal Fault ?
(1)
Ekiere Fault
(2)
(3)
~320°
amount of rotation
15-20 km
15 km
10 km
Aure Lineament
Purari Thrust-Splay (1)
Bevan Fault (2)
Kuku Fault (3)
Purari Fault
145° 20'
145° 10'
7° 00'
7° 20'
North
Youngest 3
2
Oldest 1
Miles
0 5 10
0 5 10 15
Kilometers

FIGURE 2-31

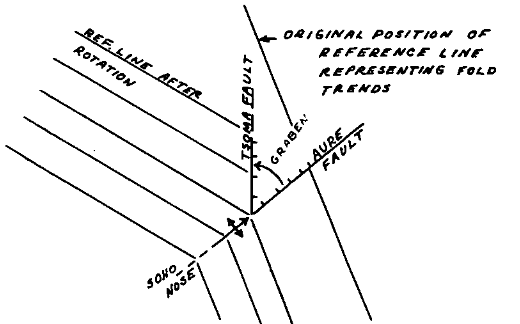


FIG. 2-33a POSSIBLE ORIGIN OF THE A-T-A GRABEN

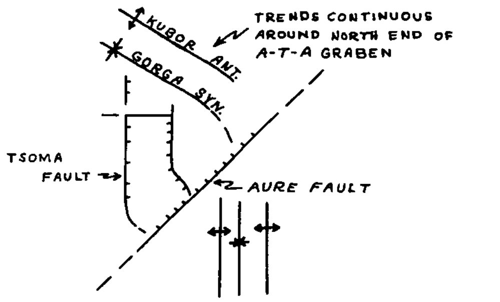
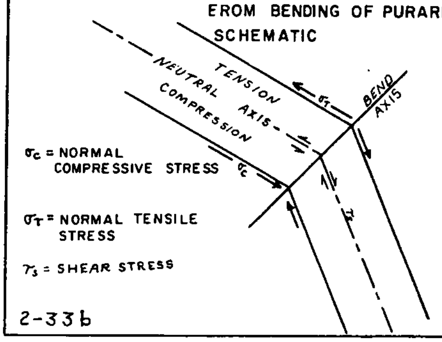
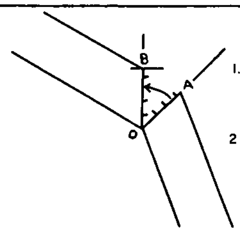


FIG. 2-34 A-T-A GRABEN IS AN INTERNAL STRUCTURE OF THE PURARI OROCLINE

THEORETICAL STRESS FIELD RESULTING FROM BENDING OF PURARI OROCLINE
SCHEMATIC



2-33b



OLD FAULT, OB, ROTATED ABOUT O FROM OA

1. POST-E STAGE FACIES & ISOPACHS DO NOT SUPPORT THIS.
2. THIS SENSE OF ROTATION MAY HAVE GIVEN RISE TO TRANSCURRENT FAULTING SEE 5c

POSSIBLE ORIGINS OF THE A-T-A GRABEN

FIG. 2-35a

ORIGIN OF FOLDING IN AURE-TSOMA-ANUNA GRABEN

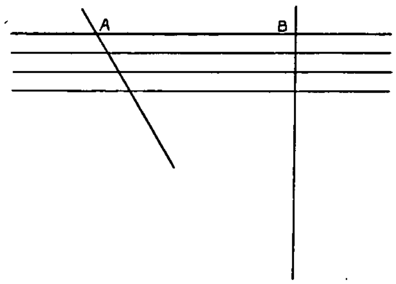
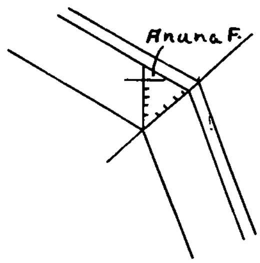


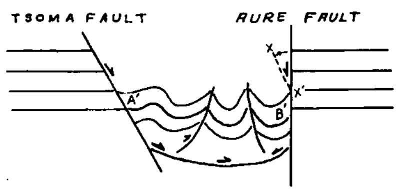
Figure 2-32a - SECTIONAL VIEW -



TENSIONAL FAULTING WITH NO ROTATION INVOLVED

1. THE ANUNA FAULT IS UNEXPLAINED, UNLESS AS A SECONDARY FEATURE DUE TO FOLDING WITH GRABEN.

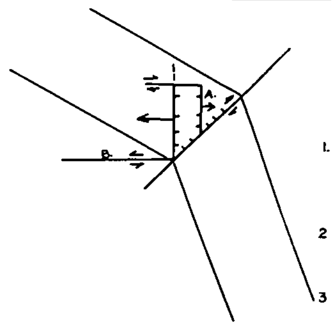
FIG. 2-35b



GRAVITY SLIDING TOWARD GRABEN

X-X' = ? GRAVITATIONAL OVERTURN TOWARD GRABEN

2-32 b

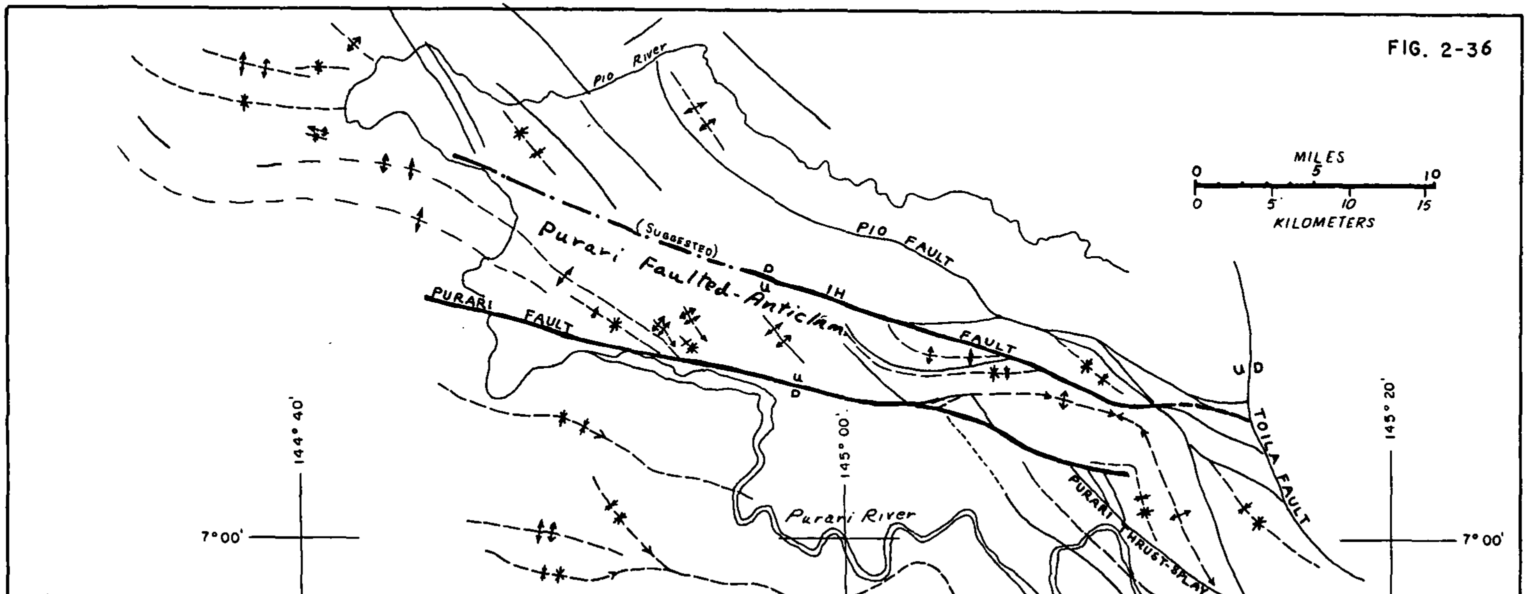


TENSIONAL FAULTING AS A RESULT OF TRANSCURRENT MOVEMENT AS REPRESENTED BY ANUNA FAULT; NO ROTATION

1. TREND OF TSOMA FAULT IS NOT OFFSET & DETRACTS FROM THIS SOLUTION
2. ABA FAULT (A) MAY MARK EASTERN BOUNDARY OF MAIN GRABEN
3. SINISTRAL TRANSCURRENT FAULTING ON PURARI & IH FAULTS (B) IS REASONABLY ESTABLISHED

FIG. 2-35c

FIG. 2-36

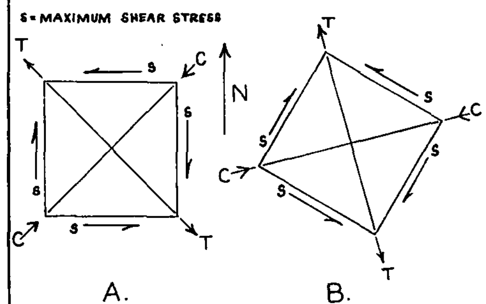


REGIONAL STRUCTURAL PATTERN
OF THE
PURARI FAULTED– ANTICLINORIUM

SOURCE OF INFORMATION:

1. REPORT LI, LI-3, CAREY, 1941
2. REPORT LW, RICKWOOD 1956
3. AUST. PETROL. CO. MAP, REFER STANLEY, 1960

POSSIBLE REGIONAL STRESS SYSTEMS OPERATIVE IN THE DEFORMATION OF THE PURARI FAULTED-ANTICLINORIUM



BOTH A & B ARE SIMPLE SHEAR STRESS SYSTEMS; B IS ORIENTED AT 120°

T = MAXIMUM TENSILE STRESS
C = " COMPRESSIVE STRESS

DOMINANT STRAIN PATTERN

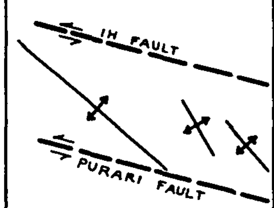


Fig. 2-37

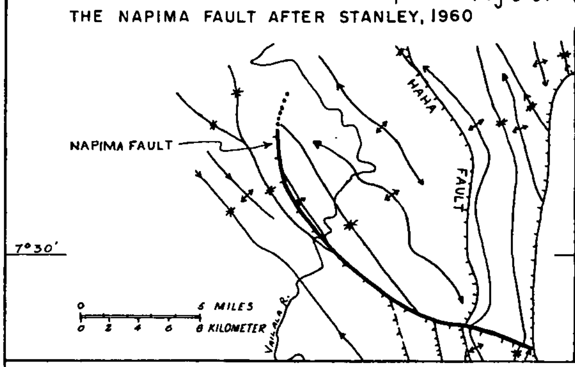
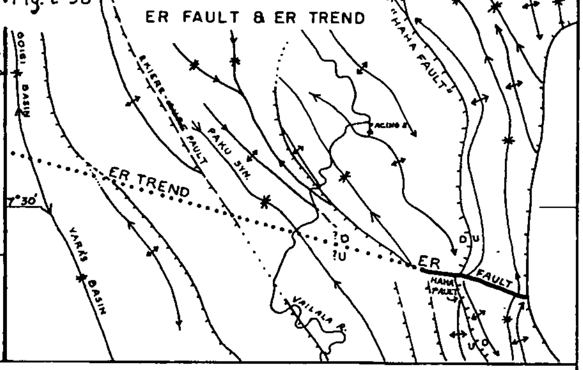


Fig. 2-38



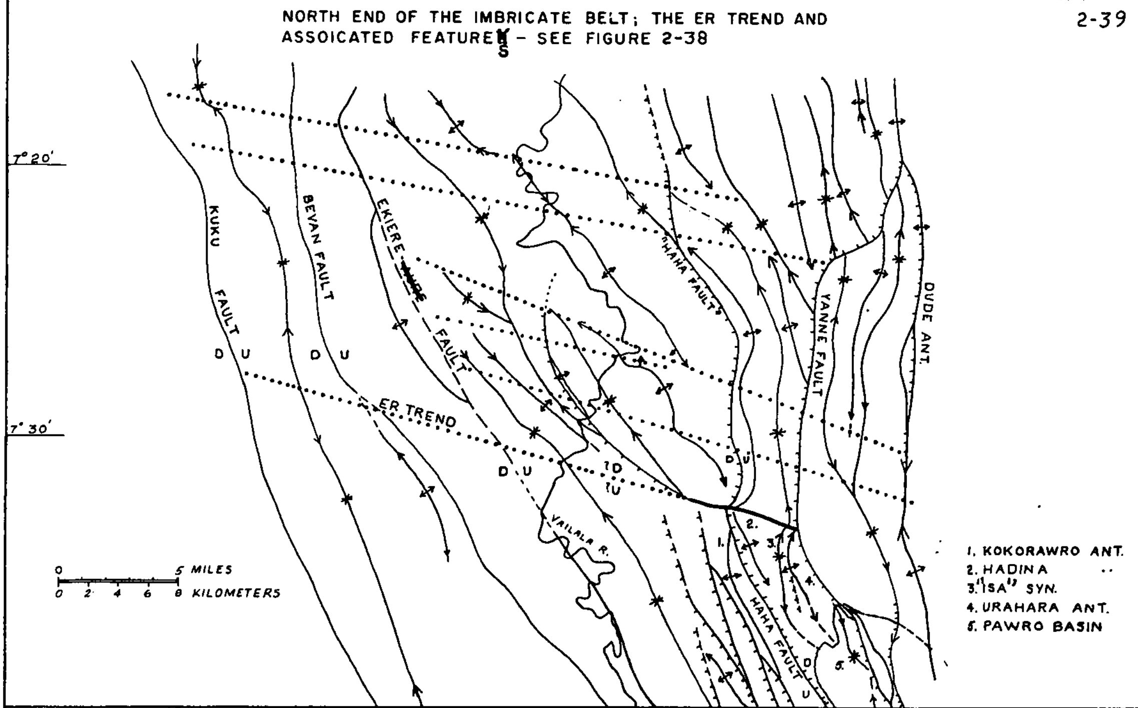


FIG. 2-39

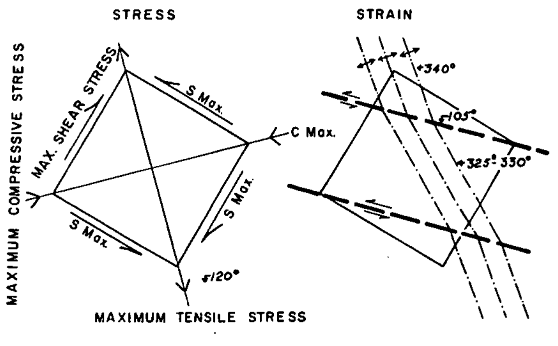


FIG. 2-40

A SIMPLE SHEAR SYSTEM WHICH HAS POSSIBLY BEEN OPERATIVE IN THE DEFORMATION (AND/OR FORMATION) OF THE STRUCTURAL TRENDS OF THE VAILALA SYNCLINORIUM AS SHOWN IN FIGURE 39. FAULTING MAY OCCUR AT DEPTH ON SUGGESTED TRENDS

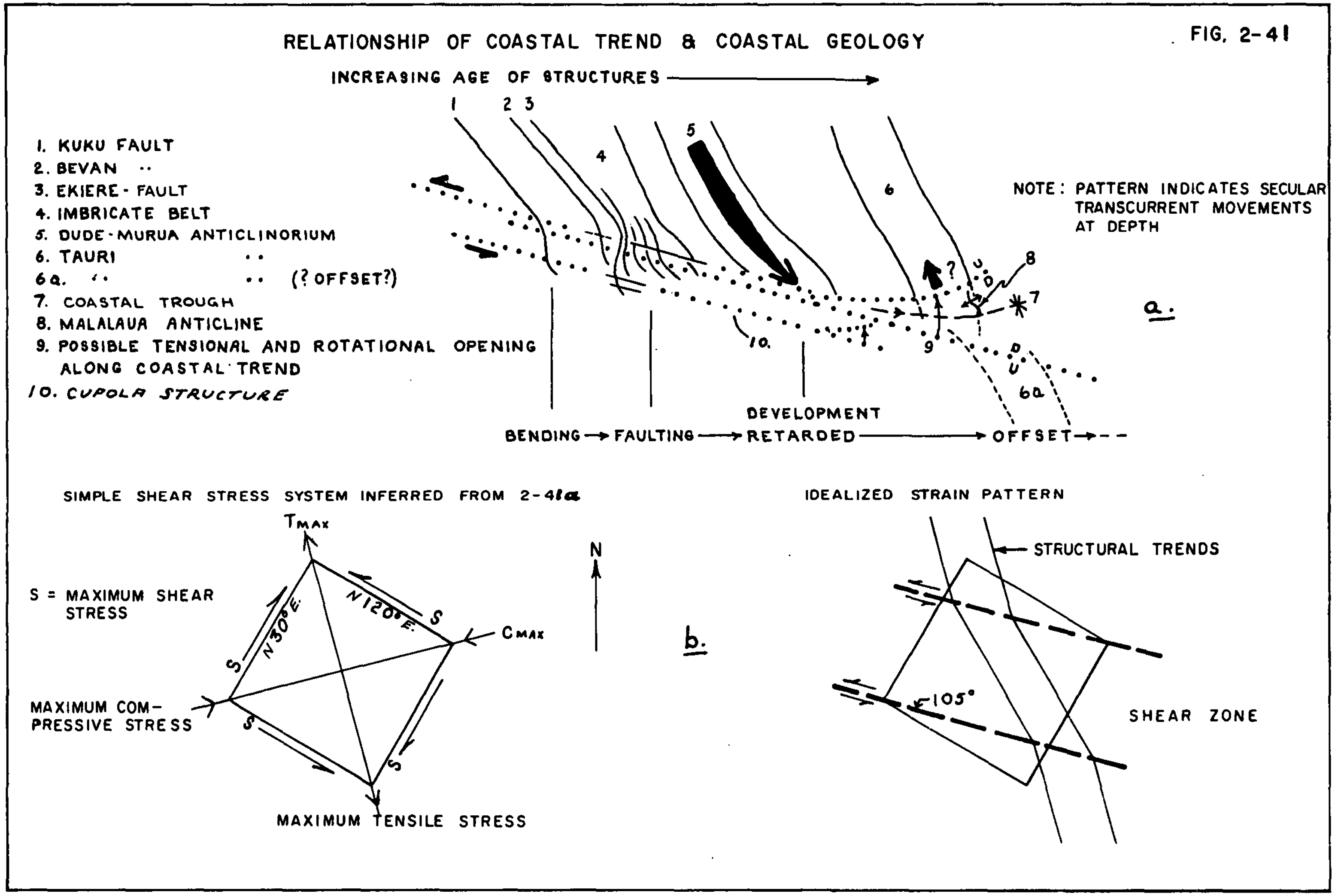
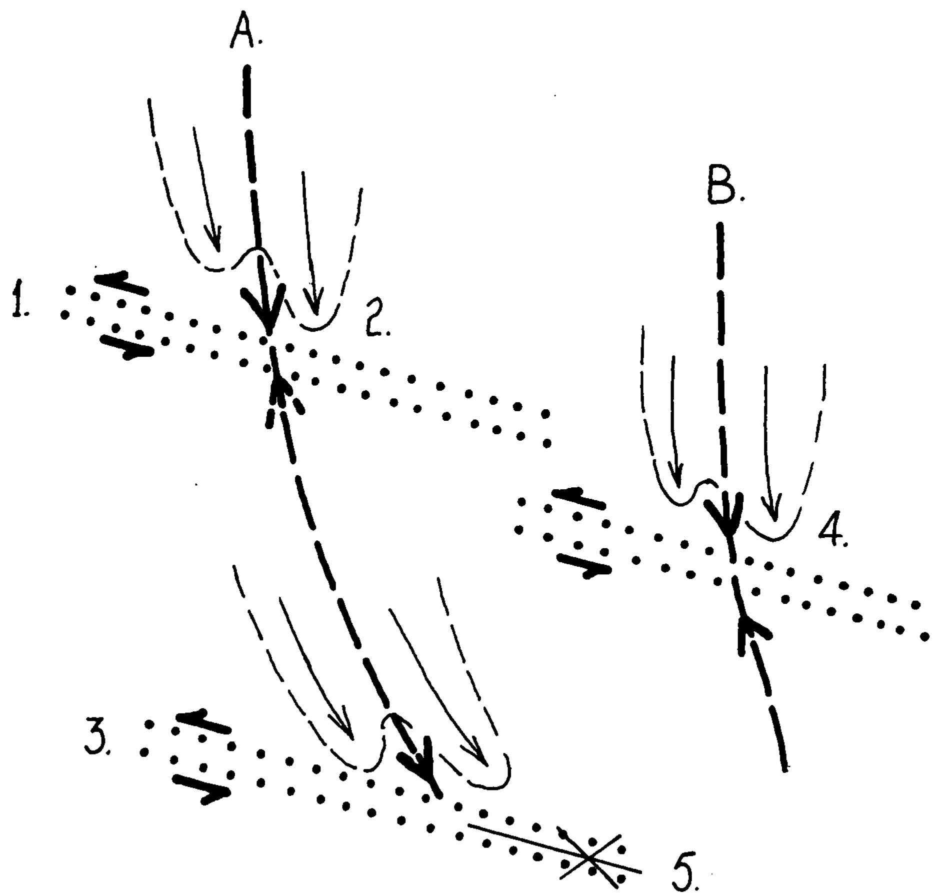

RELATIONSHIP OF COASTAL TREND & COASTAL GEOLOGY
FIG. 2-41
INCREASING AGE OF STRUCTURES
1. KUKU FAULT
2. BEVAN ··
3. EKIERE - FAULT
4. IMBRICATE BELT
5. DUDE-MURUA ANTICLINORIUM
6. TAURI ··
6a. ·· ·· (? OFFSET?)
7. COASTAL TROUGH
8. MALALAUA ANTICLINE
9. POSSIBLE TENSIONAL AND ROTATIONAL OPENING ALONG COASTAL TREND
10. CUPOLA STRUCTURE
NOTE: PATTERN INDICATES SECULAR TRANSCURRENT MOVEMENTS AT DEPTH
a.
BENDING → FAULTING → DEVELOPMENT RETARDED → OFFSET → - -
SIMPLE SHEAR STRESS SYSTEM INFERRED FROM 2-41a
TMAX
S = MAXIMUM SHEAR STRESS
N30°E.
N120°E.
CMAX
MAXIMUM COM-PRESSIVE STRESS
MAXIMUM TENSILE STRESS
N
b.
IDEALIZED STRAIN PATTERN
STRUCTURAL TRENDS
105°
SHEAR ZONE

FIG. 2-42

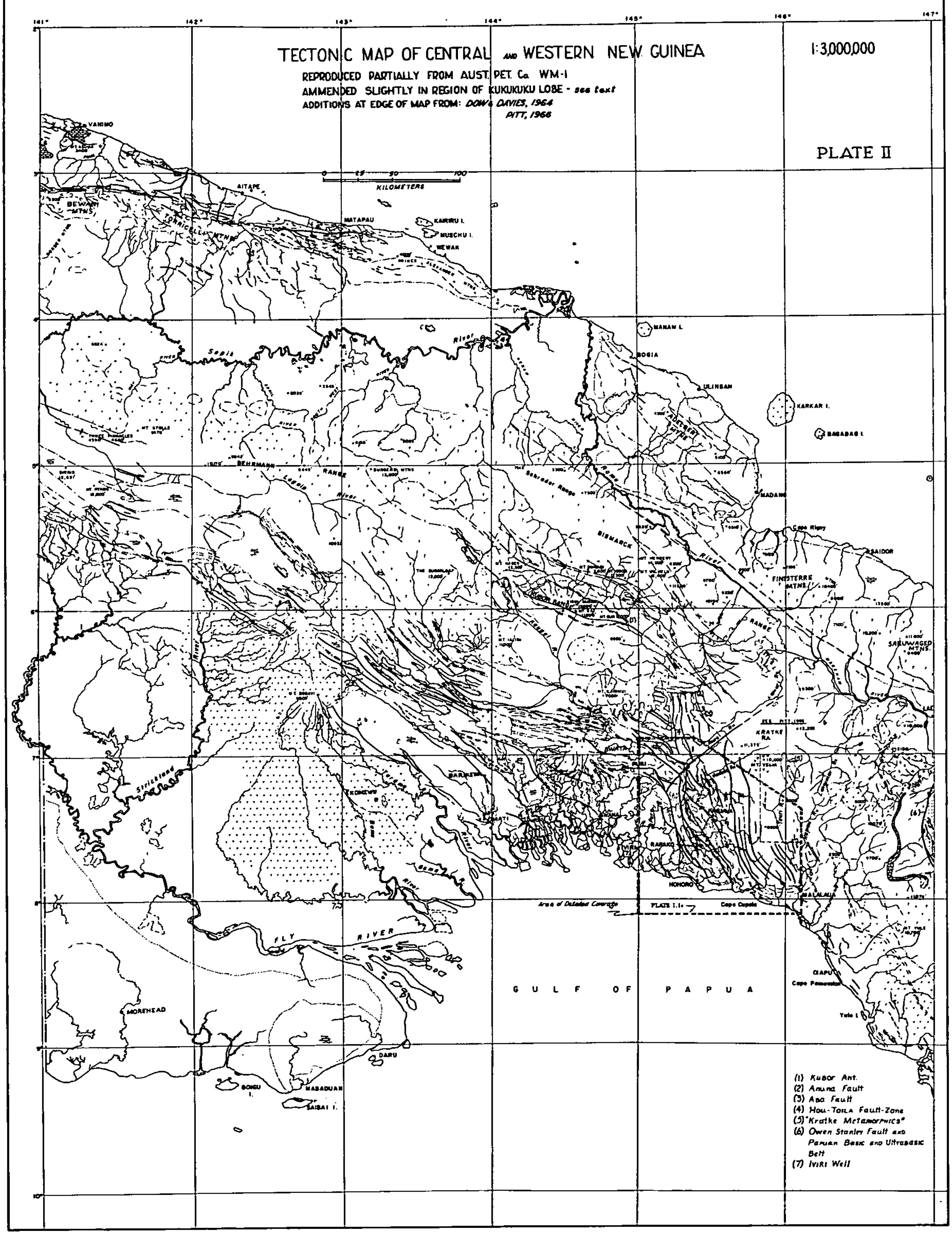
A POSSIBLE RELATIONSHIP BETWEEN MAJOR PLUNGES AND CROSS-TRENDS



A. DUDE-MURUA ANTICLINORIUM

B. TAURI ..

1. ER TREND
2. IVORI RIVER PLUNGE
3. COASTAL TREND
4. 7° 40′ PLUNGE
5. UPPER MIOCENE-PLIOCENE TROUGH (COASTAL TROUGH)


TECTONIC MAP OF CENTRAL AND WESTERN NEW GUINEA
REPRODUCED PARTIALLY FROM AUST. PET. Co. WM-1
AMMENDED SLIGHTLY IN REGION OF KUKUKUKU LOBE - see text
ADDITIONS AT EDGE OF MAP FROM: DOW & DAVIES, 1964
PITT, 1966
1:3,000,000
PLATE II
KILOMETERS
0 25 50 100
141° 142° 143° 144° 145° 146° 147°
VANIMO
AITAPE
BEWANI MTNS.
TORRICELLI MTNS.
MATAPAU
KAIRIRU I.
MUSCHU I.
WEWAK
MANAM I.
BOGIA
ULINGAN
KARKAR I.
BAGABAG I.
MADANG
Cape Rigny
SAIDOR
FINISTERRE MTNS.
SARUWAGED MTNS.
Sepik River
BEHRMANN RANGE
Schrader Range
Ramu River
BISMARCK
KRATKE RA.
KOMEWU
BARIKEWA
IHU
KIKORI
MALALAUA
Cape Cupola
Area of Detailed Coverage
PLATE I.1
FLY RIVER
Strickland
GULF OF PAPUA
Cape Possession
MOREHEAD
DARU
BOIGU I.
MABADUAN
SAIBAI I.
(1) Kubor Ant.
(2) Aruna Fault
(3) Aba Fault
(4) Hou-Toila Fault-Zone
(5) "Kratke Metamorphics"
(6) Owen Stanley Fault and Papuan Basic and Ultrabasic Belt
(7) Iviri Well

3. TECTONIC ANALYSIS

INTRODUCTION

One of the most important and at the same time most difficult problems concerning the tectonics of the Kukukuku Lobe is the relationship between the pre-Tertiary and Tertiary geological history of the region. The difficulties arise firstly from the extensive cover of Tertiary rocks in this region, and secondly from a lack of geological field work in areas of probable pre-Tertiary outcrop, *viz.* the area of the Kratke Range.

The Paleozoic geological history of Papua and the Territory of New Guinea is virtually unknown. The only undoubted Paleozoic, or older, rocks thus far found in Papua and the Teritory of New Guinea are the Kubor Granodiorite, Omung Metamorphics and thin Permian limestone veneer of the Kubor Range (Rickwood, 1955) and the granitic basement which has been drilled in the delta region of southwest Papua and which crops out at Mabaduan on the southern coast of the delta region (Geol. Soc. Aust. Journ., Vol. 8, 1961). For this reason, the problems of the Paleozoic history of Papua and New Guinea are largely neglected in this study.

The problem of the relationship of the Kukukuku Lobe to the Mesozoic geosynclinal and orogenic elements of New Guinea can be approached by considering the probable extension of these elements into the region of the Kukukuku Lobe. The first objective of this section, therefore, is to outline briefly the pre-Tertiary geotectonic elements of New Guinea, as they have been established in areas to the west, east and north of the Kukukuku Lobe, and thereby to form a basis for the extension of these elements into the region of the Kukukuku Lobe. For the most part, it will be convenient to include a description of the major tectonic elements of the Tertiary in these discussions.

The second objective of this analysis is to summarize the configuration and development of the major tectonic elements of the Kukukuku Lobe and then to relate these to the tectonic evolution of New Guinea as a whole.

The third and final objective of the analysis is to relate the configuration of the Kukukuku Lobe, in its regional context, to a comprehensive stress system. From this stress system, a mechanism is proposed which accounts for the development of the Purari Orocline and, therefore, for the configuration of the Kukukuku Lobe. The regional applicability and implications of this stress system are discussed, and the stress system is then related, briefly, to the gross tectonic pattern of the southwest Pacific.

3.1 THE MAJOR TECTONIC ELEMENTS OF THE REGION WEST OF THE AURE LINEAMENT

3.1.1 WEST IRIAN

Visser and Hermes (1962) have made a regional synthesis of geological data gathered by the Nederlandsche Nieuw Guinee Petroleum Maatschappij between 1935 and 1960 during its exploration for oil in West Irian. From their study, the main elements of the geosynclinal framework of West Irian are summarized below (refer figure 3-1).

Because of complexity of the region to the west of Geelvink Bay (noted below) and the many special problems which this complexity introduces, I have not been able to include the detail of this region in my analysis. In the following pages, therefore, when I use the geographical term New Guinea, it should be read as New Guinea - to the east of Geelvink Bay.

A. NORTH NEW GUINEA PROVINCE

> ".....a eugeosyncline, characterized by its ultra-basic rocks and greenschists, overlain by several thousand meters of basic intrusives (extrusives ? - AK) with intercalated radiolarites and other sediments. This stage, which may be called the 'magmatic' stage, started not later than Upper Cretaceous (Senonian - AK). Tectonic movements took place around T23 (late Oligocene - AK), but did not lead to more than local emergence. In the area east of Geelvink bay the 'magmatic' stage was followed by a 'sedimentary' stage which lasted from middle Miocene (late Lower Miocene of my thesis - AK) to Pleistocene times....the southern part of the 'magmatic' basin (the northern flank of the Central Ranges - AK) was uplifted and became an erosional area supplying detrital material to (the) 'sedimentary' basin. The lower part of the 'sedimentary' sequence consists of some 2,000 m. of graded greywackes, silt-stones and claystones of T27 to lower T33 age (late Lower Miocene to early Middle Miocene - AK) which are probably turbidites. They are overlain by a 4,000 m. to 7,000 m. sequence of sandy and clayey sediments, locally with limestones, which may still contain turbidites in its lower part but becomes paralic towards the top. Fossils have been found indicating upper T34 to T43 age (late Middle Miocene to Pliocene - AK). The apparent hiatus in T33 - T34 (in the late Middle Miocene, presumably essentially equivalent to the unconformity at the base of the Iavokia Mudstone - AK) may be only a marginal feature and it is quite probable that in the centre of the basin sedimentation continued uninterruptedly" (p.132)...

Concerning the ultrabasic rocks, it is stated:

> "....The nature of the contacts, extrusive, intrusive or tectonic, could not be ascertained .... (p.101).... In the Auwewa Formation pebbles of serpentinite occur in some places and since this formation is locally of M23 (Upper Cretaceous, Senonian - AK) age, the ultrabasics should be older ...." (p.123)

Gabbro dikes occur in the ultrabasics and are probably later intrusions (p.123). Because the greenschists associated with the ultrabasics occupy an insignificant area relative to that of the ultrabasics, and because no other rock unit is known into which the ultrabasics could have been intruded Visser and Hermes, following de Roever, suggest indirectly that:

"....the ultrabasic rocks are tectonically emplaced fragments of the peridotite mantle...." (p.133)

A similar conclusion has been reached with regard to the Papuan Basic and Ultrabasic Belt, by geologists working in New Guinea (refer 3.2.1).

