

MAGNETOSTRATIGRAPHY OF GLACIAL LAKE SEDIMENTS
AND DATING OF PLEISTOCENE GLACIAL DEPOSITS IN TASMANIA

by

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Declaration.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and contains no copy or paraphrase of material previously published or written by any other person, except where due reference is made in the text.

A handwritten signature in black ink, appearing to read 'M.J. Pollington', with a long horizontal stroke extending to the right.

M.J. Pollington.

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ABSTRACT

Magnetostratigraphic techniques have been applied to Quaternary glacial deposits of western, central western and central northern Tasmania. The aims of this study were to examine the validity of the application of these techniques to glacial lake sediments, to separate glacigenic deposits that were beyond the range of radiocarbon dating and to compare the stratigraphy determined by these methods with the established stratigraphy, on the basis of their magnetic polarity.

The extant model of the glacial stratigraphy of Tasmania is based on morphostratigraphic, lithostratigraphic and biostratigraphic mapping, and the analysis of weathering characteristics, particularly weathering rind analysis. The model recognises at least three glaciations, the Margaret or Last Glaciation, the Henty Glaciation and the Linda Glaciation. The magnetostratigraphic framework developed as a result of this study has largely confirmed the established stratigraphic framework, with the exception of some deposits of Henty Glaciation age.

The Henty Glaciation has been considered to be the Penultimate Glaciation in Tasmania, and hence of Middle Pleistocene age. Evidence from the Henty Surface has demonstrated that some of the deposits in the Henty Glaciation type area must be > 730 ka in age and hence of Early Pleistocene age.

The Linda Glaciation has been considered to be of very considerable age by many earlier workers. This study has demonstrated that the Linda Glaciation and its equivalents are > 730 ka in age, and hence of Early Pleistocene or even Late Tertiary age. The Linda Glaciation appears to have been a complex event, consisting of either a number of glacial advances, or two or more separate glaciations.

Magnetostratigraphic techniques have been shown to be useful and valid techniques for the determination and clarification of the ages of Middle and Early Pleistocene deposits in stratigraphic sequences. Glacial lake sediments have been shown to be suitable material for the application of such techniques. The suitability of material for palaeomagnetic analysis varies considerably, so some results are considered to be more reliable than others. Accordingly, a reliability index based on a number of factors has been constructed. Glacial lake sediments derived from sources containing dolerite or volcanic detritals are particularly suitable as they have strong magnetic signatures.

Correlation of the glacial events of Tasmania with those of New Zealand and South America is not possible at present. Magnetostratigraphy will provide a means of correlating these events when similar frameworks have been established for these areas.

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Chapter 1 AIMS

1.1 Introduction

This thesis is concerned with the application of palaeomagnetic techniques to the dating of the Quaternary glacial deposits of western, central western and central northern Tasmania.

Tasmania is an island some 68331 km² in area and is the southernmost state of Australia. It lies between 40° 38' and 43° 39' S latitude and 144° 36' and 148° 23'E longitude (Fig 1.1) and is separated from the mainland of Australia by Bass Strait, a shallow sea approximately 240 km wide. It is separated from New Zealand to the east by the Tasman Sea and from Antarctica to the south and South America to the west by the Southern Ocean.

The island is marked by rugged relief, with very little of its surface close to sea level, but the mountains are of relatively low altitude compared with those of New Zealand and South America. Six peaks exceed 1500 m in height and a further 28 exceed 1220 m. The main physiographic feature of the island is a relatively undissected, dolerite-capped plateau, the Central Plateau, that slopes generally south-eastward from an average level of 1065 m in the north to 610 m in the south; a substantial part of this plateau is above 900 m. A remnant of this plateau is represented by the 1500 m Ben Lomond plateau of north-eastern Tasmania. The Central Plateau is bordered on the west and south-west by a series of mountain ranges that lie parallel to the coast, the West Coast Ranges. None of these mountain ranges are sufficiently high to maintain a permanent snow cover.

Tasmania experiences a temperate maritime climate because of its latitude and position in relation to the oceans and because no part of the island is more than 115 km from the sea. It is dominated by the westerly maritime airstream, being located on the northern edge of the wind belt known as the 'roaring forties'. It is influenced by a westerly wind flow throughout the year, with the south and west coastal areas experiencing strong winds and heavy rain. The combination of mountainous terrain in the western half of the state and the prevailing westerly winds produces a marked west-east variation in the climate, particularly in the rainfall pattern. The average annual rainfall ranges from about 1500 mm on the west coastal regions to 3500 mm at Lake Margaret on the West Coast Range, whilst in the north west of the state it ranges from 1000 mm near the coast to 1600 mm in the higher inland areas. In the north east of the state it ranges from 500 mm on the coast to 1300 mm on the more elevated areas.

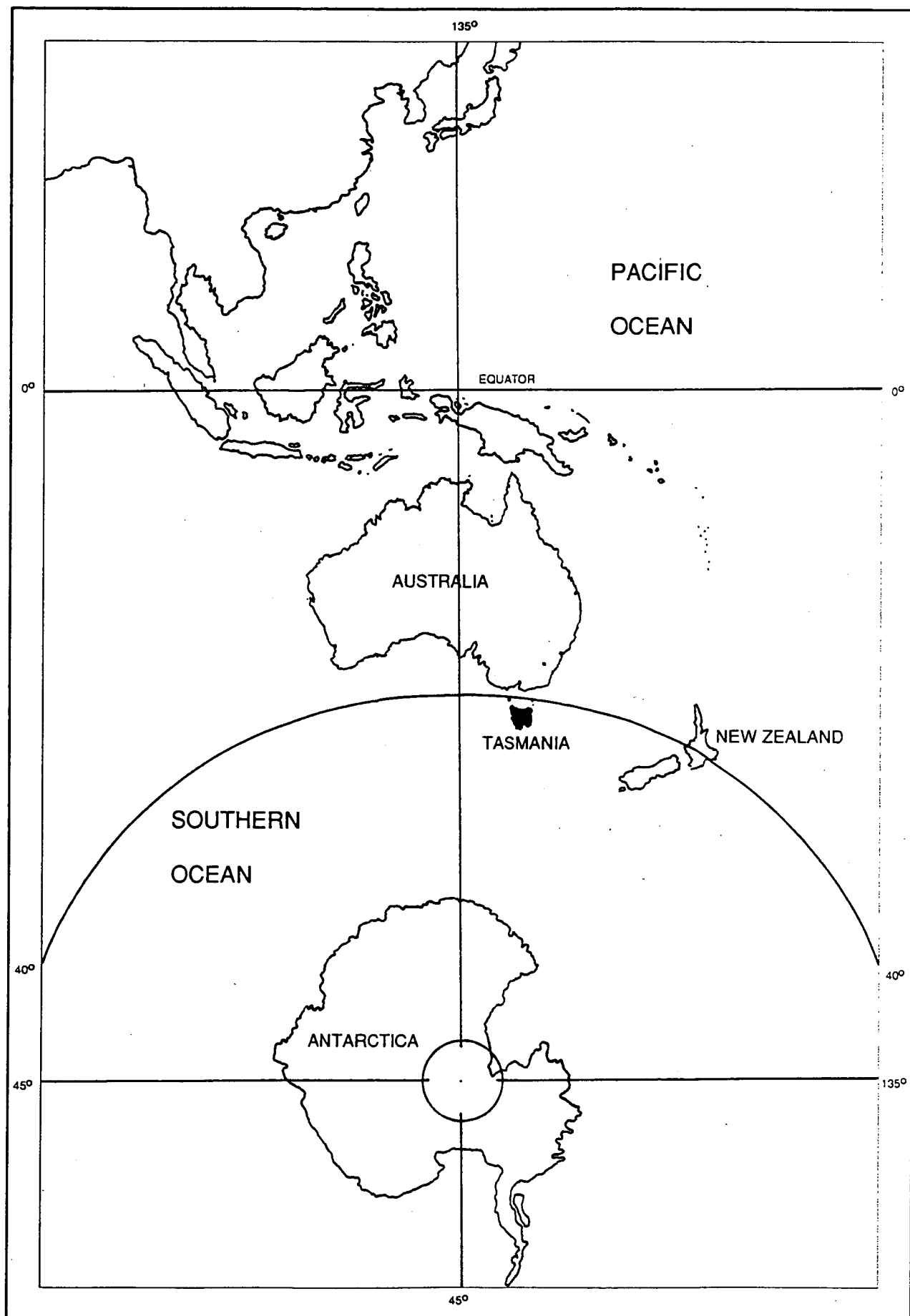


Fig. 1.1 Location map of Tasmania.

The eastern half of Tasmania, including the Central Plateau and the Ben Lomond Plateau, is dominated by flat-lying dolerite sills. The western half is geologically complex, the West Coast Range being composed of the Cambrian Mount Read Volcanics, Ordovician quartzites and conglomerates, and Precambrian metamorphics.

The vegetation of the island is dominated by rain forest and sedgelands in the western part, and moorland and alpine communities in the very elevated areas. In the centre and east, sclerophyll forest is the dominant vegetation type, except for the Ben Lomond plateau where rain forest occurs around the northern margins and moorland on the more elevated areas (Davies 1965, Gee and Fenton 1979).

At the present time there is no permanent snow and hence no glaciers; during the Quaternary, however, glacial ice was present on the West Coast Ranges, and extended well down into the associated valleys; on the Central Plateau, from which it extended into the valleys of the Mersey and Forth in the Central North; and on the Ben Lomond plateau in the north east of the state.

The earliest recorded discoveries of ice action in Tasmania were made by Gould (1860), and references to the effects of glacial ice were made by a number of explorers and early geologists working on the mining fields of the West Coast between the 1880s and the early 1920s (Sprenst 1887, Dunn 1893, 1894, Johnston 1894, Moore 1894, Gregory 1904, Waller and David 1904, Ward 1909, David 1926a, 1926b). Between 1922 and 1945 A. N. Lewis developed a multiple glaciation model based on the erosional evidence of glaciation throughout the island (Lewis 1922, 1926, 1934, 1936, 1939, 1945). The next major period of study occurred between the mid-1950s and the early 1970s; this work largely questioned the multiple glaciation model (Gill 1956, Jennings and Ahmad 1957, Jennings and Banks 1958, Banks and Ahmad 1959, Ahmad *et al.* 1959, Davies 1962, Derbyshire 1963, 1968, Derbyshire *et al.* 1965, Peterson 1968, 1969, Derbyshire and Peterson 1971). In the mid-1960s, however, Paterson recognised two glacial stages in the Mersey-Forth area of central northern Tasmania (Paterson 1965, 1966, Paterson *et al.* 1967). The application of carbon dating techniques, pollen analysis of organic sediments and systematic mapping in the 1970s saw a return to the multiple glaciation model and revealed an increasingly complex picture (Bowden 1974, Colhoun 1976, 1985b, Kiernan 1983, 1985, Fitzsimons 1988). The locations of glacial sequences studied since the early 1970s are shown in Fig. 1.2.

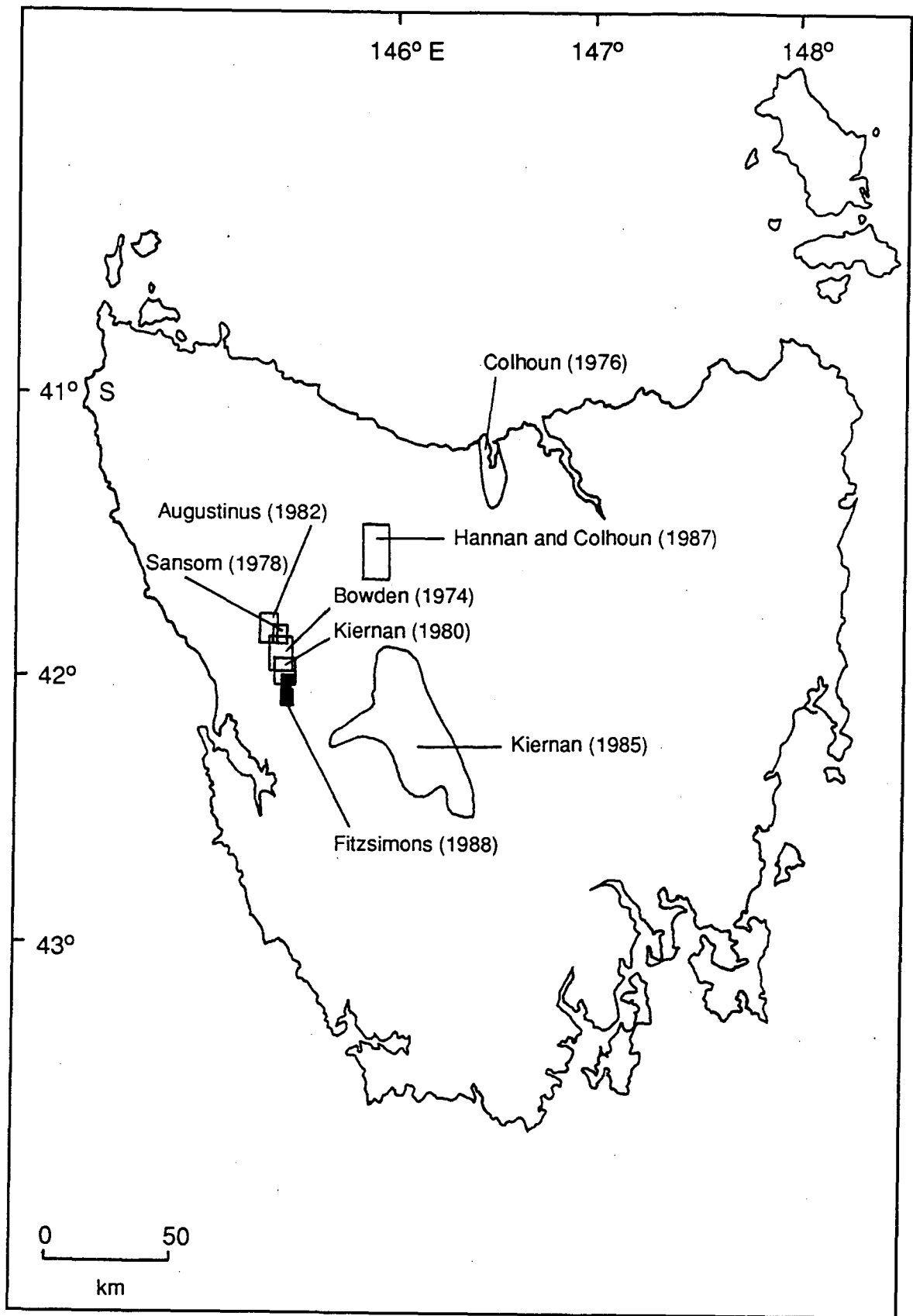


Fig. 1.2 Quaternary glacial sequences studied in Tasmania (after Fitzsimons, 1988).

1.2 Aims

The broad aim of this study was to apply palaeomagnetic techniques to the dating of glacial lake silts and clays, to test the extant model of glacial stratigraphy of Tasmania and to differentiate Middle Pleistocene and Early Pleistocene sediments and events. This method has previously been applied only once to glacial sediments in Tasmania, and then only at two sites (Barbetti and Colhoun, 1988).

Specifically the aims of this research were to utilize palaeomagnetic studies of glacial lake sediments and other similar sediments to achieve the following:

a) Separate glacial deposits in Tasmania older than 50 ka in age, and therefore beyond the range of radiocarbon dating, into those that exhibit normal and reversed polarity signals. Samples with a normal polarity are likely to belong to the Brunhes Chron, are therefore less than 730 ka in age and are of Middle or Late Pleistocene age. Samples with a reversed polarity are likely to belong to the Matuyama Chron and are of Early Pleistocene age; samples with a normal polarity but greater than 730 ka in age are likely to be of Early Pleistocene age also, and may belong to the Jaramillo or Olduvai normal events of the Matuyama Chron.

b) Examine whether palaeomagnetic evidence supports the time frames suggested by other methods for glacial advances in Tasmania.

c) Obtain some idea of the extent of the total time span during which Tasmania has experienced glaciation.

d) Pinpoint in time, if possible, any glacial advance that may have occurred by the location of a palaeomagnetic boundary within one sediment body (e.g. Brunhes/Matuyama boundary).