B. CENTRAL NEW GUINEA PROVINCE

"....represents the accompanying miogeosyncline. Sedimentation was practically continuous from Permo-Carboniferous to Plio-Pleistocene time, at least some 6,000 m. of predominantly shallow water sediments being deposited. The Paleozoic and Mesozoic sediments were mainly clastic; their terrigenous material was derived from parts of the Australian continent to the south (underlines are mine - AK). In the western peninsulas, however, the trend of the facies boundaries away from the Australian continent and parallel to the Banda arcs, makes a southern supply difficult to visualize. From the beginning of the Tertiary to late Miocene (late Middle Miocene - AK) extensive platforms developed on which carbonates were deposited. At different times clastic sediments were introduced in certain areas:

the Sirga formation of T21-T26 age (Oligocene to early Lower Miocene - AK), which reflects an uplift of the north-western part of the miogeosyncline (is) probably connected with movements that affected the eugeosyncline at about this time; the clastic formations of T27-T34 age (late Lower Miocene to early Middle Miocene - AK) deposited in the miogeosynclinal Salawati, Bintoeni, Akimeugah and Iwoer Basins; and finally the thick T41 - T42 (Upper Miocene to Pliocene of my thesis - AK) clastics that filled the southern part of the miogeosyncline - the periorogenic belt.

Nearly all the Tertiary clastic material was derived from the uplifted northern part of the miogeosyncline (underlines are mine - AK) .... (p.133)..... Granite intrusions occur locally, and at the eastern end of the peri-orogenic belt some young (Plio-Pleistocene - AK) andesitic volcanism ....

The North and Central New Guinea provinces together form a marginal orthogeosyncline .... From early Miocene times, however, the development of the two parts of the eugeosyncline east and west of Geelvink bay was quite different, and in general the western region shows a more complex history than the eastern ....

> The complexity of the western region as compared to that of the eastern one is reflected also in the structural trends ....
>
> The great majority of igneous rocks of this province are <u>granitic to quartz dioritic intrusives and extrusives</u> .... '' (p.121)

The intrusives are of post-Silurian to pre-Permo-Carboniferous age in the central Vogelkop and of post Aure Group age in the Carstenz and Antares regions (p.122).

It should be noted, here, that the only undoubted, in situ, fossiliferous lower Paleozoic rocks known in New Guinea occur in the mountainous region to the west of Geelvink Bay (Silurian, Kemoem Formation; p.63). Pebbles of Silurian and Devonian rocks have been found on the southern slope of the Central Ranges, but no outcrops of these rocks have been seen.

Visser and Hermes stress, and it is worth re-emphasizing, that the Tertiary clastics of this Province were deposited in a series of 'isolated' basins which were separated by carbonate platforms (p.198). This reveals that both the uplift of the source areas (Central Ranges) and subsidence in the basinal areas were spotty and discontinuous along the length of the mountain chain. The two Tertiary basins of the Vogelkop, *viz.* the Salawati and Bintoeni Basins, are thought to represent open-marine, relatively deep water basins, whereas the two basins on the south flank of the Central Ranges, *viz.* the Akimeugah and Iwoer Basins are believed to represent shallow-marine to paralic environments (p.198).

The Aure Trough of Papua and the Territory of New Guinea which is the main concern of this thesis is yet another of these 'isolated' Tertiary Basins. From its pelagic character, the Aure Trough would compare most closely with the Salawati and Bintoeni Basins of the Vogelkop, rather than with the basins on the south flank of the Central Ranges, *i.e.* the Aure Trough is not a simple continuation of the latter basins. A general similarity between the Tertiary history of West Irian and that of Papua, however, is readily apparent.

C. SOUTH NEW GUINEA PROVINCE

The South New Guinea Province has been described as follows:

> "... relatively thin, practically horizontal formations separated by large hiatuses (occur here), (it) evidently belongs to a rigid block, the Australian continental shield, which was occasionally flooded by the miogeosynclinal seas .... (p.133) ... The South New Guinea province was land during all or most of the period from Permo-Carboniferous to Jurassic, but subsided in Lower Cretaceous. Glauconitic sandstones and clays were deposited of which 0-600 m. have been preserved. The province emerged again at some unknown time between the upper Cretaceous and early Tertiary .... (p.127) .... 371-821 m. of shoal limestones were found in three wells drilled, thickening from south to north (Digoel Formation of late Lower Miocene to late Middle Miocene age - AK) .... (p.129).... In the South New Guinea province clastic sediments (Boeroe formation) were encountered in three wells ... The thickness decreases southwards from 1049 to 240 m. The beds are horizontal and there is probably a hiatus between the Boeroe formation and the underlying limestones ...." (p.130)

3.1.2 PAPUA AND THE TERRITORY OF NEW GUINEA

Smith (1964), has recently completed a regional synthesis of that part of Papua and the Territory of New Guinea to the west of the Kukukuku Lobe. The major elements of the Mesozoic geosynclinal framework recognized by Smith are shown in figure 3-2 (reproduced from Smith's figures 14, 16, 17 and 18). The Tertiary elements of this region are considered in a following section.

Broadly, Smith has recognized two major Mesozoic sedimentary provinces. The first of these is a stable platform of south-western Papua which is characterized by thin, dominantly calcareous sediments and gentle oscillatory movements. The platform appears to have been flooded from north to south, beginning in the Jurassic over most of the area. To the south of the subsurface Komewu Fault, the formations are essentially horizontal, relatively thin and are separated by large hiatuses while to the north of this pre-Lower Miocene fault the

Mesozoic section is both thicker and strongly folded. I regard this fault, therefore, as effectively marking the northern edge of the platform.

To the north of the platform, a geosynclinal province is recognized, this province being characterized by rapid subsidence and the deposition of a thick clastic sequence (4,000-5,000 m. mainly mudstones and sandstones). The geosynclinal province has been severely folded and faulted by subsequent deformations.

By inspection of figure 3-2, it can be seen that Mesozoic depositional framework was neither simple nor static. It consisted of a series of lows and highs that migrated in time and space. From north to south, the following intra-geosynclinal elements have been recognized by Smith: The "Northern Massif", Bismarck Massif, Wahgi Trough, Kubor Massif, Kutubu Trough and the Morehead Basin. I regard the existence of a Mesozoic "Northern Massif" as doubtful and will discuss this problem later (refer section 3.1.4).

From the characteristic lithological associations, I suggest that the geosynclinal province can be subdivided into a eugeosynclinal province, to the north of the Kubor Massif, and a miogeosynclinal province to the south of the Kubor Massif. The Wahgi Trough is characterized by at least 6,000 m. of coarse-to conglomeratic graywacke sandstones, mudstones and interbedded basic to intermediate marine volcanics. These beds frequently show signs of rapid deposition, such as graded-bedding, flute and scour marks and slump structures (Dow and Dekker, 1964). These are typical eugeosynclinal associations.

Contrasted to this, volcanics have not been recorded in the Mesozoic sediments to the south of the Kubor Massif, and shallow water characteristics are present in even the thickest measured sections. For example, in Barikewa No. 1 Well where the thickest known section of Jurassic rocks in Papua has been found, oolitic mudstones and limestones and a rich macrofauna are present in the thick (1,000 m.+) basal unit. In the Lower Cretaceous rocks of this well, glauconitic and well-sorted, rounded sandstones occur (Geol. Soc. Aust. Journ., Vol. 8, p.26-27). Similarly, quartz sandstones and glauconitic sandstones are common in the Jurassic of the Strickland Gorge section (*ibid*, p.20). In the Wok Feneng section (headwaters of the Fly River), clean, well-rounded, glauconitic quartzose sandstones occur in both the Jurassic and Cretaceous sections (2,500 m.+). Here, the basal Jurassic beds are 300 m. of coarse arkosic conglomerates (maximum diameter 20 cm.; *ibid*, p.17). In the Lower Cretaceous Purari Graywacke of the Paw Valley, shelly graywackes and a rich molluscan bed(s) are present, and in the Cretaceous (Cenomanian) of the Lake Tebera region a rich molluscan fauna is present and glauconitic sandstones are common, with some rocks being 50% glauconite (*ibid*, p.21). The Lower Cretaceous sandstones and shales of the Pio Gorge, although generally unfossiliferous, contain thin molluscan beds and sandy gastropodal limestones.

The non-volcanic and frequently shallow water character of these thick Mesozoic sections to the south of the Kubor Massif are taken as typical <u>miogeosynclinal</u> associations. These characteristics make these beds similar to the <u>Kembelangen Formation</u> (Jurassic - Cretaceous) of the Central New Guinea Province of West Irian, which is interpreted as a generally shallow-water miogeosynclinal type deposit (Visser and Hermes, 1962, p.74). As with the Kembelangen Formation, deeper water deposition toward the north is indicated in this region by the common occurrence of a rich pelagic fauna, particularly in Cretaceous beds in the northernmost sections, *e.g.* Wok Tungom, Wok Luap, Wok Feing sections (Geol. Soc. Aust. Journ., Vol. 8, p.17, 19-20). This can be compared to the Barikewa section, where the fauna is not so rich and the upper two divisions (700 m.) of the Jurassic are generally barren of fossils (*ibid*, p.27-28).

On this basis, it is reasonable to suggest that the Kubor Massif corresponds broadly to the northern edge of the Central New Guinea Province, or miogeosyncline, of West Irian. Similarly, the South New

Guinea Province corresponds broadly to the area south of the Komewu Fault in southwest Papua. It is notable that the Mesozoic miogeosynclinal province is a clastic province rather than a limestone province. As in West Irian, it ~~is~~ was not until the Paleogene, or perhaps late upper Cretaceous, that carbonates became wide-spread in the miogeosynclinal and shelf areas of Papua.

Again as in West Irian, the primary source area for the Mesozoic miogeosyncline seems to have lain to the south. This is suggested by the overall coarsening of these rocks from north to south; figure 3-2b illustrates this well for the Jurassic. Further, it is difficult to visualize a suitable northward source for the quartz-rich sandstones, particularly in the Jurassic, such as described above.

The problem of source areas, however, is more complex in Papua and New Guinea than known relationships suggest to be the case for West Irian. The Kubor Massif, or northern edge of the miogeosynclinal province, has been proven to have been a structural high during the Mesozoic and a source area for basal conglomerates of Permian age and later Mesozoic sediments (Rickwood, 1955; refer figure 3-2). Further, the Lower Cretaceous Purari Graywacke of the Paw Valley (refer figure 3-2) requires a northerly source such as the Kubor Massif. This is true firstly, because the Lower Cretaceous is dominantly in a mudstone facies to the south of the Paw Valley, *e.g.* at Barikewa, in the Kereru Range and at Puri (Tubo Shales; refer figure 3-2), and secondly because the Purari Graywacke contains prominent proportions of clear quartz and acidic feldspars (up to 15% and 55% respectively; Edwards, 1950, p.164), which together suggest a northerly somewhat granitic source area.

The exposure and erosion of the Kubor Massif and concomitant southward shedding of detritus, therefore, complicates the picture of Mesozoic source areas in Papua and New Guinea. This points to an important distinction between this region and West Irian, where the earliest recognized uplift and erosion of the northern edge of the miogeosyncline was during the early Tertiary or possibly late Cretaceous. It will be noted at this juncture, however, that the unconformity at the base of the Kembelangen Formation in the Digoel Range of West Irian points to pre-Kembelangen deformation and uplift. The basal conglomerates of the Kembelangen Formation consist mainly of quartz and slate fragments (Visser and Hermes, 1962, p.74) and, it is probable that these conglomerates were derived from the north. This unconformity, however, is apparently restricted to the Digoel Range as the Kembelangen Formation is regionally conformable on, and/or transitional with underlying formations (*ibid*, p.70-75). With respect to the Tertiary in West Irian and Mesozoic (and Tertiary, refer later) of Papua, the northern edge of the Mesozoic miogeosyncline, as well as forming a hinge-zone between mio- and eugeosyncline, formed a mobile area of active uplift and erosion.

It will be observed from figure 3-2d that the platform, or shelf environment extended northward through the Mesozoic and Paleogene at the expense of the geosynclinal environment. A similar feature is evident in the late Cretaceous and early Tertiary history of the South and Central New Guinea Provinces of West Irian. Smith (1964, p.132) has attributed this phenomenon to a temporary relaxation of regional extensional stresses at this time. Three additional factors which probably have been instrumental in producing this effect can be listed as follows:

1) <u>Regional epeirogenic uplift</u>. This is indicated by the absence of late Cretaceous rocks over a large part of the platform region (refer figure 8, Geol. Soc. Aust. Journ. Vol. 8, 1961). The absence of late Cretaceous rocks over this area is believed to be due partly to <u>pre-Eocene erosion</u> and partly to non-deposition. Similarly, Eocene rocks are absent over a large area of western Papua (*ibid*, figure 12). Again, this is believed to be due partly to non-deposition and partly to subsequent erosion of an originally thin sequence (*ibid*, p.56). Non-deposition and erosion over this <u>area of previously thick sedimentation</u> indicates that substantial

uplift occurred in this region during the late Cretaceous and early Tertiary. That the uplift was epeirogenic is indicated by the facts that angular unconformities are nowhere recorded and the formations in the southern part of the uplifted region are essentially horizontal.

2) Filling of the geosyncline. The Tertiary deposition of limestone in the shelf region is probably, to some extent a reflection of filling and shallowing of the depositional basin.

3) An effective decrease in the supply of detritus from the south. This is indicated by the predominance of limestones over the shelf area from the early Tertiary onwards, whereas clastics predominate prior to the Tertiary.

Essentially, ~~this~~ '3' above means that the sourthern source (Australia), which had dominated sedimentation in New Guinea during the entire early Mesozoic, ceased to be important to New Guinea during the late Cretaceous to early Tertiary, and this is what I regard as the most fundamental feature to be explained. There are three basic explanations which can be offered: (a) the source area may have subsided, (b) subsidence may have occurred between New Guinea and the source area thereby providing a catchment for southerly derived detritus before it reached New Guinea, or (c) New Guinea may have moved northward relative to Australia and, thus, out of range of this source area. The first explanation (a) can reasonably be ruled-out, because Upper Cretaceous beds are not present in the Great Artesian Basin of northern Australia and, effectively, the early Cretaceous (say Albian or, perhaps, Cenomanian) marks the end of Mesozoic deposition in the Great Artesian Basin (Geol. Soc. Aust. Journ., 1960, Chap. 10). The latter two explanations ((b) and (c)) are mutually compatible in that a relative northward translation of New Guinea should have caused extension and subsidence between Australia and New Guinea. From my tectonic analysis, which follows, I suggest that this combination is probable, *i.e.* a relative northward translation of New Guinea causing crustal stretching and subsidence between Australia and New Guinea in the area of the Arafura Sea. A direct reflection of these movements is probably represented in the late Cretaceous - early Tertiary Komewu Fault of southwest Papua. In contrast to Smith's hypothesis, therefore, I would suggest that the northward migration of the platform realm and accompanying carbonate deposition are probably the initial expression of the northward translation and extension which have been a dominating factor in the geological history of New Guinea since the late Cretaceous (probably Senonian). This view is argued in the following pages.

It will be recalled, that fossiliferous pre-Upper Cretaceous rocks have not been found in the eugeosynclinal North New Guinea Province of West Irian. An early Mesozoic eugeosynclinal suite such as found in the Wahgi Trough of New Guinea, has not been recorded in West Irian. Visser and Hermes (1962, p.120), suggest that the metamorphic rocks (mainly quartz-mica schists) of the northern edge of the Central New Guinea Province are possibly metamorphosed equivalents of the Mesozoic and Paleozoic miogeosynclinal clastics of the Central New Guinea Province, *i.e.* the Kembelangen, Tipoema, Brug and Aifam Formations. These metamorphic rocks are believed to have been derived from claystones and sandstones (*ibid*), however, and do not show volcanic associations as would be expected in a metamorphosed eugeosynclinal suite. In the Cyclops Mountains and on the islands of Japen and Biak, in the North New Guinea Province, green-schists associated with ultrabasics occur. These are believed to have been derived largely from basic igneous rocks and are believed to be of pre-upper Cretaceous age (*ibid*; refer previous section). These metamorphic rocks, the New Guinea Metamorphics, are possibly the metamorphic equivalents of an early Mesozoic (? and older) eugeosynclinal suite. As noted earlier, however, the green-schists are of limited extent and form a relatively insignificant outcrop compared to the associated ultrabasic rocks.

Accompanying the recognition of an early Mesozoic eugeosynclinal province in Papua and New Guinea an additional element, the intraeugeosynclinal Bismarck Massif, has been recognized and apparently has no counterpart in West Irian.

3.1.3 NORTH FLANK OF THE BISMARCK RANGE AND THE NORTHERN COASTAL RANGES

Rocks of Upper Cretaceous (Senonian) age, chiefly mudstones and pelagic limestones, crop out in fault slices on the north flank of the Bismarck Range at the eastern end. These rocks are at least 300 m. thick and are overlain conformably by 1,000 m.+ of black shales, slates, conglomerates and thin limestones of Eocene age. The Eocene rocks are, in turn, (?) disconformably overlain by 3,000 m.+ of limestones, sandstones, mudstones and possibly andesitic volcanics belonging to the early Lower Miocene. Late Lower Miocene rocks are present in the top part of this sequence. Basic to intermediate intrusives are numerous in these rocks and the sequence is often slightly metamorphosed. (Information from McMillan and Malone, 1960, p.20-28).

A similar section, again displaying a gradational relationship between Upper Cretaceous and Tertiary rocks, has been recorded on the north flank of the Bismarck Range at the northwestern end and in the Schrader Range (Dow and Dekker, 1964). Here 2,000 m.+ of basic marine volcanics (Kombruf Volcanics) of Upper Cretaceous age are conformably overlain by at least 1,000 m.+ of siltstones, fine-grained graywackes, and limestones of Upper Cretaceous to early Lower Miocene age (Asai Beds). These rocks are metamorphosed to low grade schists and phyllites wherever found in this area. Schistosity usually follows bedding, but obliterates bedding in some places (*ibid*, p.23); Dow and Dekker conclude,

> "....The metamorphism of the fine-grained sediments to phyllite and schist may be due partly to shearing within the Bundi Fault zone, but contact metamorphism by gabbro dikes within the Fault zone was probably the most important factor ...." (p.27).

Because the metamorphism of the Asai Beds is not confined to the Bundi Fault-Zone (*ibid;* also, Corbett, 1963), it seems unlikely that such a local origin for the metamorphism is an entirely sufficient explanation. The Asai Beds are more probably a low grade regional metamorphic rock as Corbett suggests (*ibid,* p.3). The metamorphism more probably relates mainly to either the emplacement of the Marum Basic Belt (refer below) or to regional shearing along the North New Guinea Boundary, (refer next section).

The Bundi Fault-Zone effectively forms the northern flank of the Bismarck Range at the northwestern end. To the north of this fault-zone, no rocks older than Upper Cretaceous (? Senonian) have been found. Immediately to the south of this fault-zone, the Kompiai Formation (Middle Cretaceous) possibly underlies the Kombruf Volcanics conformably, but this relationship is not established; these formations may be in fault contact (Dow and Dekker, 1964, p.19). If a conformable relationship, as suggested by Dow and Dekker, is correct then these beds are probably of Middle Cretaceous age (*ibid,* p.18) and a continuous sequence from the Lower Jurassic through the early Lower Miocene would be present in this area (at least 4,000 m.).

At the northwest end of the Bismarck Range a large, elongate (90 x 15 km.) belt of basic and ultrabasic rocks, the Marum Basic Belt, has been mapped. The outcrop of the Marum Basic Belt is limited on the south by the Bundi Fault-Zone and, where known, is always associated with important faulting. There is no clear evidence as to the age of the Marum Basic Belt nor to the mode of its emplacement, whether tectonic or intrusive. Dow and Dekker conclude,

> "....Contacts between the Basic Belt and sediments are either faulted or poorly exposed, but the belt appears (my underlining - AK) to intrude Asai Beds of Eocene age ...." (p.29)

It has further been concluded that the basic rocks of the Marum Basic Belt show evidence of shearing during a late stage of crystallization, that the basics were intruded by the ultrabasics as a plug and that the ultrabasics show evidence of strong deformation at high temperatures (*ibid*, p.30-31). It seems probable, therefore, that both intrusion and faulting have been responsible for the emplacement of the Marum Basic Belt. That the Marum Basic Belt was probably emplaced in a hot state is suggested by the above observations and is consistent with the proposed intrusion and metamorphism of the Asai Beds. As well, there is some evidence of solid state re-intrusion of serpentinite in this area (*ibid*, p.31). Later, probably late Lower Miocene, gabbros (Oipo Intrusives), also, intrude the rocks of this area (*ibid*).

Before proceeding, a brief summary is warranted. The north flank of the Bismarck Range is characterized by a generally continuous Upper Cretaceous (Senonian) through early Lower Miocene section of basic marine volcanics, fine-grained clastics and limestones some 4,000 m. to 6,000 m. thick. These rocks are possibly gradational with Middle Cretaceous rocks and, therefore, Lower Cretaceous rocks, and are gradational with the late Lower Miocene above. A disconformity possibly occurs between the Eocene and early Lower Miocene. These rocks are closely associated, both spatially and temporally, with important basic and ultrabasic (?) intrusions. The oldest fossiliferous rocks known to the north of the Bismarck Range, more specifically to the north of the Bundi Fault-Zone, are of Upper Cretaceous, Senonian age.

To the north, the Bismarck Range and Central Ranges of New Guinea are separated from the Northern Coastal Ranges of New Guinea by the contiguous Ramu-Markham and Sepik Depressions. Except for the Border Mountains at the border between New Guinea and West Irian, the Ramu-Markham and Sepik Depressions are continuous with the Meervlaakte of West Irian and form a major intramontane depression across New Guinea, here called the North New Guinea Depression. Faulting determines the southern edge of this depression on the north flank of the Bismarck Range, *e.g.* the Bundi Fault-Zone, and along the north flank of the Central Ranges in West Irian (Visser and Hermes, 1962, p.162).

Ultrabasic rocks have wide spread occurrence along both the northern and southern edge of this depression. This depression will be further described and discussed in a later section.

The Northern Coastal Ranges of New Guinea are, from west to east: the Cyclops-Serra Mountains, Bewani Mountains, Torricelli Mountains, Prince Alexander Mountains, Adelbert Mountains and the Finisterre-Saruwaged-Cromwell Mountains. These ranges form an en echelon, but roughly linear mountain chain that trends parallel to the north New Guinea Depression and form its northern margin.

The Northern Coastal Ranges are built principally of Tertiary sediments. The ranges are strongly faulted but are generally anticlinal, with the oldest rocks exposed in the core of the ranges. The easternmost ranges, the Finisterre-Saruwaged-Cromwell and Adelbert Mountains, are composed entirely of sediments and volcanics. The oldest rocks exposed in the core of these two ranges are Oligocene and early Lower Miocene respectively. Narrow crystalline cores are exposed in each of the western ranges. The crystalline cores consists mainly of greenschists and ultrabasic, basic and intermediate igneous rocks (van Bemmelen, 1949, p.711; Visser and Hermes, 1962, p.120, 123). The crystalline core of the Bewani Mountains is formed entirely of igneous rocks, but metamorphics occur with the igneous rocks to the east in the Torricelli and Prince Alexander Mountains. Granites are believed to occur in the Cyclops Mountains (Visser and Hermes, 1962, p.123-124), and minor occurrences are reported in the Bewani, Prince Alexander and Torricelli ranges (David, 1950).

In the Bewani Mountains, Eocene limestones and red and green shales which are perhaps as old as Upper Cretaceous age are believed to rest directly on the crystalline core (APC Rept. EE). As with the Cyclops Mountains and North New Guinea Province in general (refer section 3.1.1), the lower part of the Tertiary sequence (up to early Lower Miocene) in the Northern Coastal Ranges is dominated by basic volcanics intercalated with pelagic marine sediments, *i.e.* similar to the "magmatic" stage of Visser and Hermes. In the Bewani Mountains, these volcanics directly overlie and appear to grade into basement in places (APC Rept. EE). The volcanics decrease in importance upward in the section, giving way to sandstones, mudstones, limestones and conglomerates (~~ibid~~ David, p.673), *i.e.* similar to the "sedimentary" stage of Visser and Hermes.

By way of example, in the Finisterre-Saruwaged Range, the lowest beds exposed (Oligocene to early Lower Miocene) consist~~s~~ of "thousands of feet" of limestone, agglomerate, conglomerate, mudstones, sandstones and interbedded basic pillow lavas (Kei Limestone, Gasua Limestone, Finisterre Agglomerate, "Mebu Series"), which are intruded by basic dikes (APC Repts. GK and GN). These rocks are steeply dipping to vertical and occupy a belt about 20 twenty kilometers wide on the south flank of the range (*ibid*). On the northern flank of the Bewani and Torricelli Ranges, equivalent beds (Bliri Group) are estimated to be 2,000 m. to 3,000 m. thick (APC Rept. WI). An unconformity between the early Lower Miocene and overlying late Lower Miocene and/or younger rocks has been found in the Finisterre-Saruwaged Range (APC Rept. GN) and is thought, though not proven, to be general in the Northern Coastal Ranges (APC Rept. WI). Here, late Lower Miocene to Pleistocene rocks represent a marine section of about 5,000 m. ("Lower Mena", "Upper Mena", "Ouba Series", Wanang Beds). Unconformities occur between each of the aforementioned units, the unconformity between ~~ween~~ the "Upper Mena" and the "Ouba Series" being an intra-Pliocene unconformity (APC Rept. WI). These rocks consist of sandstones, mudstones and limestones, and are strongly conglomeratic. The conglomerates contain boulders up to two meters in diameter, consisting mainly of material derived from the underlying units. No volcanics are reported among these rocks (APC Repts. GK and GN).

Summarizing, the preceding discussions reveal that there is a very close correspondence between the geological history of the area to the north of the Bismarck Range and that of the North New Guinea Provice of

West Irian. From Geelvink Bay eastward to the Owen Stanley Ranges, a distance of some 1,200 km., northern New Guinea is characterized by an essentially continuous Upper Cretaceous (Senonian) to early Lower Miocene sequence of dominantly fine-clastics and basic volcanics to the order of 5,000 to 6,000 m. thick. Upper Cretaceous (Senonian) rocks are the oldest sediments known in this area, but the distribution of rocks of this age is uncertain. In the Northern Ranges of New Guinea, Eocene rocks overlie older ~~ultra~~basics and greenschists unconformably, but Upper Cretaceous (Senonian) rocks of limited occurrence have been found in the vicinity of the Cyclops Mountains in West Irian and as derived fauna in the Bliri Group of the Bewani and Torricelli Mountains. Several levels of unconformity are known, but it is likely that over a large part of this area, say between the Northern Coastal Ranges and the Bismarck Range, deposition has been essentially continuous since the Senonian.

The major features of the geological history of this region can now be summarized as follows:

a. Volcanics are a major constituent of the early Lower Miocene and these decrease while clastics coarsen upward in the section. Rocks of the early Lower Miocene are of the order of 2,000 m. to 3,000 m. thick.

b. The late Lower Miocene to Pleistocene section (non-sequence) in this region is dominantly clastic, often conglomeratic and is of the order of 5,000 m. thick.

c. The presence of, often thick, shallow-water limestones, *e.g.* the Kei, Gasua, and Gowop Limestones, coarse boulder conglomerates and agglomerates indicates that local shoals and volcanic foci were present in this region. Unconformities and, again, locally coarse conglomerates also reflect local uplifts, but the region is believed to have remained essentially a deep-water, open marine environment until the Pliocene; if anything, the depositional basin as a whole is thought to have deepened during the late Lower Miocene to Pliocene interval (Visser and Hermes, 1962, p.105, 109; APC Rept, GN).

Because of the great thickness, general pelagic associations and early fine-clastic character of these rocks, along with their turbidite character (as reported in West Irian) and basic volcanic and ultra-basic associations, northern New Guinea is believed to represent a eugeosynclinal habitat.

d. In the Finisterre-Saruwaged Range, late Lower Miocene to Pleistocene rocks overlie the early Lower Miocene unconformably, and this relationship is believed to be general in the Northern Coastal Ranges. This again recalls the situation in the North New Guinea Province of West Irian, where the Auwewa Formation (Upper Cretaceous - early Lower Miocene) is believed to be unconformably overlain by the Makats Formation (late Lower Miocene - Middle Miocene) and most certainly by the Mamberamo Formation (Middle Miocene at the base).

e. Visser and Hermes (*ibid*) believe that the bulk of the clastic material in the North New Guinea Province of West Irian was derived from the south, *i.e.* from the uplifted northern edge of the Central New Guinea Province. Osborne (APC Rept. LE) has similarly argued the case for a southerly source for the Miocene clastic sediments of the Bewani and Torricelli Mountains. It is known that parts of the Bismarck Range were exposed and supplying detritus during the early Tertiary. The general coarsening of the rocks of northern New Guinea upwards in the section is, therefore, probably a reflection of the rise of the Central Ranges as well as of the Northern Coastal Ranges themselves.

3.1.4 CONCLUSIONS

Figure 3-1 shows the major sedimentary provinces recognized in West Irian (Visser and Hermes, 1962) and the proposed extension of these provinces into Papua and New Guinea eastward to about 145° E long. The terminology proposed by Visser and Hermes ~~(ibid)~~ has been adopted. These provinces show a close parallelism to major orographic features, *e.g.* the Central Cordillera, or backbone of New Guinea and the North New Guinea Depression, and trend west-northwest at about 100°-110°.

The main elements recognized are a platform, a miogeosyncline and a eugeosyncline. Together, the two latter features form the basic elements of an orthogeosynclinal system that has been termed the Papuan Geosyncline (David, 1950, p.703). The term Papuan Geosyncline, as defined *(ibid)*, has a much wider application, both in time and space, than one can confidently deduce in New Guinea.

Evidence in hand suggests that initial sedimentation in the Papuan Geosyncline began generally in the Permo-Carboniferous in West Irian (exclusive of the Vogelkop) and somewhat later in Papua and New Guinea, probably in the Triassic. The pre-Jurassic rocks in New Guinea possibly represent part of an earlier geosynclinal cycle which has largely been obliterated by pre-Jurassic tectonism and erosion. At any rate, certainly from the early Jurassic onward, a well developed orthogeosynclinal system evolved along the whole of this region. It would perhaps be reasonable to restrict the term Papuan Geosyncline to post-Triassic phenomena, especially since the bulk of our knowledge of New Guinea comes from rocks of this age, but a thorough examination of this problem has not been undertaken and is beyond the scope of this thesis.

In New Guinea, a well-developed early Mesozoic eugeosynclinal sequence has been recognized to the north of the Kubor Range, ~~i.e.~~ viz. the Wahgi Trough, whereas equivalent rocks representing a similar environment have not been recognized in West Irian.

Within the early Mesozoic eugeosynclinal province of New Guinea a positive element, the Bismarck Massif, has been recognized which, again, has no known equivalent in West Irian. This seems to be a real difference between these regions but, in part, may be due to lack of critical geological information from the northern flank of the Central Ranges in West Irian.

It will have been observed that I have correlated the Kubor Massif with the northern edge of the Central New Guinea Province, or miogeosyncline, on the one hand, but have correlated the Bismarck Massif with the southern edge of the Northern New Guinea Province on the other hand. The latter correlation is made mainly with respect to the characteristic relatively continuous succession of Upper Cretaceous (Senonian) to Recent sediments* in the North New Guinea Province. The southern margin of the North New Guinea Province and the northern margin of the Central New Guinea Province have, therefore, been defined on different criteria in New Guinea, whereas these boundaries are regarded as mutual in West Irian.

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* It should be pointed-out here, that while deposition was apparently continuous between the Cretaceous and the Tertiary in the Wahgi Trough as well as in the North New Guinea Province (McMillan and Malone, 1960; Rickwood 1955) post-late Lower Miocene rocks are generally absent or poorly developed in the Wahgi Trough. The Uppermost Cretaceous rocks in the Wahgi Trough seem to be conformable with the Tertiary, although the highest fossils found in the Chim Group are Cenomanian. The upper part of the Chim Group indicates a shallowing environment (Rickwood), which seems more closely related to the environment represented by the Lower Tertiary Eocene-Oligocene shelf limestones than to the eugeosynclinal environment of the pre-Senonian rocks. Definite Senonian fossils have not been found in the area between the Bismarck and Kubor Ranges and it may be that a large disconformity exists between the Cenomanian and the Tertiary in this area. However, to the southwest of the Kubor Range, the Mango Marls are of Senonian age, and it has been assumed, therefore, because of the apparent gradation with the Tertiary, that the Senonian is represented only in the uppermost part of the Chim Group. This contrasts markedly with the thick sections of these rocks to the north of the Bismarck Range. Further, the extensive basic and ultrabasic rocks characteristic of the southern margin of the North New Guinea Province, *e.g.* the Marum Basic Belt, are absent in the Wahgi Trough.

This leads to an important observation. The boundary between the North New Guinea Province and the Central New Guinea Province is taken as the boundary between miogeosynclinal and eugeosynclinal facies provinces. In New Guinea contemporaneous miogeosynclinal and eugeosynclinal facies provinces of the Mesozoic geosyncline <u>can be observed in juxtaposition</u> and, therefore, a boundary between these provinces can confidently be placed. In West Irian, however, the late Paleozoic-Mesozoic eugeosynclinal province has not been recognized, and it is <u>the late Paleozoic-Mesozoic miogeosynclinal province of the Central New Guinea Province</u> which <u>has been compared to the late Cretaceous-Recent eugeosynclinal province of the North New Guinea Province</u>. The boundary between these provinces as delineated in West Irian, is a late Cretaceous to Recent feature, and it can only be an assumption that pre-late Cretaceous facies trends parallel this boundary. I think that such an assumption is probably unwarranted.

The boundary between the North New Guinea and Central New Guinea provinces in West Irian is the site of strong faulting, along which the uplift of the Central Ranges commenced in the late Cretaceous or early Tertiary, more or less coincident with the incipient development and subsidence of the North New Guinea Province as now known. Along this boundary metamorphic rocks and extensive basic and ultrabasic intrusions and/or tectonic emplacements were contemporaneously uplifted to form a source area for the newly developing North New Guinea Province. A broadly similar late Cretaceous to Recent development is seen to the north of the Bismarck Range, which forms the northern edge of the Central Ranges in New Guinea. The north flank of the Bismarck Range is, also, strongly faulted and marks the site of extensive basic and ultrabasic intrusions and/or tectonic emplacements. Early Tertiary uplift of the Bismarck Range is evident from Eocene and early Lower Miocene conglomerates which contain material that has been derived from this range. I have, therefore, regarded the north flank of the Bismarck Range as marking the southern boundary of the North New Guinea Province. This boundary, so placed and extended into West

Irian along the southern boundary of the North New Guinea Province as placed by Visser and Hermes, is a reasonably integral and contemporaneous feature which:

(a) forms the northern edge of the Central Ranges of New Guinea

(b) is marked by numerous and extensive fault-zones

(c) permitted or accommodated the uplift of the Central Ranges, beginning in the late Cretaceous (Senonian) or early Tertiary

(d) permitted or accommodated extensive basic and ultrabasic intrusions and/or tectonic emplacements in its early history

(e) separates the late Cretaceous to Recent rising zone of the Central Ranges from the late Cretaceous to Recent subsiding zone of the north New Guinea eugeosynclinal province.

For these reasons, it can be suggested that this boundary is principally a fault, or fault-zone, which began development in the late Cretaceous. To facilitate discussion, this boundary will be called the <u>North New Guinea Boundary</u> and, henceforth, the term North New Guinea Province will be restricted to the region to the north of the North New Guinea Boundary. Now, the prime import of this discussion becomes the relationship between the North New Guinea Boundary and pre-late Cretaceous geosynclinal trends.

It has previously been suggested that the Kubor Range, or Kubor Massif marked the northern edge of the Central New Guinea Province during the Mesozoic ~~in that~~ because the Kubor Range marks the boundary between the Mesozoic miogeosynclinal and eugeosynclinal facies provinces. This boundary will now be called the <u>Kubor Hinge</u>. The Kubor Hinge <u>cannot</u> be directly correlated with the North New Guinea Boundary because the latter is a late Cretaceous to Recent feature, whereas the tectonic history of the Kubor Hinge can be traced back to the early Mesozoic or, perhaps, late Paleozoic. A feature similar to the Kubor Hinge cannot be recognized in West Irian, because a late Paleozoic-Mesozoic eugeosynclinal province has not been recognized. Similarly, equivalents of the Wahgi Trough and Bismarck Massif (referring here to the pre-late Cretaceous history of this massif) have not been recognized in West Irian. The present trends of the Kubor Hinge, Wahgi Trough and Bismarck Massif can be compared to the trend of the North New Guinea Boundary, as in Figure 3-1, and it can be seen that these trends presently strike obliquely into the trend of the North New Guinea Boundary. Because of the nature and relatively young age of the North New Guinea Boundary, it can, therefore, be suggested that the *North New Guinea Boundary developed discordantly to the previously existing geosynclinal framework and that it disrupted this earlier framework*. In other words, the North New Guinea Boundary can be regarded primarily as a fault-zone which has superposed new and different trends on the earlier geosynclinal framework. By this reasoning, therefore, it will be expected that the pre-late Cretaceous facies provinces in West Irian *do not parallel* the North New Guinea Boundary, *i.e.* the boundary between the North New Guinea and Central New Guinea Provinces, as placed by Visser and Hermes, probably does not coincide with the pre-late Cretaceous miogeosynclinal/eugeosynclinal boundary.

The *South New Guinea Province* is characterized by a relatively thin section of essentially flat-lying units which are separated by large hiatuses. As suggested by Visser and Hermes, and others before, these are characteristics of a *relatively* rigid block, and the South New Guinea Province is best regarded as a continuation of the continental shield of Australia. In support of this, granite crops out on the south coast of Papua at Mabaduan and has been drilled (at about 3,000 m.) as far north as Komewu No. 2 (Geol. Soc. Aust. Journ. No. 8, 1961, p.8-14). Farther northward, at Barikewa No. 1 fresh, angular arkoses that are believed to be unconformable beneath the Jurassic were drilled at about 4,200 meters. This has been taken to indicate a close proximity to a granitic basement (*ibid*). Similarly, coarse arkosic material at the base of the Jurassic rocks in the Wok

Feneng section is believed to represent proximity to granitic basement. In the Strickland Gorge section Lower Jurassic rocks are faulted against granite (*ibid*, p.20). Finally, pre-Permian metamorphic rocks (Omung Metamorphics, Rickwood, 1955) and granodiorite crop out in the Kubor Range. It is probable, therefore, that the Central New Guinea Province, or miogeosynclinal provice, is also, underlain by the northward continuation of the Australian continental shield. For the reasons that are to follow, I suggest that the Kubor Hinge marked the proper northern edge of the Australian continent during the greater part of the Mesozoic.

From at least the Lower Jurassic, and certainly earlier in some cases, to say approximately the Upper Miocene, the South New Guinea Province was the site of shallow platform-type deposition, the Central New Guinea Province of miogeosynclinal deposition, and the Wahgi Trough of eugeosynclinal deposition. From the Upper Cretaceous onward, the North New Guinea Province was the site of eugeosynclinal deposition. In New Guinea at least, the Mesozoic miogeosynclinal province was separated from the eugeosynclinal province by a mobile basement ridge, *viz.* the Kubor Hinge, or Kubor Massif. In even the most general terms, this geosynclinal system was (and is) marginal to continental Australia, i.e. the system forms an orthogeosyncline in the sense of Kay (1951).

Drake, Ewing and Sutton (1959) and, more recently Heezen and Drake (1963) have pointed-out the striking analogy between Kay's (1951) reconstruction of the Appalachian orthogeosyncline and the 'geosyncline' now existing along the eastern margin of the United States of America. Dietz (1963) has presented a different, but grossly similar, interpretation of these features. Broadly, these authors demonstrate the similarities between : (a) the present continental shelf of the U.S.A. and the Appalachian miogeosynclinal province, (b) the present continental slope and associated basement ridge of the U.S.A. and the Blue Ridge of the Appalachians, *i.e.* the boundary between the miogeosyncline and the eugeosyncline, and (c) the present continental rise of the U.S.A. and the Appalachian eugeosynclinal province. This provides a model to which we may compare the orthogeosynclinal system of New Guinea and Papua.

We know almost certainly that the continental shield of Australia extends into Papua and West Irian but how far it extends is the problem. Following from the analogy presented by the aforementioned authors, I suggest (a) that the miogeosynclinal province or Central New Guinea Province corresponded to a continental shelf, (b) that the Kubor Hinge corresponded to a continental slope and (c) that the eugeosynclinal province, or Wahgi Trough (and later the North New Guinea Province) corresponded to a continental rise sedimentary prism.

Accepting this series of analogies, the point of immediate relevance to this discussion is that the continental slope effectively marks the edge of the continental crust of eastern U.S.A. (Drake et al., 1959). To the east of the continental slope, the continental crust is greatly thinned (to 8-10 km.) and rapidly thins out to zero thickness to the east (*ibid*, refer figure 3-4; taken from Heezen and Drake, 1961, figure 1). Carey (1958) has demonstrated the general tectonic significance of regarding the continental slope as the true edge of continents. It might be expected, therefore, that the true edge of the Australian (pre-Mesozoic) continent is coincident with the Kubor Hinge, and that to the north of this the continental crust (or what was the continental crust during the early stages of geosynclinal deposition) is greatly reduced in thickness, thinning finally to zero thickness toward the north.

On the premise of this analysis, additional observations can be made:

1) In that the eugeosynclinal province is regarded as a continental rise sedimentary prism, it will be expected that the early Mesozoic sediments, after attaining a maximum thickness somewhere to the north of the Kubor Hinge, will then thin toward the north (refer figure 3-4).

2) The common occurrence of ultrabasic and basic 'intrusives' in the North New Guinea Province, and the concomitant lack of these rocks to the south, are tenable either as tectonically emplaced remnants of the peridotite mantle (Visser and Hermes, 1962, p.123), and/or as fragments of the oceanic crust and "old sea floor" (Dietz, 1963, p.329). This is because the continental crust (Pre-Mesozoic) is envisaged as being greatly thinned to the north of the Kubor Hinge, *i.e.* ultrabasic and basic rocks are here within easier reach of the sedimentary pile. Some of the sediments of the North New Guinea Province may have been deposited directly on an oceanic crust (refer Figure 3-4). Basic volcanism would be a natural occurrence in the eugeosynclinal province (and acid volcanism highly improbable), as Dietz (*ibid*) points out.

A statement regarding the "<u>Northern Massif</u>" of Smith (refer figure 3-2) need now be made. Smith has followed van Bemmelen (1949, p.712), who referred to this massif as the "borderland of Northern Melanesia".

The "Northern Massif" as depicted by Smith (refer figure 3-2) is certainly not valid for the Upper Cretaceous (Senonian), as a thick sequence of rocks of this age crops out on the north flank of the Bismarck Range, and these rocks show no signs of derivation from a "Northern Massif". The situation prior to the Upper Cretaceous is more indefinite, but there are no, even partially compelling reasons for assuming the existence of a "Northern Massif" prior to the Upper Cretaceous. From all evidence at hand, the depositional basin deepened into the open ocean toward the north. A massif in the position depicted by Smith, would be expected to have strongly influenced the character of the sediments in this region, but there are no reflections of this "massif" in the known sedimentary relationships. As well, gravity and seismic evidence indicate that the present ocean basin to the north of New Guinea is underlain by an oceanic crust, although perhaps a thin sialic crust underlies the Bismarck Sea. If this "massif" existed, where has it gone? It certainly has not subsided beneath the ocean basin to the north of New Guinea.

For these reasons, and in view of the analysis I have offered, I suggest that the "Northern Massif" of Smith and/or the "borderland of Northern Melanesia" of van Bemmelen are non-existent. A similar conclusion has been reached by Visser and Hermes (1962) in their study of West Irian.

Finally, this reasoning leads to the conclusion that in New Guinea, the North New Guinea Province developed entirely to the north of the pre-Mesozoic continental shield of Australia. We must, therefore, consider the possibility that the crust on which this province formed was either an oceanic type crust, new crust or, at most, a thin continental-type crust. The following quote from Osborne (APC Rept. EE, 1942, p.37), concerning the Bewani and Torricelli Mountains, suggests that this part of the North New Guinea Province did indeed form on an oceanic type crust:

> "....The base (of the early Lower Miocene, or Lower Bliri Group - AK) consists of conglomerates made up principally of volcanic pebbles and boulders with some diorite and limestone, probably Eocene, in a volcanic matrix, and obvious basaltic lavas with limestone inclusions, apparently becoming more homogeneous downwards so that it is impossible to say that they are volcanic or very fine grained plutonic rocks. These seem to overlie coarse-grained diorite."

3.2 MAJOR TECTONIC ELEMENTS OF THE REGION EAST OF THE KUKUKUKU LOBE

3.2.1 OWEN STANLEY RANGES AND FLANKING BASINS

The Owen Stanley Ranges are formed by an extensive core of metamorphic and igneous intrusive rocks that comprise the largest and most continuous crystalline complex thus far mapped in Papua and the Territory of New Guinea. This metamorphic complex forms the backbone of the 'tail' region of eastern Papua and New Guinea and has been termed the "Morobe Arc and Owen Stanley folded zone" by Glaessner (1950).

The northeast flank of the crystalline core of the Owen Stanley Ranges is formed by the extensive Papuan Basic and Ultrabasic Belt, which is about 350 km long and 50 km wide at its widest. The Papuan Basic and Ultrabasic Belt is largely separated from the metamorphic rocks of the range by the important Owen Stanley Fault, but locally intrusive relationships have been suggested (Smith and Green, 1961). The basic belt is formed of layered basic and ultrabasic rocks consisting of dunites and peridotites (which are most commonly serpentinized), gabbros, dolerites and norites (*ibid*). The age of the Papuan Basic and Ultrabasic Belt is not definitely known, but is generally regarded as being of Upper Cretaceous to Oligocene age (*ibid;* Dow and Davies 1964, Paterson and Kicinski 1956).

Quoting from Dow and Davies (1964),

> ".....The Papuan Ultrabasic Belt was probably magmatically emplaced.....The evidence for both magmatic emplacement and age is very meagre as contacts with supposed older rocks are almost invariably sheared. The only evidence of age is the fact that the Belt is overlain by volcanics of the Iauga Formation, which are conformably overlain by Miocene ("f1-2" stage) limestone (Patterson and Kicinski, 1956)......(p.22).
>
> .....An alternative hypothesis (J.E. Thompson, pers.comm.) is that the Belt is a segment of the simatic crust which has reached its present position through relative lateral and vertical movements of the Pacific crust and the Owen Stanley metamorphic block. The boundary between ultramafic and feldspathic rocks may, under the conditions of high temperature and pressure prevailing at depth, have corresponded to the Mohorovicic Discontinuity. The vertical movement required to expose the Mohorovicic Discontinuity is probably of the order of ten miles. Recent lateral and vertical movement of nearly three miles on the Owen Stanley fault has been shown by the present survey (p.21) and horizontal displacements of between ten and eleven miles along Quaternary faults have been postulated in the D'Entrecasteaux Islands (Davies and Ives, 1961). With tectonic activity on this scale it is not difficult to envisage elevation of a segment of oceanic crust through a distance of ten miles.....(p.17).

> ....Green (1961) working separately, has reached a similar conclusion and, in support of this hypothesis, cites the difficulty of envisaging a magma chamber of appropriate dimensions undergoing prolonged differentiation in the active orogenic environment in which the Belt occurs.....(p.23)."

The rocks of the basic belt are believed to have been emplaced after the folding and matamorphism of the metamorphic complex of the Owen Stanley Ranges, but the basic and ultrabasic rocks have undergone a later folding (Smith and Green, 1961). Smith and Green (*ibid*) believe that the basic belt may be responsible in part for the metamorphism of the Urere Metamorphics (late Cretaceous to ? Eocene).

In addition to the basic and ultrabasic rocks, diorites and granodiorites have intruded and thermally metamorphosed the metamorphic complex of the Owen Stanley Ranges (*e.g.* the Morobe Granodiorite of late Cretaceous to (?) Eocene age; Glaessner 1950, Smith and Green 1961, Pitt 1966).

Very broadly, two groups of low-to medium-grade, regional metamorphic rocks have been recognized in the various areas studied in the Owen Stanley Ranges. The correlation of these two groups from area to area is uncertain (Pitt, 1966), and it should not be taken here that I am implying direct correlations in the following discussion - this is almost certainly not the case.

The upper group ("Kaindi Series" and "Kemp Welch Series" of Stanley, 1923; Snake River Graywacke, Dow 1961; Kea Formation, de Vertueil and Rickwood, 1946; Urere Metamorphics, Smith and Green 1961; Sampa Beds, Dow and Davies, 1960) generally consists of low-grade sericite schists, phyllites, sheared graywackes, conglomerates and recrystallized limestones. The Urere Metamorphics contain abundant basic volcanic extrusives and are described as hornfels rather than regional metamorphics. A Cretaceous fauna has been found in the Snake River Graywacke (Cenomanian; Glaessner, 1949), Sampa Beds (Cenomanian; Dow and Davies, 1964) and Kea Formation (Cenomanian or Senonian; de Vertueil and Rickwood, 1946). Globigerina have been found in the "Kemp Welch

Series", indicating that these metamorphics are not older than the Cretaceous (Stanley, 1923). Fossils have not been found in the Urere Metamorphics, but a Cretaceous age was suggested by Smith and Green and an Eocene age has been suggested by Pitt (1966). Basic and ultrabasic rocks of the Papuan Basic and Ultrabasic Belt are believed to intrude the Urere Metamorphics (Smith and Green, 1961).

The relationship between these metamorphics and the underlying metamorphics is somewhat problematical (Pitt, 1966), but they are generally regarded as overlying the higher grade metamorphics unconformably (Dow and Davies, 1964; Dow, 1961; Smith and Green, 1961). Dow (1961) mapped an unconformity between the Snake River Graywacke and the underlying greenschists (Kaindi Metamorphics), but Pitt (1966) has suggested that this 'unconformity' is more probably a fault. Both the Sampa Beds and the Urere Metamorphics have been mapped* as unconformably overlying greenschists (the Kaindi Metamorphics and Gorupu Metamorphics respectively; Dow and Davies, 1964; Smith and Green, 1961). The Kea Formation is (?) conformably overlain by Eocene rocks which are in fault contact with schists, gneisses, calc-silicate rocks and recrystallized limestones ("Kaindi Series" of de Vertueil and Rickwood, 1946). The "Kemp Welch Series" overlies older metamorphics unconformably (Stanley, 1923).

Rocks similar to the "Kaindi Series" of de Vertueil and Rickwood have been mapped in the Kokoda area and are described by Paterson and Kicinski (1956) as schists, gneisses and garnetiferous calc-silicate rocks of the greenschists to albite-epidote-amphibolite facies (<u>Owen Stanley Metamorphics</u>). These rocks are contact metamorphosed (low temperature) by the Papuan Basic and Ultrabasic Belt (*ibid*). Paterson

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* More recent and detailed mapping of the 'contact' between the Kaindi Metamorphics and the Snake River Graywacke and the Kaindi Metamorphics and the Sampa Beds has revealed that an unconformity most probably <u>does not</u> exist between these units, and the Kaindi Metamorphics are best regarded as being at least partially of Cretaceous age (J. Smitt, Aust. Bur. Min. Res, pers. comm., 1965).

and Kicinski regarded these rocks as older than the Kaindi Metamorphics of Dow (or the lower part of the "Kaindi Series" of Fisher, 1944), and suggested a Paleozoic age. The <u>Owen Stanley Metamorphics</u> of Paterson and Kicinski are part of the now obsolete "Owen Stanley Series" of Stanley (1923), which Stanley regarded as Precambrian. Rocks that are similar to the Owen Stanley Metamorphics have been described from the D'Entrecasteaux Islands and Louisiade Archipelago (Stanley 1923; de Keyser, 1961).

Because rocks of Cretaceous age are known to be involved in the metamorphic complex of the Owen Stanley Ranges, and because of the complete lack of any positive evidence of rocks of pre-Mesozoic age occurring here, Pitt (1966) has made the pregnant suggestion that pre-Mesozoic rocks are probably absent in the Owen Stanley Ranges.

Of prime interest to this discussion is the structural trend of the Owen Stanley Ranges. In contrast to the region to the west, where an essentially rectilinear, west-northwesterly trend is prevalent over a distance of some 1,200 km., the Owen Stanley Ranges form a marked, strongly curvilinear trend. At the northwest end, the trend of the Owen Stanleys is north-south to north-northeast from the Markham River for a distance of about 100 km. to the south. From here, the trend curves into a north-northwest orientation (320°-330°) for the next 275 km., and, thence, into a west-northwest trend (285°-295°) for some 350 km. to the southeast tip of New Guinea. The west-northwest trend is extended for at least another 350 km. in the Louisiade Archipelago. The local folding and faulting in the crystalline backbone, as far as is known, is essentially parallel to the trend outlined above. The Owen Stanley Fault, which forms the boundary between the Papuan Basic and Ultrabasic Belt and the metamorphic core of the ranges, parallels this trend (refer Figure 3-5, taken from Pitt 1966). Important cross faults have been mapped at the southeast end of the Owen Stanley Ranges, and these generally trend north-south to northeast-southwest (Smith and Green, 1961; ~~Dow~~ Davies and Ives, 196~~7~~5). The south coast of Papua at the southeastern end is remarkably linear and falls off rapidly to the deep ocean (refer figure 3-24). This coast is probably fault-controlled.

The northeast flank of the Owen Stanley Ranges is formed by thick Eocene to Recent sediments. These sediments are believed to form the southwest limb of the Cape Vogel Eugeosyncline and to thicken toward the axis of the eugeosyncline, which is believed to be situated between the north coast of New Guinea and the D'Entrecasteaux Islands (Paterson and Kicinski, 1956).

The sediments on the northeast flank of the Owen Stanley Ranges have a somewhat patchy outcrop due to numerous intrusions and a cover of Recent extrusions and Recent alluvium. Along the southeastern end of the island, in the Goodenough Bay region, a thick sequence of cherts, tuffs, shales and sandstones crops out. These beds are probably of Eocene to Oligocene age (*ibid*, p.51).

In the Cape Vogel area about 4,200 m. of Upper Miocene to Pliocene, largely terrestrial to paralic sandstones, conglomerates, marls, tuffs, agglomerates and volcanic breccias crop out (*ibid*, p.58-60).

Further to the northwest, 600 m. + of basic to andesitic lavas, agglomerates and tuffs, tuffaceous sandstones and thick limestones of early to late Lower Miocene age have been measured to the north flank of the Ajura Kiljala Range (just west of Mt. Lamington; *ibid*, p.53-56). These beds are disconformably overlain by thin sandstones and conglomerates of Pliocene age which are, in turn, overlain with angular unconformity by about 4,000 m. of Pleistocene to Recent andesitic volcanics of the Hydrographer Range and Mt. Lamington.

Still further to the northwest, altered basic volcanics, siltstone and recrystallized limestones (Salamaua Volcanics) and mudstones, greywackes, and recrystallized limestones (Nipanata Beds), which are both of (?) Eocene age, crop out (Dow and Davies 1964). These are overlain, possibly with angular unconformity, by basic marine volcanics of Miocene age (Mageri Volcanics; *ibid*). These rocks are intruded by numerous basic to intermediate igneous dikes, and Dow and Davies believe the (?) Eocene rocks of this area to be intruded by the basic and ultrabasic rocks of the Papuan Basic and Ultrabasic Belt.

In general, the Tertiary rocks on the northeast flank of the Owen Stanley Range are only gently folded, but are commonly strongly faulted.

Similar to the northeast flank of the Owen Stanley Ranges, the <u>southwest flank</u> was a site of thick deposition during the Cenozoic. The southwest flank differs from the northeast flank, however, in two important aspects. Firstly, the Cenozoic rocks of the southwest flank are strongly folded and faulted and secondly, Upper Cretaceous rocks (Senonian; <u>Barune Sandstone</u> and <u>Bogoro Limestone</u>; Glaessner, 1952) have been found to be included in these structures in the Port Moresby area.

Glaessner (1952) suggested that the Eocene unconformably overlies the Cretaceous in the Port Moresby region, but Pitt (1966) argues that deposition was essentially continuous from at least the Senonian to the Middle Oligocene in this region. The following information is taken from Glaessner (1952).

The Senonian to middle Oligocene succession is of the order of 3,000 m.+ in this region and consists mainly of cherts, limestones, tuffaceous sandstones, and mudstones. The Port Moresby Group of Eocene age comprises the bulk of this succession. Facies evidence suggests a deepening of the depositional environment and concomitant thickening of sediments toward the Owen Stanley Ranges. Granitic detritus in the westernmost exposures of these beds has led Glaessner to suggest the presence of a granitic land mass off the coast of Papua during the deposition of these beds. An increase in the tuffaceous content of these rocks toward the northeast has been taken to indicate the existence of a volcanic source in that direction. These beds have been strongly thrust-faulted and folded into tight, southwesterly-facing folds. This folding probably occurred shortly after the middle

Oligocene and was accompanied or followed by basic and ultrabasic intrusions. Thin terrestrial (?) Upper Miocene rocks unconformably overlie these beds and are, in turn overlain unconformably by essentially flat-lying Pliocene volcanics (Astralobe Agglomerates).

About 115 km. to the northwest of Port Moresby in the Angabunga River area, some 1,200 m. of sandstones, limestones, shales and phyllitic shales (Mafulu Group) of Eocene age are belived to (?) conformably overlie the Cretaceous (Cenomanian or Senonian) Kea Formation, which consists of about 2,500 m. of mudstones, shales and low grade phyllites (de Vertueil and Rickwood, 1946). These rocks are intruded by abundant basic dikes (*ibid;* Pitt 1966). Low-grade phyllites, shales and sheared gr~~e~~aywackes crop out in the Tiveri River and are believed to be equivalent to the Kea Formation and/or the Mafulu Group. These rocks are overlain unconformably by rocks of Upper Miocene and Pliocene age. In the Mt. Yule region (?) 1,000 m. of basic metavolcanics, tuffs and conglomerates were measured by Pratt and Whittle (MB, 1938), and Pitt (1966) believes these rocks to be of Eocene age.

To the northwest of Port Moresby, the Lakekamu Embayment and subsidiary structural basins are filled by an extensive cover of Pleistocene and Recent alluvium which masks most of the geology between the southwest flank of the Owen Stanley Ranges and the southwest coast of Papua. Lower Miocene to Pliocene rocks lap on to the southwest flank of the Owen Stanley Ranges unconformably, but the relationship of these rocks to older rocks in the central part of this depression is unknown. Along the northeastern edge of the Lakekamu Embayment, in the central and southeastern portion, thick Lower Miocene to Pliocene volcanics (about 6,000 m.) with marine intercalations crop out (Geol. Soc. Aust. Journ., Vol. 8, p.97). The relationship of these rocks to the underlying rocks is unknown. At the northwestern end of the Lakekamu Embayment, probably 10,000 m.+ of Lower Miocene to Pliocene sandstones, mudstones, limestones and conglomerates are present at the southern end of the Muiai Syncline. Volcanics are lacking in this region, but these rocks appear to unconformably onlap older (?)

volcanics and metamorphic rocks of the Owen Stanley Ranges.

As well as the (?) middle Oligocene folding in the Port Moresby area, Pitt (1966) has found evidence of Lower Miocene, Upper Miocene, Pliocene and post-Pliocene folding movements in this region. It seems doubtful, therefore, that the 'depositional axis' remained in the same place throughout the Cenozoic, but it does seem probable that deposition has been essentially continuous in many parts of the region since the early Miocene (or possibly Senonian?).

The folds of this region are characteristically long and sinuous in plan, and rise like islands from the surrounding alluvium. In general, the folds have a westerly or southwesterly-facing, *i.e.* away from the Owen Stanley Ranges, and are oriented sub-parallel to the main trend of the Owen Stanleys. An important exception to this rule is that the folds near the coast characteristically have a <u>northeasterly</u>-facing, which suggests tectonic movement <u>toward</u> the Owen Stanley Ranges. From almost any point of view, this suggests the presence of a structurally high area off the present coast of Papua.

A. SUMMARY

The aforegoing descriptions have been kept as brief and general as is plausible, because the problems concerning the Owen Stanley Ranges and flanking sedimentary troughs are complex and not completely resolved. Pitt (1966) has recently completed a detailed study of the tectonic history of this region as part of the Papuan Project and has freely and generously supplied discussions and much of the information on which the above simplified description is based.

Basically, three tectonic elements have been recognized. The crystalline backbone of the Owen Stanley Ranges is the major and most ancient of these elements. The flanking troughs of thick Cenozoic sedimentation that parallel the crystalline backbone are the other two elements. The tectonic history of these elements can be summarized as follows:

1. <u>The Owen Stanley Crystalline Backbone</u>

a) The backbone of the Owen Stanley Ranges is formed of low-to medium-grade regional metamorphic rocks. The upper part of these metamorphics includes rocks of Cretaceous age (Cenomanian, and possibly Senonian on the southwest flank). One or more unconformities are present in these metamorphics. To date, there is no conclusive proof that pre-Mesozoic rocks occur in these metamorphics.

b) These metamorphic rocks have been folded and faulted on a trend that is grossly parallel to the regional trend of the Owen Stanley Ranges.

c) As well as more basic intrusives, intermediate batholithic intrusions have invaded these metamorphic rocks and are probably of Upper Cretaceous to Oligocene age, *e.g.* the Morobe Granodiorite.

d) On the northeast flank, ~~of~~ the metamorphic rocks of the Owen Stanley Ranges are separated from the Cape Vogel Eugeosyncline by the Papuan Basic and Ultrabasic Belt of Upper Cretaceous to Oligocene age. The Papuan Basic and Ultrabasic Belt seems to be partly intrusive, but the fact that it is generally separated from the metamorphic rocks of the Owen Stanley Ranges by the Owen Stanley Fault suggests that it is mainly a tectonically emplaced body. The Papuan Basic Belt is generally post-metamorphism and post-folding ~~of~~ in relation to the metamorphic rocks of the Owen Stanley Ranges, but may in part be responsible for some of this metamorphism and folding. The Papuan Basic and Ultrabasic Belt is, itself, folded and faulted.

2. The Cape Vogel Eugeosyncline

a) Incomplete and patchy but, at the same time, thick sediments of Eocene to Recent age occupy this sedimentary basin. The rocks are mainly volcanics, sandstones, conglomerates, cherts and limestones. Thick accumulations of terrestrial to paralic sediments occur in this succession.

b) Numerous basic to acid dikes of Oligocene to Pleistocene age have intruded these rocks. Basic and Ultrabasic rocks of the Papuan Basic and Ultrabasic Belt have possibly intruded these rocks, also.

c) For the most part, the rocks of the Cape Vogel Eugeosyncline are only gently folded and faulted, but important unconformities at various places within the succession indicate that tectonic movements, which were possibly mainly local in nature, have occurred nearly constantly throughout the Cenozoic history of this region.

3. The 'Southwest Flank Basin'

a) A thick succession of late Cretaceous (? Senonian) to Recent sandstones, mudstones, conglomerates, limestones, cherts and volcanics have accumulated in this basin. Volcanics are more important along the north side of the basin, in the central and southeastern parts.

b) Numerous local unconformities, and perhaps regional unconformities (say at the top of the middle Oligocene ?), are present in this region, indicating that the region has been tectonically active throughout much of its history. The site (s) of maximum sediment accumulation is unlikely to have remained static throughout deposition, but some parts of this region may have remained the site of uninterrupted sedimentation.

c) The Eocene and late Cretaceous (Senonian ?) beds exposed along the north flank of the basin are slightly metamorphosed and have been intruded by numerous basic dikes. The Senonian to ~~M~~middle Oligocene succession of the Port Moresby region has been intruded by both basic and ultrabasic igneous rocks.

d) This region has been strongly folded and faulted at different times in different places and, in general, folding movements are recognizable from the ~~M~~middle Oligocene onwards.

e) The northeasterly-facing of the folds in the coastal region suggest tectonic transport toward the northeast, *i.e.* toward the Owen Stanley Ranges, and therefore, the probable existence of a tectonic high off the present coast. Regionally, folds and thrusts in this basin are aligned subparallel to the main trend of the Owen Stanley Ranges and face away from the Owen Stanleys, *i.e.* suggesting tectonic transport away from the Owen Stanley Ranges.

3,2.2 CONCLUSIONS

The problems most pertinent to this discussion are how, and if, the tectonic elements recognized here join, through the region of the Kukukuku Lobe, with those recognized to the west of the Kukukuku Lobe.

The crystalline backbone of the Owen Stanley Ranges is a tectonic element involving late Cretaceous and older rocks, *i.e.* it is certainly in part, if not entirely, a Mesozoic feature. It will be expected, therefore, that if the Mesozoic tectonic elements of western New Guinea are related to the crystalline backbone of the Owen Stanley Ranges, they will bend abruptly southward in the area of the Kukukuku Lobe to parallel the Owen Stanley trend.

All of the tectonic elements recognized to the east of the Kukukuku Lobe are essentially <u>eugeosynclinal</u> in character. The greenschist and albite-epidote-amphibolite metamorphic facies of the metamorphic rocks, the important basic and ultrabasic associations and the thick volcanic and sedimentary sequences described are typical eugeosynclinal associations. Broadly, then, this would place this entire region into a general tectonic environment like that to the north of the Kubor Hinge.

In that the metamorphic rocks of the Owen Stanley Ranges include beds of Cretaceous age, they are unlike those of both the Kubor and Bismarck Ranges. The granodiorite intrusions of the Owen Stanley Ranges, *e.g.* the Morobe Granodiorite, are later than that of either the Bismarck Range (pre-Lower Jurassic) or that of the Kubor Range (pre-Permian). On the other hand, the Cretaceous metamorphics of the Owen Stanley Ranges find at least a broad parallel in the low-grade metamorphics of the Upper Cretaceous (Senonian) to early Lower Miocene Asai Beds and underlying Kombruf Volcanics, which are exposed on the north flank of the Bismarck Range and in the Schrader Range. A somewhat closer analogy can perhaps be drawn between the northern flank of the Bismarck Range and the southwestern flank of the Owen Stanley Ranges in that Upper Cretaceous (Senonian) and Eocene (to Middle Oligocene ?) rocks are probably conformable on the southwest flank of the Owen Stanleys, *i.e.* in the 'Southwest Flank Basin', and both age groups are here slightly metamorphosed in a similar manner to the northern flank of the Bismarck Range. In general, the 'Southwest Flank Basin' is similar to the North New Guinea Province from the point of view of general continuity of deposition throughout the late Cretaceous and Cenozoic.