1.3 Thesis Structure

This thesis is separated into six chapters. Chapter One is a general introduction and deals with the aims of the thesis. The problem on which the thesis is based, the Tasmanian Glacial Stratigraphy, the use of magnetostratigraphy and glacial lake sedimentation, are discussed in Chapter Two. The field and laboratory methods used in this study are discussed in Chapter Three. The data collected are presented in Chapter Four and critically analysed in Chapter Five. Conclusions deriving from analysis of the data and the validity of the methodology are presented in Chapter Six.

Chapter 2 PROBLEM

A stratigraphic framework for the Quaternary glacial events of Tasmania has been established by a succession of workers over the past 130 years. This framework has changed over time and there are still some significant 'unsolved' problems. It was considered that the application of magnetostratigraphic techniques to appropriate glacial sediments might assist in clarifying some of these problems. Glacial lake sediments were seen as having potential for magnetostratigraphic analysis. Each of these three aspects, glacial stratigraphy, magnetostratigraphic techniques, and glacial lake sediments, is discussed in greater detail below.

2.1 Tasmanian Glacial Stratigraphy

The glacial history of Tasmania has been summarised by Colhoun (1985) and Colhoun and Fitzsimons (1990). The first reported observations were made by Gould (1860). Over the next sixty years further observations were made by various geological surveyors, particularly following the discovery of minerals on the West Coast Range, but these observations were confined to describing landforms of glacial erosion and deposition, and no coherent stratigraphic framework emerged.

Over the period 1922 -1945 A. N. Lewis, a Hobart lawyer, studied extensively the erosional evidence left by glaciation. On the basis of this work he proposed a multi-glacial model, consisting of three glaciations, for western Tasmania. The youngest glaciation he called the Margaret Glaciation, the penultimate the Yolande Glaciation and the oldest the Malanna Glaciation. He also indicated that the Malanna Glaciation was the most extensive and that the Yolande and Margaret Glaciations were of decreasing intensity (Lewis 1922, 1926, 1934, 1936, 1939, 1945).

Lewis' findings were re-examined in the 1950s as new exposures of glacial deposits were produced by construction work in western and north-central Tasmania. This re-examination was based on the stratigraphic evidence provided by glacial deposits, as opposed to Lewis' approach which was based mainly, but not entirely, on glacial erosional features. Gill (1956) concluded that the rhythmites of Lewis' Malanna Glaciation in the Linda Valley were of last glaciation age on the basis of a radiocarbon date of $26,480 \pm 800$ yr BP (W323). This date was taken to suggest that all glacial deposits were of last glaciation age (Jennings and Ahmad, 1957, Jennings and Banks, 1958, Ahmad *et al.*, 1959, Davies, 1962, 1967, Derbyshire *et al.*, 1965). Banks and Ahmad (1959) strengthened this viewpoint by demonstrating that the supposed glacial deposits at Malanna were Tertiary lacustrine and fluvial deposits. However, the distribution and character of some glacial

deposits could not be explained by only one glaciation (Derbyshire *et al.*, 1965, Derbyshire, 1968, Derbyshire and Peterson, 1971). The existence of two glacial stages in the Mersey-Forth area was recognised by Paterson (1965, 1966) and Paterson *et al* (1967).

In the 1970s significant developments in the understanding of the glaciation of Tasmania were brought about by systematic mapping of glacial deposits combined with radiocarbon dating. This work suggested that glacial deposits predating the Last Glacial Maximum were widespread (Banks *et al.*, 1977). Subsequent studies demonstrated that the glacial stratigraphy was more complex than previously thought. Colhoun (1985b) suggested that at least three glaciations separated by full interglaciations had occurred; these were named the Margaret (youngest), Henty, and Linda (oldest). More recent studies have supported the multiple glaciation model, although some suggest an even more complex model (Fitzsimons, 1988, Kiernan, in 1989).

2.1.1 Stratigraphy of Areas Covered by this Study

This study has been based on the stratigraphic frameworks established by the following workers:

(1) West Coast Sites:

- | | |
|--------------------------|---|
| a) Pieman and Boco area: | Sansom (1978), Augustinus (1982),
Augustinus and Colhoun (1987). |
| Rosebery Opencut: | Colhoun and van de Geer (1987). |
| b) Henty Surface: | Bowden (1974), Bengert (1987),
Colhoun <i>et al</i> (1989). |
| c) Linda Valley: | Kiernan (1983). |
| d) King Valley: | Fitzsimons (1988),
Colhoun & Fitzsimons (1990). |

(2) North Central Sites:

Hannan & Colhoun (1987), Hannan (1988).

(3) West Central Sites:

Kiernan (1985), Kiernan (1989).

The stratigraphic framework developed in each of these studies was based on morphostratigraphic mapping of the landforms and deposits, pollen analysis of organic deposits with suggested biostratigraphic correlations, radiocarbon dating, weathering rind analysis and amino-acid dating (Colhoun and Fitzsimons 1990). The magnetostratigraphy determined from this study will be compared with these established stratigraphic frameworks.

2.1.2 West Coast Sites

The West Coast Region can be considered as a number of sub-areas: the Pieman and Boco area (including Rosebery and Williamsford), the Henty area, and the King and Linda valleys.

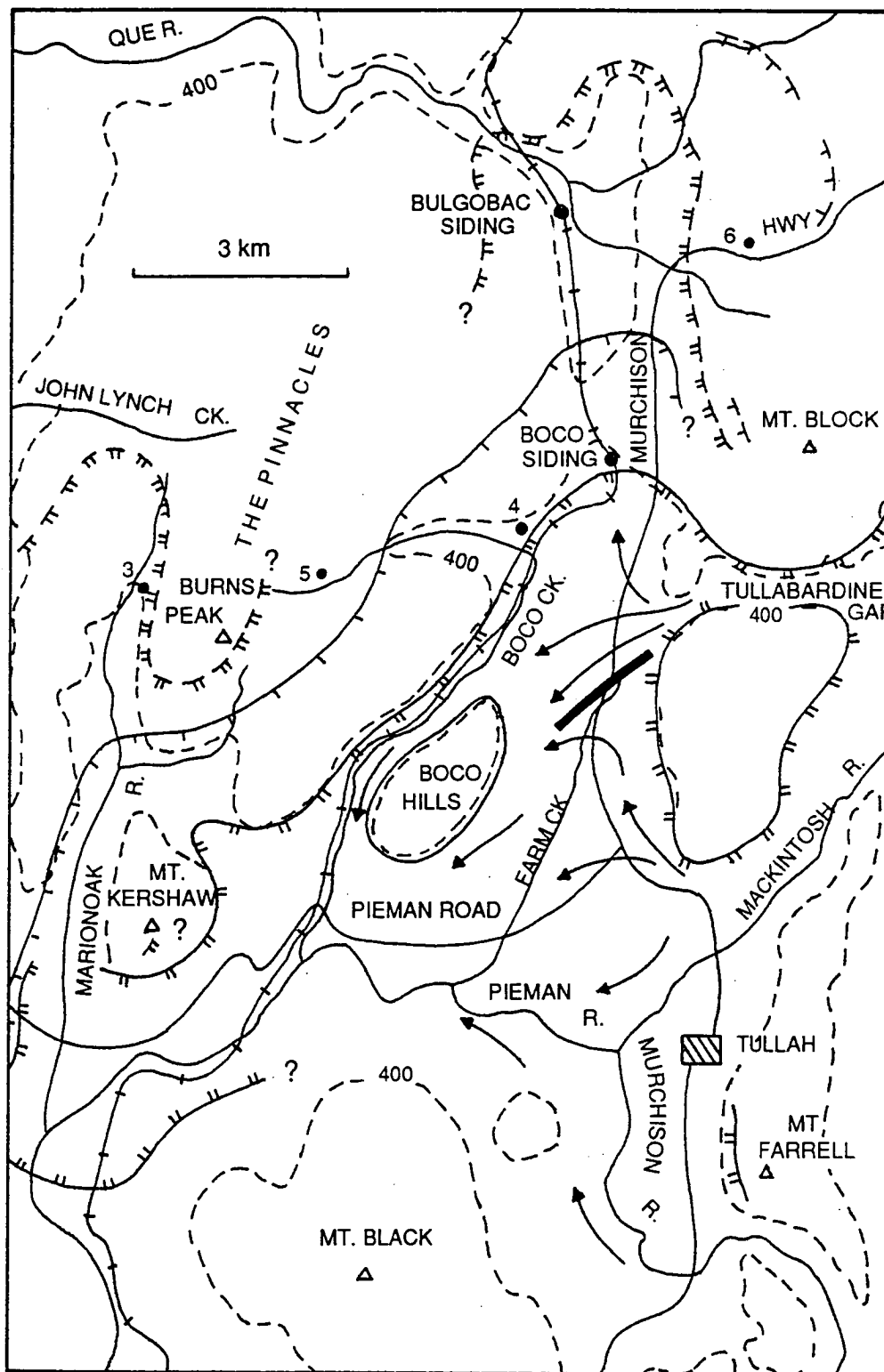
a) Pieman and Boco Area

Augustinus and Colhoun (1986) identified four glaciations in the Pieman and Boco valleys, differentiating the various drift sheets on the basis of weathering rind thickness, percentage absorption of water, specific gravity of rock clasts, the weathering characteristics of the till matrices and post-depositional modification of landforms. Deposits belonging to the last glaciation were not identified in this area. The glaciations, the ice limits of which are shown in Fig. 2.1, are thus of Penultimate and earlier age.

The glaciations are represented in order of increasing age by the Boco drift, subdivided into the Boco I and Boco II drifts on the basis of variations in the weathering characteristics, Bulgobac and Que drifts respectively. The Boco deposits were considered to be >130,000 years of age and the Bulgobac deposits to be at least 10 times older, that is >1.3 million years of age. On this basis the Bulgobac deposits would be of Early Pleistocene or Late Tertiary age (Colhoun, 1985), and the Que drift even older. However, Fitzsimons (1988), after examining the evidence used by Augustinus and Colhoun (1986) to differentiate the Bulgobac and Que deposits, concluded that none of this evidence suggested that the two deposits were any different. These glacial events, together with the weathering rind data on which suggested ages are based, are shown in Table 2.1.

Table 2.1 Formations of the Pieman and Boco Valleys and suggested ages based on weathering rind analysis.

GLACIAL EVENT	MEAN WEATHERING RIND THICKNESS	SUGGESTED MINIMUM AGE	
Boco II	5-12mm	>130 ka	Mid Pleist.
Boco I	13 mm	> 430 ka	Mid Pleist.
Bulgobac	130mm	>1300 ka	Early Pleist.
Que			Early Pleist.



- Boundary of Pieman and Tullabardine ice lobes
- Boco II ice flow directions
- Boco II drift limit
- Boco I drift limit
- Bulgobac drift limit
- Que drift limit

Fig. 2.1 Reconstructed ice limits in the Pieman and Boco Valleys (after Augustinus and Colhoun, 1986).

Glacial deposits in the Rosebery Opencut Mine were considered to be Boco Glaciation deposits (not differentiated) by Colhoun (pers. comm. 1987) and Colhoun and van de Geer (1987). Wood from the deposit has an amino-acid age of Isotope Stage 7 (Pillans pers. comm.). The implication is that the wood is of second last interglacial age and was incorporated into the till by the Boco ice during Isotope Stage 6 (Colhoun, pers. comm. 1989).

b) Henty area

Two glaciations, the Margaret and the Henty, have been identified in this area. The limits of these glaciations are shown in Fig. 2.2. The last glaciation, the Margaret Glaciation, is defined by a topography of undissected moraines (Rolleston and Hamilton), largely unweathered deposits and radiocarbon ages of < 25 ka BP (Colhoun, pers. comm. 1989).

Henty Glaciation deposits, best seen in the King Valley (Fitzsimons, 1988), were first described from the Henty Bridge site on the Lyell Highway. Colhoun (1985) concluded that these deposits were older than the late Margaret Glaciation because they had a radiocarbon dating of >34,600 yr BP (Gak- 5595). On this basis he concluded that they probably represented the Penultimate glaciation. Subsequent radiocarbon dating at Newton Creek produced an age of >33950 yr BP (Beta 21759). At Langdon River organic deposits had an age >43,000 yr BP (SUA-2278) and an interglacial rainforest flora; amino-acid dating suggested that these deposits belong to Isotope Stage 7. This suggests that the "Henty" deposits of the Henty Surface do not belong to the original Henty Glaciation but must be older than the second last interglacial, and may therefore represent either a Middle or Early Pleistocene glaciation (Colhoun, pers. comm. 1989).

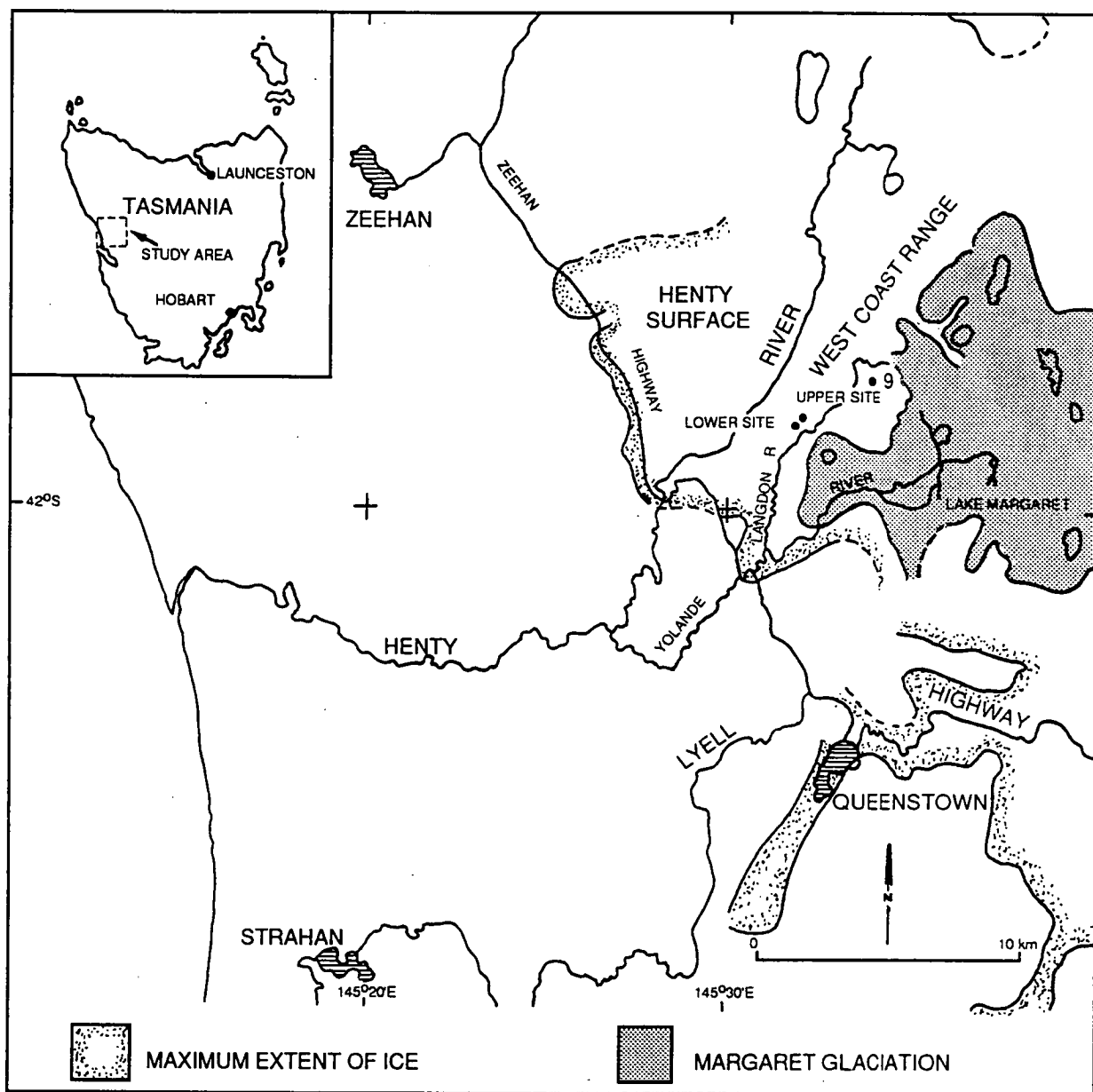


Fig. 2.2 Reconstructed ice limits on the Henty Surface
(after Colhoun, 1985, and Colhoun *et al*, 1989).

c) King and Linda Valleys

Fitzsimons (1988) identified four glaciations with nine ice advances in the King Valley (Table 2.2). He recognised the Late Pleistocene Margaret Glaciation as having two advances, the Dante with a maximum about 19 ka BP and the Chamouni with a maximum prior to 49 ka BP (SUA 2599).