Approaching the problem from a slightly different aspect, it is possible to compare and contrast the Northern Coastal Ranges and the Cape Vogel Eugeosyncline. Whereas the Northern Coastal Ranges are characterized by a thick, nearly continuous, dominantly deepwater or pelagic Tertiary succession, the Cape Vogel Eugeosyncline is characterized by a patchy, although thick, Cenozoic succession that includes long local hiatuses and a thick terrestrial paralic section. Volcanics are important throughout the section of the Cape Vogel Eugeosyncline, whereas volcanics have their main import in only the lower part of the section in the Northern Coastal Ranges. The Cape Vogel Eugeosyncline then, as known (*i.e.* the deepest part of this basin is probably now covered by the sea), does not find a direct continuation in the sedimentary basin of the Northern Coastal Ranges *i.e.* the North New Guinea Province.

From still another aspect, the metamorphics of the Owen Stanley Ranges and those of the Northern Coastal Ranges warrant comparison. The metamorphic rocks (largely greenschists) and basic and ultrabasic rocks of the Northern Coastal Ranges are believed to be of pre-late Cretaceous age, because unmetamorphosed rocks of Senonian age have been found at one locality to the west of the Cyclops Mountains and a derived fauna of this age occurs in the Miocene rocks of the Bewani and Torricelli Mountains. Generally speaking, rocks of Eocene to Oligocene age are believed to rest unconformably on a crystalline core in the Northern Coastal Ranges. These metamorphic, basic and ultrabasic rocks are probably, therefore, pre-Senonian and are certainly pre-Tertiary. The metamorphic greenschists at the northern end and on the northeastern flank of the Owen Stanley Ranges include rocks at least as young as Cenomanian but younger fossils have not been reported from these rocks. As in the Northern Coastal Ranges, basic and ultrabasic rocks, *viz.* the Papuan Basic and Ultrabasic Belt, are closely associated with the metamorphic rocks of the Owen Stanley Ranges.

On the basis of the aforegoing ~~reasoning~~ discussion, I suggest that the following statements are not unlikely:

1. The crystalline core of the Owen Stanley Ranges can broadly be continued, and find a rough equivalence in the crystalline cores of the Northern Coastal Ranges.

   a) This implies that some of the metamorphic greenschists of the Northern Coastal Ranges are possibly as young as Cretaceous (Cenomanian or, less likely, Senonian).

2. The 'Southwest Flank Basin' can be extended generally as a continuation of the North New Guinea Province.

3. If seeking a westward continuation of the Cape Vogel Eugeosyncline, and if it exists, it should then be located to the <u>north</u> of the Northern Coastal Ranges.

The detail of these proposed extensions through the area of the Kukukuku Lobe will be undertaken in a subsequent section.

3.3 THE BOUGUER ANOMALY PATTERN OF PAPUA AND NEW GUINEA; RELATIONSHIP TO MAJOR TECTONIC ELEMENTS

As part of the Papuan Project, Shirley (1964) and St. John (196~~4~~7) have conducted a regional gravity survey of Papua and New Guinea. Figure 3-6 is a partial reproduction of a preliminary Bouguer Anomaly map that has been prepared by St. John. This map incorporates some 10,000 gravity stations established during oil exploration work and about 180 gravity stations of Shirley, as well as about 300 gravity stations established by St. John.

The first observation to make (refer figure 3-6) is that gravity values fall rapidly toward the Central Cordillera and Owen Stanley Ranges. This suggests broadly that the 'backbone' of Papua and New Guinea is a rooted mountain chain. Brooks (1964, pers. comm.) has suggested that this corresponds generally to his preliminary evaluation of seismic data for this region, which indicates that the Mohorovicic Discontinuity falls to a depth of approximately 50 km. beneath the Central Ranges of New Guinea.

With the exception of the gravity low centered over the Finisterre Range, gravity values rise to strong positive values to the north and east of the 'backbone'. The rapidly rising positive gradient recorded along the northwestern end of the north coast of the Territory of New

Guinea is most probably indicative of a rapidly thinning sialic crust, *i.e.* it appears that true oceanic crust underlies the deep ocean to the north west of the New Guinea coast. To the southeast of, say Wewak, the picture is not simple. While gravity values rise sharply toward the coast, the values recorded to the southeast of Wewak are only moderately positive. The oceanic area to the north of the New Guinea coast and to the southeast of Wewak is largely less than 2,000 m. deep, and it could be that this area is underlain by a thin sialic crust, whereas the area to the northwest of Wewak is underlain only by oceanic crust (Shirley, 1964).

The next feature to observe is that the Kubor and Bismarck Ranges represent gravity maxima in a strongly negative environment. This is most probably at least a partial reflection of the fact that these ranges remained positive elements during much of their Mesozoic and Cenozoic history, *viz.* the Kubor Massif and Bismarck Massif. Thicker sedimentation to either side of these ranges relative to the thin sedimentation over the ranges, can probably account for most of the relatively positive character of the Bouguer anomalies over these ranges. In addition, the present erosional configuration of these ranges would increase this effect, *i.e.* crystalline rocks are now exposed in the core of these ranges with thick sediments to either side.

Both the Papuan Basic and Ultrabasic Belt and the Marum Basic Belt are marked by strong gravity maxima. In contrast to the Papuan Basic and Ultrabasic Belt, which is consistently marked by Bouguer anomalies in excess of 120 milligals, the Marum Basic Belt forms only a local maxima in a region which is characteristically strongly negative. In the area of the Marum Basic Belt, however, a thick section of both Mesozoic and Cenozoic rocks occurs, and this must mask the inherent positive nature of the Marum Basic Belt to some extent.

As can be observed from Figure 3-6, the Owen Stanley Ranges for the most part are not as strongly negative as is the Central Cordillera. While the gravity minimum along the Owen Stanleys generally parallels the range, the gravity values become more positive toward the southeast. This possibly reflects a diminishing importance of the root beneath the Owen Stanley Ranges to the southeast and/or a greater horizontal effect of the oceanic crust beneath the ocean to either side of New Guinea (St. John, 1964, pers. comm.).

Recognizing the fact that the Owen Stanley Ranges are marked by a strong negative Bouguer anomaly, while at the same time the Papuan Basic and Ultrabasic Belt is marked by a strong positive Bouguer anomaly, suggests that the strong negative anomaly centered over the Finisterre Range (actually the most negative values on the map!) together with the local maximum over the Saruwaged-Cromwell Range possibly marks the continuation of the crystalline backbone of the Owen Stanley Ranges and the Papuan Basic and Ultrabasic Belt beneath the Finisterre-Saruwaged-Cromwell Ranges.

A final point of general observation is that the region of the Kukukuku Lobe marks the position of a strong cross-trend(s) in the Bouguer Anomaly pattern. From north to south the 'Finisterre minimum', 'Bismarck maximum' and 'Kubor maximum' close-off in the region of the cross-trend. On the east, the 'Owen Stanley minimum' plunges toward the cross-trend and the 'Papuan Basic Belt maximum' closes-off toward the cross-trend. In gross form, therefore, the cross-trend marks a regional transverse gravity low across Papua and New Guinea, *i.e.* with the exception of the 'Finisterre Minimum" the Bouguer values overall major tectonic features fall toward the area of the cross trend. The 'Finisterre minimum' has a local salient which crosses the Markham Valley and enters into the Watut Valley to the south in this region. For convenience, this cross trend can be referred to informally as the '<u>Aure-Lamari minimum</u>'.

This 'Aure-Lamari minimum' is most probably a reflection of the break in the crystalline backbone of Papua and New Guinea and of the marked change in the structural grain which occurs here. I would suggest, therefore, that this minimum is fundamentally an expression of the Purari Orocline and Aure Lineament.

In the area of the Kukukuku Lobe, two distinct north-south trends are outlined by the Bouguer anomalies. These are the 'Delta minimum' centered over the eastern portion of the Delta Embayment, and the 'Kukukuku maximum', which is centered over the southern end of the Kukukuku Lobe. To the east, the 'Kukukuku maximum' is flanked by a somewhat ill-defined gravity minimum, the 'Lakekamu minimum', which trends north-south. On a regional scale, however, Bouguer Anomaly values fall steadily to the east and northeast of the 'Kukukuku maximum' or toward the trough of the 'Owen Stanley minimum'.

It has been pointed-out, that the 'Delta minimum' does not find a satisfactory explanation in terms of a thick Tertiary section, because the Tertiary section is relatively thin over the Delta Embayment. Similarly, the 'Kukukuku maximum' cannot be explained in terms of a thin Tertiary sequence because the Tertiary section attains maximum thickness in the Kukukuku Lobe. As far as the Tertiary rocks are concerned then, the relationships are just the reverse of what would be expected beneath the 'Delta minimum' and the 'Kukukuku maximum'. The 'Delta minimum' and 'Kukukuku maximum' must, therefore, find explanation in the sub-Tertiary geological column. The problem of these gravity-defined features is, thus, directly related to the continuation of Mesozoic and/or older tectonic elements beneath the area of the Kukukuku Lobe.

To the west of, say 145° E longitude, the Mesozoic miogeosynclinal and eugeosynclinal provinces trend directly into the structural trend of the Kukukuku Lobe (refer figure 3-2). The miogeosynclinal province is marked by sediments of the order of 4,000 m.+ thick, while the eugeosynclinal province is marked by sediments of the order of 6,000 m. + to 10,000 m.+ thick. The Kubor and Bismarck Massifs mark positive elements in this geosynclinal system. Basing judgment on the structural trends of the Owen Stanley Ranges and the Kukukuku Lobe, it is reasonable to expect that the main elements of the Mesozoic geosynclinal system must somehow bend rather sharply to the south if they are to be continued through the region of the Kukukuku Lobe. The Mesozoic isopach maps published in the Geol. Soc. Aust. Journ. Vol. 8 (1961, figure 9., p.39) represent the general consensus of opinion as to the continuation of these features through the region of the Kukukuku Lobe. In general, this map suggests that the Mesozoic section thickens rapidly from a relatively high area centered beneath the Delta Embayment (total Mesozoic thickness less than 2,000 m.) to a thickness of over 6,000 m. beneath the Kukukuku Lobe. With this generalized picture, the 'Delta minimum' and the 'Kukukuku maximum' become even more anomalous than when considering the Tertiary section alone.

A pre-Eocene high has been outlined beneath the Delta Embayment (Geol. Soc. Aust. Journ. Vol. 8, p.44, Figure 10) or beneath the 'Delta minimum'. That this high presently exists in some form can scarcely be denied, but evidence that it was a high during early Mesozoic deposition is either lacking or questionable. This high is most probably a late Cretaceous feature which was essentially superposed on the Mesozoic geosynclinal system. This observation is made by the authors of Geol. Soc. Aust. Journ. Vol. 8, but their Mesozoic isopach map, described above, does not make the situation clear. This late Cretaceous-pre-Eocene high falls directly across the trend of the Kutubu Trough (Mesozoic thickness 4,000 m. ±), and trends nearly north-south, or essentially perpendicularly to the main trend of the Mesozoic geosynclinal system. At any rate, Mesozoic non-deposition and/or pre-Eocene erosion have resulted in a Mesozoic section estimated to be of the order of only 2,000 m. ± beneath the Delta Embayment and 'Delta minimum', *i.e.* implying that a section of at least 2,000 m. of Mesozoic sediments were not deposited and/or were eroded from this high relative to the thickness of Mesozoic sediments now present to the northwest in the Kutubu Trough (refer figure 3-2).

The actual thickness of Mesozoic rocks now present beneath the Delta Embayment is extremely important to this discussion, but is not known from direct observation. It is known, however, that rocks of Eocene age directly overlie rocks of Lower Cretaceous age in both the Puri and

Wana wells, *i.e.* indicating that pre-Eocene erosion and/or non-deposition have without doubt occurred in this area. Seismic work has suggested that crystalline basement lies at a depth of about 5,000 m. in the Wana and Puri areas (refer Chapter 2). Knowing that the total Tertiary section is of the order of 3,000 m. in the Delta Embayment, this leaves 2,000 m. ± as the best estimate of the total Mesozoic section now present beneath the Delta Embayment and 'Delta minimum'. By this reasoning, it is not likely, therefore, that the 'Delta minimum' can be accounted for in terms of a thick Mesozoic section, *i.e.* the controlling factor must be either the configuration of the crystalline basement, or a hitherto unforseeable thickening of the Mesozoic section beneath the Delta Embayment. To state it differently, the problem of the nature of the 'Delta minimum' cannot be solved simply by suggesting that the Kutubu Trough turns southward down the axis of this minimum, because the thickness of sediments now present the 'Delta minimum' is the relevant factor.

Turning now to the 'Kukukuku maximum'; if we accept that the configuration of the Tertiary sequence cannot explain this feature, then two basic suggestions can be made.

Firstly, we can assume that the Mesozoic section beneath the 'Kukukuku maximum' is of geosynclinal proportions (say 4,000-8,000 m.) as would be expected from regional relationships. If this is the case, then the 'Kukukuku maximum' could possibly be explained by the combination of a thin to negligible sialic crust and an uplifted portion of sub-sialic (simatic) material beneath the maximum. This would imply that the sialic crust has effectively thinned to zero thickness beneath this thick Mesozoic and Tertiary pile, and in turn would strongly suggest that the trough in which these sediments accumulated was of a tensional origin. A corollary to this suggestion is that if a root is to subsequently form beneath the 'Kukukuku maximum', it could only be formed from sediments and/or sub-sialic mantle material.

The second suggestion that can be made, is that the Mesozoic section is of thin to zero thickness beneath the 'Kukukuku maximum'. For instance, a crystalline massif such as the Kubor Massif may have been present beneath the area of the 'Kukukuku maximum' prior to the thick Tertiary sedimentation in this area. Such a massif may have been responsible for either syn-depositional thinning or post-depositional erosion of the Mesozoic section across this area. If this were the case, we might expect a relative gravity maximum across this area as is the case with the Kubor (and Bismarck) Range. Supposing this to be the case, we would in turn expect that a relatively thick section of Mesozoic rocks is now present to either side of the 'Kukukuku maximum', *i.e.* the difference in the thickness of the Mesozoic section thereby accounting for the Bouguer anomaly pattern. This suggestion is compatible with the presence of the 'Delta minimum' to the west (and 'Muiai minimum' to the east), but it is at variance with the known geology of the Delta Embayment as discussed above. It might be argued, however, that the sub-Tertiary geology of the Delta Embayment changes rapidly to the east of the Puri and Wana areas, where it is known at least to some extent. Specifically, it might be proposed that the pre-Tertiary high beneath the Delta Embayment is sharply bounded to the east of Puri and Wana by the subsurface extension of the Aure Lineament beneath the area of the Delta Embayment. This proposal and its consequences are discussed in the following section.

Either of the aforementioned explanations of the 'Kukukuku minimum', *viz.* (a) that the sialic crust has been thinned, to perhaps zero thickness, beneath this maximum, or (b) that a feature which is tectonically similar to the Kubor Massif possibly exists beneath this maximum, suggests that the area to the east of the 'Kukukuku maximum' probably represents a Mesozoic tectonic environment which is similar to that proposed for the area to the north of the Kubor Massif. The Bouguer anomaly pattern, therefore, indicates that the 'boundary' between the Mesozoic mio- and eugeosynclinal provinces extends at present, either down the trend of the 'Kukukuku maximum' ("b" above), or perhaps to the west of this ("a" above). Broadly, this conclusion is compatible with the earlier deduction that the southwest flank of the Owen Stanley Ranges is analagous with the northern flank of the Bismarck Range. In turn, this would suggest a probable continuation of the tectonic environment represented by the Bismarck Range down the trend of the "Kratke Metamorphics" and (?) the Tauri Anticlinorium.

3.4 THE MAJOR TECTONIC ELEMENTS IN THE REGION OF THE PURARI OROCLINE; AND THEIR DEVELOPMENT

The Tertiary history of the Kukukuku Lobe is very complex and not completely understood. If a broad outlook is adopted, however, a relatively simple pattern emerges.

The development of the Purari Orocline is held to be the most important factor in the tectonic evolution of this region. Basically, four major tectonic elements can be recognized and traced through the Tertiary development of the ~~Purari~~ Orocline. These elements are:

(1) a shelf area, the Puri Shelf, situated to the west of the Aure Lineament.

(2) a trough area, the Aure Trough, with its north-south axis approximately down the center of the Kukukuku Lobe,

(3) a tectonically active eastern margin of the Aure Trough, the Kapau Margin, and

(4) The Aure Lineament.

These elements were not static in their development but show a definite pattern of migration through time and space which records the overall development of the Purari Orocline. A review of the first three of these elements in their regional context will be helpful at this point.

3.4.1 THE PURI SHELF

The term Puri Shelf is a new term which is introduced as a name for the area to the west of the Aure Lineament where Tertiary rocks were deposited at one time or another in a shelf facies. The name is taken from the Puri area where Lower Miocene and Eocene rocks are developed entirely in a limestone facies.

The rocks of the Puri Shelf are typically developed in a thin (1,000 m. ±) limestone facies. The limestones may be either shallow water, shoal-type limestones or/and more argillaceous, pelagic-type limestones. In the Middle and Upper Miocene rocks to the south of the Purari River, the 'shelf' facies is still thin, but is dominantly argillaceous with thin developments of marls and calcareous sandstones.* Hiatuses occur in the Tertiary limestone succession of the Puri Shelf, *e.g.* as between the Eocene and Lower Miocene rocks of the Puri area, but nowhere have angular unconformities been found. Shelf deposition was evidently more continuous to the north, because ~~as~~ rocks of Oligocene age are common in the Bismarck area (300 m. ±; Rickwood, 1955; McMillan ~~Mcmillan~~ and Malone, 1960) but ~~whereas~~ they are generally of patchy occurrence or absent to the south of the Kubor Range. This is probably due to a combination of both erosion and non-deposition to the south of the Kubor Range (APC Rept. LW).

The northern edge of the Puri Shelf can be mapped approximately. It shows a reasonably steady southward migration from Eocene time onwards (refer figure 3-7), being progressively replaced by a trough facies from north to south (refer next section). By comparing figure 3-7 with ~~to~~ figure 3-2d, it can be seen that this is directly opposite to the Mesozoic trends established by Smith (1964), *i.e.* the shelf environment

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* This is probably a reflection of the increased amount of clastic detritus being brought into the shelf area at this time from the rapidly rising mountains to the north and east.

migrated northward during the Mesozoic.

The causes of the northward migration of the Mesozoic shelf environment have been briefly discussed and have been attributed to some combination of in-filling and <u>epeirogenic uplift</u> of the Mesozoic miogeosynclinal province and to a northward translation and extension of New Guinea. ~~These phenomena, in turn, are perhaps related to the suspected late Cretaceous (say, pre-Senonian) metamorphism and ultrabasic emplacements of the (?) Northern Coastal Ranges and Owen Stanley Ranges, but the relationship is not certain.~~ At any rate, the early Mesozoic geosynclinal cycle essentially came to a close in the late Cretaceous and the geosynclinal area to the south of the North New Guinea Boundary was replaced by a carbonate platform early in the Tertiary. To this extent, then, the Puri Shelf is a superposed feature which developed somewhat independently of sub-Tertiary geology. Except for the Eocene and Oligocene extension of the Puri Shelf into the Bismarck Range, however, the Puri Shelf was confined to the early Mesozoic miogeosynclinal province. From the Eocene onward, this platform area was broken up progressively from north to south, and consequently, the Puri Shelf migrated southward.

3.4.2 THE AURE TROUGH

The Aure Trough is formed by a compound system of, largely fault-defined, sedimentary troughs. These troughs, and therefore, the Aure Trough as an integral feature, reveal a definite pattern of development; the troughs in the area to the west of the Aure Fault becoming <u>progressively younger toward the south</u>, while the troughs in the area of the Kukukuku Lobe become <u>progressively younger from east to west</u> across the area.*

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* It should be noted at this point that an extraordinary thickness of Lower Miocene limestones (3,000 m.) developed in a narrow, linear trough in the Delta Region of southwest Papua. This trough, the Omati Trough (Geol. Soc. Aust. Journ. Vol. 8), is not a part of the Aure Trough, however, and does not 'fit', either spatially or temporally with my analysis of the Aure Trough.

The rocks of the Aure Trough consist typically of fine- to coarse-grained, volcanic sandstones, mudstones, conglomerates and thin, pelagic limestones. Lavas, agglomerates and tuffs occupy an important part of the section on the south flank and at the southeast end of Bismarck Ranges, and have been recorded along the eastern margin of the Aure Trough in the area of the Kapau and Langimar rivers. Primary tuffs probably occur in most of the sections of the Aure Group examined in detail in this thesis, but lavas and agglomerates are conspicuously absent. It is worthy of note, that no volcanics (aside perhaps from volcanic ashes and tuffs) have been reported from the Tertiary sections to the south of the Kubor Range, *i.e.* from the region which corresponds to the pre-Tertiary miogeosynclinal region. This statement is, of course, excluding the extensive Plio-Pleistocene volcanism of western Papua.

A cumulative section, taking the maximum thickness of each Tertiary age-group recognized, would be roughly of the order of 15,000 m. to 18,000 m. thick in the area of the Aure Trough. This is an unreal picture, however, as individual age groups rarely, if ever, seem to have had the same depositional axis as either the preceding or subsequent age group. The concept of a cumulative section does, however, serve to profoundly illustrate the fact that the area of the Aure Trough was consistently an area of marked subsidence during the Tertiary. Coupled to this, the sections present in the Aure Trough are entirely marine, except for minor occurrences of non-marine rocks of Pliocene age and, for the most part represent relatively deep-water sequences with mainly pelagic foraminiferal associations. From this type of argument, it has been concluded that the Aure Trough did not merely passively subside beneath the weight of the incumbent sediments, but that it was the site of independent, active tectonic subsidence as well.

The Aure Trough is basically a large fault-controlled depositional trough, which was formed by a compound series of lesser fault-troughs. The faulted nature of the Aure Trough is shown particularly well in the

Pio-Purari area, in the configuration of the Karova Trough and in the Kapau River area. There are no broad areas of transition between the shelf facies of the Puri Shelf on the one hand and the trough facies of the Aure Trough on the other. Instead, the shelf facies changes abruptly to a trough facies, and this change is accompanied by a rapid thickness increase toward the trough. This, more generally, is indicative of the faulted nature of the Aure Trough.

The combined importance of sustained subsidence and faulting suggests that tensional ~~normal~~ faulting controlled the formation of the Aure Trough. It is concluded, therefore, that <u>the Aure Trough is fundamentally a fault-trough</u>, or more precisely a series of fault-troughs, which was <u>formed by extensional stresses in the earth's crust</u>. The pattern of development of the Aure Trough is the subject of subsequent discussions.

It has been shown that the site of maximum deposition within the Aure Trough was not static through the Tertiary. Instead, during the Tertiary the axis of deposition shifted progressively southward in the area to the west of the Aure Lineament, and progressively westward in the area to the east of the Lineament. This relationship is shown in figure 3-8. Figure 3-8 should be compared with ~~to~~ figure 3-7, which shows the southward migration of the Puri Shelf. From the pattern illustrated in figure 3-8, it would be expected that the thickest development of Eocene rocks to the southeast of the Aure Lineament would occur along the western and southwestern margin of the Owen Stanley Ranges. This is what is indicated from the regional summary presented earlier and, consequently, the late Cretaceous-Eocene trough has been drawn in this somewhat hypothetical position.

Judging from the continuity of the Upper Cretaceous (Senonian) and early Tertiary sequences, both on the north flank of the Bismarck Range and on the southwest flank of the Owen Stanley Ranges, and because these rocks fit well into the pattern of development of the Aure Trough, it can be suggested that the Aure Trough had begun development by Upper Cretaceous time. The problem is not simple, however, and it is difficult to say firstly, that the Aure Trough had not begun development earlier and secondly, that the late Cretaceous-early Tertiary sequence on the north flank of the Bismarck Range is not more closely related to the regional development of the North New Guinea Province. Because both the Aure Trough and (but perhaps to a lesser degree) the North New Guinea Province are essentially young discordant features that have displaced and disrupted the pre-existing geosynclinal framework, it is probable that initial development of these features was coeval. Because we know that the initial development of the North New Guinea Province was not earlier than the Upper Cretaceous, and because either the Aure Trough and/or the North New Guinea Province was in existence ~~in~~ during the Upper Cretaceous, it can be tentatively suggested that the initial development of both of these features occurred during the Upper Cretaceous. It then becomes a problem to decide how the pattern of development of the Aure Trough is related to that of the North New Guinea Province. This problem is discussed in a subsequent section.

A hypothetical pattern that reasonably approximates and explains the configuration of figures 3-7 and 3-8 is offered in figure 3-9. In figure 3-9, the axis of sedimentation of each individual age group is considered the axis of a tensional fault-trough, or tensional opening. This pattern reflects the configuration of the Purari Orocline, and the development of the Aure Trough can, therefore, be considered as a mechanism by which the Purari Orocline has formed.

3.4.3 THE KAPAU MARGIN

In addition to the individual trough elements that can be recognized within the Aure Trough, a tectonically active eastern margin can be recognized throughout the development of the Aure Trough. This feature can be outlined with a fair degree of certainty in the lower Kapau River area, and the term Kapau Margin has been adopted for this reason.

In the early Lower Miocene, a structural high to the east of the Kapau River area supplied coarse conglomeratic material to the Hells Gate Group. This source contained rocks of Eocene and Cretaceous age, as well as metamorphic rocks (which may, partially, be of the same age). This high area was possibly related to the (?) Oligocene folding of the Port Moresby area and/or the low-grade metamorphism of the Eocene and Cretaceous rocks along the southwest flank of the Owen Stanley Ranges. The unconformity at the base of the Hells Gate Sub-Group is probably related to this early Tertiary deformation, and the Yuyebba Creek Beds of Oligocene to early Lower Miocene age were possibly included in this early deformation.

Prior to and during the deposition of the Hells Gate Sub-Group then, an uplifted and probably folded area containing Cretaceous, Eocene and (?) Oligocene rocks, was exposed on the east side of the Aure Trough and formed the eastern margin of the trough. This is the earliest positive evidence of the Kapau Margin. From this time onward, it can be shown that the Kapau Margin migrated steadily westward across the Aure Trough.

In a similar manner, the Tauri Anticlinorium formed the eastern margin of the Aure Trough during late Lower Miocene to early Middle Miocene deposition. The main folding of the Tauri Anticlinorium probably occurred during late Lower Miocene time, or perhaps very early in the Middle Miocene.

During the late Middle Miocene, the Dude-Murua Anticlinorium was folded and uplifted and formed the eastern edge of the Aure Trough. From the late Middle Miocene to the Pliocene, this tectonically active eastern margin moved steadily westward across the Vailala River and Purari River area in the form of the ? McDowal, Bevan and Kuku Faults.

It can be seen, therefore, that the Kapau Margin progressed westward across the Kukukuku Lobe from the very early Tertiary to the Pliocene. The uplifted and folded areas that mark the Kapau Margin gradually coalesced during this time to form the uplift now called the Kukukuku

Lobe. It should be mentioned at this point, that with the uplift of the Tauri Anticlinorium, the Muiai Trough was initiated on the east side of the uplift and developed through Middle Miocene to Recent times somewhat independently of the development of the Aure Trough to the west.

Broadly, a similar, but in this case southward progression of folding and uplift can be traced in the area to the west of the Aure Lineament.

In the Finisterre-Saruwaged Range, and in the Lamari River area at the southeast end of the Bismarck Range, there is an angular unconformity between the early and late Lower Miocene, which indicates that folding and uplift occurred in these areas prior to the late Lower Miocene. But, while subsidence seems generally to have continued throughout most of the Tertiary in the Finisterre area, to the south there are no rocks of Middle Miocene age known between the Anuna Fault and the Bismarck Range to the north. Here, rocks of Lower Miocene age are overlain unconformably by thin Pliocene volcanics (Aifunka Volcanics) and Quaternary sediments. Further, the late Lower Miocene of this area seems to represent a shallow-water depositional environment. This indicates that the uplift which began in this area during the late part of the early Lower Miocene continued for the most part through late Lower Miocene deposition. Similarly, along the regional strike to the west, rocks of Middle Miocene age possibly occur to the north of the Kubor Range in the Lai Syncline but, again, these rocks are of a shallow-water to paralic facies (Rickwood, 1955 p.77-78). It seems probable that, if deposited at all, only a thin sequence of Middle Miocene rocks was deposited to the north of the Kubor Anticline, and certainly the main development of rocks of this age was to the south of the Kubor Anticline and to the north of the Bismarck Range. This suggests that uplift and erosion were the dominant factors to the north of the Kubor Anticline after the Lower Miocene. This uplift corresponds to the coarsening of the sediments in the North New Guinea Province after the early Lower Miocene. ~~"e" stage deposition.~~

~~That~~ The uplift

of the Central Ranges continued and steadily progressed southward during the Upper Miocene and Pliocene as is well shown by the present distribution of these age groups and by reconstructed isopach and lithofacies maps for these age groups. These rocks have been strongly folded and faulted by late Miocene and Pliocene deformations in the Purari River area.

There is demonstrated, therefore, a southward migration of uplift and tectonism during the Tertiary, progressing from the early Lower Miocene deformation in the Finisterre and Bismarck area to the Pliocene deformation in the Purari River area. This corresponds to the Kapau Margin in the area to the east of the Aure Lineament.

An additional point should be noted. Firstly, the Bismarck Range was a marked high area during the deposition of the early Lower Miocene sediments and supplied abundant, coarse conglomeratic material to these rocks. The uplift of the Bismarck Range during early Lower Miocene deposition, therefore, fits generally into this pattern of early uplift toward the north and may, in fact, be the earliest and northernmost uplift in this pattern of southward migrating uplifts. ~~that affected the Aure Trough~~. The difficulty with placing the initial early Lower Miocene uplift of the Bismarck Range into this pattern is firstly, that the Bismarck Range is known to have been a relatively high area much earlier (pre-Lower Jurassic and probably later as well), and secondly a younger early Lower Miocene uplift is known to the north in the Finisterre area. In other words, the pattern of southward migrating uplift may not be as simple as I have indicated. As pointed out, however, the Finisterre area differs from the area to the south of the Bismarck Range in that ~~it~~ the Finisterre area remained an area of general subsidence throughout most of the Tertiary. Perhaps then, it would be best to consider the Bismarck Range as the northernmost limit of the pattern that is demonstrated in preceding paragraphs, and to regard the Finisterre area as an independent area. An alternative, and favored way of viewing the problem is to consider the Bismarck Range as basically an older positive element, the uplift of which was merely enhanced during the ~~"e" stage~~ early Lower Miocene by the southward migrating progression of Tertiary uplifts.

Related to this problem is the uplift of the Kubor Range, which is also known to have been a relatively positive area during the Mesozoic. It is worthy of note, that conglomeratic material derived from the Kubor crystalline rocks is concentrated in the late Lower Miocene to either side of the Kubor Anticline. This suggests that the Tertiary uplift of this range became important near the end of the early Lower Miocene, which is later than the earliest Lower Miocene uplift of the Bismarck Range. This then possibly fits into the pattern of Tertiary uplift in the same manner as does the Bismarck Range, *i.e.* the southward migration of Tertiary uplift merely enhanced the positive nature of this older massif.

The southward migration of uplifts to the west of the Aure Lineament, and the westward migration of the Kapau Margin are depicted in figure 3-10. By comparing figure 3-10 ~~to~~ with figure 3-8, it can be seen that the successive uplifts essentially correspond to the axis of sedimentation for the preceding stage. This reveals a direct relationship between these features. This correlation is expressed more broadly in the present morphology of Papua and New Guinea with respect to the Tertiary Trough. The briefest scrutiny of the map (see Plate III) reveals that the greatest uplift has occurred over the site of the Tertiary trough, whereas the area which persisted as a shelf environment throughout the Tertiary now forms the great low lying delta regions of southwest Papua. ¶ It is important to observe that while uplift and folding were occurring in any one area, subsidence and the deposition of thick conformable sedimentary sequences were occurring contemporaneously in the adjacent trough areas to the south and west. The adjacent trough areas were not folded until a later stage. This relationship is shown diagrammatically in figure 3-11. Such relationships make it difficult to explain the uplifted and folded areas simply in terms of regional compressive stresses alone, and it would seem that relatively local stresses, which resulted primarily in vertical movements, provide the best solution for these localized folded-uplifts. In addition, we have to consider the fact that the localized uplifts have consolidated to produce an absolute regional uplift. In other words, once a localized uplift became established, it remained uplifted and participated in the overall regional uplift which has continued to the present.

The Tertiary history of any one area to the south of the Bismarck Range or west of the Owen Stanley Ranges can now be summarized as follows:

(1) General subsidence, followed by;

(2) Strong local subsidence (with less intensive and more general subsidence continuing to the west or south), followed by;

(3) Uplift and folding, which has been followed by;

(4) Continued uplift to the present, accompanied, to some degree by folding.

To the north of the Bismarck Range, the Finisterre-Saruwaged Range seems to have generally remained an area of subsidence throughout most of the Tertiary, although repeated folding and uplift occurred as is evidenced by the unconformities of post Lower Miocene age in this area (refer section 3.1.3).

Generalizing, the North New Guinea Province as a whole was characterized mainly by a net subsidence throughout most of the Tertiary and, in this respect, forms a marked contrast to the area of the Central Ranges, ~~to the south of the Bismarck Range,~~ where Tertiary tectonic movements have resulted in the net uplift of the region.

3.4.4 SUMMARY

Three principal tectonic elements are recognized in the late Cretaceous-Tertiary development of the Kukukuku Lobe and adjacent areas. These are the Puri Shelf, the Aure Trough and the Kapau Margin. These features show a directional development through time, becoming younger toward the south in the area to the west of the Aure Lineament, and younger toward the west in the area of the Kukukuku Lobe to the east of the Aure Lineament. The development of these features records the secular development of the Purari Orocline.

The Aure Trough is believed to be basically a fault-defined, tensional trough, which developed from north to south and east to west as a series of lesser, tensional fault-troughs. It will be expected, therefore, that the sub-Tertiary foundation on which the Aure Trough formed will have been thinned beneath this trough.

The southward migration of the Puri Shelf is taken to reflect the southward development of the Aure Trough, *i.e.* the southward progression of tensional faulting determined the northern edge of the Puri Shelf. Arguing by analogy, it might be expected that the Puri Shelf once extended into the present area of the Kukukuku Lobe to the east of the Aure Lineament. If this were the case, it would be expected, in turn, that this feature will have migrated westward through time. This proposal is depicted in figure 3-7.

The Kapau Margin was formed by successive, rather localized folded-uplifts, which are progressively younger toward the west. These uplifts consolidated through time to produce the Kukukuku Lobe as we presently see it. Local uplift and folding followed one phase behind local trough formation, affecting primarily the preceding axis of strongest subsidence. As uplift and folding proceeded in ~~the~~ one area, *e.g.* the Tauri Anticlinorium, subsidence and trough formation proceeded contemporaneously in the adjacent area to the west, *e.g.* the Karova Trough. A broadly similar sequence of events is recognized in the area to the west of the Aure Lineament, but in this case the folding and uplift progressed from north to south across the region.

3.4.5 INTERPRETATION

Having recognized the Puri Shelf, Aure Trough and Kapau Margin as three of the principal tectonic elements of the Kukukuku Lobe, the basic features which require explanation are:

1) The tensional nature of the Aure Trough

2) The net uplift of the region

3) The localized, folded-uplifts of the Kapau Margin and similar features to west of the Aure Lineament

4) The secular, directional development of each of these elements.

A. THE TENSIONAL NATURE OF THE AURE TROUGH

Figure 3-9 depicts what I regard as the basic configuration of the Aure Trough. The proposed configuration is most probably too simplified and, certainly, later and lesser deformations have somewhat distorted the original configuration (refer Chapter 2; later this chapter). The important point is that this general configuration seems to be the most fundamental in the Tertiary tectonic history of the Kukukuku Lobe, and most of the lesser order deformations of the Kukukuku Lobe seem to have been controlled by this basic framework. The essence of this interpretation is that the individual thickness maxima are regarded as marking the axis of tensional fault-troughs. These fault-troughs are thought to have originated as normal faults, which were opened by dextral transcurrent movements such as revealed in the examination of the Aure Lineament. It is suggested that the block to the west of the Aure Lineament has moved northward (and is probably still moving) at a more rapid rate than the block to the east, and that the block to the east of the Aure Lineament has been rotated and dragged by the western block. The implications of this suggestion are discussed later (refer section 3.4.6).

It is thought that the proposed configuration explains particularly well the position of thickness maxima in areas adjacent to the Aure Lineament, *e.g.* the Lower Miocene maximum to the south of the Bismarck Range, the Middle Miocene (?) maximum in the Tsoma River area and the Upper Miocene and Pliocene maxima in the Purari River area. This is because the tensional opening in the troughs should have been both earlier and greater the closer an area is situated to the Aure Lineament.

The Tensional Origin Of The Aure Trough With Respect To Distribution Of Volcanics And Intrusions, And Implications As To Crustal Section

The increased importance of volcanics and Tertiary intrusions in sections closest to the Aure Lineament should be noted, *e.g.* compare the Lai Syncline section to the Lamari River Area, and I believe this is partially a result of the increased amount of extension toward the Aure Lineament. ~~Extending~~ Pursuing this observation, it would be expected that volcanics and Tertiary intrusions will be important in the Tertiary sections to the east of the Aure Lineament in the univestigated northern regions of the Kukukuku Lobe (Kratke Range). This problem is complicated somewhat by two considerations. Firstly, the area to the east of the Aure Lineament has been affected by tectonic stresses somewhat different from those which have affected the area to the west of the Lineament. The area to the east of the Aure Lineament seems to have been subjected to a considerable compressive stress that has not affected the western area to the same degree. This is a separate problem, however, and is discussed subsequently.

The second consideration that bears on this proposal involves the kind of crustal foundation on which the various parts of the Aure Trough have developed. The most striking observation which can be made in this respect is that nowhere to the south of the Kubor Range and west of the Aure Lineament have volcanics been recorded from any part of the section (excluding perhaps tuffs and ashes and the Plio-Pleistocene volcanics of western Papua and New Guinea), whereas they are common to

<u>the north</u>. This suggests that the crustal section beneath the area to the north of the Kubor Range (and Kubor Anticline) is different from the crustal section to the south of this range. I have suggested that the Kubor Hinge effectively marked the northern edge of the Australian continent during most of the Mesozoic. From this, I then suggested that volcanics could more easily have been introduced to the Mesozoic sections to the north of the Kubor Hinge, and this suggestion would, presumably, apply to the Tertiary sections to the north of the Kubor Range. Further, although Tertiary intrusions (mostly basic) are common in both the Kubor and Bismarck Ranges, the amount of Tertiary intrusives in the Lamari River area is striking. It is relevant that neither Mesozoic nor Tertiary intrusives have been recorded in the area to the south of Kubor and west of the Aure Lineament (again, excluding the Plio-Pleistocene volcanoes and minor intrusives of uncertain age in the vicinity of Mt. Michael).

Together, the distribution of both volcanics and intrusives suggests that the crustal section is exerting the primary control on these phenomena. A secondary control relating to proximity to the Aure Lineament is indicated, however.

From the point of view of estimating the type of crustal section that underlies the Kukukuku Lobe, the occurrence of volcanics <u>across the strike</u> of the Kukukuku Lobe is extremely important. In as much as the trends to the east of the Aure Lineament are regarded as having been rotated and dragged into their present configuration, and for reasons discussed elsewhere (refer section 3.4.6), it is reasonable to suggest that a feature of tectonic significance similar to that of the Kubor Hinge presently exists somewhere beneath exposure in the Kukukuku Lobe. Simply by analogy, the supposed southward extension of the Kubor Hinge will have been important in determining the distribution of volcanics within the Aure Trough. This suggestion will probably hold true, also, for the distribution of volcanics in whatever Mesozoic sections might occur beneath the region of the Kukukuku Lobe. The problem gains import from my suggestion that the Kubor Hinge marked the edge of the Australian continent during the Mesozoic. If this is acceptable, and providing that the Kubor Hinge can be recognized in the region of the Kukukuku Lobe, then we may make a reasonable prediction as to the type of crustal section on which the Aure Trough was formed.

The known occurrences of volcanics to the east of the Aure Lineament are critical to this problem, and a brief summary of these occurrences will be helpful. Volcanics of Miocene (?Lower) age have been reported on the west flank of the Owen Stanley Ranges in the upper Langimar and upper Kapau River areas and are important in sections of (?) Eocene to Pliocene age along the southwest flank of the Owen Stanley Ranges (refer section 3.2.1). Further, numerous intrusions (post-Eocene) have been recorded in sections on the southwest flank of the Owen Stanley Ranges (refer 3.2.1). It is partially for these reasons that I have regarded the Owen Stanley Ranges and the 'Southwest Flank Basin' as genetically similar to the North New Guinea Province, *i.e.* similar to the area to the north of the Bismarck Range. Minor volcanics are present in the Middle Miocene Be Creek Beds on the Tauri anticlinorium and volcanic conglomerates of similar age are present in the Muiai Syncline. Judging from this then, the hypothetical continuation of the Kubor Hinge would lie to the west of the Tauri Anticlinorium.

Proceeding now with a slightly different kind of argument, the occurrence of huge boulders (2 m. to 3 m.) of volcanics, metamorphics and granitic 'basement' rocks in the conglomerates of the Morai River Formation becomes extremely significant. These boulders suggest firstly, that primary lavas and/or intrusives were present in a very near source area and secondly, that 'basement' rocks were very close at hand and within the reach of erosion. The mere presence of volcanics would suggest a tectonic environment similar to the north side of the Kubor Range, and the 'basement' rocks would suggest a possible derivation from a massif similar to Kubor, over which pre-Morai River Formation rocks had been thinned, either by erosion and/or non-deposition, so as to expose 'basement'. The argument can be extended in that Lower Miocene through Upper Miocene sections of the Vailala River areas seem to require a southerly or southwesterly source for derived 'basement', Cretaceous and Eocene material. For these reasons, it is suggested that a feature similar to the Kubor Hinge does extend beneath the area of the Kukukuku Lobe, and that it most probably lies in the subsurface somewhere to the west of the 'Kukukuku maximum'.

The exact position of the Kubor Hinge thus extended must, of course, remain a matter of speculation, even if the reasoning thus far presented is entirely acceptable. My opinion is that the eastern or northeastern edge of this feature is generally coincident with the steep western edge of the Karova Trough, *i.e.* with the general line of the Yanne'ia Anticline. This opinion is offered for three reasons. Firstly, it offers a reasonable explanation for the sudden shelving of the Karova Trough toward the west. Secondly, it allows for the possibility of a structural rise of the Kubor Hinge toward the southwest to provide a source area. Finally, it would provide a reasonable explanation for the supposed shelving within the Lower Miocene stages to the south and west of Kariava. This proposal must be regarded as an over simplification because the recognition of this trend is based mainly on speculation, and because later features such as the Er Trend and the Coastal Trend (refer Chapter 2) have most probably displaced the older trends in this region to some extent.

Consequences of the proposed continuation of the 'Kubor Hinge' can be listed as follows:

1) It will be expected that a thick Mesozoic miogeosynclinal succession exists to the southwest of this trend, and that a thick Mesozoic eugeosynclinal section exists to the northeast.

2) I regard it unlikely, therefore, that the 'Kukukuku maximum' is to be explained in terms of a thin Mesozoic section, and it is suggested that a sialic crust of zero effective thickness is basically the most likely explanation of the gravity maximum. From the aforegoing reasoning, this might be expected for two reasons:

   (a) The pre-Mesozoic sialic crust was probably thin beneath this area, and the effect of Tertiary fault-trough formation would have been to thin the sialic crustal section even more.

   (b) The Karova Trough probably represents the greatest cumulative section of the Aure Group, primarily by virtue of the great thickness of Middle Miocene rocks present here. It is perhaps significant, therefore, that the 'Kukukuku maximum' falls over the area of thickest accumulation of the Middle Miocene stage.

3) The suggested continuation of the Kubor Hinge beneath the Kukukuku Lobe almost certainly requires dextral offset of this feature by the Aure Lineament if it is to match-up with the Kubor Anticline (amount of offset unknown).

4) By virtue of exclusion, it is in order to suggest that the Bismarck Range (Bismarck Massif) finds a probable continuation in the "Kratke Metamorphics" and Tauri Anticlinorium. This probably requires a dextral offset of these trends of about 40 kilometers across the Aure Lineament.

   (a) By analogy with the Bismarck Range, it might be expected that the shelf facies of the Eocene originally extended as far eastward as the "Kratke Metamorphics" and Tauri Anticlinorium. This proposal is depicted in figure 3-7.

B. ISOSTATIC BEHAVIOR OF THE AURE TROUGH THROUGH TIME

The mechanism proposed for the origin of the Aure Trough, *i.e.* by a sequential development of tensional fault-troughs, provides an inherent reason why subsequent uplift should occur in this region and, in turn, requires that a mechanism be available to produce this uplift.

As nearly as can be judged, the width of the individual fault-troughs of the Aure Trough is of the order of thirty 30 to forty 40 kilometers for the older troughs, *e.g.* the Kariava Trough, and about ten to twenty 20 kilometers for the younger troughs, *e.g.* the Upper Miocene to Pliocene Purari Trough. On the average, each trough accumulated sediments of at least of the order of 6,000 m. to 8,000 m. thick, before being raised to a level of continuous erosion. As we nowhere have recognized both the top and bottom of a continuous Tertiary sequence in any of the troughs, and because sections of the order of 6,000 m. are exposed in several places, *e.g.* the Yaveufa Syncline, M'bwei Sa section and Murua River section, it is not improbable that thicknesses of the order of 10,000 m. accumulated in some of these troughs, *e.g.* the Karova Trough. This would represent a substantial negative isostatic load on the earth's crust, but, because of the limited size and relatively short life of these troughs and because the regional stress seems to have been tensional during their formation, it is highly improbable that the individual troughs would have developed in local isostatic equilibrium.

Carey (1957) has suggested a mechanism by which crustal rifting and concomitant isostatic compensation can occur (refer figure 3-12; taken from Carey, 1957, figure 3, p.184). From figure 3-12, it will be noted that the widening rift is compensated by crystalline flow of the sub-sialic crust toward and upward beneath the rift zone. This mechanism is thought to be generally applicable to the formation of the Aure Trough, as described below.

It has been observed that the component troughs of which the Aure Trough is formed would each have represented a substantial negative isostatic load on the earth's crust. That such a load could not long exist (and particularly in a regional tensional stress field) is shown by features such as the rapid post-glacial isostatic rise of Fennoscandia and a similarly rapid isostatic rise of the bed of Lake Bonneville after the lake had drained. However, while the limited size of the component troughs most probably would not have permitted these troughs to develop in local isostatic equilibrium, the negative load of each trough would have caused almost immediate isostatic compensation on a regional scale, *i.e.* a regional upward bulge of relatively dense sub-crustal material would have occurred to compensate for this negative load, as shown in figure 3-12. With both the passage of time and the accompanying increase in the size of the Aure Trough, isostatic compensation would have tended to become increasingly local both with respect to the individual troughs and with respect to the continually growing Aure Trough as a whole. The larger the Aure Trough became, the greater would have been the tendency for the trough as a whole to develop in isostatic equilibrium. Stated differently, the earliest-formed component of the Aure Trough could have formed with the greatest departure from local isostatic equilibrium and the last-formed with the least departure. The second-formed trough, by increasing the negative load, would have caused a greater tendency for the first-formed trough to compensate locally and, similarly, the third-formed trough would have increased the tendency for the first- and second-formed troughs together to compensate locally.

The allowed, or necessary time-lag between the early-formed troughs and the local isostatic compensation of these troughs is the factor that requires the subsequent uplift of these sedimentary troughs. The negative load, itself, arises from the fact that water and sediments fill the newly formed rift, effectively replacing a pre-rift crust of presumably greater density. The need for subsequent uplift arises because the troughs were formed and filled at a rate too rapid for local compensation to occur. By way of example, we can assume for simplicity that the pre-rift crust is formed of homogeneous sialic crustal material with a density of 2.90 and with its upper surface at sea level. Further we can assume a sub-sialic crustal density of 3.30. Now, if a rift trough is formed in the sialic crust at a rate too rapid for local isostatic adjustment to occur, and is completely filled with ten kilometers of sediment with an average density of 2.50, then to achieve complete local isostatic compensation an equivalent volume of sub-sialic crust would subsequently have to rise five kilometers beneath the trough and, presumably, uplift the sediments by this amount. More generally, the amount which the sub-sialic crust must rise to achieve local compensation would be greater or less, depending on whether the sediment to sial density ratio is respectively less than or greater than the sial to sub-sial density ratio. Further, if the rift troughs do not fill to sea level, then the density contrast is increased, the negative load is greater and, therefore, the sub-sialic crust must be raised even higher than if the troughs are completely filled with sediment. This same effect is caused by erosion of the uplifted sediments of the early-formed troughs, which effectively increases the negative load and, therefore, requires more compensating uplift than was initially the case.

The uplift resulting from isostatic compensation, as described above, should have been controlled by fault-trough formation, with uplift being greatest in the region where the fault-troughs developed with greatest disparity from isostatic equilibrium, *i.e.* in this case in the area of the oldest troughs. That this is true, at least to the first approximation, can be seen by comparing the outlines of the Aure Trough with the present morphology of Papua and New Guinea (refer Plate III). Further, if this mechanism is valid for the area of the Aure Trough, the uplift should show a directional development that is consistent with that of the trough development but which follows a phase behind it. That this is the case has been shown in preceding discussions. This mechanism then, offers an explanation for the southward and westward migration of regional uplift in the areas to the west and east of the Aure Lineament respectively. Isostatic compensation may, in fact, have been the dominant mechanism of uplift to the west of the Aure Lineament, but regional compression is held to have been important as well in the area of the Kukukuku Lobe.

As mentioned above, the initial formation of the Aure Trough would most probably have been accompanied by a gentle, regional compensating uplift. Through time, and with the growth of the Aure Trough, local compensation would have tended to replace regional compensat~~ory~~ion ~~movements~~ and, most probably, would have caused subsidence of these previously arched areas. Such features are perhaps expressed physically by geological events which have occurred in this region.

If it can be assumed that the Aure Trough was initiated during the late Cretaceous (Senonian) in the area to the north of the Bismarck Range, then the late Cretaceous to Lower Miocene gentle oscillations and subsequent gentle subsidence which occurred to the southwest in the region of the Puri Shelf, *viz.* the Wana Swell (Geol. Soc. Aust. Journ. Vol. 8) may be partially accounted for by this mechanism. Related to this, active erosion in the area of the Purari Faulted-Anticlinorium at various times during late Eocene to Middle Miocene deposition may in part be accounted for by the "tilted rim" mechanism of Carey as illustrated in figure 3-12. In the same manner, early uplifts to the north, for example the early Lower Miocene high in the Bismarck Range, and the supposed southwestern source area in the Vailala-Purari region are, perhaps, related to this mechanism.

The subsidence of the North New Guinea Province, like that of the Aure Trough, is believed to have been caused by crustal extension. This being the case, the mechanism of isostatic compensation here described would presumably apply to the North New Guinea Province. The tilted rim mechanism would, therefore, offer one method of accounting for the uplift and configuration of both the Central Ranges and the Northern Coastal Ranges.

Another broad generalization which may be made is that with increased lateral flow of sub-crustal material toward the rifting zone through time, *i.e.* accompanying the increasing importance of local compensation, subsidence in peripheral regions should have become more pronounced. This mechanism should have combined with the proposed southward migration of tensional faulting to enhance the southward migration of the Aure Trough and clastic transgression of the Puri Shelf.

This analysis leads to an important observation. From gravity data (refer Section 3.3, figure 3-6), the Central Ranges of Papua and the Territory of New Guinea seem to be a 'rooted' mountain chain. The aforegoing analysis suggests that the pre-Aure Trough crust has been thinned by the development of the Aure Trough, and that isostatic compensation should have tended to uplift the relatively dense sub-sialic crust beneath this region. Contrary to a thickening of the sialic crust to form this root, my analysis forces me to suggest that this root has probably formed by the alteration of sub-sialic crustal material.

The problem of rooted mountain chains is of large scope, and a full examination of the problem is not possible in this thesis. A few relevant observations and a tentative suggestion can be made, however.

Firstly, the strongly negative Bouguer anomalies in Papua and the Territory of New Guinea correspond broadly to the area of thick Tertiary sediments, which corresponds in turn to the region of strong Tertiary uplift.

Secondly, although gravity observations are few in the Central Ranges of West Irian, the information available shows that these ranges are the site of <u>positive</u> Bouguer anomalies (Visser and Hermes, 1962; p.184; refer figure 3-13). This has been taken to indicate that the Central Ranges of West Irian are <u>not</u> 'rooted' (*ibid*, p.183), and has led Visser and Hermes to suggest that the Tertiary to Quaternary uplift of these ranges has <u>not</u> been <u>due</u> to the isostatic adjustment of a mass deficiency. In fact, it can be observed from figure 3-13 that the most negative Bouguer anomalies in this region lie in the topographically low area to the north of the Central Ranges and south of the Northern Coastal Ranges.

Thirdly, there is no direct equivalent of the Aure Trough in West Irian. The Tertiary Akimeugah and Iwoer Basins on the south flank of the Central Ranges (refer Section 3.1.1) of West Irian are isolated, shallow-water-to-paralic basins which are separated laterally by extensive carbonate platforms. These basins are separated from the North New Guinea Province by the Central Ranges, which served as a source area for the clastics of the basins. In contrast, the Aure Trough is dominantly a deep-water, pelagic basin which is much more extensive and which dominates the geology of central Papua and the Territory of New Guinea.

With the above three observations as a foundation, and in so far as the strongly negative Bouguer anomalies of this region can be regarded as expressing the existence of a root, it can be suggested that the existence of this root is controlled to a first approximation by the Aure Trough or, perhaps, by the superposed influence of the Aure Trough on pre-existing features. Extending this, the root might in turn be related to the mechanism of isostatic compensation discussed above. This mechanism it will be recalled, advocates the isostatic rise of the sub-sialic crust by some unknown amount, but probably of the order of at least ten kilometers, beneath this region. The uplifted material would have, presumably, been at equilibrium prior to uplift, at a temperature some 300°C higher and a pressure about 2 kilobars higher than in its uplifted position. Perhaps then, the changes attending the adjustment of this material to new equilibrium conditions of lower temperatures and pressures could have been responsible for the formation of a root of lower density.

Finally, superposing the formation of a light root on the mechanism of isostatic compensation discussed above would enhance the amount of isostatic uplift required to balance the negative load of the sedimentary troughs and, therefore, the development of a root could be expected to have caused further regional uplift.

C. LOCALIZED FOLDED-UPLIFTS OF THE KAPAU MARGIN

The localized, essentially independent nature of the folded-uplifts of the Kukukuku Lobe in both time and space has been demonstrated, *e.g.* the Tauri Anticlinorium and the Dude-Murua Anticlinorium. This suggests that vertical movements have been primarily responsible for the configuration of these folded-uplifts. The cause of the vertical movements must now be sought.

In this respect, it is believed that the significance of the 'Kukukuku maximum' (Bouguer anomaly) over the area of the Dude-Murua Anticlinorium cannot be overemphasized. The presence of a positive Bouguer anomaly over this uplifted region of extremely thick sediments, makes it untenable to suggest that the uplift is the result of a density inversion mechanism.

It has been argued that the sialic crust has an effective zero thickness beneath the 'Kukukuku maximum'. Extending this argument, it is now suggested that compressive tectonic stresses have forceably injected part of the sub-sialic crust (perhaps altered mantle material ?) upwards beneath the 'Kukukuku maximum', thereby resulting in both uplift of the Dude-Murua Anticlinorium and the positive Bouguer anomaly over this area.

The 'Kukukuku maximum' is broadly symmetrical with respect to flanking minima, and this again suggests a vertical response to compressive stresses, rather than a simple directed compression from either east or west.

A key to the interpretation of the Kukukuku Lobe and Purari Orocline lies in the recognition of the fact that compressive stresses have been regionally important in this region. By my analysis of the origin of the Aure Trough, this is not to be unexpected.

The Aure Trough is thought to have developed as a sequence of tensional fault-troughs that were opened by a dextral simple shear stress couple and by dextral movement on the Aure Lineament. The block to the west of this lineament has actively moved northward relative to the passive block to the east of the Lineament and, consequently, the eastern block has been rotated and dragged. Therefore, if the interpretation is valid, the original tensional openings on the eastern block inevitably must have been rotated into the compressive stress field of the dextral simple shear stress couple, *i.e.* structural trends striking between 120° and 210° are regarded as being in the compressive stress field of this couple (refer next section). It is suggested, that once a depositional trough was rotated clockwise into a trend more northerly than 300° - 120°, the compressive stress of this simple shear stress couple tended to close and fold the trough, with further clockwise rotation increasing this tendency. The gross structure of the major northerly-trending folds and the general uplift of the Kukukuku Lobe are believed to have been caused by these compressive stresses, *e.g.* the Vailala Synclinorium, Dude-Murua Anticlinorium, Karova Syncline, Tauri Anticlinorium and, probably, the Muiai Syncline. It is proposed, also, that the Tertiary uplift of the Owen Stanley Ranges is a result of this stress system.

The preceding interpretation allows three general observations to be made:

1) Each local fault-trough should have, and seems to have controlled the position of the successive uplifts.

2) This mechanism permits active uplift and folding to occur adjacent to active and contemporaneous tensional subsidence

to the southwest, as seems to be necessary for this region, *i.e.* while one fault trough was actively being rotated and opened by the dextral shear couple, the adjacent and older trough to the northeast, by virtue of having formed and commenced rotation earlier, would have entered the compressive stress field earlier and, presumably, folding and uplift would have been initiated earlier. The proposed mechanism therefore, predicts the position and sequence of folded-uplifts observed in this region.

3) By this mechanism, areas near the Aure Lineament would have been rotated into the compressive stress field earlier than areas further away from the fault. This should have had two, possibly regionally important, consequences:

(a) Uplift and folding should have commenced earlier, and would be expected to be greater, in areas closest to the Aure Lineament, because rotation and drag began earlier and were more severe here. This is, most probably, demonstrated by the overall southerly plunge of the Kukukuku Lobe, by the thinning of Upper Miocene and Middle Miocene stages (east of the Ekiere Fault) toward the north and by the suspected unconformity at the base of the Aure Group on the flanks of the Tuoa Anticline.

(b) From the point of view of depositional history, it will be expected that the youngest beds in any one trough will occur, and attain maximum thickness in areas distant from the Aure Lineament. This condition is possibly realized in the Karova Trough in which the Middle Miocene stage reached its maximum development at the southern end of the Kukukuku Lobe.

D. FOLDING WEST OF THE AURE LINEAMENT

The structural configuration of the region to the west of the Aure Lineament need now be examined. By the proposed interpretation of the Purari Orocline, this region has not been, and should not have been rotated into the compressive stress field of the dextral simple shear stress couple, yet this area has been folded and strongly uplifted. This problem cannot be fully examined in the context of this thesis, but a few brief observations can demonstrate that in addition to a difference in trend, there are other fundamental differences between the structural configuration to the west of the Aure Lineament and that to the east of the Lineament. This is immediately apparent from the gross aspect of the geological map (Plate II) from which it can be observed that:

1) The long, linear fold trends of the Dude-Murua and Tauri Anticlinoria have no direct counterparts to the west of the Aure Lineament. To the west of this lineament the tectonically similar region, at least to a first approximation, between the Kubor and Bismarck Ranges is characterized by large, broad synclines which are of the same order of size as the Karova Syncline and the Vailala Synclinorium, *e.g.* the Kratke, Orolwat and Yaveufa Synclines. These synclines are separated by large faults, and neither well-formed anticlines ~~or~~ nor anticlinoria are ~~absent.~~ present.

2) The extensive metamorphic basic and ultrabasic terrain of the Owen Stanley Ranges has no counterpart (with respect to areal extent of exposure) to the west of the Aure Lineament. To the west of the Lineament, metamorphic rocks, ultrabasic rocks and associated igneous intrusives occur only as narrow, linear belts in the cores of anticlinal mountain ranges, *e.g.* the Kubor, Bismarck and Northern Coastal Ranges. It is inferred from this that uplift has been generally greater in the area to the east of the Aure Lineament.

3) Whereas the area to the west of the Aure Lineament has been both locally and regionally uplifted, old structural highs and lows have not been strongly inverted and retain their inherited structural relationships, *e.g.* the Kubor and Bismarck Massifs relative to the Wahgi and Kutubu Troughs. In contrast, the old trough areas to the east of the Aure Lineament have undergone successive inversion and now represent anticlinorial areas.

Carey (1962) has demonstrated the inherent fallacy in merely <u>assuming</u> that the uplift and deformation of mountain chains necessarily means that regional compressive stresses have been responsible for this deformation. This points to something of a paradox that has arisen in the geological study of New Guinea. Geologists working in the Central Ranges and southern foothill fold belt of western Papua and New Guinea, because of the south-westerly facing of structures in this region, have most commonly attributed this deformation to a compression <u>from the northeast</u> (at random, see Geol. Soc. Aust. Journ. Vol. 8, 1961). In contrast, Visser and Hermes (1962) have concluded from their study of West Irian that crustal shortening and primary thrusting <u>toward the north</u> has been the dominant cause of deformation. It is interesting to note that Visser and Hermes have reached the conclusion of primary northward thrusting in an area where a broad, folded foothill belt is not present on the south flank of the main range.

Figure 3-13 is a cross-section of West Irian as visualized by Visser and Hermes (1962, from figure III - 25, p.184). The northward dipping thrusts on the south flank of the Central Ranges are regarded by Visser and Hermes as "secondary thrusts" (p.183), without further explanation. These authors suggest, also, that because large elevation differences were present during the Tertiary evolution of these mountains (with reference here to the structurally high Central Ranges relative to the flanking Tertiary basins), gravitational gliding away from the uplifted Central Ranges may have been important. They raise an objection to the gliding hypothesis, however, in the form of,

> "However, the observed compressional phenomena (folds and thrusts) in the crestal parts (of the Central Ranges - A.K.) between Tafelberg and Wilhelmina peak are difficult to reconcile with the tension the hypothesis requires in that belt." (p.186)

Further,

> "The fact that two disturbed zones are separated by wide areas of simply tilted beds (southern slopes) or adjoined by flat-lying strata (Weyland Mountains) can be interpreted to mean that, apart from the primary thrusts in the north, the stress was relieved essentially in two main belts - an upper, crestal, thrust belt and a lower one in the foothills." (p.183)

This type of problem has been discussed in Chapter Two and, following Carey (1962), it has been suggested that gravity gliding away from the rising orogen need not result in a tensional gap if the outward gliding is caused by the spreading tendency of a vertically rising mass, *i.e.* what are essentially sub-horizontal gravity thrusts can turn down into the heart of the rising zone.

In addition to this type of lateral spreading, there are yet two other, more surficial, types of lateral spreading. The first is simply gravitational gliding such as Visser and Hermes consider. This type of gliding may be likened in kind to a land-slide, and like a slide such gliding requires a tensional gap at the heel of the slide. This type of gliding has been amply demonstrated in many places, *e.g.* the Bear Paw Range of South Dakota, and as Visser and Hermes suggest may be present in West Irian. This form of lateral spreading results basically from vertical movements, whatever their origin, which generate slopes that are unstable with respect to the viscosity and/or shear strength of the uplifted material. The second type of surficial lateral spreading is due simply to the removal of lateral support, say as in an upfaulted horst, or a horst which has been isolated by down-faulting to either side. Given time and size, such a laterally unsupported block must spread either by faulting or flowage into the structurally low areas to either side. Such behavior has been reasonably demonstrated by Berg (1961) and Wise (1963) in their discussions of the Frontal Ranges of the Rocky Mountains. Any one, or all of these kinds of lateral spreading may occur in large mountain ranges. The essential driving force is gravity coupled to differential vertical movements, and each type of spreading ~~may~~ can occur irrespective of the origin of the vertical movements. In a mountain range such as the Central Ranges of West Irian, which is essentially horst-like in character and is flanked by and thrust over young basins to either side, we might conceivably suggest that this thrusting is due entirely to the mechanisms noted above. We need additional evidence, which is notably lacking at present, to suggest a directed compression from either north or south, and for this reason I am unwilling to accept the concept of a directed compression from either direction as the fundamental explanation for these structures.

These considerations, in addition to the overall aspect of the cross section of figure 3-13, permit me to suggest that vertical movements in the central ranges, leading to lateral spreading and thrusting toward the structurally low areas to either side have been a prime factor in the structural configuration illustrated in figure 3-13. This is opposed to the northward directed compression hypothesis offered by Visser and Hermes and, in general, negates a need for regional compression and crustal shortening (also, refer later, section 3.4.6).

Smith (1964)~~unpub).~~ has come to similar conclusions regarding the structure of the Central Ranges and southern foothill folded belt of western Papua and New Guinea. Smith's conclusions are:

> ...."The primary tectogenesis or folding that accompanied the orogenic phase of diastrophism was the direct manifestation of vertical movements of the crust, although much of the form of the primary structures, particularly the central cordilleran anticlinoria, was inherited from the earlier geosynclinal patterns controlled by extensional stresses.

.... Secondary tectogenesis stands at the bottom of the hierarchy of crustal movements in western Papua and New Guinea both from the standpoint of magnitude and duration of movement. The foreland folding that falls into this category resulted from local compressional stresses developed in the allochthonous sedimentary sheet sliding off the main orogenic anticlinoria"..... (p.301).

As with the argument regarding the foothill thrusting in West Irian and the thrusting associated with the Dude-Marua Anticlinorium, it is suggested that the foothill thrusting and folding in Western Papua is, at least partially, due to the spreading effect of the vertically rising cordilleran zone, and most probably the youngest and outermost of these thrusts turn downward into the rising orogenic zone, *e.g.* the Kuku and Bevan Faults.

Vertical oscillations and secondary tectogenesis do not complete the picture, however, and there is yet another very important dimension to the structural pattern of this region. Carey (1938, 1957) recognized the fundamental importance of sinistrally coupled, simple shear transcurrent movements in the fundamental tectonic configuration of New Guinea. Following on, Smith has extended this reasoning and has recognized what he has termed the Cordilleran Shear Zone. The Cordilleran Shear Zone is depicted in Figure 3-14 (adapted from Figure 31 of Smith, 1964). Smith's conclusion regarding the effect of transcurrent movements on the tectonic configuration of western Papua and the Territory of New Guinea is as follows:

..."Both primary and secondary structures bear the stamp of more fundamental horizontal movements; *viz.* (the) sigmoidal plans, intersecting trends and the horstlike form of the main cordillera, all indicate that horizontal movements have strongly influenced the patterns of faulting and folding." (p.301)....