The Henty Glaciation consisted of three ice advances and an interstadial. Whilst recognising the inherent problems involved in using weathering rind analysis for dating purposes, Fitzsimons (1988) indicated that the Henty deposits were 3-5 times as strongly weathered as the Margaret Glaciation deposits. He interpreted this weathering evidence as indicating that the Henty Glaciation predated the Last Interglacial, and was therefore >130 ka old.

The Moore Glaciation consisted of two ice advances separated by an interstadial. The mean weathering rinds on Jurassic dolerites in these sediments are much thicker (14-17 mm) than on the Cableway Formation of the Henty Glaciation (5 mm) and the Baxter interstadial deposits have an amino-acid age of Isotope Stage 10. On this basis the Moore Glaciation was considered to be of early Middle Pleistocene age (Colhoun and Fitzsimons, 1990).

The Regency Interglacial deposits were considered to be stratigraphically older than the Moore deposits (Fitzsimons, 1988). However, these deposits have an amino-acid age of Isotope Stage 8 (Colhoun and Fitzsimons, 1990). Although this conflict of dating has not been resolved, the stratigraphy based on field evidence has been accepted at this stage because of the experimental nature of the amino-acid dating (Colhoun, pers. comm. 1990).

Fitzsimons (1988) considered the Linda Glaciation to be quite old, possibly Early Pleistocene. These deposits have very thick weathering rinds (mean of 70 mm, Kiernan, 1983) and a reversed DRM polarity (Barbetti and Colhoun, 1988). This glaciation is therefore >730 ka in age. This information is summarised in Table 2.2 and the limits of these glacial advances are shown in Fig. 2.3.

Table 2.2 Formations of the King and Linda Valleys and their interpretation (after Fitzsimons, 1988).

CLIMATIC STAGE	FORMATION	INTERPRETATION	MEAN WEATHERING RIND THICKNESS	SUGGESTED MINIMUM AGE
Holocene	Long Marsh	post glacial		
	Dante	glacial advance		19 ka Late Pleist.
Margaret Glaciation	Chamouni	glacial advance	1-2 mm	>49 ka Late Pleist.
	Dunn *	glacial advance		
	David *	glacial advance		
Henty Glaciation	Nelson	interstadial		
	Cableway *	glacial advance	5 mm	>130 ka Mid. Pleist.
	Moore *	glacial advance	14-17 mm	Mid. Pleist.
Moore Glaciation *	Fish +	glacial advance		
	Baxter	interstadial	amino-acid age Isotope Stage 10	Mid. Pleist.
	Traveller +	glacial advance		
Regency Interglacial	Regency	interglacial	amino-acid age Isotope Stage 8	age uncertain
Linda Glaciation	Thureau	glacial advance	70 mm	> 730 ka Early Pleist.

* The names used here have been adopted by the Stratigraphic Nomenclature Committee of the Geological Society of Australia and the Tasmanian Department of Mines for the Queenstown geological map sheet.

+ These formations represent local advances from cirques.

The names used in Fitzsimons (1988) are: Bull Rivulet (Dunn), Blackwood (David), King (Cableway), Governor (Moore), Governor Glaciation (Moore Glaciation)

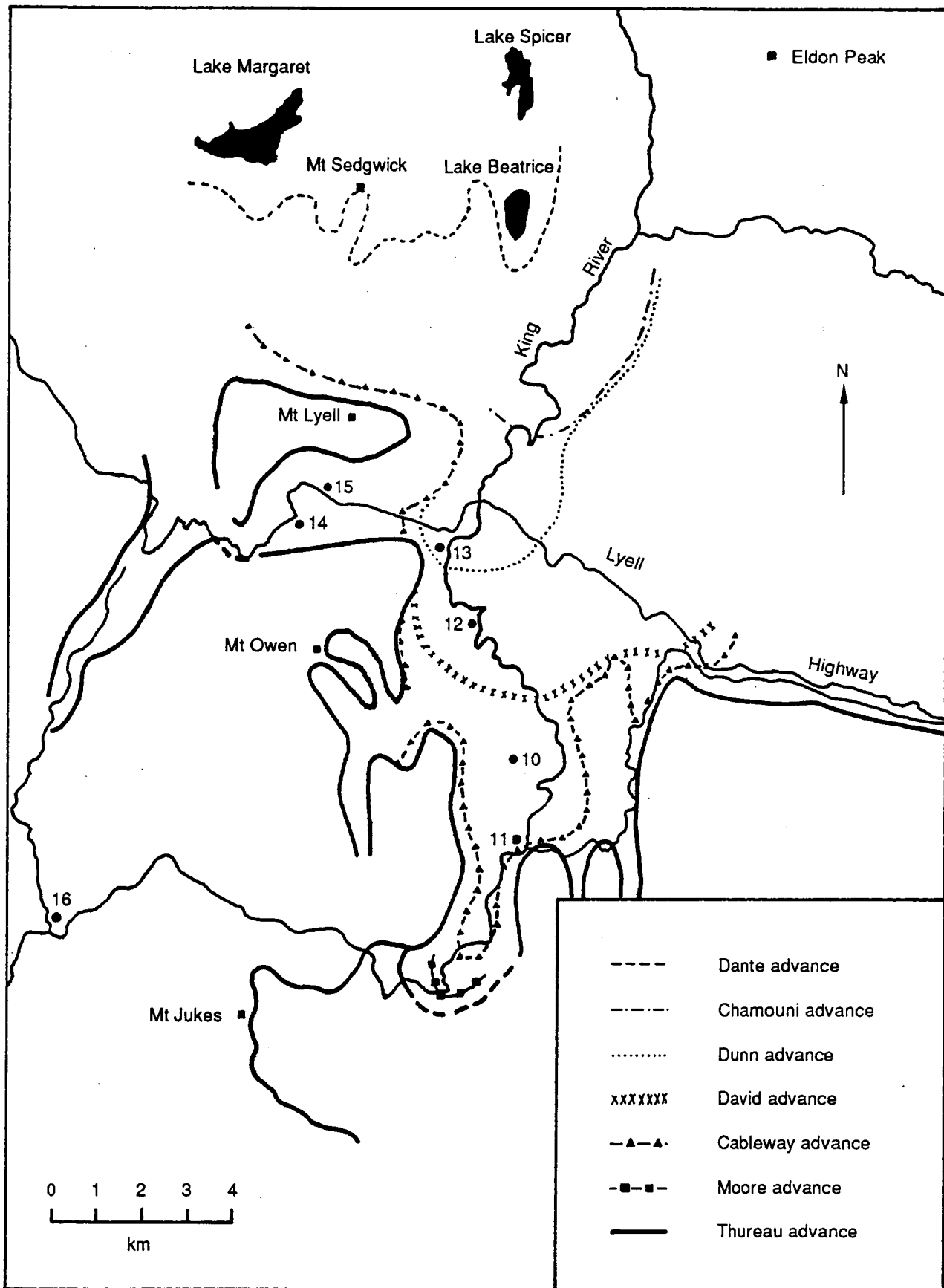


Fig. 2.3 Reconstructed ice limits in the King Valley (Fitzsimons, 1988).

2.1.3 North Central Sites

Hannan (1988) and Hannan and Colhoun (1987) recognised three glaciations in the upper Mersey Valley, on the basis of four criteria. These were the geographic distributions of the drift deposits, the clearly represented end-moraines associated with the Rowallan Glaciation, the superposition of Rowallan on Arm Till and the significant differences in weathering of clasts. The most recent glaciation they called the Rowallan Glaciation, the Penultimate glaciation the Arm Glaciation and the oldest the Croesus Glaciation. They assumed that the ice attained its maximum extent during the Rowallan Glaciation before 13400 ± 600 yr BP, on the basis of a radiocarbon date (SUA-2188) from Dublin Bog. On the basis of weathering rind analysis they suggested that the Arm Glaciation occurred at least 100 ka BP and the Croesus Glaciation at least 1700 ka BP. Hannan and Colhoun (1987) considered the Rowallan, Arm and Croesus Glaciations to be the correlates of the Margaret, Henty and Linda Glaciations of the West Coast respectively.

In the Forth Valley rhythmites and glacial deposits occur at Lemonthyme Penstock. These have been presumed to be correlates of the Linda Glaciation (Colhoun, pers. comm. 1987), based on their extensive degree of weathering. In addition, tillites associated with a much older glaciation have been encountered in drill holes. These tillites were assigned to a Lemonthyme Glaciation by Colhoun (1975) and were believed to be of Tertiary age.

The suggested minimum ages based on mean weathering rind data and the reconstructed ice limits are shown in Table 2.3 and Fig. 2.4 respectively.

Table 2.3 Formations of the Mersey and Forth Valleys and suggested ages based on weathering rind analysis (after Hannan & Colhoun, 1987, Hannan, 1988, Colhoun, pers. comm. 1989).

GLACIAL EVENT	MEAN WEATHERING RIND THICKNESS	SUGGESTED MINIMUM AGE	
Rowallan	0.2 - 0.9 mm	13.5 ka	Late Pleist.
Arm	1.1 - 4.5 mm	100 ka	Mid Pleist.
Croesus	7.9 - 50.8 mm	1700 ka	Early Pleist.
Lemonthyme			Tertiary

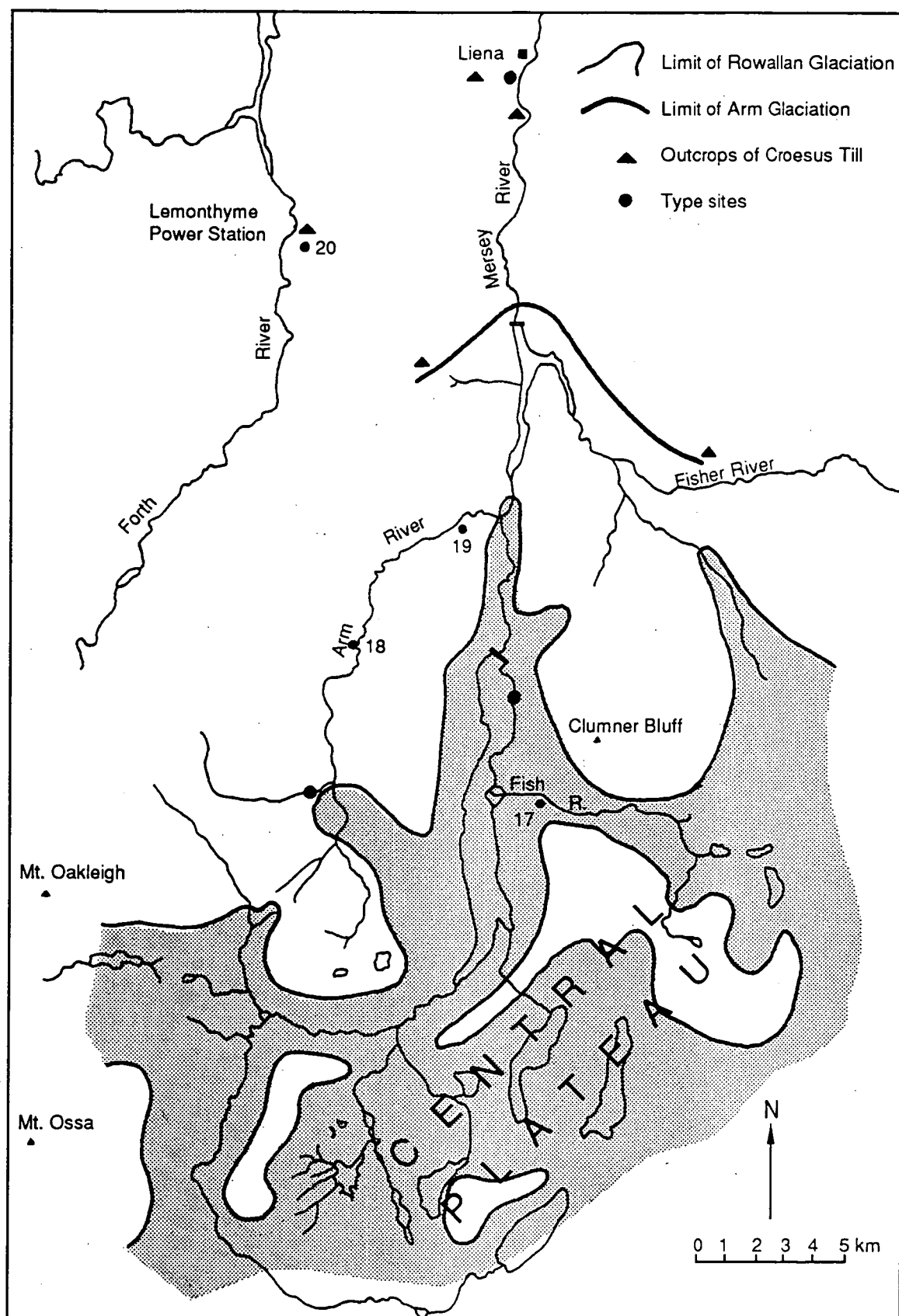


Fig. 2.4 Reconstructed ice limits in the Mersey Valley (after Hannan, 1988).

2.1.4 West Central Sites

Kiernan (1989) has suggested that the upper Franklin Valley has experienced multiple glaciation, with as many as five or six separate glacial events. The recognition of these glacial events is based on the determination and comparison of the mean thickness of the dolerite weathering rinds from the various tills deposited in the area. He regards the Undine and Dixon tills, with the thinnest weathering rinds, as being of Last Glacial age, the Beehive till as representing the Penultimate Glacial Stage and the Taffys Creek, Wombat Glen and Stonehaven deposits as representing earlier separate glaciations. His suggested minimum ages for these glaciations, based on weathering rind analysis, are shown in Table 2.4 and the reconstructed ice limits for the upper Franklin Valley are shown in Fig. 2.5.

Table 2.4 Formations of the upper Franklin Valley and suggested ages based on weathering rind analysis (based on Kiernan, 1989).

GLACIAL EVENT	MEAN WEATHERING RIND THICKNESS	SUGGESTED MINIMUM AGE	
Dixon	1.6 mm	18.8 ka	Late Pleist.
Beehive	4.1 mm	130 ka	Mid Pleist.
Taffys Creek	7.4 mm	220 ka	Mid Pleist.
Wombat Glen	12.0 mm	375 ka	Mid Pleist.
Stonehaven	41.2 mm	950 ka	Early Pleist.
Collingwood		?	Early Pleist.

Thus, previous research has indicated that there is widespread evidence for the glacial deposits of Tasmania belonging to different periods of glaciation. Ages ranging from Last Glaciation to Early Pleistocene/Late Tertiary have been suggested from all those regions that have been studied fairly intensively.