Examination of figure 3-14, in conjunction with the geological and topographic maps of this region, reveals the important fact that structural trends in this area are oriented more northwesterly than:

(a) The morphological trend of the Central Ranges, or 'backbone' of New Guinea,

(b) the inferred pattern of the Cordilleran Shear Zone, which parallels the Central Ranges, and

(c) the trends of the late Cretaceous-Tertiary geosynclinal framework which, also, parallel the trend of the Central Ranges.

Thus, while the gross trend of the geosynclinal framework to the west of the Aure Lineament (refer figures 3-1 and 3-14) has not been rotated into the compressional stress field of the dextral simple shear stress couple of the Aure Lineament, the primary structures, *e.g.* the 'central cordilleran anticlinoria' of Smith, and the 'secondary' structures, *e.g.* the south flank foothills folded belt, have a preferred orientation in this compressive stress field. This suggests that the 'primary' uplift and folding of the 'central cordilleran anticlinoria' and, therefore, the 'secondary' structures of the foothill folded belt, have in the first instance been controlled to some degree by this simple shear compressive stress field acting somewhat independently of the basic geosynclinal framework. Carrying the reasoning a step further, however, the compressive stress field in this region can be related, in turn, to the sinistrally coupled simple shear stress system of the Cordilleran Shear Zone, which parallels both the trend of the late Cretaceous - Tertiary geosynclinal framework and that of the Central Ranges of New Guinea. The fundamental control would seem, therefore, to be either the Cordilleran Shear Zone, or the inherited geosynclinal framework.

I have extended the Cordilleran Shear Zone into West Irian as shown in figure 3-14. The detail of the extension to West Irian is illustrated in figure 3-15, the main features of which are:

(a) the slightly north of west trend of the main cordillera,

(b) the faulting which parallels this trend, and

(c) the manner in which the folds intersect this trend obliquely.

The relationship of these trends to the North New Guinea Boundary is, also, demonstrated in this diagram. By this interpretation, the main range in West Irian is essentially a horst, bounded by primarily sinistral~~ly~~ ~~coupled~~ transcurrent faulting; the oblique folding and faulting is believed to be related to this faulting as shown in the diagram. It should be noted, that this interpretation neither invalidates nor denies the possibility that secondary folding and thrusting have occurred as a result of primary vertical movements. In fact, folding which parallels the main shearing trend, and the main horst (such as at 'A' in Figure 3-15) is probably best related to secondary gliding and/or lateral spreading of the main uplift. Similarly, secondary folding and thrusting are, also, likely to have occurred with respect to the main northwesterly-trending anticlinoria.

Consider now the area to the north of the Central Ranges. I have previously called attention to the great intramontane depression that stretches across Northern New Guinea, *viz.* the North New Guinea Depression, and which separates the Central Ranges from the Northern Coastal Ranges. This depression parallels the north flank of the Central Ranges, the North New Guinea Boundary and the Cordilleran Shear Zone, and the Meervlakte-Sepik sector of the depression essentially parallels the axis of the North New Guinea Province. The Ramu sector of this depression will be considered separately in a later section (refer Section 3.4.5,E).

Carey (1957, p.290-291, figures 20 and 21) has pointed to evidence which suggests that generally westerly-oriented, sinistrally coupled simple shear stresses have controlled the pattern of deformation in the region of the Bewani and Torricelli Mountains. The evidence lies mainly in the facts that firstly, the folding in these areas trends northwesterly to north-northwesterly, or obliquely to the main trend of the Sepik depression and secondly, in the cognate, northeasterly - trending normal faults, *i.e.* normal faults perpendicular to the fold trend, which are associated with these folds (refer Plate II). This kind of argument can be extended into West Irian as shown in figure 3-16. This figure shows firstly, that this region has deformed principally by faulting. Visser and Hermes (1962, p.170) have noted the conspicuous lack of true folded structures in this region. Secondly, there are three conspicuous directions of faulting, *viz.* west-northwesterly, northwesterly to north-northwesterly and north-easterly to east-northeasterly. The west-northwesterly trend seems to be the most important trend in that:

(a) This trend parallels the Meervlakte depression and forms the North New Guinea Boundary,

(b) most other structures end against this trend, and

(c) the oldest rocks and ultrabasics are brought up on this trend.

To the west, the island of Japen is bounded by faulting along this same trend, which possibly connects directly to the faulting on the north flank of the Gauttier Mountains. Similarly, in New Guinea the major bounding faults of the Bewani, Torricelli and Prince Alexander ranges have a westerly trend (refer Plate II). The northwesterly trend is oblique to the main depression and is closely associated with the few folds that are present. In figure 3-16, I have included my interpretation of these strains in relation to a simple shear stress system that reasonably accounts for the mapped trends of deformation. This stress system is the same as that proposed for the Cordilleran Shear Zone and these stress systems can be directly compared through figures 3-14 and 3-16.

By this interpretation, the North New Guinea Province is regarded as a major trend of sinistral shearing along which marked subsidence was essentially continuous throughout the Tertiary. The North New Guinea Boundary conforms to this trend and can be regarded therefore, as a fundamental zone of sinistral~~ly~~ ~~coupled~~ transcurrent faulting. In effect, this interpretation proposes that the North New Guinea Province eugeosyncline is basically a shear zone and, in so far as the North New Guinea Boundary can be regarded as marking the late Cretaceous - Tertiary continental margin, I am suggesting that the continental margin per se was a result of sinistral shearing along this line. Further, I am suggesting that these strains are related in a definite manner to a simple shear stress system with the orientation illustrated in figures 3-14 and 3-16.

The cause of the vertical uplift of the Central Ranges, with particular reference to West Irian, now becomes the fundamental problem (as has proved the case in most studies of orogenic zones). A partial explanation of this uplift in terms of isostatic compensation has been offered in the preceding section. Further explanation is suggested in the following paragraph.

Vertical adjustments along the major shearing trends of the proposed stress system are to be expected, because these trends are always subject to an extensional component of normal stress. Even at depths where actual extensional stresses are no longer possible due to the weight of the overburden, fractures along these trends will form zones of relatively easy vertical movement. This is true because the extensional component of normal stress always reduces the total normal stress across these surfaces. The subsidence of the North New Guinea Province is held to be a result of the extensional stress normal to this shearing trend and, similarly, the uplift of the Central Ranges along this trend can be related indirectly to this factor. The actual cause of the uplift along this trend, however, is not a property of this stress system, but the stress system does provide a reasonable explanation for the fact that uplift, or more broadly vertical adjustment, has found a relatively easy avenue along this trend. The cause of this uplift must arise from some, essentially independent factor, and I suggest that at least part of the cause can be found in isostatic adjustments that have resulted from the development of the North New Guinea Province.

Finally, I will now draw attention to the fact that the inferred direction of sinistral transcurrent shearing in the Cordilleran Shear Zone and the North New Guinea Province is compatible with the direction of dextral shearing on the Aure Lineament, because ~~in that~~ these strain directions are conjugates of a single simple shear stress system. It should be noted, however, that while strains similar to that of the Cordilleran Shear Zone have been recognized in the area of the Kukukuku Lobe, *e.g.* the Er Trend, Coastal Trend and Purari Faulted - Anticlinorium, it is the dextral conjugate which has dominated the tectonic history of the Kukukuku Lobe.

Conclusions

It is concluded that deformation in the region to the west of the Aure Lineament has been controlled primarily by the simple shear stress system illustrated in figures 3-14, 3-15 and 3-16. The Central Ranges as a whole have been uplifted along the trend of the sinistral conjugate of this system. The North New Guinea Province has subsided along this trend probably because of extension normal to this trend.

The North New Guinea Boundary separates the uplifted area from the area of subsidence, forming a late Cretaceous - Tertiary boundary between a miogeosynclinal province to the south and a eugeosynclinal province to the north. This boundary is interpreted as a fundamental zone of sinistral transcurrent faulting that has determined the northern margin of the Australian continental shield from the late Cretaceous or early Tertiary time onward.

Uplift, folding and faulting in the compressional trend of this stress system have been important, yielding the characteristic form of the 'central cordillera anticlinoria' and Cordilleran Shear Zone et cetera. In as much as the North New Guinea Boundary is believed to have been initiated in the late Cretaceous or early Tertiary, it is probable that the Cordilleran Shear Zone originated at this time. Because the uplift of the Central Ranges seems to have proceeded from north to south, it might be concluded that faulting along this trend progressed from north to south and, therefore, the Cordilleran Shear Zone may be younger toward the south. Certainly the youngest structures in Western Papua occur at the southern margin of the fold belt.

Secondary folding and faulting have probably occurred, reflecting in some form the lateral spread of the vertically rising Central Ranges. These structures have probably developed both in relation to the overall west-northwesterly trend of the Central Ranges, or in relation to the main, northwesterly-trending 'central cordillera anticlinoria'. The former case is probably dominant in West Irian and the latter case in Western Papua.

E. FINISTERRE-SARUWAGED-CROMWELL RANGE

The Finistere-Saruwaged-Cromwell Range forms a notable exception to the rule that in the area to the west of the Aure Lineament the troughs have not been inverted relative to the pre-existing structural highs. This range was the site of very thick sedimentation during the Tertiary (ca.6000 - 10000 m.) and is remarkable, in that it has been uplifted to an elevation equivalent to either the Owen Stanley Ranges or the Central Ranges of New Guinea. The present elevation of this range (up to 4000 m.) is essentially twice that of the Northern Coastal Ranges to the west *e.g.* the Adelbert Range etc. which have maximum elevations of about 2,000 meters. Further, the Finisterre-Saruwaged sector of this range is the site of the strongest negative Bouguer Anomaly in Papua and New Guinea (refer figure 3-6).

The anomalous elevation of the Finisterre-Saruwaged-Cromwell Range is conspicuous in that the range is situated at the apex of the Planet Sphenochasm (Carey, 1957).

According to Carey (1957, p.292), the Planet Sphenochasm has been opened by the anticlockwise rotation of New Britain. It is perhaps best, therefore, to consider the Finisterre-Saruwaged-Cromwell Range as a compressional wedge that formed as a result of, and as a complement to the rotational opening of the Planet Sphenochasm, in the same manner as Carey has related the Biscay Sphenochasm and rotation of Spain to the compressional wedge of the Pyrenees (Carey, 1955, 1957). In other words, the unique inversion, elevation and strongly negative Bouguer anomaly values of the Finisterre-Saruwaged-Cromwell Range may be the result of a unique cause - the opening of the Planet Sphenochasm. The orientation of this range and the strong southward directed thrusting on the south flank of the range are compatible with this suggestion. The supposed relationship is illustrated in figure 3-17.

The Ramu-Markham Depression can now be regarded as virtually marking the thrust boundary of this compressional wedge and is here regarded as being fundamentally of a different nature from the contiguous Sepik Depression.

Judging from the pre-late Lower Miocene folding and uplift of the Finisterre-Saruwaged sector of this range, it might be suggested that the Planet Sphenochasm had begun to form by, if not before, this time. The repeated evidence of post-Lower Miocene folding and uplift in the Finisterre-Saruwaged sector, at witnessed by the unconformities in this area, could then be regarded as a natural consequence of continued development of the Planet Sphenochasm.

3.4.6 THE AURE LINEAMENT AND THE SIMPLE SHEAR STRESS SYSTEM OF THE PURARI OROCLINE; AND REGIONAL APPLICATIONS

From a study of the Kukukuku Lobe per se, we are able to deal only with Miocene to Recent phenomena with any degree of certainty. By examining the Kukukuku Lobe in its regional context, I have attempted to demonstrate that the late Cretaceous (Senonian) to Recent tectonic history of Papua and New Guinea shows a generally consistent pattern of development that is discordant with, although not entirely independent of, pre-late Cretaceous development. The following discussion concerns only the late Cretaceous to Recent tectonic history of this region. Aside from the few general comments made previously, the pre-late Cretaceous history of this region is beyond the scope and intent of this study.

I have proposed that the three basic elements of the Kukukuku Lobe as described in the preceding discussions, *viz.* the Puri Shelf, Aure Trough and Kapau Margin, can be related to the fourth principal element, the Aure Lineament, and to dextral transcurrent movements along this Lineament. These four elements, together, constitute the Purari Orocline and record its development.

The Purari Orocline is the major tectonic element in the region of the Kukukuku Lobe, and the unique Aure Lineament is the most important single structure of this orocline. At the Aure Lineament, the regional structural grain changes abruptly from northwesterly to the west, to northerly to the east. The northeasterly-trending Aure Lineament is oblique to both of these trends. The Aure Lineament is primarily a dextral transcurrent fault which has dragged, rotated and in the case of the pre-Upper Miocene features, offset all structural and sedimentary elements which cross it. The nature of the transcurrent movements that have occurred on the Aure Lineament are particularly well shown in the mutual relationship of the Kuku, Bevan and McDowal Faults. The Aure Lineament, then, reveals one basic mechanism by which the Purari Orocline has developed, *i.e.* by dextral transcurrent movement on this Lineament.

It has been repeatedly stressed that the Aure Lineament and, therefore, the Purari Orocline, have had a secular development. Consideration of the Aure Lineament alone, suggests that this lineament began development in the early Lower Miocene.

The gross form and tectonic development of the Aure Trough parallel the form and development of the Purari Orocline. My analysis of the Aure Trough has led to the suggestion that this trough developed as a result of dextral~~ly coupled~~ simple shear stresses and dextral movement on the Aure Lineament. It is suggested that the secular enlargement of the Aure Trough records the secular development of the Purari Orocline. The <u>dilation</u> of the Aure Trough is, therefore, the <u>second mechanism</u> by which the Purari Orocline has formed. The Aure Trough is thought to have been initiated during the late Cretaceous (Senonian), and it follows that the Purari Orocline commenced development at the same time.

The Purari Orocline has not, therefore, been the result of an episodic bending of New Guinea (Carey, 1938; Smith, 1964), but has evolved slowly and reasonably consistently since the late Cretaceous. Structural and stratigraphic relationships in the Purari River area show that the Purari Orocline continued to develop through the Pliocene, and it is probable that the orocline continues to develop at present.

It is proposed that the development of the Purari Orocline is a result of the simple shear stress system shown in Figure 3-18. The three features which are held to be significant in identifying this stress system are as follows:

1) The orientation of the Aure Lineament (N45° E) and the dextral~~ly coupled~~ rotation and probable dextral offset of trends intersected by this fault. This fault is taken to represent the dextral conjugate of the proposed stress system.

2) The orientation of the Purari Faulted-Anticlinorium, Er Trend and Coastal Trend (ca. N100° - 110°E). These features reflect sinistral transcurrent movements and are taken to represent the sinistral conjugate of the proposed stress system.

   The Coastal Trend requires a tensional component to account for the marked subsidence along this trend. Similarly, the Ih Fault, which marks the northern boundary of the Purari Faulted-Anticlinorium, probably originated as a tensional fault. The conjugate shears as related to the proposed stress system have a component of extensional normal stresses across them, which satisfies this requirement~~s~~. Because these shears have a normal extensional component of stress across them, which is due to the applied simple shear stresses, they will always trend to be easy avenues for vertical adjustments, *i.e.* even with depth the normal stress across these fractures will be reduced. This provides a rationale for the extensive uplift of the Purari Faulted-Anticlinorium as an integral feature.

3) The north to north-westerly orientation of the Vailala Synclinorium, Dude-Murua Anticlinorium, Karova Syncline and Tauri Anticlinorium, which are the principle folds of the Kukukuku Lobe. These folds require a compressive stress oriented in an east-northeasterly direction.

The development of the North New Guinea Boundary, the Cordilleran Shear Zone and the North New Guinea Province is essentially contemporaneous with that of the Aure Trough and Purari Orocline, and these features show strong evidence of sinistrally coupled, simple shear deformation. These trends are oriented in the sinistral conjugate of the stress system proposed for the Purari Orocline, and it is suggested that these features, also, represent the sinistral conjugate of this stress system. The North New Guinea Province has been the site of strong subsidence throughout its history. This trend is oriented in a direction which should be extending, and it can be suggested that the subsidence of this province is in part, if not wholly, due to this extensional movement, *i.e.* this is a zone of stretching as well as one of sinistral transcurrent movements and is, therefore, similar in aspect to the Coastal Trend but is older and of a much larger scale.

For the same reason as mentioned in number two above, the North New Guinea Boundary and similar trends should be zones of relatively easy uplift, and this has probably been an important factor in the gross uplift of the Central Cordillera and the Cordilleran Shear Zone. The same factor probably relates to the extensive occurrence of basic and ultrabasic rocks along this zone and to the early volcanic history of the North New Guinea Province as well.

A. THE DEVELOPMENT OF THE PURARI OROCLINE

Figure 3-18 illustrates the basic tenets of any simple shear stress system. These can be summarized as follows:

1) The planes of maximum shear stress are equal in magnitude, opposite in sense and are planes of zero normal stress.

   (a) Because of the co-efficient of friction inherent in the material being stressed, shear strain, or failure, occurs at an angle to the plane of maximum shear stress. This angle is half the angle of internal friction (denotes by ϕ in figure 3-18) and is assumed to be 15 degrees. The plane of shear failure is, therefore, subject to a component of normal stress.

2) The applied shear stress induces tensile and compressive stresses which are maximum, and equal in magnitude to the maximum shear stress, on mutually perpendicular planes which are oriented at 45° to the planes of maximum shear

stress. The planes of maximum compressive and maximum tensile stresses are planes of zero shear stress and are respectively, maximum and minimum principal planes of stress.

3) The direction of the intermediate principal stress is perpendicular to the plane containing the maximum and minimum principal stresses, or perpendicular to the page in figure 3-18.

There exists in this stress system a rational explanation for the development of the Purari Orocline. The principal point to note here is that the major shear failures have a normal component of tensional stress across them. Figure 3-19 diagrammatically illustrates the mechanism proposed for the development of this orocline. The basic features that allow this mechanism to be proposed are as follows:

1) The probable origin of the Aure Trough by tensional faulting.

2) The secular and directional development of the Puri Shelf, Aure Trough and Kapau Margin.

3) The secular development of the Aure Lineament and the dextrally coupled northward rotation of features intersected by this Lineament, which can be seen from the mutual relationship of the Kuku, Bevan and McDowal Faults.

4) The overall configuration of the Purari Orocline.

The evolution of the Purari Orocline can now be envisaged as follows:

During the late Cretaceous, the Aure Trough and North New Guinea Province were intiated by faulting that was probably oriented generally in the sinistral conjugate direction of the inferred stress system. Faulting oriented more toward the plane of maximum tension would not have been unlikely, but this trend (N75^{o}E) is generally rare in this region, and the present orientation of the North New Guinea Boundary suggests the sinistral conjugate direction was probably dominant. Coincident with this faulting, or shortly thereafter, the area to the west of the Aure Lineament began to move northward, relative to the area to the east, in the dextral conjugate direction of this stress system. This movement tended firstly, to dilate and rotate the initial faulting, and secondly to cause new sinistral faults to develop progressively toward the south. The tectonic environment to this point is one mainly of translation and extension, promoting a general subsidence with very strong subsidence in the dilating fault troughs. The Aure Lineament may have formed at this time, but it is possible that it was either a somewhat later consequence of these movements, or that it was a pre-existing weakness which permitted movements to occur. The dilation of the initial sinistral faults would have taken up some, and perhaps all of the differential movements required. At least as early as the earliest Lower Miocene, however, the Aure Lineament accommodated differential dextral translation between the area to the west and the area to the east. As northward translation and extension persisted to the west of the Aure Lineament, the early-formed troughs to the east were progressively rotated into a trend more northerly than 300^{o}, whereupon they were ~~would have been~~ subjected to the normal compressive stress field of this stress system. Presumably, this would have tended to close the troughs in the same sequence as they were formed, thereby yielding a sequential pattern of folded-uplifts. The earliest formed trough would, therefore, have become an uplifted source area for the adjacent trough to the southwest and so on. Isostatic compensation would have enhanced this process. Upon rotation past 300^{o}, the compressive stresses on the troughs would have increased to a maximum at 345^{o}, and the normal stresses would have remained compressive until the troughs had been rotated and/or dragged into an orientation of N30^{o}E, thus providing a reasonable explanation for the westward migration, or spread of regional uplift.

The main northwesterly to northerly fold trends and uplift of the Kukukuku Lobe, *e.g.* the Vailala Synclinorium, Dude-Murua Anticlinorium, Karova Syncline, Tauri Anticlinorium (?) and Muiai Syncline, and the Tertiary uplift and present configuration of the Owen Stanley Ranges are held to be accountable to this mechanism. Rotation past 345° should have caused dextrally coupled drag of the type which is demonstrated in the configuration of the McDowal Fault and ~~probably~~ possibly along the line of the Yanne Fault and, again, along the eastern flank of the Tauri Anticlinorium.

Whereas the area to the east of the Aure Lineament has been rotated and dragged by the dextral stress couple and by dextral movement on the Aure Lineament, the area to the west of the lineament has not (at least to the same extent).

The gross orientation of the North New Guinea Province and North New Guinea Boundary, remain essentially in the direction of the sinistral conjugate. Likewise the Purari Faulted-Anticlinorium, which formed the north boundary of the late Lower Miocene shelf, and the north edge of the early Lower Miocene shelf retain a west-northwesterly orientation that is inferred to be essentially primary. It is for this reason that I suggest that the area to the west of the Aure Lineament has been the actively moving block, while the area to the east has been passively rotated and dragged. Movements to the west have involved mainly a northward translation and extension, probable sinistral offsets and rotations, as well as a small amount of pivotal movement due to a greater amount of extension closer to the Aure Lineament. The basic relationship which is thought to exist between the trends to either side of the Aure Fault is schemmatically illustrated in figure 3-20a. With regard to the relatively simple northward drag and rotation of the area to the east of the fault, however, the trends to the west are more complex. The complexities become multiplied when trying to determine the original sedimentary trends because of gaps in our geological information. Figure 3-20 summarizes the different kinds of intersection the trends to the west make with the Aure Lineament, all of which tend to complicate the basic pattern suggested in figure 3-20a.

B. THE AMOUNT AND RATE OF HORIZONTAL MOVEMENT IMPLIED BY THE CONFIGURATION OF THE PURARI OROCLINE

In estimating the amount and rate of horizontal movements that have occurred during the evolution of the Purari Orocline, we must consider the combined affect of extension~~,~~al translational and rotational movements.

Using the Bismarck Range and the southern edge of the Pliocene depositional trough in the Delta Embayment as trough-boundary markers, we can roughly estimate that the area between has been extended twenty-five 25 to fifty 50 kilometers during the Tertiary development of the Aure ~~this~~ Trough (refer figure 3-21). The lower figure assumes no isostatic adjustment during trough formation, and the latter assumes that the trough developed in complete isostatic adjustment. The real case is likely to have been somewhere between these extremes. In addition, we have not considered the thick Upper Cretaceous to Tertiary sediments to the north of the Bismarck Range, nor have we considered the effect of water depth. The figure of fifty 50 kilometers is, therefore, probably closer to the proper amount of extension involved.

I have suggested that the Eocene shelf has probably been offset about forty 40 kilometers by the Aure Lineament. This implies a rate of movement of about one kilometer per million years, assuming this offset to be entirely a post-Eocene feature. If we extrapolate this rate of translation back to the late Cretaceous (Senonian), *i.e.* to the time of incipient formation of the Aure Trough and Purari Orocline, we can speculate that pre-late Cretaceous features may be offset about ninety 90 kilometers by the Aure Lineament (using here an approximate figure of ninety 90 m.y. for the base of the Senonian; Kulp, 1961).

If now, we assume that the areas to either side of the Aure Lineament extended by the same amount, the dextral transcurrent offsets which are thought to have occurred on the Lineament must be added to those caused by extension. This assumption is probably not strictly valid, since extension is likely to have continued to the west of the Lineament while contemporaneous compression was occurring to the east of the Lineament, *i.e.* part of the offset on the Aure Lineament may simply be a result of greater extension to the west of the Lineament rather than purely differential translation across the Lineament.

Actual offset on the Aure Lineament reveals only part of the movements which have occurred. The Kukukuku Lobe has been rotated and dragged northward by the Aure Lineament. The mutual relationship of the Kuku, Bevan and McDowal Faults, demonstrates this clearly and indicates that northward rotation has occurred at a rate of about two kilometers per million years since the early Upper Miocene. Again, extrapolating this rate of rotation to the base of the Senonian suggests that this rotation will have amounted to about 180 kilometers since the incipient formation of the Aure Trough and Purari Orocline. This implies a similar amount of northward translation of the area to the west of the Aure Lineament, which must be added to the amount of translation suggested by probable offsets along the Aure Lineament. The actual rate of rotation may be somewhat higher than indicated, for the reasons that the pre-rotational trend of the Kuku Fault etc. is not certainly known, and because the pre-Upper Miocene rate of movement may have been more rapid, *e.g.* a comparison of the areal extent of the Upper Miocene and Pliocene troughs to that of pre-Upper Miocene troughs suggests that this might be true.

To the extent that my aforegoing assumptions are valid, we may then sum these movements and tentatively estimate that, at least 320 kilometers of northward translation and extension have occurred during the development of the Purari Orocline. Probable offset across the Aure Lineament is only a small part of this movement and, for the most part, the Kukukuku Lobe has moved along with the area to the west.

On the assumption that the amount of rotation and drag of the area to the east of the Aure Lineament should approximate the amount of translation to the west of the Lineament, the problem of amount of movement can be approached from a different angle. If we can assume that a line now marking (approximately) the position of the Upper Cretaceous - Eocene trough on the southwest flank of the Owen Stanley Ranges was originally rectilinear and oriented at about 105°, then we can estimate that the northward rotation of this line has been about 350 to 450 kilometers since this trough began to form in the late Cretaceous (refer figure 3-24). The amount of northward translation to the west of the Aure Lineament would be greater both by the amount of offset on the Lineament and by any greater amount of extension that occurred to the west of the Lineament.

The preceding arguments are admittedly speculative in that they involve a good deal of extrapolation. Both arguments, however, are logical conclusions of my interpretation of this region and both yield generally consistent results. The movement deduced from the first argument predicts the movement recognized in the second argument and, conversely, the movement recognized in the second argument requires the movement deduced in the first argument.

Do not cross-out

~~My conclusion is that the development of the Purari Orocline has~~ involved at least 300 to 400 kilometers, say 360 km. for convenience, of combined extension, translation and rotation since its inception in the Upper Cretaceous (Senonian). This requires a gross rate of movement of about four kilometers per million years. Such a rate is entirely plausible judging from known standards. For sample, Crowell (1962) and Hill and Diblee (1953) have reasonably established post-early Miocene transcurrent offsets of 260 kilometers (Crowell) and 285 kilometers on the San Andreas Fault. This implies a rate of movement of about ten kilometers per million years, which is more than twice the rate needed to form the Purari Orocline by the proposed mechanisms.

3.5 THE SIMPLE SHEAR STRESS FIELD OF THE PURARI OROCLINE IN RELATION TO THE TECTONIC PATTERN OF THE SOUTHWEST PACIFIC

A most fundamental advance in our understanding of the tectonics of New Guinea came in 1938, when Carey recognized the essential role that simple shear deformation has played in determining the tectonic configuration of this island. My analysis supports ~~this~~ Carey's view and has led me to suggest that the major late Cretaceous-Tertiary features of the island, here examined, are basically ~~a~~ the result of simple shear deformation *e.g.* the Aure Trough, Purari Orocline, North New Guinea Province, North New Guinea Boundary and the Cordilleran Shear Zone. Carey's 1938 synopsis provides a lucid summary of this deformation and leads into the next topic, which is the relationship of New Guinea to the tectonic pattern of the southwest Pacific:

> "As our knowledge and understanding of the mechanics of orogenesis progresses, more and more evidence is being found of large scale couples or continental shearing stresses in the deformation of the earth's crust.
>
> The entire fabric of New Guinea seems to have the hall-mark of such a shear system. In the areas where the writer has worked almost every anticline bears the stamp of rotational stress either in the configuration of its axis, its relation to its neighbors, or its association of compression and cognate tension. Almost every thrust, and they are legion, tells the same story, either by its place in the fault pattern, by its attitude, by the trend of the slickensides, on its surface or through its displacement of the strata, or its association with a complementary thrust trend. The mountain orogens themselves bear similar testimony, both in their internal architecture and their external trend .... structures large and small, all point to one conclusion - that New Guinea has been sheared westwards under a colossal shear system, on a grander scale than has been demonstrated anywhere else on the globe....." (p.62).
>
> "The stresses which are responsible for this great westerly displacement are of continental dimensions, they are probably related to the main architectural pattern of the globe...." (p.76)

In subsequent works, Carey (1957, 1963) has amplified these conclusions, leading to the recognition and definition of the Tethyan Torsion Zone. The Tethyan Torsion Zone is an equatorial, globe-encircling zone, some 10^{o} wide, of sinistrally coupled shearing between the northern and southern hemispheres. The shearing arises, presumably, from sinistrally coupled torsion between the northern and southern hemispheres and, therefore, is probably a result of the earth's rotation.

Figure 3-23 (from Carey, 1963, figure 11, p.376) illustrates Carey's interpretation of the Tethyan Torsion Zone in the southwest Pacific. This interpretation proposes that the Pacific Margin has been sinistrally offset about 60^{o} longitude, or approximately 7000 kilometers, by the Tethyan Torsion Zone.

Paleomagnetic studies have lent support to the existence to the Tethyan Torsion Zone and to the fundamental role it has had in the tectonic development of the southwest Pacific. Irving and Green (1957) and Irving (1958) have shown that Australia has rotated anticlockwise about 90^{o} with respect to the present poles, since the Jurassic, which is the sense of rotation required and predicted by the recognition of the Tethyan Torsion Zone. Recent unpublished paleomagnetic data (Pitt, 1966) suggests, likewise, that New Guinea has rotated anticlockwise about 60^{o} since the late Cretaceous.

In addition to anticlockwise rotation, the paleomagnetic data show, also, that there has been a gross northward movement of both Australia and New Guinea. The northward movement of Australia is substantiated by paleoclimatic reconstructions, and has long been used as evidence for continental drift by the proponents of this theory (see Carey, 1957), *e.g.* Permian glacials are widely distributed in Australia and invertebrate faunas suggest a cool Mesozoic climate (David, 1950, p.515).

Consideration of the paleomagnetic data for both Australia and New Guinea together suggests that Australia and New Guinea have participated generally in the same gross anticlockwise rotation and northward migration, *i.e.* they have moved essentially as a unit. This would be expected if the Australian continent extends into the Central Cordillera of New Guinea as I have suggested.

It is proposed that the stress system suggested for the Purari Orocline is a direct expression of the Tethyan Torsion Zone, and the suggested relationship is illustrated in figure 3-23. In the development of the Purari Orocline, Aure Trough and Aure Lineament, the dextral conjugate of this system has been the dominant factor. This possibly relates to the northward migration of Australia and New Guinea and suggests, in turn, that some part of this northward movement is a direct consequence of the Tethyan Torsion Zone. The North New Guinea Province, North New Guinea Boundary and Cordilleran Shear Zone on the other hand, have been dominated by the sinistral conjugate of this stress system and seem, therefore, to be more closely related to the sinistral offset of the Pacific Margin and gross rotation of Australia and New Guinea.

The question that must now be posed is why the dextral conjugate has dominated the evolution of the Purari Orocline, when the major character of the Tethyan Torsion Zone is reflected in the sinistral conjugate. To a first approximation, the simplest explanation would seem to lie in the fact that the eastern edge of the Australian continent strikes northward into New Guinea, or at a large angle to the sinistral conjugate of this stress system. It can be tentatively suggested therefore, that the relief of these stresses was probably easier in the direction of the dextral conjugate, which more nearly parallels the continental margin. If this is the case, then the Aure Lineament will not be expected to extend far northward of say the Bismarck Range, which marks the northern edge of the Upper Cretaceous - Tertiary continental margin in New Guinea. It reasonably follows from this that the sinistral shear conjugate should be dominate in the North New Guinea Province. This situation possibly finds an analogy on the western coast of North America. Here, the sinistrally coupled

Mendocino, Pioneer and Clipperton fault-zones impinge on the continental margin at a high angle and are replaced, at least partially, by the dextral San Andreas Fault which more nearly parallels the continental margin (Carey, 1963).

This question bears on the probable southward continuation of the Aure Lineament. Continuing the Aure Lineament southward with respect to the inferred stress system, we would expect it to generally maintain its N45^{o}E orientation, perhaps dying out to the south. If however, the grain of the Australian continental margin has been important in determining the mode of failure in this region, then it might be reasonably expected that failure has made use of a pre-existing weakness in the continental structure. The Aure Lineament might conceivably be continued to the south along the steep edge of the Great Barrier Reef and into the Princess Charlotte Graben and thence along the Tasman Line as shown in figure 3-24. The Tasman Line is a fault line of fundamental importance in the continental framework of Australia, in that it formed the western edge of the Paleozoic Tasman Geosyncline and now forms the eastern boundary of the Precambrian shield in northern Queensland (Geol. Soc. Aust. Journ. Vol. 7, 1960 p.2). This in turn would allow the suggestion that the south margin of Papua has been separated from the parallel northern margin of the Australian shelf by northward translation along this line, and would imply that the amount of movement recorded by the Purari Orocline may only be about half of the actual movement that has occurred along this line. In other words, the interpretation offered in figure 3-24 suggests that a total movement of about 760 km. is required, which is still well within known rates of horizontal movements.