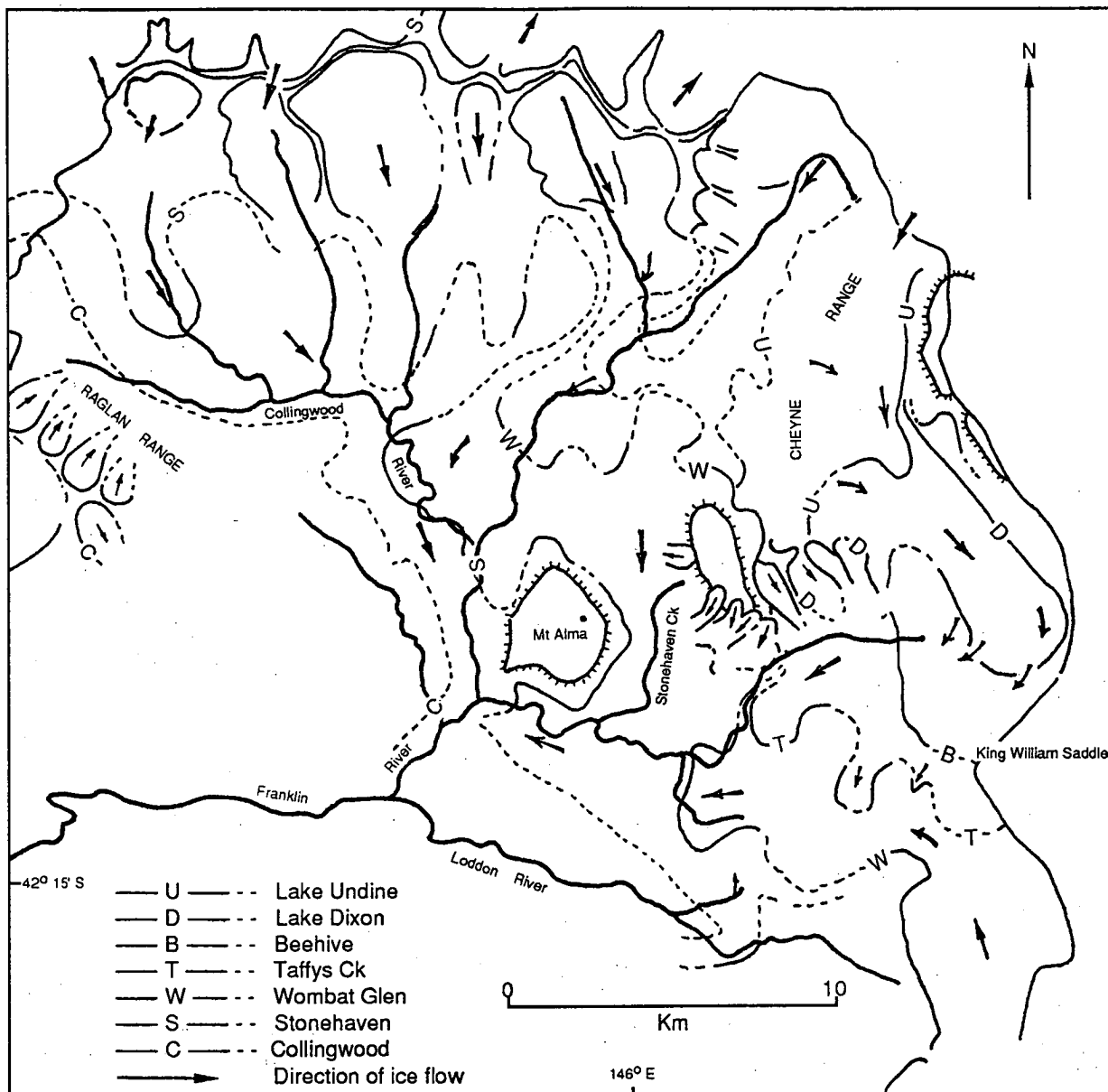


Fig. 2.5 Reconstructed ice limits in the upper Franklin Valley (after Kiernan, 1990).

2.2 The Use of Magnetostratigraphy

2.2.1 Introduction

The Subcommittee on Magnetic Polarity Time Scale (1979) has prepared a revised chapter on magnetostratigraphic classification and terminology to be included in the *International Stratigraphic Guide*. This introduction summarises aspects of that information relevant to this study.

Magnetostratigraphy is the element of stratigraphy that deals with the magnetic characteristics of rock units. The organization of rock strata into units based on variations in magnetic character is magnetostratigraphic classification.

The purpose of magnetostratigraphic classification is to organize rock strata systematically into identifiable units based on stratigraphic variations in their magnetic characteristics. Measurable magnetic properties such as magnetic susceptibility and the intensity and direction of natural remanent magnetism (NRM) can be used in such a classification. A number of useful properties of the magnetic field may be determined from NRM: reversals of polarity, the dipole field position from which is derived apparent polar wandering (APW), nondipole components (secular variation), and variations in field intensity. If any of these characters vary stratigraphically, they may be used to establish magnetostratigraphic units.

Changes in the orientation of remanent magnetism in rock strata, caused by changes in the polarity of the earth's magnetic field, provides the basis for one of the most useful kinds of magnetostratigraphic classification.

The direction of magnetisation of a rock or any mineral is *by definition* its 'north-seeking magnetisation'. If the north-seeking magnetisation points toward the earth's present magnetic north pole, the rock is said to have 'normal magnetisation' or 'normal polarity'. On the other hand, if the north-seeking magnetisation points toward the present-day south magnetic pole, the rock is said to have 'reversed magnetisation' or 'reversed polarity'.

Bodies of rock strata unified by similar magnetic characteristics which allow them to be differentiated from adjacent strata are identified as magnetostratigraphic units. These can be based on any of the measurable magnetic properties of rocks, such as magnetic susceptibility and intensity and direction of natural remanent magnetism (NRM).

Rock strata can be organised into units based on changes in the orientation of remanent magnetism in the strata, related to changes (reversals, excursions, etc.) in the polarity of the Earth's magnetic field. Such organisation is called magnetostratigraphic polarity classification.

Surfaces or very thin transition intervals in the succession of rock strata, marked by changes in magnetic polarity, are called magnetostratigraphic polarity-reversal horizons. They provide the *boundaries* for polarity stratigraphic units, although they may be contained *within a unit*, where they mark an internal change subsidiary in rank to those at its boundaries.

Bodies of rock strata, in original sequence, unified by their magnetic polarity which allows them to be differentiated from adjacent strata are referred to as magnetostratigraphic polarity units.

In such a classification time is divided into units, known as chrons, on the basis of whether the polarity is reversed or normal (Cox *et al*, 1963, 1964, Doell & Dalrymple, 1966, Mankinen & Dalrymple, 1979, McDougall, 1979). The polarity time-scale for the last 5 million years is shown in Fig. 2.6 (Berggren *et al*, 1985). This scale also shows the major events or changes in polarity for a period of time within a chron, the sub-chrons. In the Matuyama reversed chron approximately 17% of the time had a normal polarity; this would suggest an 80% + chance of any glacial event of the Matuyama chron occurring during a reversed period. In addition, any glacial event that occurred in one of the normal periods in the Matuyama chron might not be recognised unless it crossed a normal/reversed boundary or there was other evidence to suggest that it was older than the Brunhes normal chron. However, other evidence available from many of the sites studied, in particular the weathering rind analyses, together with the relatively short period of normal polarity during the Matuyama chron, would suggest that the chances of failing to recognise that an event occurred during such a normal polarity period of the Matuyama chron rather than during the Brunhes normal chron are relatively low.

"Departures of the geomagnetic field direction more than about 40 degrees away from its normal direction, for periods of 100 to 10 000 years, but without actually totally reversing are termed polarity excursions:" (Tarling, 1983). A number of excursions have been proposed during the Brunhes chron, however the existence of many of these has been questioned (Verosub, 1982). Anomalous directions may not necessarily reflect genuine observations but may have arisen from local sedimentological or tectonic effects (Verosub, 1975) or from handling or from errors in calculation. These proposed excursions have been recognised dominantly from the northern hemisphere.

CHRON	Ma	SUB-CHRON
BRUNHES (CHRON 1)	0	
	.73	
MATUYAMA (CHRON 2)	.91	JARAMILLO
	.98	
	1.66	OLDUVAI
	1.88	
		REUNION
	2.47	
GAUSS (CHRON 3)	2.92	
	2.99	KAENA
	3.08	
	3.18	MAMMOTH
	3.40	
GILBERT (CHRON 4)	3.88	COCHITI
	3.97	
	4.10	
	4.24	NUNIVAK
	4.40	
	4.47	SIDUFJALL
	4.57	
	4.77	THVERA

Fig. 2.6 The polarity time - scale showing the age of the reversals of the geomagnetic field during the last 5 million years (after Berggren *et al*, 1985).

In the southern hemisphere the Mungo excursion (Barbetti and McElhinny, 1972, 1976) has been dated at 17000 to 31000 years. The Blake Event of ca. 117,000 years ago appears to be absent from the loess of central North Island, New Zealand (Froggatt, 1988; Pillans and Wright, 1990). Pillans and Wright (1990) did, however, recognise a period of anomalously low inclination at ca. 490,000 years ago which they interpreted as representing the Emperor Event.

If it is assumed, however, that all three of these excursions occurred during the Brunhes chron in the southern hemisphere and each was of ca. 10,000 years duration, then there is a less than 5% probability of hitting one. As the Mungo excursion is far younger than the glacial events of the Middle and Early Pleistocene, the probability of the sediments of this study representing a Brunhes age excursion is less than 3%. For these reasons, excursions are not considered to be a problem in interpreting the results of this study.

2.2.2 Prior Applications of Magnetostratigraphy

Palaeomagnetic methods have been applied to Quaternary stratigraphic studies "... as a tool for correlation and relative age dating of equivalent strata or for the absolute dating of deposits". (Barendregt, 1984). Useful results have been obtained from a wide variety of materials such as varved clays (Noel, 1975, Niedziolka, 1976, Verosub, 1979, Biquand, 1982, King *et al*, 1983); other lake silts and clays (Kawai *et al*, 1972, Yaskawa *et al*, 1973, Vitorello and Van der Voo, 1977, Dodson *et al*, 1977, Mothersill, 1980, Thompson and Edwards, 1982, Ridge *et al*, 1990); lake sediments overlain by terminal moraines (Morner and Sylwan, 1987); loess (Li *et al*, 1974, Heller and Liu, 1982, 1984, Pillans and Wright, 1990); tills (Gravenor *et al*, 1973, 1974a, 1974b, Gravenor and Stupavsky, 1976, Soloyanis and Brown, 1979); cave sediments (Schmidt, 1982, Noel, 1983, Noel and St Pierre, 1984, Turner and Lyons, 1986); other sediments (Johnson *et al*, 1975, Manabe, 1977, Nakagawa and Niitsuma, 1977, Opdyke *et al*, 1977, Kodama, 1979, MacFadden *et al*, 1983); deep sea sediments (Harrison, 1966, 1974, Opdyke, 1972, Aksu, 1983). Other commonly used materials are lava flows (e.g. Hillhouse *et al* 1977) and pottery (Barendregt, 1984).

In Australia, palaeomagnetic methods have been applied to a variety of Quaternary and Late Tertiary materials including: volcanics (McElhinny *et al*, 1974); aboriginal fireplaces (Barbetti and McElhinny, 1976, Barbetti *et al*, 1977, Barton and Barbetti, 1982); weathered and lateritised surfaces (Schmidt and Embleton, 1976, Schmidt and Ollier, 1988); coastal dunes (Idnurm and Cook, 1980); Cainozoic lake sediments (Singh *et al*, 1981, Schmidt *et al*, 1982); sediments from crater lakes in western Victoria and South

Australia (Barton and McElhinny, 1980, 1981, Barton and Barbetti, 1982); cave sediments (Schmidt *et al*, 1984); saline playa lake sediments (An Zhi-sheng *et al*, 1986, Chivas *et al*, 1986); biocalcarenes (MacFadden *et al*, 1987); and glaciolacustrine sediments from western Tasmania (Barbetti and Colhoun, 1988). Barbetti and Colhoun (1988) are the first workers to use magnetostratigraphy on Quaternary glacial sequences in Australia.

2.2.3 Application to this Study

Earlier workers in western Tasmania have suggested, on the basis of weathering data, stratigraphic evidence and geographic distribution of glacial deposits, that the most peripherally located and weathered drifts are of at least Early Pleistocene age. These criteria, however, do not provide unequivocal evidence for such an age. Palaeomagnetic techniques have been used in this study to investigate this idea because if the deposits are of Early Pleistocene age they are likely to show reversed polarity.

In order to establish a magnetostratigraphic framework for the areas examined by this study, the following magnetic properties were measured:

- i) Natural Remanent Magnetisation (NRM)
(strength and characteristic magnetisation directions after AF cleaning)
- ii) Magnetic Susceptibility
- iii) Magnetic Stability

i) Natural Remanent Magnetisation (NRM)

All remanent magnetisations acquired by a specimen prior to any laboratory influences are termed the natural remanent magnetisation (NRM) of the specimen. NRM is a measure of the magnetic strength retained by the specimen and is a summation of all the components of specimen remanence acquired by natural processes.

The dominant component of the NRM of the specimens studied is assumed to be the depositional or detrital remanent magnetisation (DRM) - the magnetisation acquired by the physical rotation of magnetic particles to conform with the direction of the earth's magnetic field prevailing during the depositional processes. This magnetisation direction, acquired at the time of formation of the sediment, is called the primary magnetisation. It may be subsequently altered by the acquisition of one or more secondary magnetisations, known as overprints. In the case of sediments, a second magnetisation may be acquired during post-depositional processes, particularly during the consolidation of sediments. The resultant magnetism is called the post-depositional remanent magnetism (PDRM). A magnetisation can also be acquired by unconsolidated sediments if they are subjected to shear (SRM).

Chemical processes operating during lithification and diagenesis and during chemical weathering can also result in a chemical remanent magnetisation (CRM). Specimens may also acquire one or more magnetisations during storage and as a result of laboratory processes.

If the characteristic magnetisation directions are to be used for correlation of the sites, then the primary or depositional remanent magnetisation is required and any secondary magnetisations (overprints) must be removed. This is discussed further below.

The direction of the geomagnetic field vector, F , is usually expressed in terms of the polar co-ordinates, declination and inclination (Fig. 2.7).

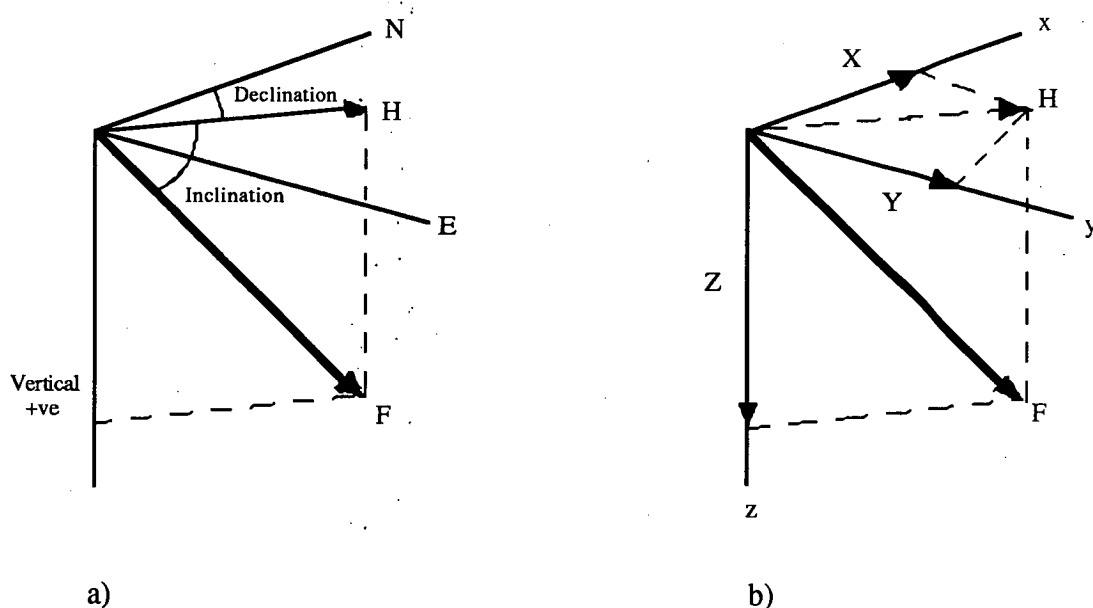


Fig 2.7 Diagram showing magnetic vector co-ordinates.

- a) polar co-ordinates; the directions are given in terms of declination and inclination. The *declination* is the angle, from the north, of the horizontal component, H , of the field of strength F . The vertical component of the vector is the *inclination*, the angle from the horizontal, positive downwards.
- b) modified cartesian co-ordinates; the magnitudes of the components X , Y , and Z of vector F are given along three mutually perpendicular axes, x , y , and z respectively. Generally x corresponds to north, y to the east, and z is positive vertically downwards.

South of the magnetic equator, negative inclination values indicate normal polarity and positive values indicate reversed polarity.

Magnetostratigraphic units can therefore be recognised on the basis of the polarity of the samples, mean declination and mean inclination values, and strength of the magnetic signal. Changes in intensity of remanence may reflect changes in the geomagnetic field strength at the time of deposition but such records are usually rapidly obliterated by the acquisition of secondary magnetisations. The strength of the magnetic signal more commonly reflects variations in lithology, and so can be used for lithostratigraphical correlations (Hailwood, 1989).

The records of geomagnetic field secular variations can also be used as a basis for magnetostratigraphic correlation on a local or regional scale. Fluctuations in the amplitude of the field direction of up to a few tens of degrees occur over time scales of 10^2 - 10^4 years (Hailwood, 1989).

ii) Magnetic Susceptibility

Magnetic susceptibility is a measure of the magnetic moment induced per unit external magnetic field applied, and so measures the ease of magnetizing a given material (Eisberg and Lerner, 1982). It thus measures the susceptibility of a material to magnetisation. The magnetic susceptibility of rocks is a function of the form and composition of their magnetic mineral components and generally falls in the range of 10^{-5} to 10^{-7} GOe⁻¹ (Gauss per oersted) in haematite bearing sediments and 10^{-3} to 10^{-4} GOe⁻¹ in basic igneous rocks (Tarling, 1971). Most of the rocks contributing magnetic minerals in Tasmania are basic Jurassic dolerites or acid volcanics of the Mount Read Formation.