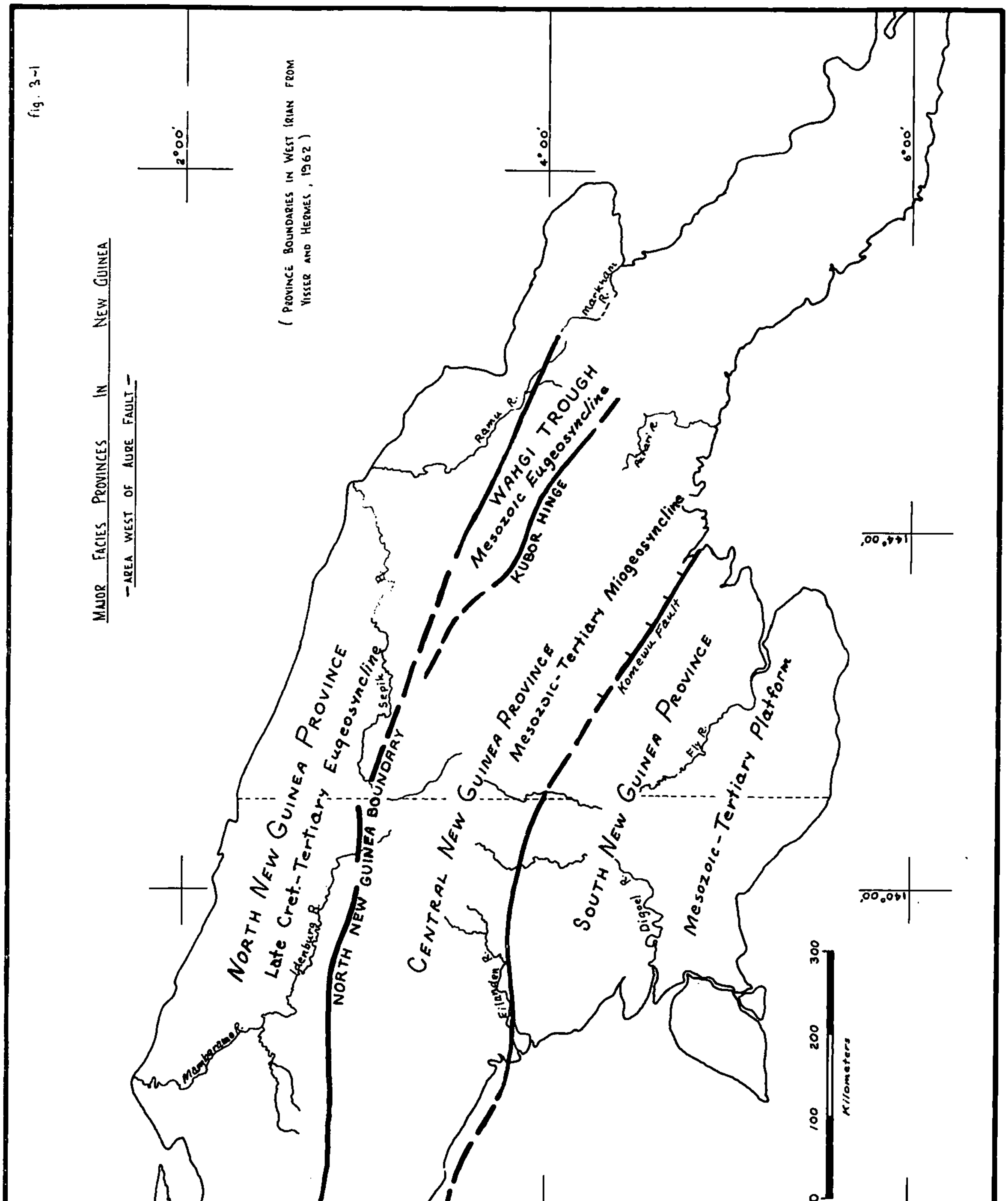


fig. 3-1
MAJOR FACIES PROVINCES IN NEW GUINEA
-AREA WEST OF AURE FAULT-
(PROVINCE BOUNDARIES IN WEST IRIAN FROM VISSER AND HERMES, 1962)
NORTH NEW GUINEA PROVINCE
Late Cret.-Tertiary Eugeosyncline
NORTH NEW GUINEA BOUNDARY
CENTRAL NEW GUINEA PROVINCE
Mesozoic-Tertiary Miogeosyncline
WAHGI TROUGH
Mesozoic Eugeosyncline
KUBOR HINGE
Komewu Fault
SOUTH NEW GUINEA PROVINCE
Mesozoic-Tertiary Platform
Ramu R.
Markham R.
Sepik R.
Fly R.
Digoel R.
Eilanden R.
Idenburg R.
Mamberamo R.
BIAK
JAPEN
2°00'
4°00'
6°00'
136°00'
140°00'
144°00'
0
100
200
300
Kilometers

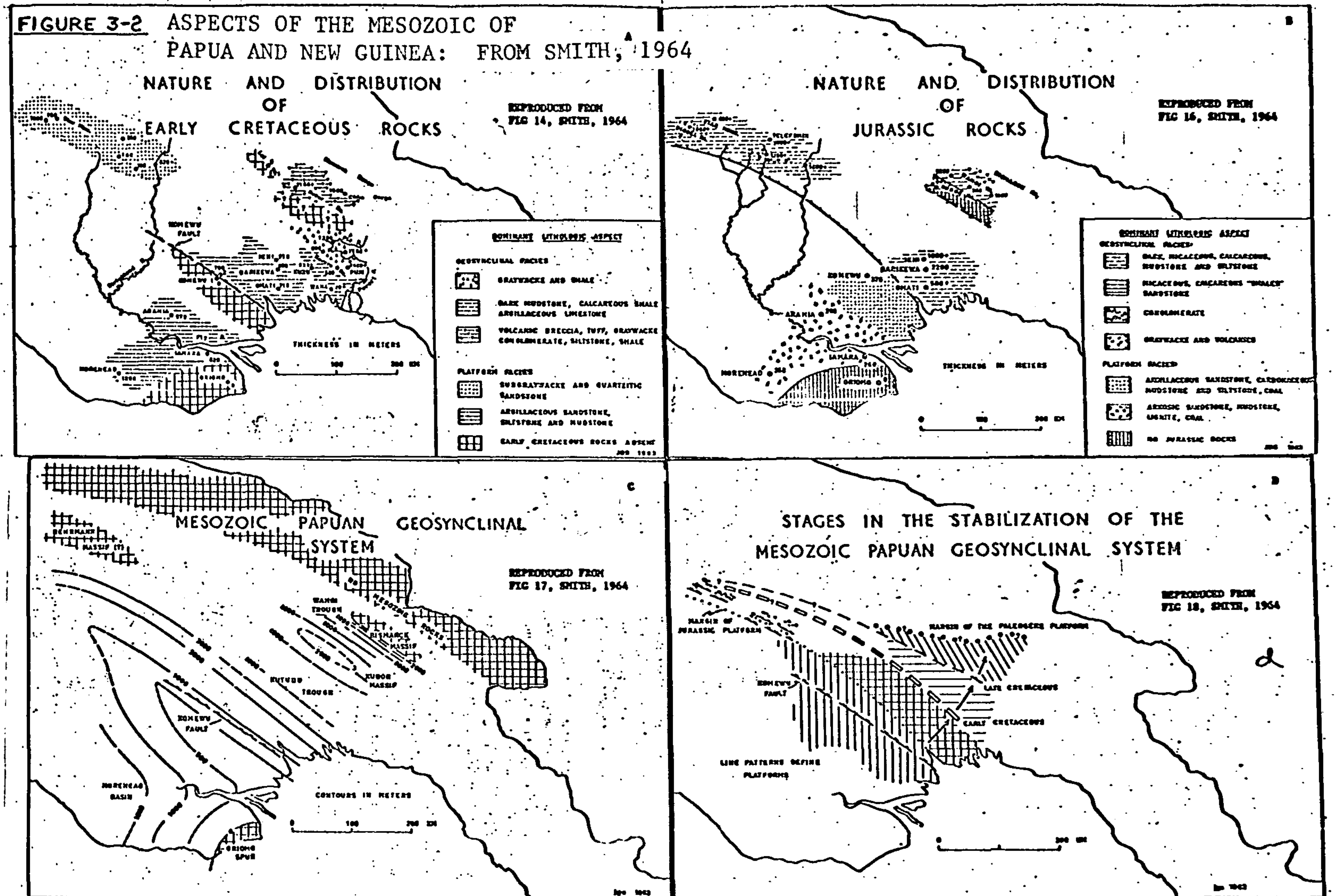
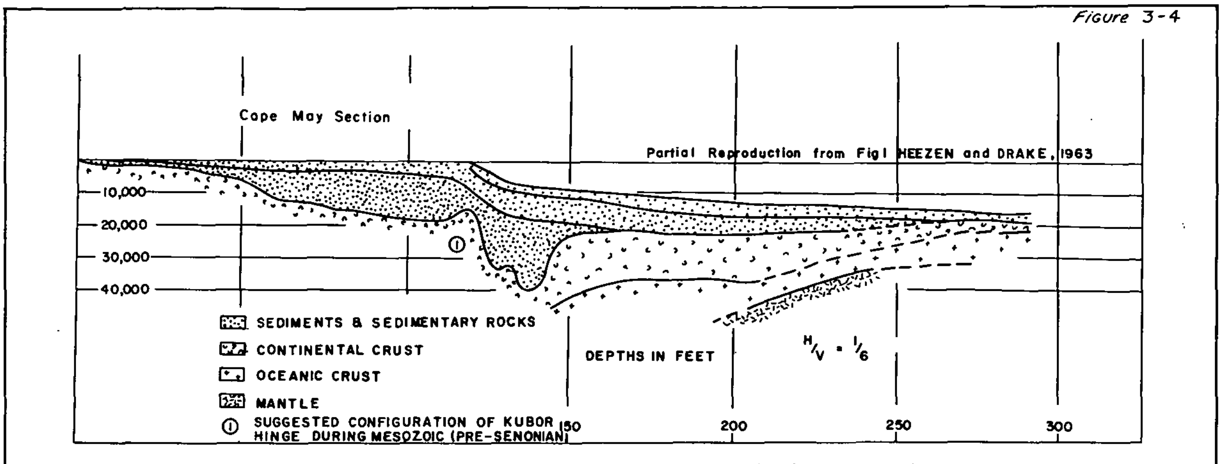
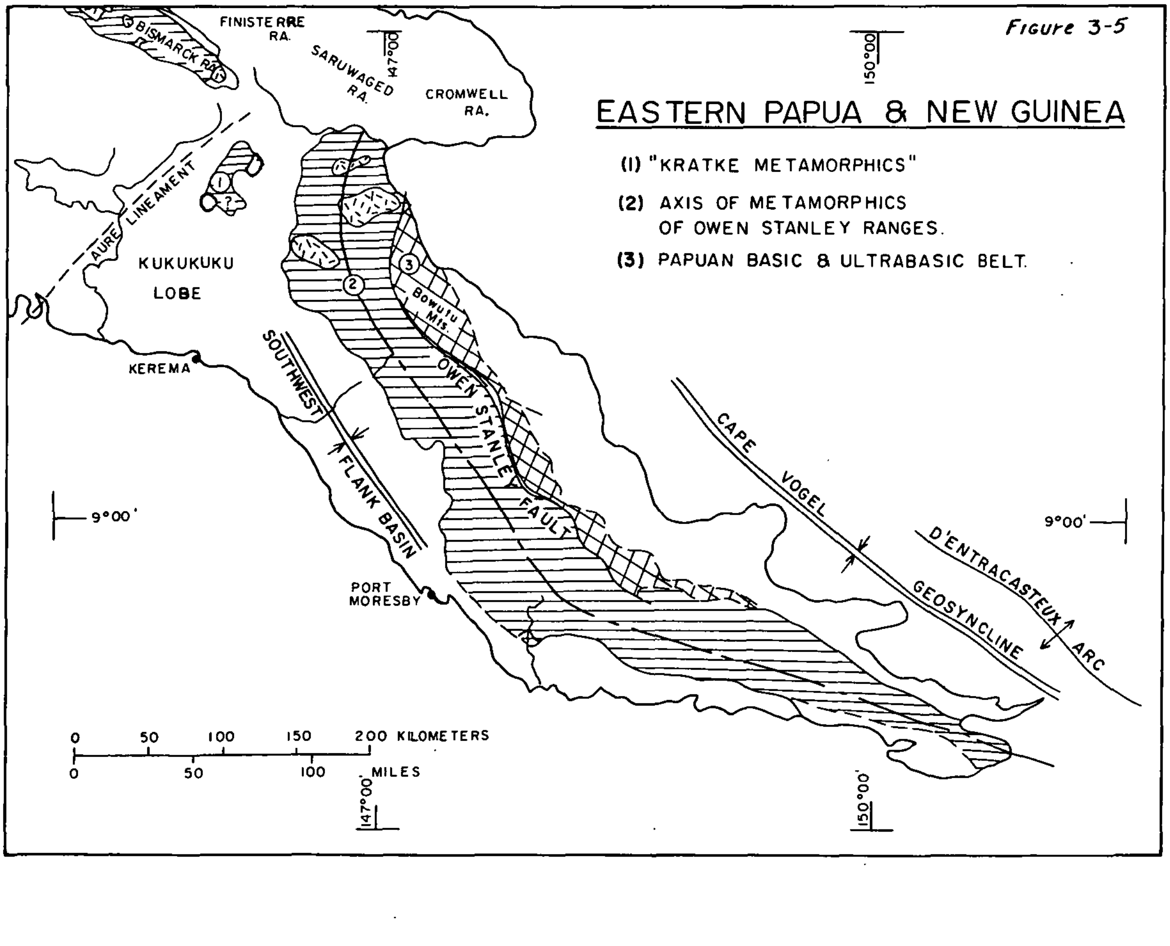


FIGURE 3-2 ASPECTS OF THE MESOZOIC OF PAPUA AND NEW GUINEA: FROM SMITH, 1964



Structural Profile of the Eastern Continental Margin of North America.



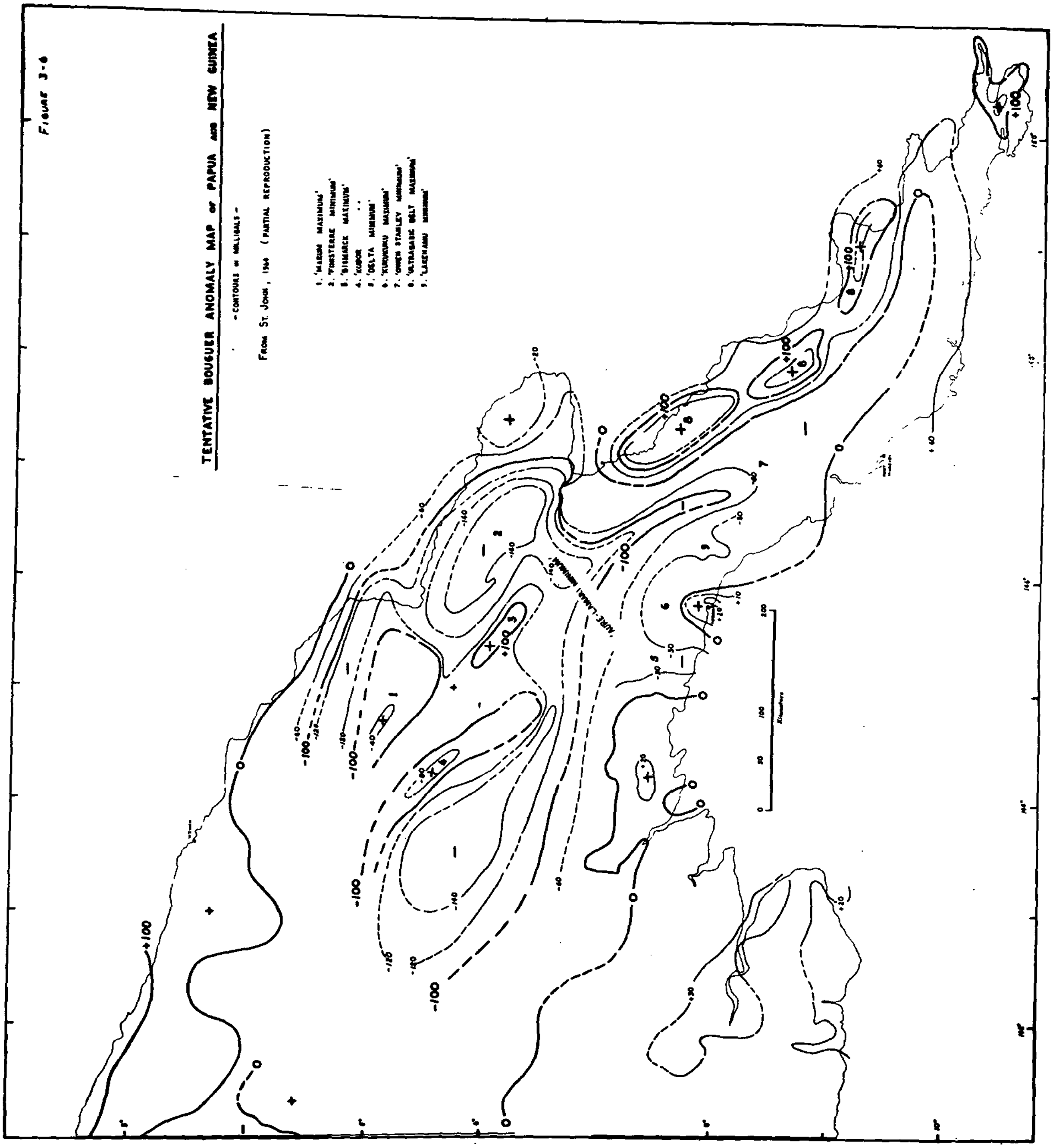
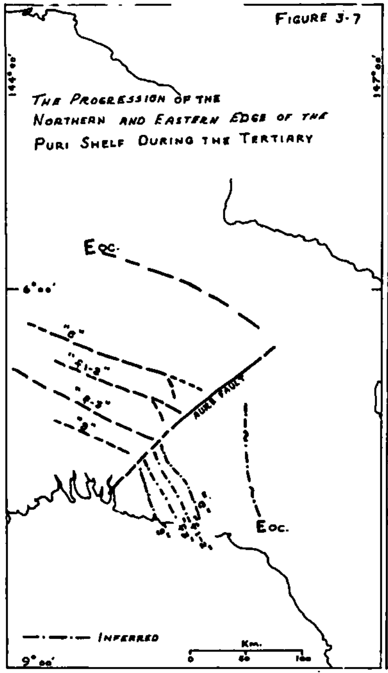
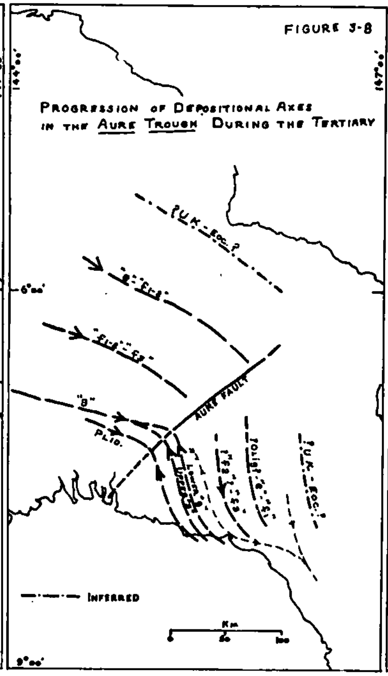
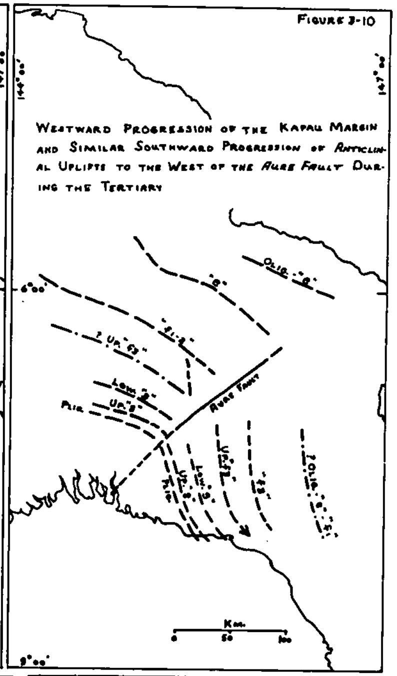


Figure 3-6
TENTATIVE BOUGUER ANOMALY MAP of PAPUA and NEW GUINEA
- CONTOURS in MILLIGALS -
From St. John, 1964 (PARTIAL REPRODUCTION)
1. 'MARUM MAXIMUM'
2. 'FINISTERRE MINIMUM'
3. 'BISMARCK MAXIMUM'
4. 'KUBOR " "
5. 'DELTA MINIMUM'
6. 'KUKUKUKU MAXIMUM'
7. 'OWEN STANLEY MINIMUM'
8. 'ULTRABASIC BELT MAXIMUM'
9. 'LAKEKAMU MINIMUM'







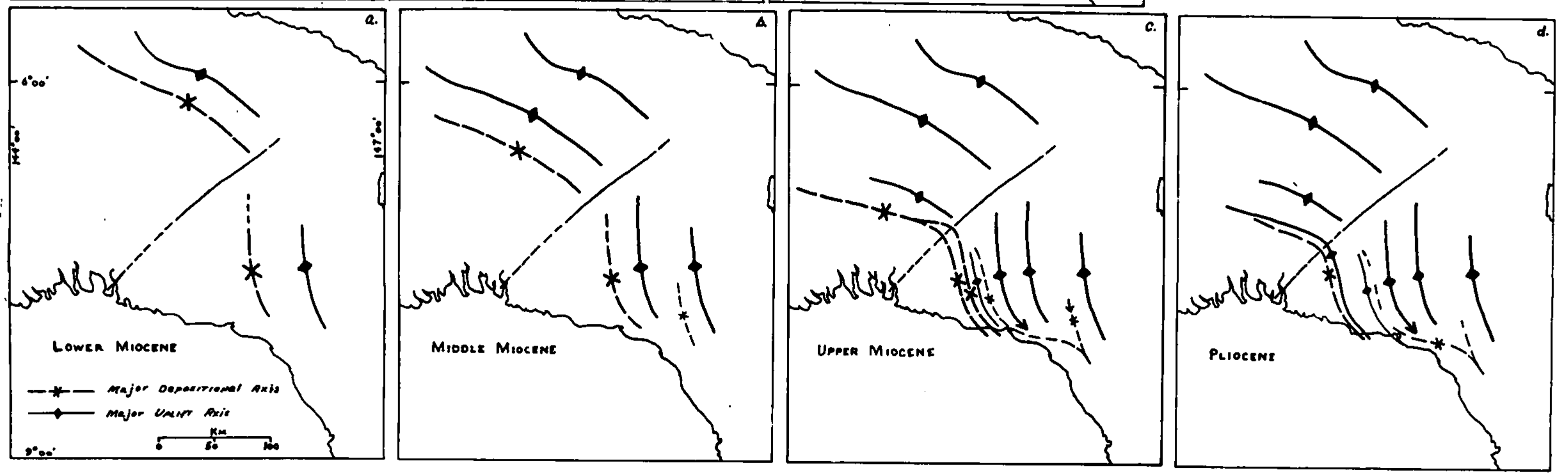


Figure 3-11 EVOLUTIONARY DIAGRAM SHOWING THE RELATIONSHIP OF UPLIFTS TO DEPOSITIONAL TROUGHS

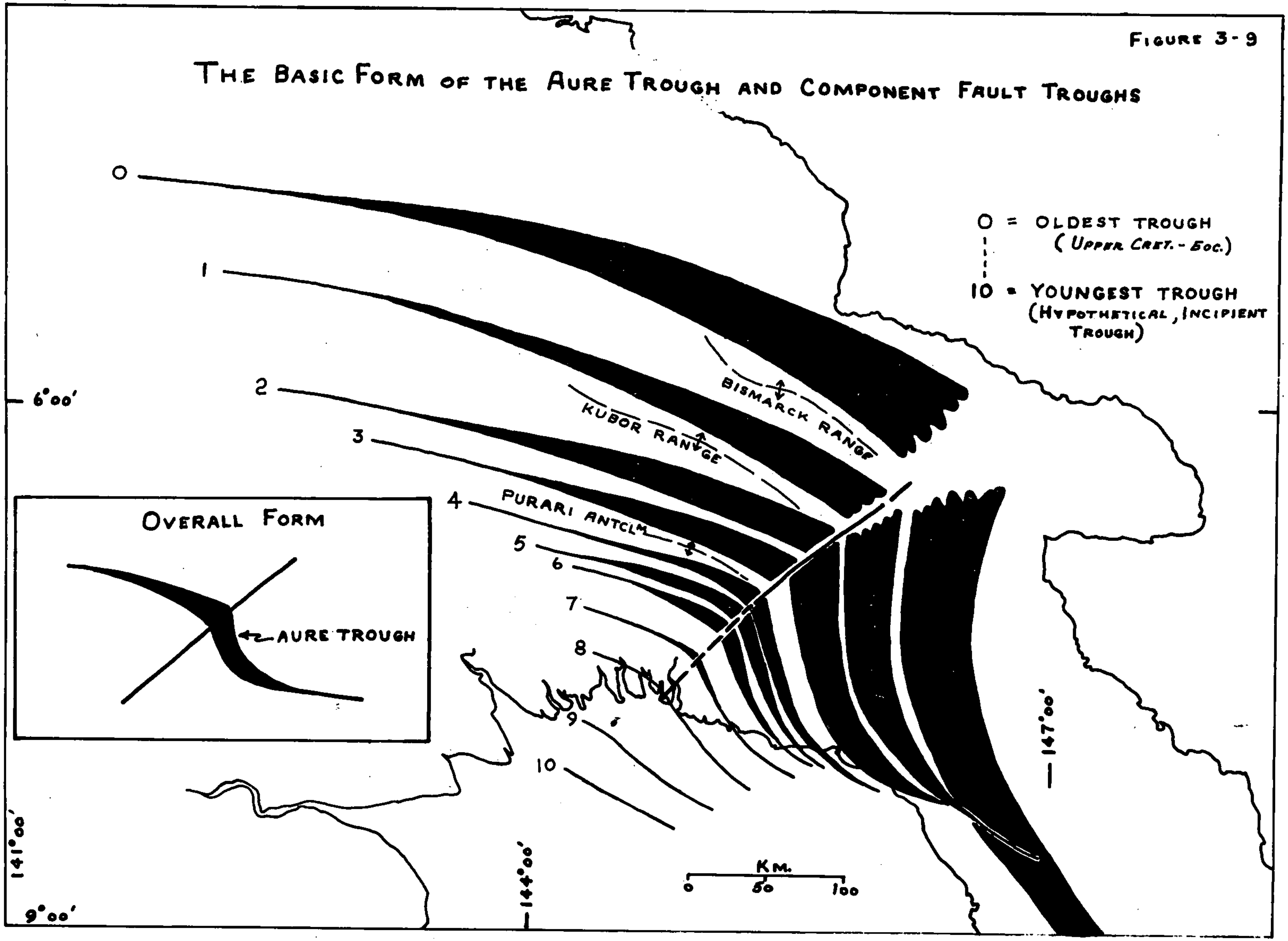
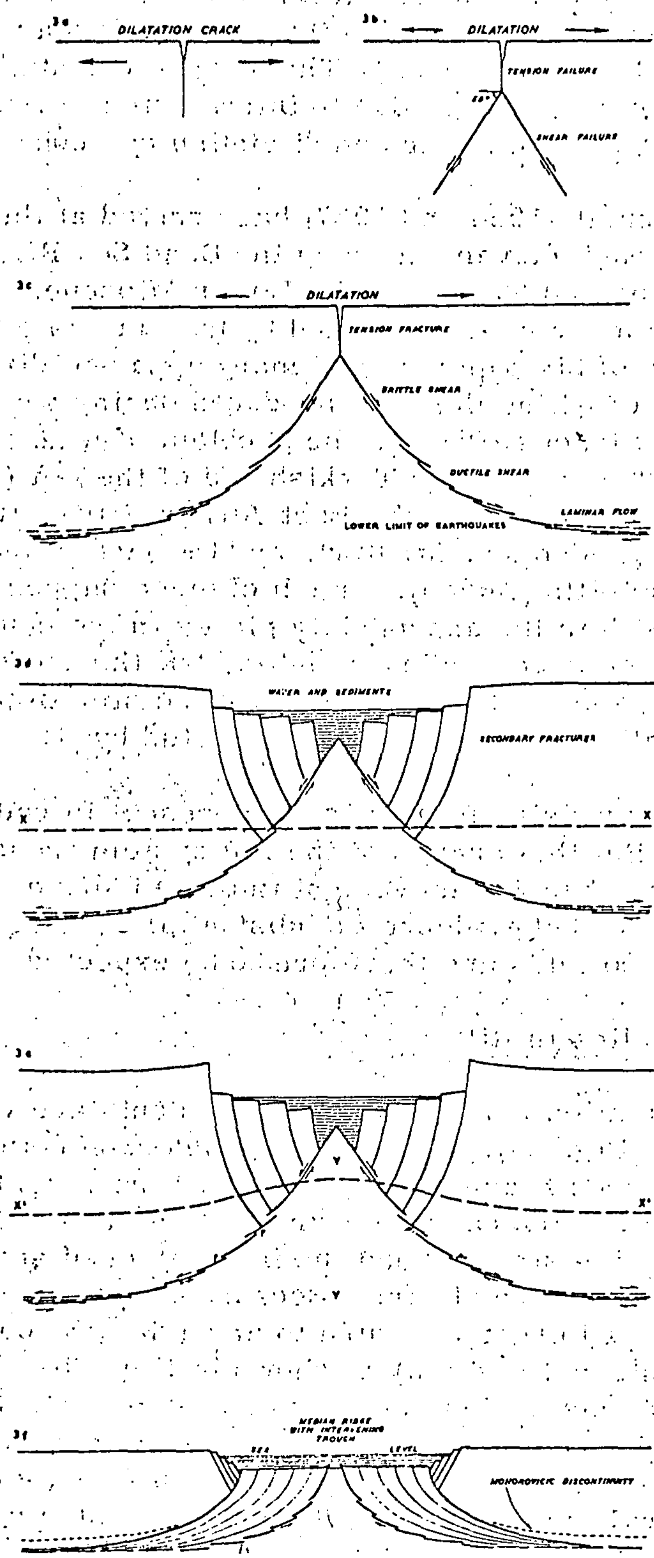


FIGURE 3-9

THE BASIC FORM OF THE AURE TROUGH AND COMPONENT FAULT TROUGHS

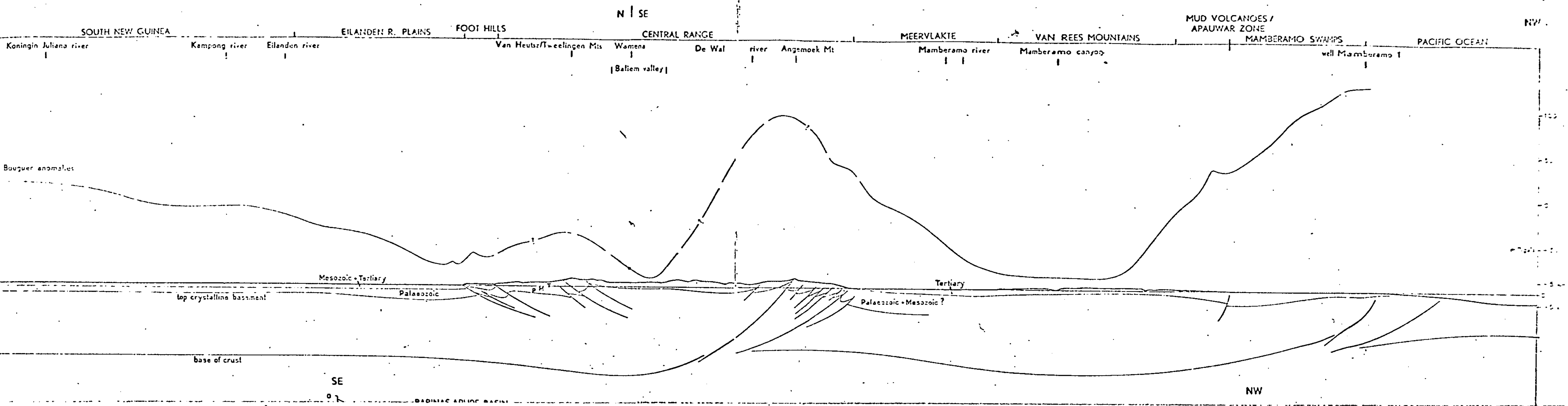
Figure 3-12 A MECHANISM FOR TENSIONAL TROUGH FORMATION AND CONCOMITANT ISOSTATIC ADJUSTMENT