The NRM and susceptibility are used to calculate the Königsberger ratio Q , the ratio in a rock of NRM to the induced magnetisation in the earth's field. It provides a test for the presence in rocks of magnetic particles possessing high and low coercivity, and thus indicates the rock's capability of maintaining a stable remanence (Collinson, 1983).

A modified Königsberger Ratio Q' is derived by dividing NRM by susceptibility. As a general rule, samples with Q' values less than 0.1 have a poor capability of maintaining a stable remanence whilst those with a value greater than 1 have a good capability.

Magnetostratigraphic units can also be recognised on the basis of significantly different susceptibility values for sediments.

iii) Magnetic Stability

If a specimen is to retain any primary magnetisation it must have some magnetic particles with relaxation times of the same order or longer than the age of the primary remanence. The determination of the relaxation time spectrum of specimens is therefore fundamental to all palaeomagnetic studies.

A variety of methods has been devised to determine the relaxation time spectrum of specimens, the most common being thermal and alternating field (AF) demagnetisation. AF demagnetisation was chosen for this study, mainly because it is a more convenient method to use for specimens collected in plastic cubes.

In alternating field demagnetisation a specimen is tumbled in an alternating field that is rapidly brought to peak intensity and then gradually reduced. The application of a magnetic field greater than the internal field to a specimen containing magnetite grains will cause the magnetisation of each domain to flip so that its 'easy' direction lies with a component in the direction of the applied field. If the specimen is tumbled within an alternating magnetic field the magnetisation of grains with coercivity equal to or lower than the peak strength of the field will have their magnetisation changed as the sample follows the changing direction of the applied field. The direction within each single domain will thus flip in opposite directions along its easy axes as the angle between the applied field and the easy axis changes. Gradual reduction of the peak field intensity results in grains being left in the directions in which they were last lying before the field decreased below their coercivity. These magnetisations will essentially cancel out each other if the easy directions are randomly oriented within the specimen. Thus, all the grains with a coercivity less than the peak applied field will have been demagnetised effectively by the time the applied field has been reduced to zero. These grains will no longer contribute to the external measured magnetic field of the specimen.

If the specimen is exposed systematically to increasingly stronger alternating magnetic fields, stepwise demagnetisation, then grains with higher and higher coercivities will be randomized. Complete measurement after each demagnetisation step gives the magnetisation remaining. Once all secondary magnetisations (overprints) have been eliminated the resultant vector will cease to change direction after each demagnetisation step. This remaining vector is the primary magnetisation vector and is assumed to be the detrital remanent magnetisation. A specimen from which all secondary magnetisations have been removed is said to be magnetically 'cleaned'.

As stepwise demagnetisation of specimens is a very time consuming process, it is normally applied to a small number of specimens representative of the varying lithologies of the site. Information from this stepwise demagnetisation is then used to determine the strength of the field at which the remainder of the specimens from the site will be demagnetised. This blanket demagnetisation treatment is therefore a short-cut and is dependent on the assumption that the bulk of the specimens from the site will have the same magnetic characteristics as those chosen for stepwise demagnetisation.

Information from stepwise demagnetisation is used to prepare either Zijdeveld diagrams, which show how the direction and intensity of the magnetic vector changes when it is subjected to each demagnetisation step, or Hoffman-Day plots, which show the direction of the magnetic vector removed at each demagnetisation step. The values at which all remaining samples are to be cleaned magnetically can be determined from these plots. This is discussed further in Chapter 3. Cleaned values are thus assumed to represent the primary magnetisation vectors of the samples.

2.2.4 Palaeomagnetic Units

All measurements in this study are given in cgs or MKSA unrationalised units. The relationship of the cgs units to the rationalised Sommerfeld SI units is shown in Table 2.5.

Table 2.5 Magnetic units..

Property	SI units	MKSA units	Conversion Factor
Intensity of remanent magnetisation of rock	Amperes per metre (Am^{-1})	Gauss (G)	$1 \text{ mAm}^{-1} = 10^{-6} \text{ G}$
Magnetic moment of rock	Ampere metre ² (Am^2)	Gauss cm^3 (G cm^3)	$1 \text{ mA m}^2 = 1 \text{ G cm}^3$
Magnetic field	Tesla (T)	Oersted (Oe)	$1 \text{ mT} = 10 \text{ Oe}$
Magnetic susceptibility (per unit volume)	Dimensionless	Gauss/oersted (G.Oe^{-1})	$1 \text{ SI unit} = 4\pi \text{ G.Oe}^{-1}$

2.3 Glacial Lake Sedimentation

2.3.1 Glacial Lakes

Lakes are very common features of glaciated areas. Strong contrast occurs between lakes of glacial erosion and lakes within areas of glacial deposition. Those lakes within areas of deposition tend to be short-lived and are infilled with sediments. Lakes of glacial erosion tend to be long-lived and some persist for very long periods of time.

This study examines lakes associated with glacial deposition close to the ice margin during deglaciation. Many of these lakes are infilled rapidly with sediments during the process of deglaciation and contain sequences of rhythmites derived directly from the glacial meltwaters. These rhythmites consist of alternating layers of silt and clay. Some may be varves, in which case each silt-clay couplet represents an annual deposition cycle. Flowtills occasionally occur in these glacial lakes and may be interbedded with the rhythmites. Such deposits are suitable for the purposes of this study.

Other lakes formed during deglaciation are infilled later. The laminated sediments formed in such lakes are not suitable for this study because their relationship in time to any particular glacial event is far less certain.

2.3.2 Formation of Glacial Lakes

Glacial lakes are formed by the ponding of meltwaters from glaciers. When a glacier starts to retreat the meltwater from the glacier may be ponded in a number of ways. Ponding may occur in rock hollows gouged out by the glacier, behind the morainic material deposited on the valley floor by the glacier, in tributary valleys cut off by ice in the main valley or between the glacier and valley walls. In addition, melting of the glacier surface produces hollows in which water and sediments accumulate.

Glacial lakes can vary in size from a few square metres for some supraglacial lakes to many thousands of square kilometres for some proglacial lakes. In the ice proximal situation of Tasmanian glaciers lakes may vary in size from small ponds to several square kilometres in area. Sediment thickness in such lakes can vary from 0.5 m to 30+ m, but is normally in the range of 3 - 6 m.

2.3.3 Relationship of Lakes to Ice Margins

A lake obviously cannot form between the ice front and its terminal moraine until the ice starts to retreat. Palaeomagnetic dating of sediments from a glacial lake therefore is normally equivalent to, or post dates slightly, the ice advance. Such a lake could also be formed, or continue to be filled/maintained, long after the ice has withdrawn. In this case dating could possibly represent a period of time from close to initial retreat to long after withdrawal of ice from the valley altogether. However, it is unlikely that rapid sedimentation typical of conditions close to the ice front would continue in the lake after the complete withdrawal of ice from the valley. Sedimentation in supraglacial lakes only occurs once stagnation and/or retreat has begun. The laminated silts deposited in a glacial lake therefore generally record the stagnation or withdrawal of the glacier, a time span most probably of only a few centuries to several thousand years. (For example, a 30 m deposit of couplets of 0.5 cm average thickness would be formed in 6000 years, a time span of no consequence for the dating concerned.) Such deposits thus record the period of time following the maximum glacial advance. They may, however, be overridden by a subsequent readvance. In terms of relative dating they do not usually date the onset of glaciation but rather the waning of the glaciation.

Deposition in lakes in tributary valleys cut off by ice in the major valley can occur any time while the tributary valley is cut off by the ice. Such glacial lakes may therefore record either the advance or retreat of a glacier, or, in some cases, both. Dating of such sediments will represent the period of time that the ice is present in the main valley, and so records a glacial event.

2.3.4 Deposition in Glacial Lakes

The deposition of sediments in a glacial lake reflects the melt regimen of the ice, the size of the lake, the amount and type of material carried by the glacier, the length of time the lake is in existence and the chemical and physical conditions prevailing in the lake. Most glacial lakes close to an ice margin are infilled with rhythmically stratified fine grained silts and clays due to settling of the suspended sediment load of meltwater streams bearing the rock flour of the glacier. In addition, larger material can be introduced into the lake, and hence the lake sediments, by floating ice on the lake surface. Such material, referred to as lonestones or dropstones, is usually introduced when the glacier calves directly into the lake, producing masses of floating ice. Larger material may also be introduced into glacial lakes by flowtills. During the thawing out of ice, till may become fluid and move

downslope as a mobile liquid flow, as a semi-plastic flow, or by creep. In the very mobile and liquid flows clasts tend to sink and some sorting and stratification occurs (Dreimanis, 1976).

The magnetic materials that are deposited in the lake take up an orientation parallel with the ambient geomagnetic field, if they are free to rotate during their suspension in the water column and other aligning forces are absent. If this orientation is preserved during the depositional process, the resultant sediment acquires a remanent magnetism, depositional remanent magnetisation (DRM), that is parallel with the field at the time of deposition. The magnetic mineral grains may, however, rotate within the water-filled interstitial cavities between the generally larger non-magnetic grains in the relatively short period of time between deposition and when compaction or cementation locks the grains in place. During this time any magnetic grains that were not aligned with the geomagnetic field during the deposition process may become aligned. The magnetism resulting from this process is called post-depositional remanent magnetisation (PDRM). The NRM of glacial lake sediments is thus acquired in the relatively short time period required for infilling of the lake and compaction and cementation of the sediments.

2.3.5 Cyclic Sedimentation

Cyclic sedimentation refers to the pattern of deposition that occurs in an environment when the same controlling mechanisms of sedimentation are repeated on a regular basis. As a result the sediments deposited show some sort of regular pattern. Such repetitive sedimentation patterns frequently occur in lakes associated with glaciers. These sediments are referred to as rhythmites in general terms; certain genetically specific rhythmites are called varves when they can be demonstrated to relate to an annual cycle of deposition.

a) Varves

Any sedimentary bed or lamination that is deposited within a period of one year can be referred to as a varve (Dictionary of Geological Terms). More specifically, such deposition usually consists of a couplet of contrasting laminae representing summer and winter seasonal sedimentation.

Gary, McAfee and Wolf (1972) have given a more specific definition. They define the term as: "A sedimentary bed or lamina or sequence of laminae deposited in a body of still water within one year's time; specifically a thin pair of graded glaciolacustrine layers seasonally deposited (usually by meltwater streams) in a glacial lake or other body of still water in front of a glacier. A glacial varve normally includes a lower 'summer' layer consisting of

relatively coarse-grained, light-colored sediment (usually sand or silt) produced by rapid melting of ice in the warmer months, which grades upward into a thinner 'winter' layer consisting of very fine-grained (clayey), ..., dark sediment slowly deposited from suspension in quiet water while the streams were icebound. Counting and correlation of varves have been used to measure the ages of Pleistocene glacial deposits. Etymol: Swedish varv, 'layer' or 'periodical iteration of layers' (De Geer 1912)" (Schluchter, 1979).

Sturm (1979) has suggested that definitions of varves need to be reconsidered because: "... varves are not formed exclusively in glacio-lacustrine conditions, varves are not exclusively caused by meltwater streams, and varves are not simply thin light/coarse and dark/fine couplets". For example, Leckie and McCann (1982) state that: "An annual period of deposition sometimes characterizes finely laminated couplets settling out of suspension from inter- and overflows (Smith, 1978) and from density underflow generated graded bedding (Gilbert, 1975, Gustavson *et al*, 1975, Gustavson, 1975),...". Also Kempe and Degens (1979) have recorded varves from the Black Sea and from Lake Van in Turkey.

The mechanisms that determine whether the sediments deposited in glacial lakes will be varved or otherwise laminated appear to be quite complex. Ludlam (1979) examined rhythmite deposition in existing lakes in the northeastern United States. He found that all the lakes currently depositing laminated sediments were thermally stratified and that some were permanently chemically stratified. He concluded that stratification had one obvious effect - it "... protects the sediment beneath the thermocline from wind driven water turbulence for as long as the stratification exists." He also found that anaerobic conditions in the bottom waters of lakes were also extremely important in determining whether rhythmites were preserved or not. Laminated sediments were only preserved in lakes in which oxygen was "... absent from the bottom waters for an appreciable fraction of the year (Ludlam, 1976)". Sediment type and the availability of food were also seen as factors in controlling the activities of benthic organisms and hence the preservation of laminated sediments (Ludlam, 1979).

Sturm (1979) pointed out that the term 'varves' was originally restricted to the glaciolacustrine environment but that recent work had demonstrated that they formed in a variety of sedimentary environments. He also concluded that "...it is demonstrated that the bimodal sedimentary structures of clastic varves may occur only if discontinuous (seasonal) influx of suspended matter is matched to the stratified water column of a partly (annually) stratified lake."

b) Rhythmites

The term rhythmites has been applied to all rhythmic laminations that occur in sediments. Accordingly, the term rhythmic sedimentation has been "...applied to a sequence of sediments which change their character progressively from one extreme type to another, a change which is followed directly by a return to the original type" (Whitten, 1985). The conditions existing in lakes adjacent to glaciers are such that sediments are deposited in a rhythmic pattern. The controlling mechanism can be the annual freezing over of the lake or some other periodic occurrence such as variations in the rate of ablation of the glacier.

The sediments examined in this study have been deposited under conditions controlled by such a mechanism but it is not clear whether this mechanism is seasonal or not. That is, none of the sites have been examined in sufficient detail to establish whether they are actually varves; no attempt has been made to identify the periodicity of the controlling mechanism. Hence, the less specific term 'rhythmites' has been applied to all those glacial lake sediments showing distinct couplets, even though some of them may well be true varves. The term 'laminated sediments' has been applied to all the glacial lake sediments that show distinct laminations but do not consist of couplets.

c) Other Laminated Deposits

Laminated deposits are not restricted to lakes associated with glaciers. Any body of water in which the sedimentation pattern is periodically altered by some mechanism, followed by a return to the original sedimentation pattern, can potentially produce laminated sediments. In such a situation laminated sediments will be formed; however, they will only be preserved, that is become part of the geological record, if the conditions in the water body are such that they are not disturbed after formation. In order for such laminated sediments to be preserved the water body needs to be devoid, or nearly so, of a benthonic fauna and the sediment surface needs to be sufficiently deep so as to be unaffected by wave action. Such laminated sediments have been recorded from fjords (Colhoun, pers. comm. 1989), from the Black Sea (Kempe and Degens, 1979), from Lake Van, a non-glacial lake in Turkey (Kempe and Degens, 1979), from the Mississippi Delta (Moore and Scruton, 1957), and from tidal mud flat environments (Reineck and Wunderlich, 1969).

2.3.6 Implications

The significance of these sedimentation patterns in a glacial environment relates to the period of time represented by the sediments. If it can be demonstrated that the sediments are true varves, then each couplet must represent one year (the period of a cycle for a varve).

The length of time represented by the sediments can then be determined simply by counting the number of varves. Thus, the number of years of deposition equals the number of varves (assuming that no varves have been removed by subsequent erosion).

If the rhythmites cannot be established as varves, then the period of time they represent can vary widely. Short term periodicity of sedimentation related to warmer and colder spells within the year induces enhanced melting and is followed by decreased meltwater and sediment input. This allows a greater proportion of finer suspended sediment to settle. In addition, material can be redistributed from higher levels by slumping on the slope of a delta and subsequent settling on the floor of the lake.

The sedimentation pattern will also indicate something of the conditions prevailing at the time. Thus, if the sediments are established to be true varves then the lake in which they were deposited would have been ice covered for part of the year. If, on the other hand they are not varves, then the lake may or may not have been ice covered during the winter season and slightly warmer conditions would have prevailed.

2.3.7 Importance of Glacial Lake Sediments for Palaeomagnetic Studies

The conditions that prevail in lakes associated with glacier ice ensure that the fine particles suspended in the water settle out slowly. As the particles settle through the water column, interact with the substrate at the sediment/water interface, and then come to rest on the substrate the magnetic particles acquire a remanent magnetisation (Verosub, 1977). This slow settling therefore enables the ferromagnetic particles to become easily aligned with the magnetic field of the time. The fine grained sediments deposited in glacial lakes are thus likely to provide a good record of the magnetic directions that prevailed at the time of their deposition.

However, sediments may frequently show departures of the direction of the remanent magnetism (particularly the inclination) from that of the ambient field. In particular, many glacial sediments show inclination values that are consistently and significantly shallower than the ambient field. This problem has been addressed by a number of workers (e.g. King, 1955, Rees, 1961, Verosub, 1977, Verosub and Bannerjee, 1977, Barton and McElhinny, 1979, Barton *et al*, 1980, Stupavsky and Gravenor, 1984, Barendregt, 1984, Ridge *et al*, 1990). A number of suggestions have been put forward to explain these errors of inclination and declination. Elongated, tabular or flat-shaped magnetic particles may be preferentially aligned both during the deposition and compaction processes and currents may systematically deviate magnetic particles from the ambient magnetic field. The

sediments may be deformed by processes such as turbidity currents, density currents, slumping, liquifaction, seismic activity, periglacial activity such as cryoturbation and congelifluction, or by collapse during decalcification. In addition, blocks of frozen glacial sediments may have been picked up, transported and deposited in anomalous stratigraphic positions by glaciers (Barendregt, 1984), or they may have been subjected to induced stress deformation by over-riding by glacial readvance (Stupavsky *et al*, 1979). Field and laboratory procedures may also introduce errors; for instance, apparently stiff clays may behave thixotropically during their collection or handling (Symons *et al*, 1980) and small errors may be caused by drying during preparation of specimens in the laboratory.

Ch. 3 METHODS

3.1 Field Methods

3.1.1 Site Selection

The sites were selected from regions in which research on the stratigraphy of the glacial deposits had been undertaken (Bowden, 1974, Kiernan, 1985, Augustinus and Colhoun, 1987, Bengier, 1987, Hannan and Colhoun, 1987, Fitzsimons, 1988). Although glacial stratigraphic work is still continuing widely in Tasmania, it was decided to investigate suitable sites from three main areas - the west coast, the north central area and the west central area - regions in which complex sequences of glacial deposits had become known.

In addition, an attempt was made to locate a suitable site in the north east of the state, in the Ben Lomond area. This attempt was, however, unsuccessful.

In these areas twenty-six sites were examined in some detail; twenty four of these sites were sampled for palaeomagnetic analysis. The location of these sites is shown in Table 3.1 and Fig. 3.1.

Table 3.1 Location of Sampling Sites and Number of Specimens.

Site	Map Sheet	Grid Ref.	Specimens
West Coast Sites:			
a) Pieman Valley Area:			
1) Lower Pieman			
Damsite Road	Rosebery	a 686788	14
2) Huskisson/Marionoak			
Divide	Pieman	b 740780	not sampled
		c.f. Barbetti & Colhoun	
3) Marionoak	Parsons	a 780848	21
4) Boco	Block	a 822858	34
5) Bulgobac	Parsons	a 794852	47
6) Que	Sophia	b 861901	30
7) Rosebery Opencut	Rosebery	a 787746	23
8) Williamsford Road	Dundas	a 764689	30
b) Henty Surface:			
9) Tyndall Creek		c 810570	43

Table 3.1 Continued.

c) King Valley:

10) Thureau Hills Rd.	Franklin	b	881355	20
Thureau Hills Ck.	Franklin	b	881355	25
Thureau Hills Ck. 3	Franklin	b	883350	9
11) Baxter Rivulet	Franklin	b	875304	20
12) King River Bridge	Franklin	b	893375	65
13) Linda Ck.	Franklin	b	872405	31
14) Gormanston Moraine	Franklin	b	834406	6
15) Gormanston Football Field	Franklin	b	838413	not sampled
			c.f. Barbetti & Colhoun	
16) King Gorge Exit	Franklin	b	785317	21

North Central Sites:

17) Fish River	Rowallan	a	363749	24
18) Arm Bridge/Arm Rd	Rowallan	a	299799	15
Arm Spur Rd.	Borradaile	a	312835	7
19) Arm River Rd.	Borradaile	a	332837	7
20) Lemonthyme Penstock	Liena	a	282936	15

West Central Sites:

21) King William Ck.	Nive	b	280263	14
22) Stonehaven Ck.	Franklin	b	154268	16
23) Double Barrel Ck.	Franklin	b	138275	15

a 1:25000 sheet b 1:100,000 sheet
c 1:100,000 HEC Anthony Power Development sheet

A few of these sites were examined as a check on other sites or to relate to previous stratigraphic work in that area (e.g. the Gormanston Moraine site as a check on the Gormanston Football Field site of Barbetti and Colhoun, 1988) . In these cases only a small number of specimens was taken. Several sites were also resampled after the initial sampling and analysis in an attempt to clarify results where the initial findings were equivocal (e.g. the Tyndall Creek site).

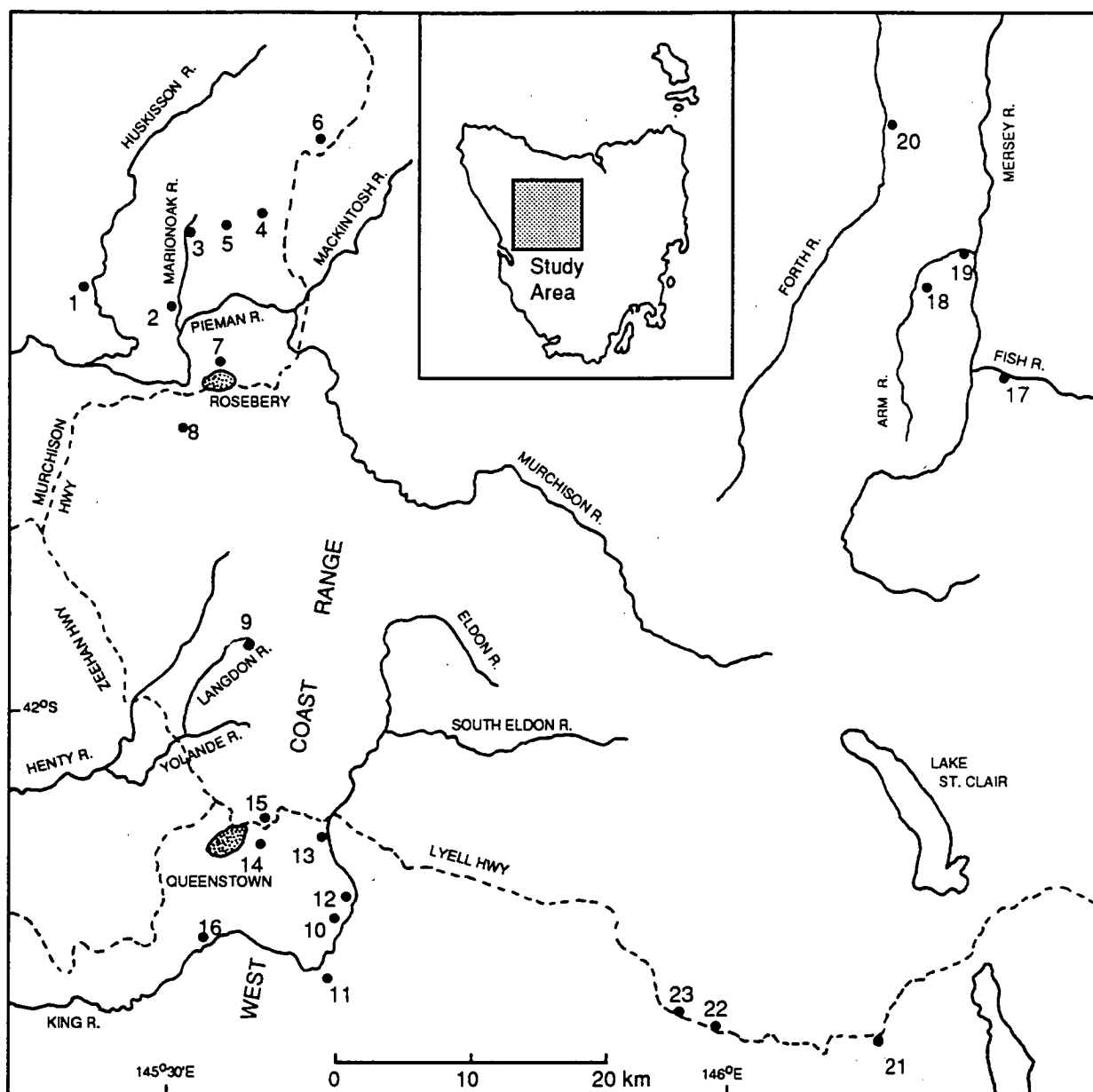


Fig. 3.1 Location map showing sampling sites.

● 9 SAMPLING SITE (REF. TABLE 3.1).

3.1.2 Sampling Methods

Five hundred and fifty two specimens were taken for palaeomagnetic analysis, the number varying from site to site according to site size and sampling difficulty. Twenty to thirty specimens were collected from most sites but in very large sites, such as the King River Bridge site, a much greater number was taken. On the other hand, difficulty of removal of suitable material from the highly indurated sediments of the Arm River Road site considerably restricted the number of specimens taken. The number of specimens taken from each site is shown in Table 3.1.

The outer layers of material were cleaned away from the sites chosen for sampling to ensure that the material collected was fresh. Specimens for palaeomagnetic analysis were collected in 8 c.c. plastic cubes pressed or lightly tapped into the sediment surface. These specimens were taken in groups or spreads across the sites and were arranged to ensure maximum possible representation of the vertical and lateral extent of the deposits. This is shown in Fig. 3.2.



Fig. 3.2 A typical spread of specimens (Baxter Rivulet silts).
* Indicates specimen.

Wherever possible, only flat-lying sediments were sampled; strongly tilted areas were only sampled when there were no other suitable alternative sites. In addition, areas of obvious disturbance resulting from such processes as slumping and ice pushing were avoided, as were areas affected by chemical weathering.

The cubes were usually collected with their upper surface parallel to the surface of the laminations and oriented towards magnetic north, specimen orientations being taken with a magnetic compass. The Nelson Formation was sampled from drill cores obtained by the Department of Main Roads, as well as from exploration trenches.

Groups of cubes were wrapped in Glad Wrap and stored in large plastic containers with tightly fitting lids. These containers were stored in a refrigerator but were kept at a temperature of about 4⁰ C to prevent the formation of ice crystals in the specimens.

3.2 Laboratory Methods

3.2.1 Introduction

All magnetic measurements were made at the Black Mountain Palaeomagnetic Laboratory of the Research School of Earth Sciences, Australian National University, in Canberra, between June 1986 and January 1989.

The sequence of treatment of the specimens is shown in Fig. 3.3. Magnetic susceptibility and natural remanent magnetisation were measured for all specimens. The magnetic stability of representative lithologies from each of the sites was investigated by progressive step-wise AF demagnetisation of selected pilot specimens. This information was then used as the basis for single-step AF cleaning of the remaining specimens. All the specimens from several problem sites were systematically demagnetised, rather than relying on information from representative specimens.

3.2.2 Magnetic Susceptibility

Susceptibility was measured for all specimens. Measurements were made with a susceptibility meter, which measures the change of inductance of a coil when a specimen is inserted into it, linked to a Digico computer programmed to convert the change in inductance to an absolute susceptibility value. At least three measurements were made for each sample, the difference between the holder and specimen and the empty holder being recorded each

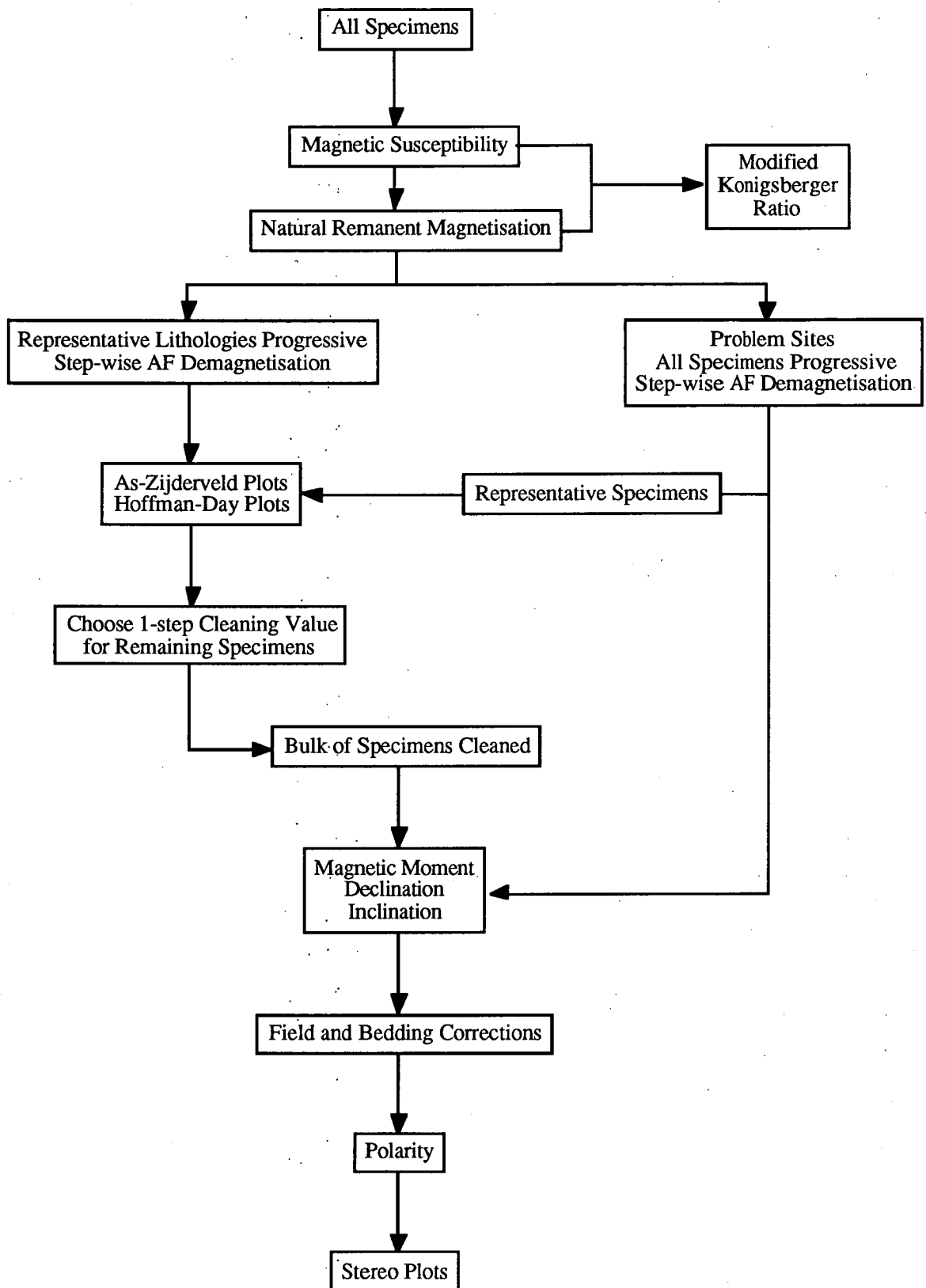


Fig. 3.3 Laboratory treatment of specimens.

time the specimen was inserted into the coil. These measurements were then averaged to obtain a susceptibility value for the specimen.

3.2.3 Natural Remanent Magnetisation

Natural Remanent Magnetisation (NRM) was measured for all specimens. Initially the NRM of all specimens was measured using a Digico spinner magnetometer. Those specimens showing an NRM of less than 0.5 μG were remeasured in a cryogenic magnetometer. Subsequently, it was decided to measure all specimens in the cryogenic magnetometer and only use the spinner magnetometer for those specimens with values beyond the upper limits of the cryogenic.

3.2.4 Modified Konigsberger Ratio

The NRM and susceptibility are used to calculate the Modified Konigsberger ratio Q' , which is the ratio in a rock of NRM to the induced magnetisation in the earth's field in situ. It is a test for the presence in rocks of magnetic particles possessing high and low coercivity, and thus indicates the rock's capability of maintaining a stable remanence (Collinson, 1983).

Specimens with a Q' value less than 0.1 (measurements in cgs units) have a poor capability of maintaining a stable remanence whilst those with a value greater than 1 have a good capability. Specimens with values between 0.1 and 1 have a fair capability of maintaining a stable remanence (C.Barton, pers. comm. 1986).