Reproduced from Carey, 1957, Figure 3

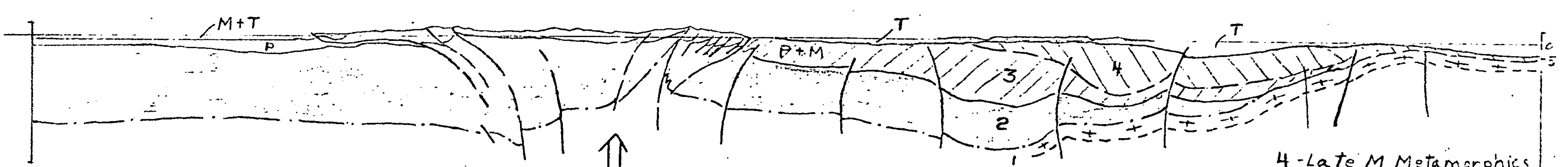


3. The development of rift valleys and rift oceans

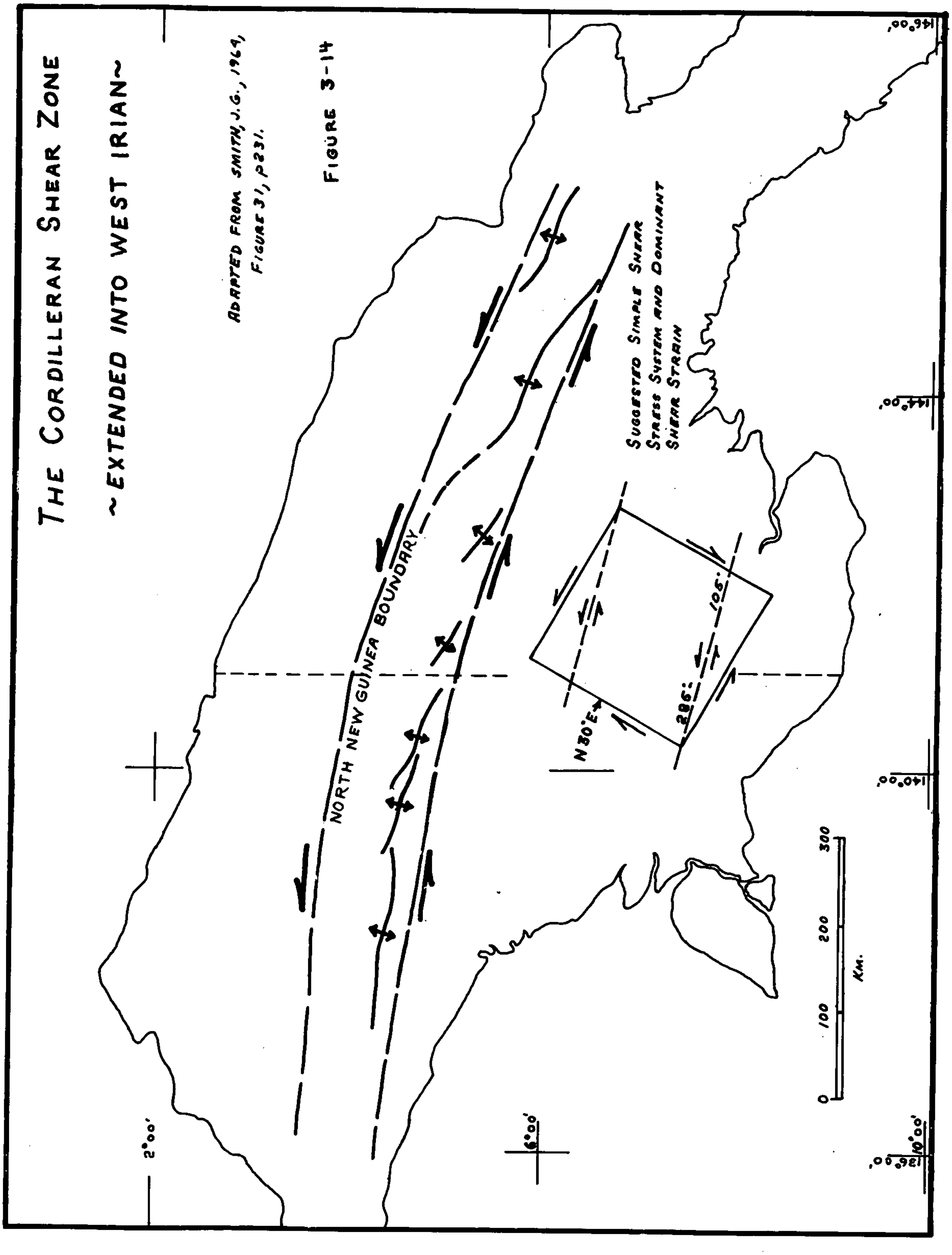
FIGURE 3-13 CROSS-SECTION OF WEST IRIAN
Reproduced from:
VISSER and HERMES, 1962, FIG. III-25



RE-INTERPRETATION



4-Late M Metamorphics
3-Early M "
2-Pre-M Crust
1-Oceanic Crust


THE CORDILLERAN SHEAR ZONE
~EXTENDED INTO WEST IRIAN~
ADAPTED FROM SMITH, J.G., 1964, FIGURE 31, p231.
FIGURE 3-14
SUGGESTED SIMPLE SHEAR STRESS SYSTEM AND DOMINANT SHEAR STRAIN
NORTH NEW GUINEA BOUNDARY
N30°E
286°
105°
0
100
200
300
KM.
2°00'
6°00'
10°00'
136°00'
140°00'
144°00'
146°00'

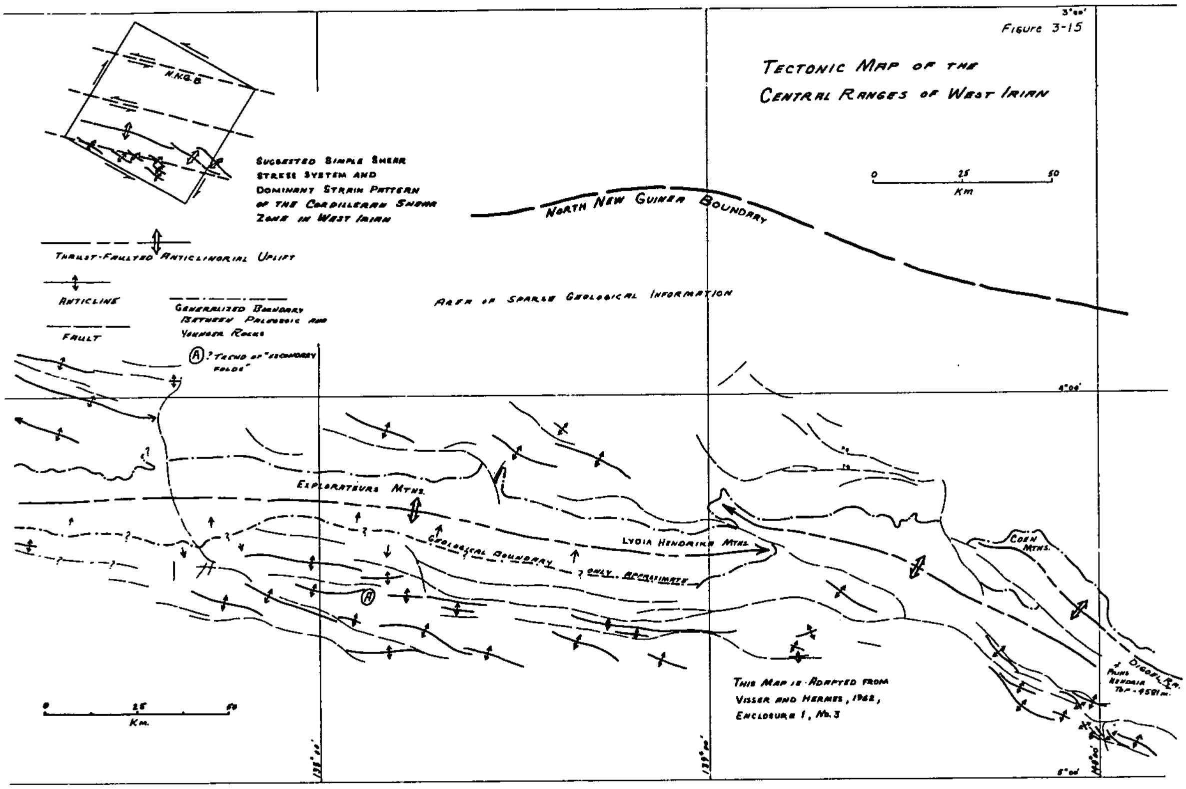


Figure 3-15
Tectonic Map of the Central Ranges of West Irian
Suggested Simple Shear Stress System and Dominant Strain Pattern of the Cordilleran Shear Zone in West Irian
N.N.G.B.
Thrust-Faulted Anticlinorial Uplift
Anticline
Fault
Generalized Boundary Between Paleozoic and Younger Rocks
North New Guinea Boundary
Area of Sparse Geological Information
Exploratеurs Mtns.
Geological Boundary
only Approximate
Lydia Hendrika Mtns.
Coen Mtns.
This Map is Adapted from Visser and Hermes, 1962, Enclosure 1, No. 3
0 25 50
Km

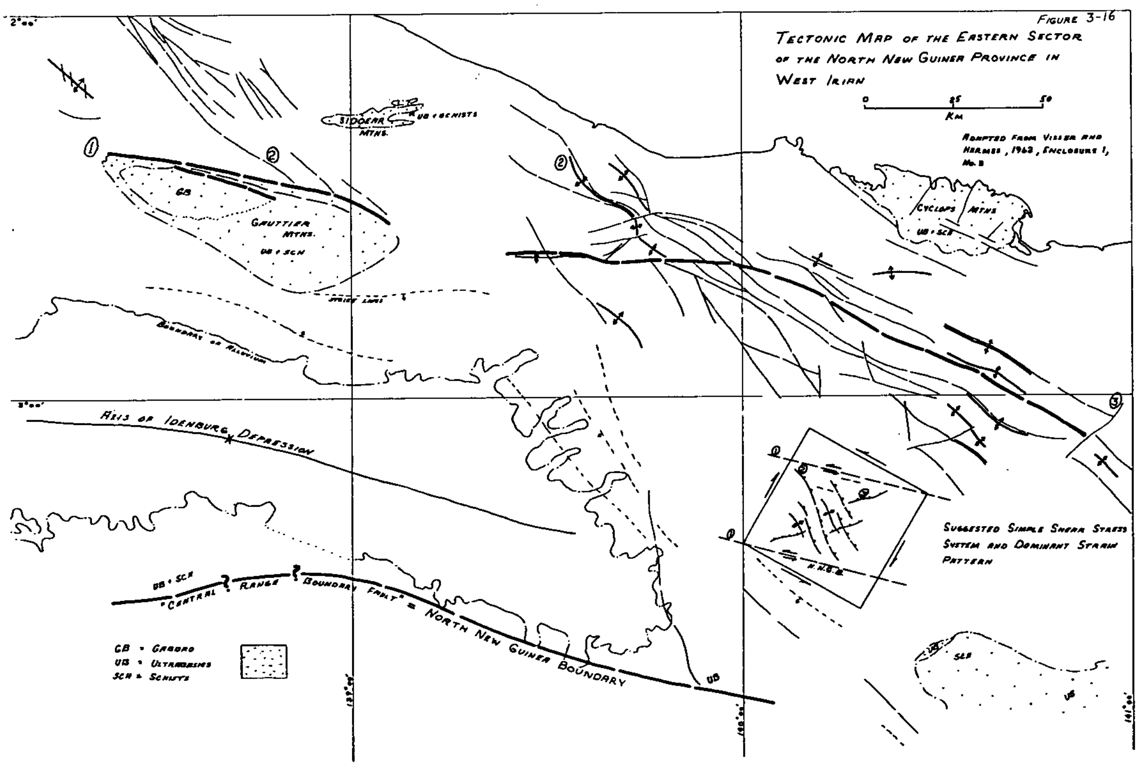
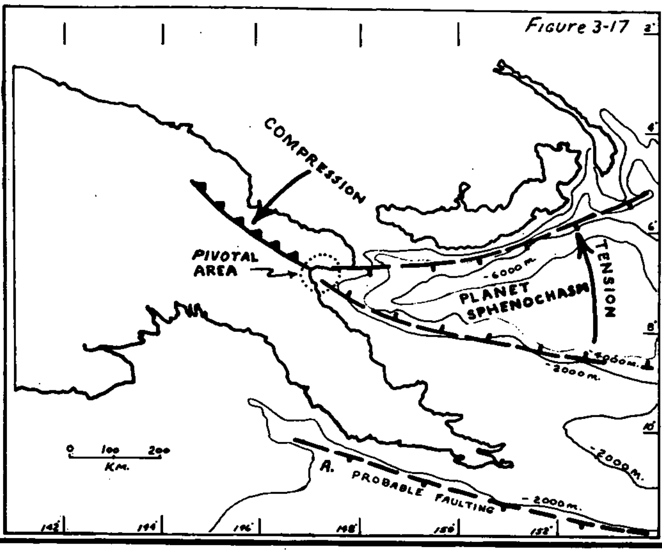
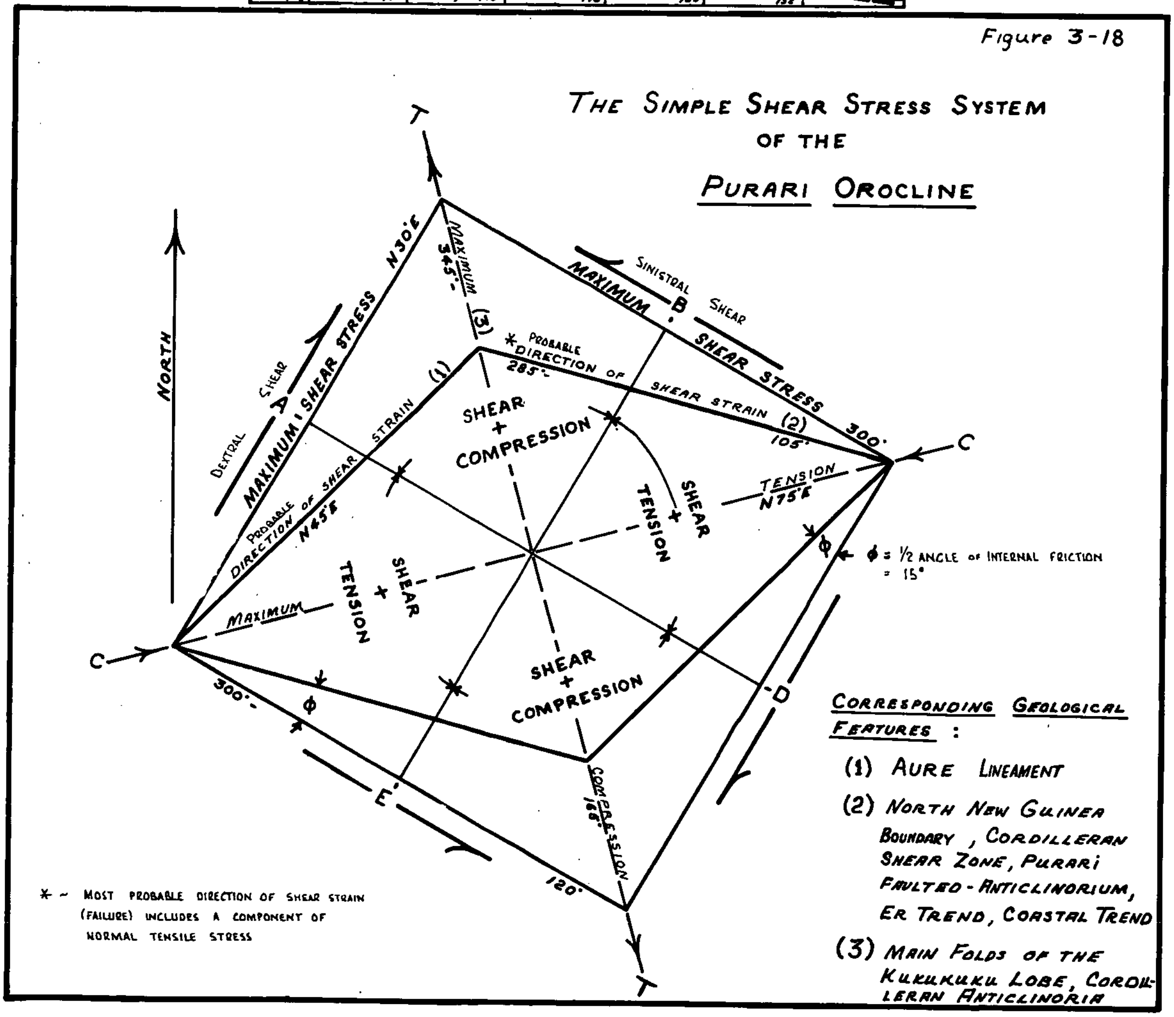
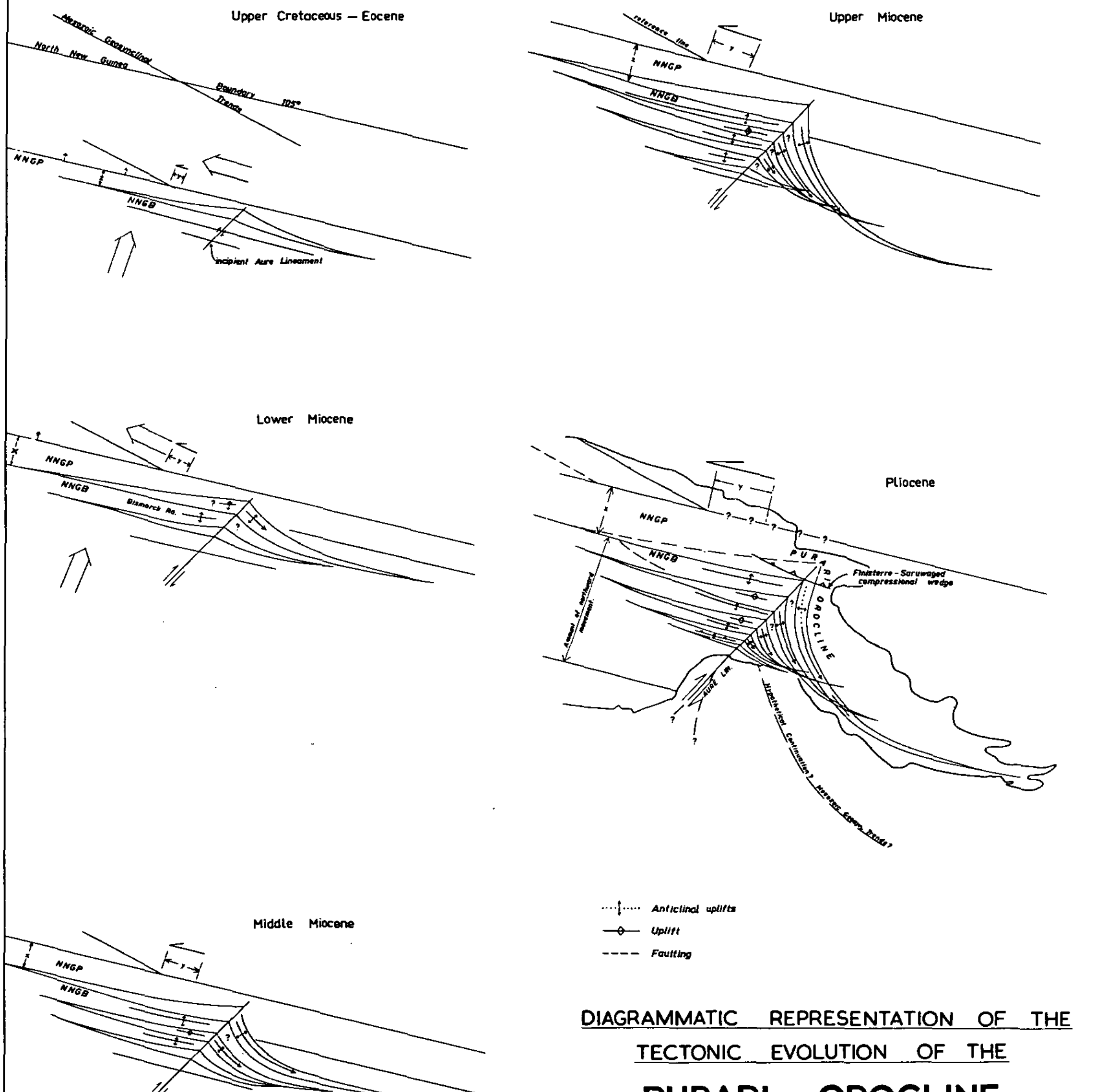


Figure 3-16
Tectonic Map of the Eastern Sector of the North New Guinea Province in West Irian
0 25 50
Km
Adapted from Visser and Hermes, 1962, Enclosure 1, No. 3
Siddeaa Mtns.
Gauttier Mtns.
GB
UB + SCH
Cyclops Mtns
Boundary of Alluvium
Axis of Idenburg Depression
"Central Range Boundary Fault" = North New Guinea Boundary
Suggested Simple Shear Stress System and Dominant Strain Pattern
N.N.G.B.
GB = Gabbro
UB = Ultrabasics
SCH = Schists

THE PLANET SPHENOCHASM AND THE COMPRESSIONAL WEDGE OF THE FINISTERRE - SARUWAGED - CROMWELL RANGES



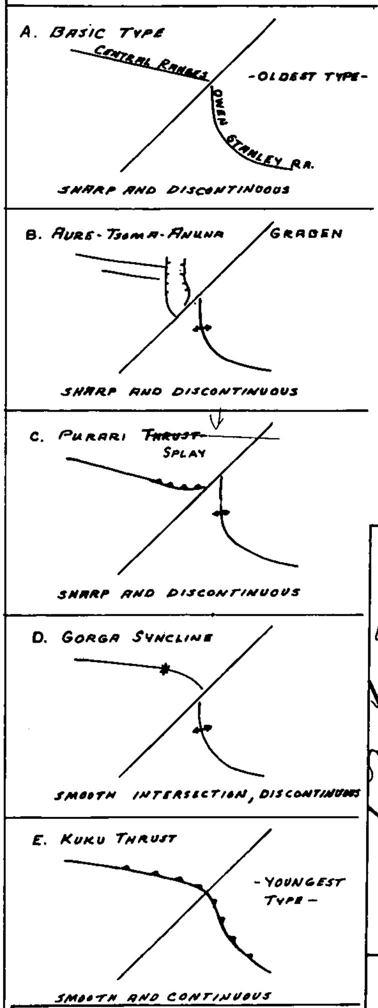




DIAGRAMMATIC REPRESENTATION OF THE TECTONIC EVOLUTION OF THE

PURARI OROCLINE

Figure 3-19



VARIOUS TYPES OF INTERSECTION OF STRUCTURAL TRENDS AT THE AURE FAULT

FIGURE 3-20

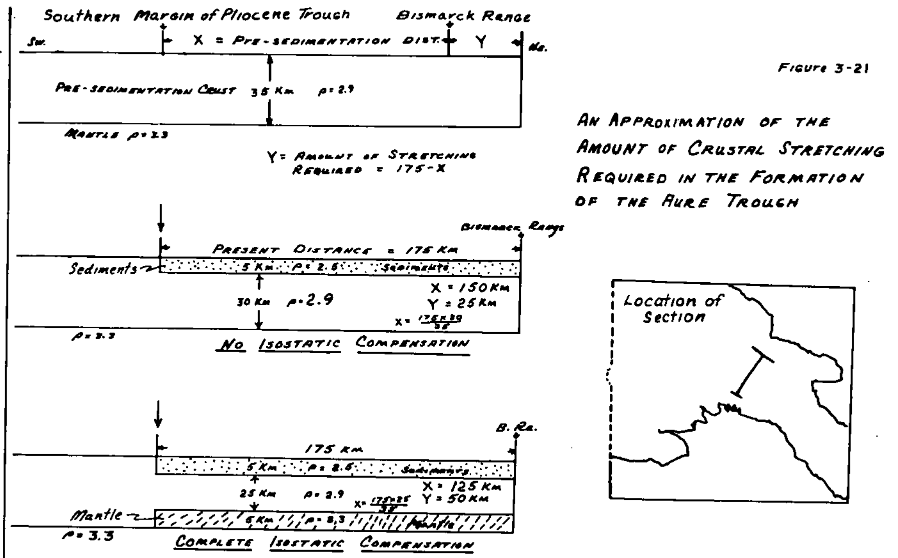


FIGURE 3-21

AN APPROXIMATION OF THE AMOUNT OF CRUSTAL STRETCHING REQUIRED IN THE FORMATION OF THE AURE TROUGH

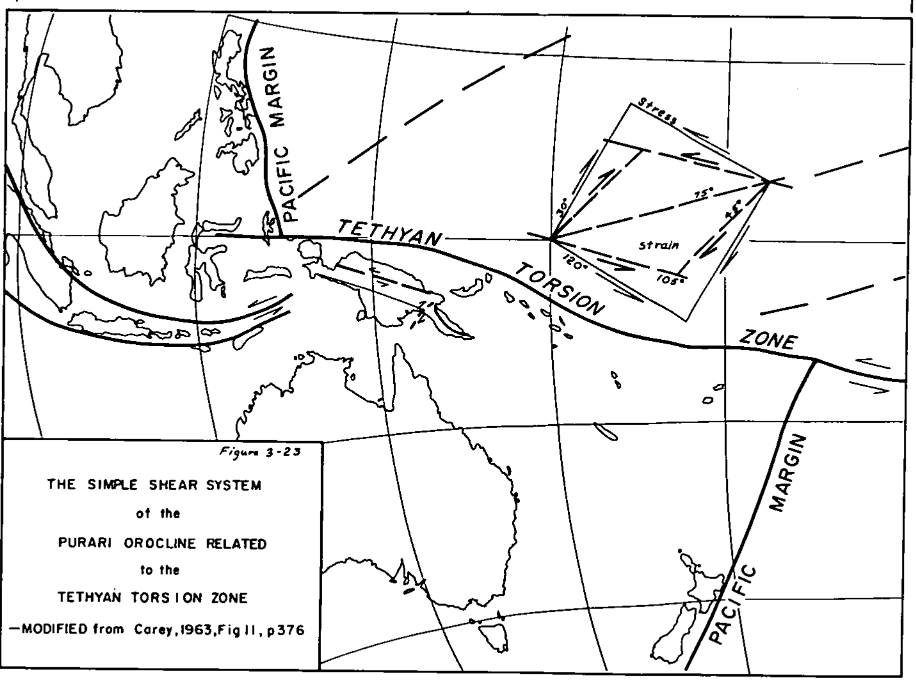


Figure 3-23

THE SIMPLE SHEAR SYSTEM of the PURARI OROCLINE RELATED to the TETHYAN TORSION ZONE

—MODIFIED from Carey, 1963, Fig 11, p376

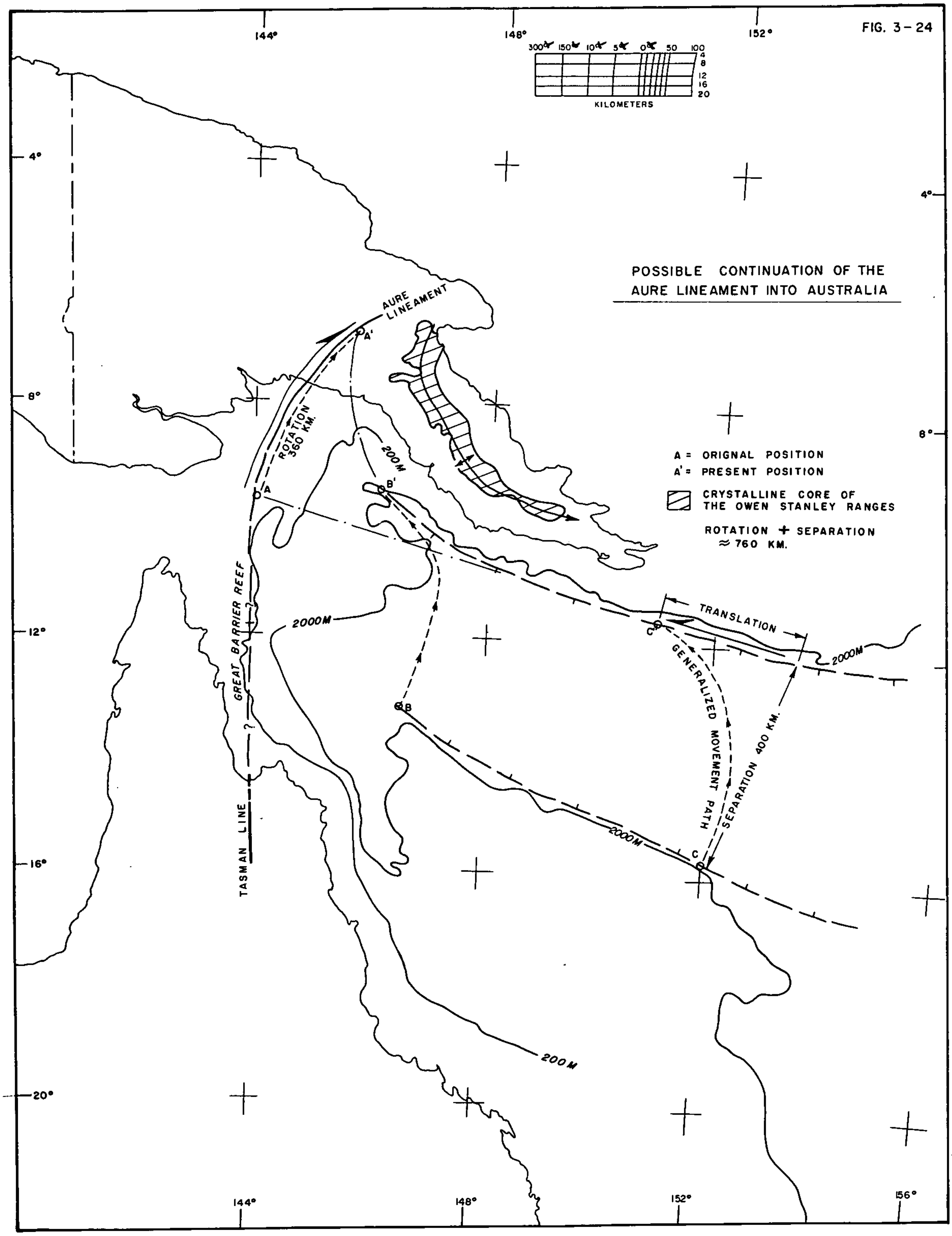


FIG. 3-24
POSSIBLE CONTINUATION OF THE AURE LINEAMENT INTO AUSTRALIA
A = ORIGNAL POSITION
A' = PRESENT POSITION
CRYSTALLINE CORE OF THE OWEN STANLEY RANGES
ROTATION + SEPARATION ≈ 760 KM.
KILOMETERS
AURE LINEAMENT
ROTATION 360 KM.
200M
2000M
GREAT BARRIER REEF
TASMAN LINE
TRANSLATION
GENERALIZED MOVEMENT PATH
SEPARATION 400 KM.
A
A'
B
B'
C
C'
144°
148°
152°
156°
4°
8°
12°
16°
20°

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Oil Search Pty. Ltd.

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LHE Hohoro Well No. 2 Completion Report, by K.H. Roberts, 1952; with Palaeontological Report by F.M. Kicinski.

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LKE Kariava Test Review, by K. Washington Gray, 1948.

LKF Memo MFG.48.9.3 - Palaeontology, Permit 2, Re-examination of Aure-Murua Boundary, Maropo Section, by M.F. Glaessner, 1948.

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" 2 - The Tauri-Saw Mountains Reconnaissance, by N. Osborne,
" 3 - The Koaru-Irava Gas Seepage, by N. Osborne and R. McWhae; with Report on Palaeontological Examination of Rock Samples from the Malalaua and adjoining area by M.F. Glaessner.

LNC Report on the Geology of the Nakoro Anticline, Permit 5, Papua, by F.K. Rickwood, 1948.

LOA Report on the Detailed Geological Survey of the Orloli Anticline, Permit 5, Papua, by J.E. Thompson, 1949.

LOB Report on the Orloli Revision Survey, Permit 5, Papua, by S. Paterson, 1950.

LP Report on the Keka-Pemani Survey, by F.K. Rickwood, 1947.

LPE Geological Survey of the Puri-Kuku Area, by G.A.V. Stanley (Report pending 1952); with Palaeontological Report by F.M. Kicinski.

LR Report on the Palaeontological Examination of Rock Samples from the Upper Vailala Survey, by M.F. Glaessner, 1948; with Report on the Upper Vailala Survey, Permits 5 and 13, Papua, by J.R.H. McWhae.

LT Report on the Purari Bend Survey, November, 1948, by F.K. Rickwood.

LU Report on the East Vailala River, Aipa Gravity Survey, Permit 5, Papua, by T.C. Richards, 1949.

LUC Review of Upoia Structure Consequent upon Completion of Well APC U.1, by A.F. McQueen, 1950; with Report on the Palaeontological Examination of the Samples from Upoia No. 1 Test Well, by G.M. Kicinski, 1951.

LUD Report on the Detailed Examination of the Upoia Upthrow Block, by K.M. Llewellyn, 1952; with Report on the Palaeontological Examination of the Rock Samples from the Upoia Survey Upthrow Block, by F.M. Kicinski and D.J. Belford, 1951.

LW Report on the Pio-Purari Reconnaissance, by F.K. Rickwood and P.E. Kent, 1956; with Palaeontological Report by F.T. Banner.

LYC Report on the Detailed Examination of the Iavokia Anticline by A.K.M. Edwards, 1947.

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NB Report on the Mafulu-Ononge Reconnaissance, by J.P. de Verteuil and F.K. Rickwood, 1946; with Report on the Palaeontological Examination of Rock Samples, by M.F. Glaessner, 1946.

WD Report on Aerial Reconnaissance over part of the Central Highlands of New Guinea, by S.W. Carey, 1939.

WI APC and IEC Review of Stratigraphy and Correlation in Australian New Guinea, by M.F. Glaessner, 1942.

WR Progress Report on the Correlation of Columnar Sections from Western Papua, by F.M. Kicinski, 1950.

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