The Modified Konigsberger Ratio was calculated for all specimens.

3.2.5 AF Demagnetisation

Specimens representative of typical lithologies at the site were systematically demagnetised over a range of values, using alternating magnetic field demagnetisation (AF demagnetisation).

A Schonstedt AC Geophysical Tumbling-Specimen Demagnetizer, Model GSD 5, was used to demagnetise specimens at peak fields up to 100 mT. In this instrument maximum presentation of the specimen's directions to the applied field is achieved by tumbling the specimen in a three-axis rotator, and the influence of the geomagnetic field is excluded by the use of a Mumetal shielding.

The ANU AF Demagnetizer, a custom-made instrument, was used to demagnetise specimens at values greater than 100 mT.

Most specimens were demagnetised at the following steps: 2.5, 5, 10, 15, 20, 30, 40, 50, 60, 80, and 100 mT. Very strongly magnetised specimens were also demagnetised at 150 and 200 mT. This step-wise demagnetisation was not continued to 100 mT when the median destructive field, the strength of the peak demagnetising AF at which half the NRM of the sample was removed, was attained at a very much lower value (e.g. 40 or 50 mT).

3.2.6 Data Processing

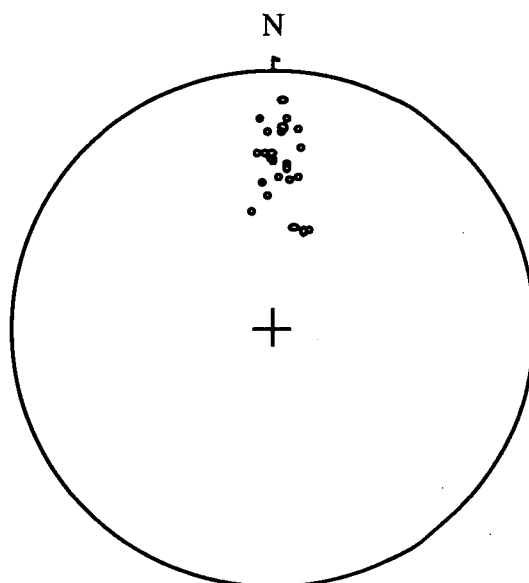
Information from the stepwise demagnetisation process was used to prepare a variety of plots; these were used to determine the values at which the remaining specimens were to be cleaned.

Initially plots were prepared using the in-house program PLODD on the BMR Hewlett-Packard system. This program produced three plots for each sample, a normalised intensity plot, an As-Zijderveld diagram and a stereographic plot. Later plots were prepared using an in-house BMR program on the Data General system. This program produced four plots for each sample, a normalised intensity plot, an As-Zijderveld diagram, a stereographic plot and a Hoffman-Day plot.

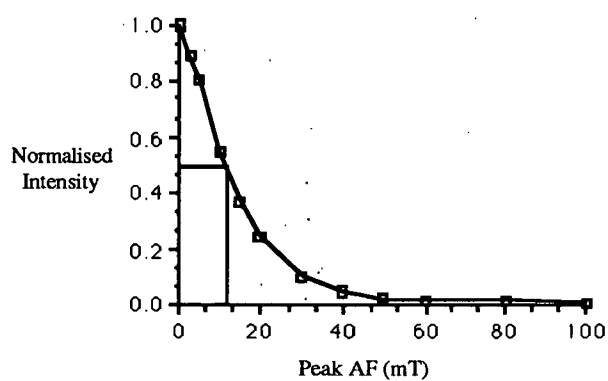
The stereographic plots are equal-angle projections which show the systematic changes in direction of magnetisation that occur with the demagnetisation of the specimen. These projections are conventionally of the lower hemisphere; downward (positive) inclinations are plotted as solid symbols and upward (negative) inclinations usually as hollow symbols.

The normalised intensity plots show the intensity after each demagnetisation step as a ratio of the intensity prior to demagnetisation, i.e. at AF 0. The intensity at AF 0 is taken to be one and the intensity at each demagnetisation step is normalised against this value by dividing the demagnetisation value by the AF 0 value.

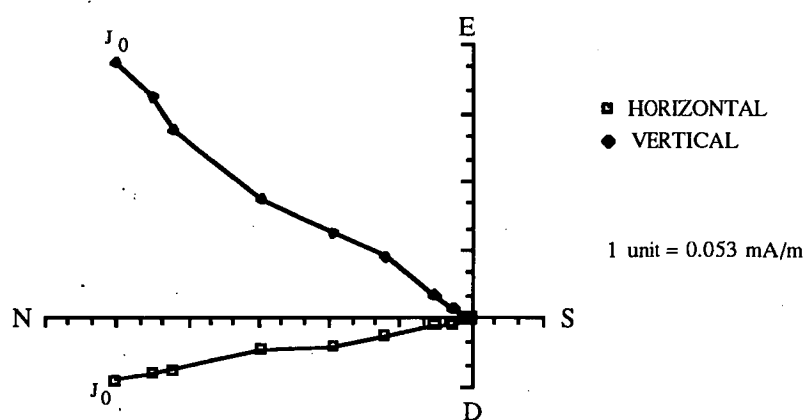
As-Zijderveld diagrams are cartesian projections on which are plotted components of the remanence after each demagnetisation step. They show both the intensity and direction of a vector during its progressive demagnetisation. The end point of the magnetisation vector after each demagnetisation step is projected on to two planes - the horizontal plane and one of the two vertical planes. If a consecutive set of demagnetisation steps is removing a single



a) stereographic plot



b) normalised intensity plot



c) As-Zijderveld diagram

Fig. 3.4 Examples of plots produced.

component of magnetism then the corresponding points will all lie on straight line segments of the projections. Once the demagnetisation steps reduce the magnetism of the specimen to a single component, the end point for all subsequent steps will lie on straight line segments directed through the origin for both the horizontal and vertical projections. The high coercivity component represented by this stable end point is assumed to be the primary magnetisation of the specimen.

Hoffman-Day plots show the direction of the magnetic vector removed at each demagnetisation step. Although these plots were generated for some of the demagnetisation data, they were not particularly helpful for this study.

3.2.7 Magnetic Cleaning

Step-wise demagnetisation was used to determine the stability of magnetisation and the primary direction of specimens and the values at which the individual site specimens were to be magnetically cleaned. This method was used because the much greater detail obtained by the use of single-step demagnetisation does not significantly improve the determination of the stability of magnetisation or the primary direction of the specimen. A trend of the direction of the vector will be obvious from several steps spread 5 - 10 mT apart. In addition, single-step demagnetisation requires a much greater amount of time for each specimen. It would be impracticable to make the extremely large number of measurements that would be required for each specimen if single-step demagnetisation was used.

The values at which the individual site specimens are to be magnetically cleaned can be determined from the As-Zijderveld diagrams. A series of values with consistent declinations, and a common trend towards the origin of the diagram for both the horizontal and vertical projections, probably indicate the primary magnetisation vector of the sample, based on the assumption that the high coercivity component is the primary component. The remaining specimens can then be magnetically cleaned at any value along this series. Their cleaned values are thus assumed to represent the primary magnetisation vectors of the specimens.

Step-wise demagnetisation of selected specimens from several sites did not provide a clear indication of the primary magnetisation vectors of these specimens. Accordingly, all the specimens from these sites were step-wise demagnetized. A primary magnetisation vector for each site was then determined or selected after careful examination of all the demagnetisation data from each of the specimens.

3.2.8 Presentation of Data

In some areas specimens had to be taken from dipping beds and in other cases it was not possible to align the sampling cubes either horizontally or towards magnetic north. Appropriate field and bedding corrections were made for these specimens. The declination values for all specimens were then converted from magnetic north to true north, using magnetic variation values from the appropriate Tasmap sheets.

Stereo plots of the appropriately corrected declination and inclination values for each specimen were prepared for each site. The cleaned and corrected data, including stereo plots, are presented by area and by site in Chapter 4.

Ch 4 DATA

4.1 Introduction

The palaeomagnetic data generated by this study are presented in this chapter. The data are summarised in Table 4.1 and full details for individual sites are presented, by area and site, in Section 4.2. Table 4.1 contains mean declination and inclination values, mean NRM, susceptibility and Modified Konigsberger Ratio values and standard deviations, and the Fisher statistics R , k and α_{95} for each site, together with details of the associated bedrock or drift material.

Natural remanent magnetisation and susceptibility were measured for each sample and this data was used to calculate the Modified Konigsberger Ratio, Q' .

Mean NRM site values ranged from 0.11 uG for the Bulgobac C site to 694 uG for the Lemonthyme Penstock site. Almost half the sites had mean values of less than 1 uG. Four sites, all in the Mersey and Forth Valleys, had values greater than 100 uG. Sites with very low mean NRM values are associated with siliceous bedrock and/or drift; all the sites with very high values (the Mersey and Forth Valleys) are associated with dolerite bedrock.

Mean susceptibility values ranged from 0.77 uG/Oe for the Thureau Hills Creek 3 site to 191 uG/Oe for the Fish River site, with over half the sites having mean values between 1 and 10 uG/Oe. The majority of the sites thus had values within the range of 0.1 to 10 uG/Oe, the normal range for sedimentary rocks (Tarling, 1971). The Mersey and Forth Valley sites had by far the highest values, mean values ranging from 9 to 15 times the maximum of Tarling's range.

Mean Modified Konigsberger Ratio values ranged from 0.04 for the Bulgobac C site to 6.17 for the Gormanston Moraine site. Eight of the thirty one sites had a mean value greater than one and thus had a good capability of maintaining a stable remanence; five had a mean value of less than 0.1 and hence had only a poor capability of maintaining a stable remanence. The remaining sites had a fair capability of maintaining a stable remanence.

In an attempt to establish the relative reliability of the results a reliability matrix was constructed for each site on the basis of the following seven criteria:

- a) percentage of inclinations of the one type
- b) mean Modified Konigsberger Ratio
- c) spread of declinations in degrees
- d) spread of inclinations in degrees

- e) number of samples
- f) α_{95} value
- g) K value

Data for each of the criteria were divided into five groups to form a scale from one (the least reliable) to five (the most reliable) and each site was allocated to a position on the scale for each of the criteria. All criteria were given equal weight and the seven ratings for each site were averaged to obtain an overall rating for the site. Further details regarding the reliability index, including the group boundaries for each of the seven criteria, are given in Appendix 1. The reliability index determined by this method is shown for all sample sites in Tables 5.1 and A1.2.

Table 4.1 Mean Values for Declination, Inclination, NRM, Susceptibility, and Modified Konigsberger Ratio.

SITE	Dec. deg.	Inc. deg.	N ¹	R ²	k ³	α_{95} ⁴	NRM		Susc.		Q ⁵		Bedrock	Drift
							μ G	sd	μ G/Oe	sd		sd		
West Coast Sites														
<u>a) Pieman Area</u>														
1. Lower Pieman Rd.							0.70	0.14	1.99	0.38	0.36	0.08	siliceous ⁶	
	166	22	6	9.04	9.4	16.6								
	181	-32	4	3.74	11.6	28.2								
3. Marionoak							0.51	0.73	2.52	0.71	0.21	0.33	volcanics?	
	175	36	19	17.76	14.5	9.1								
	77	-28	2		<=3									
4. Boco	351	-55	34	33.39	54.3	3.4	89.5	115.23	16.5	16.31	4.1	2.63	volcanics	
5. Bulgobac A	150	35	28	27.57	63.2	3.5	32.2	23.86	26.1	13.29	1.2	0.43	volcanics	
Bulgobac B							0.20	0.12	2.95	0.42	0.07	0.04	siliceous	
	179	18	4	3.86	21.4	20.3								
	146	-23	1											
Bulgobac C							0.11	0.04	2.69	0.28	0.04	0.02	siliceous	
	199	14	5	4.90	38.5	12.5								
	180	-14	5	4.63	10.7	24.5								
6. Que							0.51	0.24	4.99	1.69	0.11	0.06	V ⁷ in till	
	195	40	28	26.25	15.4	7.2								
	321	-41	2		<=3									
7. Rosebery Opencut	355	-54	23	21.64	16.2	7.8	4.6	10.09	6.77	5.88	0.43	0.34	volcanics	Continued....

Table 4.1. Continued.

SITE	Dec. deg.	Inc. deg.	N	R	k	α 9 5	NRM μ G	sd	Susc. μ G/Oe	sd	Q' sd	Bedrock	Drift
8. Williamsford Road							0.28	0.15	1.82	0.30	0.16	0.09	?
	163	25	22	18.90	6.8	12.9							
	228	-19	3	2.05	2.1	128.1							
<u>b) Henty Surface</u>													
9. Tyndall Creek A							1.1	1.34	4.05	0.34	0.27	0.31	C ⁸ & V
	133	25	17	14.24	5.8	16.3							
	150	-27	5	4.04	4.2	42.7							
Tyndall Creek B							1.2	1.18	3.86	0.36	0.30	0.28	C & V
	123	26	15	13.82	11.9	11.6							
	144	-32	6	4.51	3.3	43.3							
A & B combined (reversed)	128	26	32	28.01	7.8	9.8							
<u>c) King River Area</u>													
10. Thureau Hills Rd.	185	38	20	18.55	13.1	9.4	0.41	0.25	3.12	0.50	0.13	0.07	D ⁹ & siliceous
10A. Thureau Hills Ck. 1							0.64	0.87	0.93	0.28	0.72	0.94	D in till
	197	-52	8	5.83	3.2	36.8							
	197	14	1										
Thureau Hills Ck. 2	33	-41	12	8.79	3.4	27.7	0.48	0.91	0.77	0.80	0.55	0.69	D in till
Thureau Hills Ck. 3	353	-68	9	8.82	43.5	7.9	0.84	0.65	1.27	0.39	0.71	0.55	D in till
11. Baxter Rivulet	345	-51	15	12.00	4.7	19.9	0.30	0.13	2.58	0.96	0.12	0.05	siliceous continued...

Table 4.1 Continued.

SITE	Dec. deg.	Inc. deg.	N	R	k	α 9 5	NRM μ G	sd	Susc. μ G/Oe	sd	Q' sd	Bedrock	Drift
12. King River Bridge A	core						8.43	7.10	15.2	3.96	0.55	0.46	D in till
		-40	22										
		61	1										
King River Bridge B	core						6.07	3.45	15.8	3.74	0.39	0.21	D in till
		-39	11										
		21	4										
King River Bridge C & D	336	-40	27	26.13	30	5.2	10.27	6.65	12.76	2.64	0.79	0.46	D in till
13. Linda Creek							7.1	5.13	10.5	4.46	0.66	0.35	D & V in till
	19	-38	29	27.21	15.7	7							
	8	9	2	1.99	146.2	20.8							
14. Gormanston Moraine	198	60	6	5.98	313.7	3.8	37.9	9.11	6.11	0.35	6.2	1.34	D & V in till
16. King Gorge Exit							0.20	0.22	2.60	0.25	0.08	0.09	siliceous
	165	-59	16	12.91	4.8	18.7							
	336	41	3	2.62	5.3	60.1							

continued....

Table 4.1 Continued.

SITE	Dec. deg.	Inc. deg.	N	R	k	α 9 5	NRM μ G	sd	Susc. μ G/Oe	sd	Q' sd	Bedrock	Drift
North Central													
17. Fish River	4	-36	24	23.36	36.2	5	195	101	191	37.4	1.0	0.46	dolerite
18. Arm River Bridge ¹⁰	358	-34	22	20.84	18	7.5	261	95	91.8	19.2	2.8	0.64	dolerite
19. Arm River Road	33	-20	7	6.97	227.6	4	547	153	158	12.2	3.4	0.96	dolerite
20. Lemonthyme Ck.							694	230	158	23.9	4.5	1.58	dolerite
	171	53	14	13.37	20.6	9							
	96	-29	1										
West Central													
21. King William Ck.	8	-53	14	13.33	19.3	9.3	0.23	0.04	4.47	0.59	0.05	0.01	dolerite
22. Stonehaven Ck.							9.1	9.39	8.50	5.8	1.1	0.94	D in till
	5	-67	13	12.73	44.6	6.3							
	166	34	2	1.85	6.6	123.6							
23. Double Barrel Ck.							5.9	9.95	13.8	11.3	0.60	0.96	D in till
	165	-48	5	3.89	3.6	47							
	206	34	7	5.81	5	29.9							

¹ Number of vectors.² Length of the resultant vector.³ Precision parameter.⁴ Angular radius of the cone of confidence about the observed mean within which there is a 95% probability that the true mean direction lies.⁵ Modified Konigsberger Ratio.⁶ quartz rich sandstones, siltstones, quartzites⁷ Cambrian Mount Read Volcanics⁸ Ordovician West Coast Range Conglomerate⁹ Jurassic dolerite¹⁰ Includes Arm Road/Arm Spur Road site.

4.2 Site Descriptions and Palaeomagnetic Results.

4.2.1 West Coast Sites

a) Pieman Area

Site 1: Lower Pieman Road Site

This site is located in a road cutting on the southern side of the Lower Pieman Dam site Road, 35 km east of the dam (Rosebery, Sheet 3637, 1:25000, GR 686788) (Fig. 3.1). The site is 200m above sea level.

At this site rhythmites, consisting of alternating layers of pale grey and fawn silty clays, overly massive fawn till. The rhythmites contain large, elongated nodules (up to 4 by 2 cm.) of hard fawn material scattered throughout. They dip at 10 to 15 degrees to the north-east and become sandy in the eastern part of the cutting. These deposits represent the lowermost deposits in the Pieman Valley, and are some nine km further downstream from the site studied by Barbetti and Colhoun (1988) (Site 2). They have not been studied in any detail by previous workers.

These deposits are outside the limits of the Bulgobac Glaciation from the Marionoak-Huskisson divide (Barbetti and Colhoun, 1988), and they represent the maximum extent of the ice at any time (Colhoun, 1985). The Bulgobac Glaciation was considered to be the probable equivalent of the Linda Glaciation by Barbetti and Colhoun (1988), and therefore of Early Pleistocene age. The Lower Pieman site should therefore be at least of Early Pleistocene age.

Fourteen specimens were taken from this site. All the specimens were demagnetised over the normal range of steps, almost all to 100mT. On the basis of this information, 15 mT was chosen as representing the primary magnetisation of the sediments and the values at this demagnetisation step were used to prepare the stereoplot (Fig. 4.2). The results of the progressive demagnetisation of specimen LP6, a typical specimen, are shown in Fig 4.1.

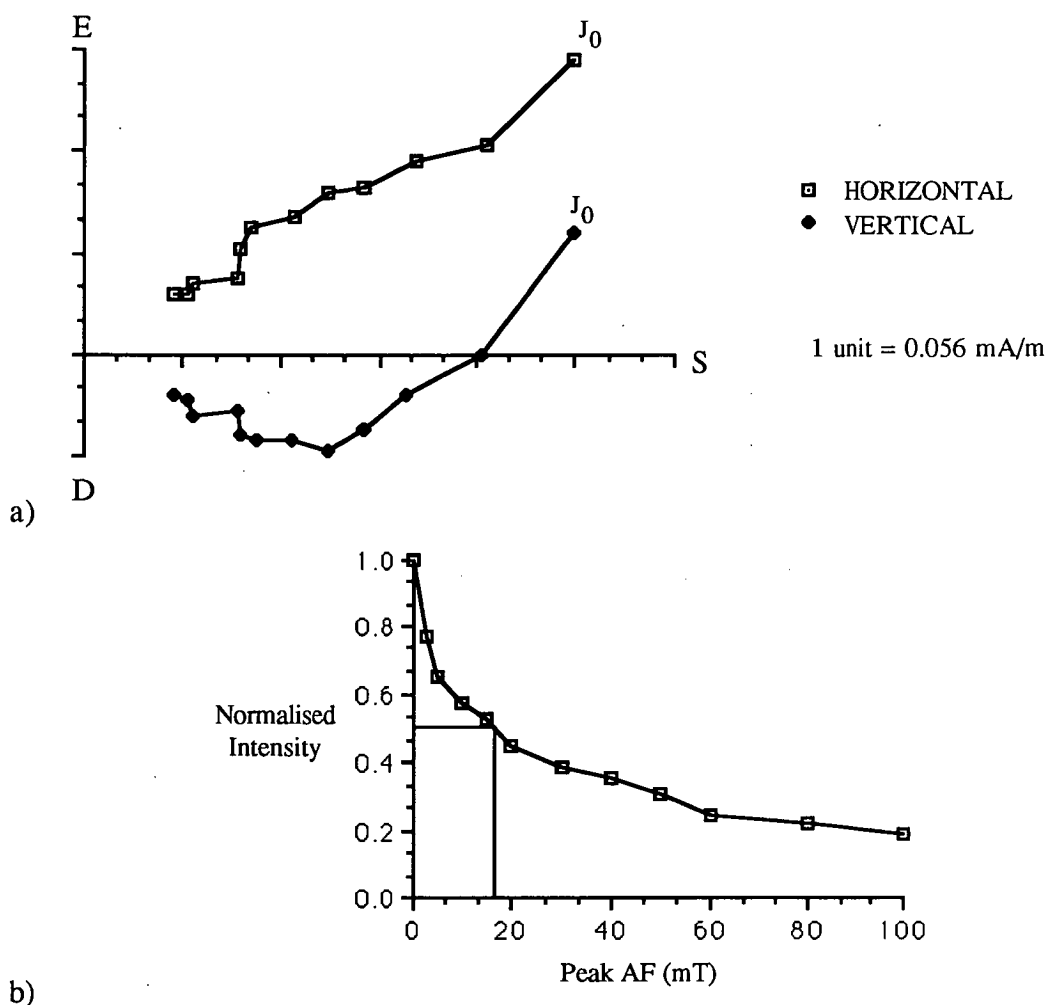


Fig. 4.1 a) Zijdeveld plot, specimen LP 6.
b) Normalised intensity plot, specimen LP 6.

The Zijdeveld plot indicates that this specimen has two major components of magnetisation. The lower stability component is isolated during AF treatment to 15 mT. Thereafter the plot shows some small variations in direction with each demagnetisation step, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a decrease in intensity of magnetisation with each step of AF treatment. Intensity decreases fairly rapidly initially, MDF being reached at 16.7 mT, but thereafter it decreases much more slowly. This specimen therefore has a hard major component of magnetisation.

The specimens form a reasonably tight grouping on the stereoplot (Fig. 4.2) but are of mixed polarity. The results are therefore considered to be equivocal and so it is not possible to conclude the polarity of the site.

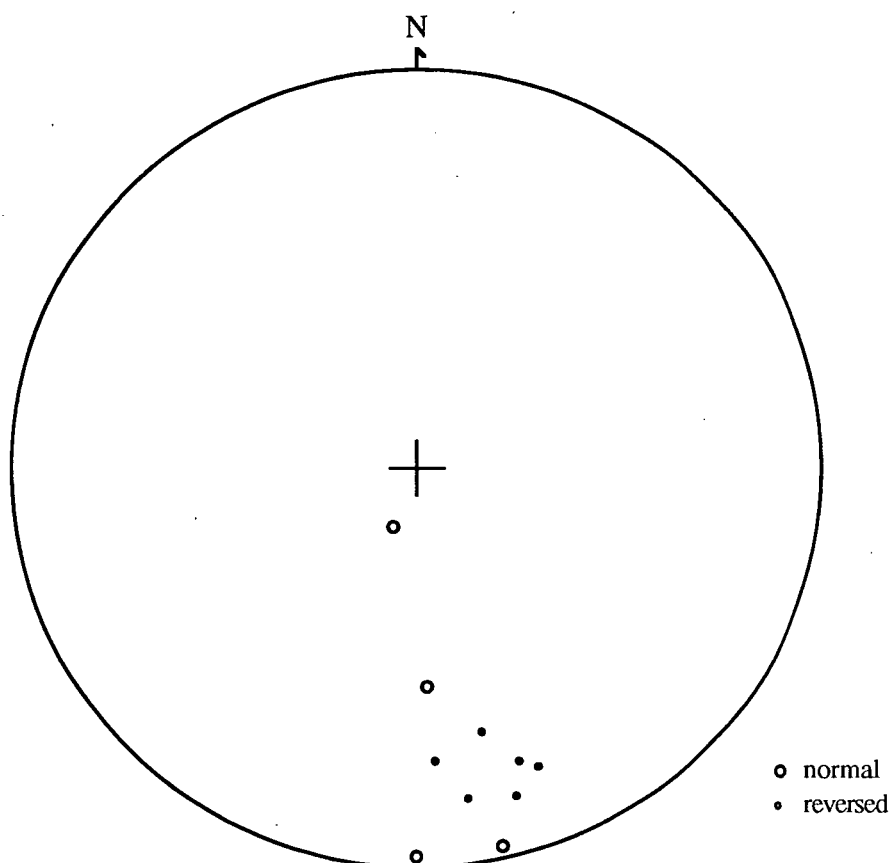


Fig. 4.2 Lower Pieman Road stereoplot (15 mT).

Six of the specimens have a reversed polarity, with a mean declination of 166 degrees and a mean inclination of 22 degrees, and four specimens have a normal polarity, with a mean declination of 181 degrees and a mean inclination of -32 degrees. Four of the specimens have an MDF (Median destructive field) < 5mT; these specimens are considered to be useless and are therefore excluded from the plot.

The specimens were very weakly magnetised, NRM values ranging from 0.485 to 0.996 μG and with a mean value of 0.7 μG . Susceptibility ranged from 1.19 to 2.65 $\mu\text{G}/\text{Oe}$, with a mean of 1.99 $\mu\text{G}/\text{Oe}$.

The Modified Konigsberger Ratio ranged from 0.27 to 0.58, with a mean of 0.36. These specimens therefore have a poor capability of maintaining a stable remanence.

The rhythmites at this site do not, therefore, provide a clear idea of the age of the lowermost drift in the Pieman Valley.

Site 2: Marionoak-Huskisson Divide

This site is located in a road cutting on the Lower Pieman Damsite road where it crosses the divide between the Huskisson and Marionoak valleys (Pieman, Sheet 7914, 1:100 000, GR 740780) in the Pieman Valley (Figs. 2.1 and 3.1). It is approximately 200 m above sea level.

This section is 90 m long and up to 10 m high and "...consists of glacial lake silt and clay rhythmites that overlie basal till on rock." (Barbetti and Colhoun, 1988), and is shown in Fig. 4. 3. The till includes flowtill and is overlain conformably by the laminated sediments. In the middle of the section the laminated sediments become increasingly contorted and are overlain by flowtill in places towards the top. The eastern end of the section consists of till and flowtill. Structures within the sediments show pushing from the east. This indicates local overriding and suggests that all the sediments were deposited directly in contact with ice during one glacial event (Colhoun, pers. comm. 1990).

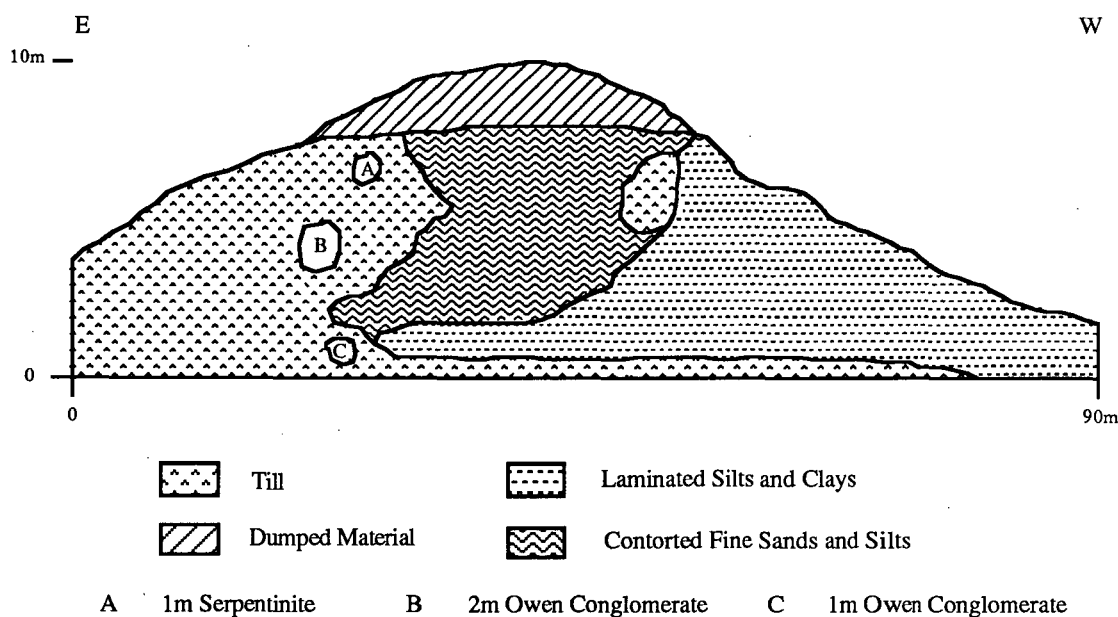


Fig. 4.3 Huskisson-Marionoak Divide section (Colhoun, pers. comm. 1988).

The site is 2 km west of end-moraines, west of the Marionoak River, that were taken by Augustinus and Colhoun (1986) to indicate the limits of the Boco Glaciation. They considered the Boco Glaciation to be of Middle Pleistocene age. On this basis the Marionoak-Huskisson divide site must be at least Middle Pleistocene in age, but may be of Early Pleistocene age.

The stereoplot prepared by Barbetti and Colhoun (1988) is shown in Fig. 4.3. They interpreted the results as indicating a reversed polarity for this site. The specimens, however, show a mixed polarity and a significant scatter on the plot.

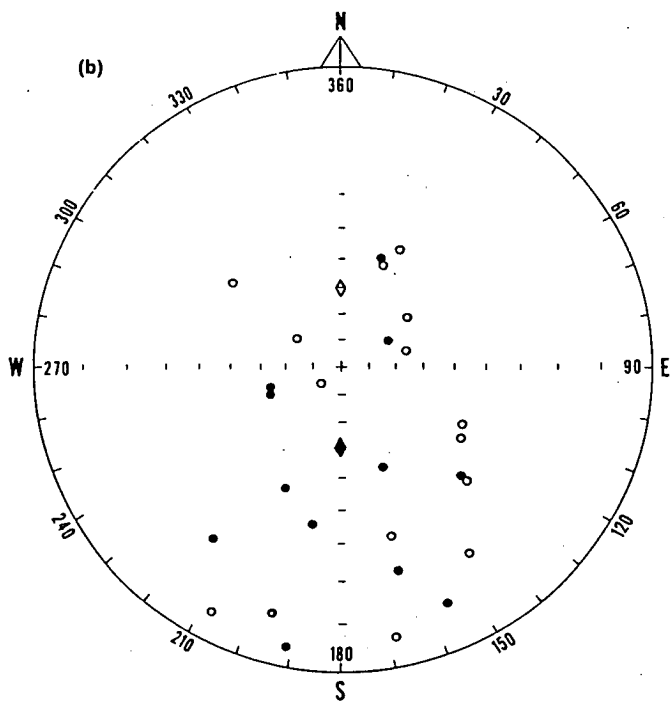


Fig. 4.4 Marionoak-Huskisson Divide stereoplot (Barbetti and Colhoun, 1988).

These results were considered to be equivocal and so the Lower Pieman Damsite Road site (Site one) was sampled to see if the results could be clarified at another site.

Thus neither site in the lower Pieman Valley is suitable for palaeomagnetic analysis and the drifts cannot be dated by this method.

Site 3: Marionoak Site

The Marionoak site is located in a road cutting on the southern side of the Boco Siding forestry road, one km west of the Boco/Marionoak divide (Parsons, Sheet 3638, 1:25000, GR 780848), and is 520 m above sea level (Figs. 2.1 and 3.1).

The stratigraphy of the site is complex, consisting of laminated silts (sampled) overlain respectively by highly deformed laminated silts, massive sandy gravel, very poorly sorted massive gravel (flowtill?), bedded sands and sandy gravels, and very poorly sorted gravel (Fig. 4.5). The laminated silts are interbedded with silty sand, sand, and coarse sand. In the lower part the silts are light grey, relatively undeformed, and horizontally bedded. Deformation increases towards the top of the section and the grain size increases rapidly. The presence of an Owen Conglomerate erratic on top of the sediments suggests that ice covered and overrode the lake. This is consistent with the deformation in the upper part of the sequence. Fitzsimons (pers. comm. 1987) has interpreted the site as representing an ice marginal, ice dammed lake, that was buried by a prograding delta and overridden by ice. Thus all the sediments represented at this site were deposited very close to an oscillating ice margin.

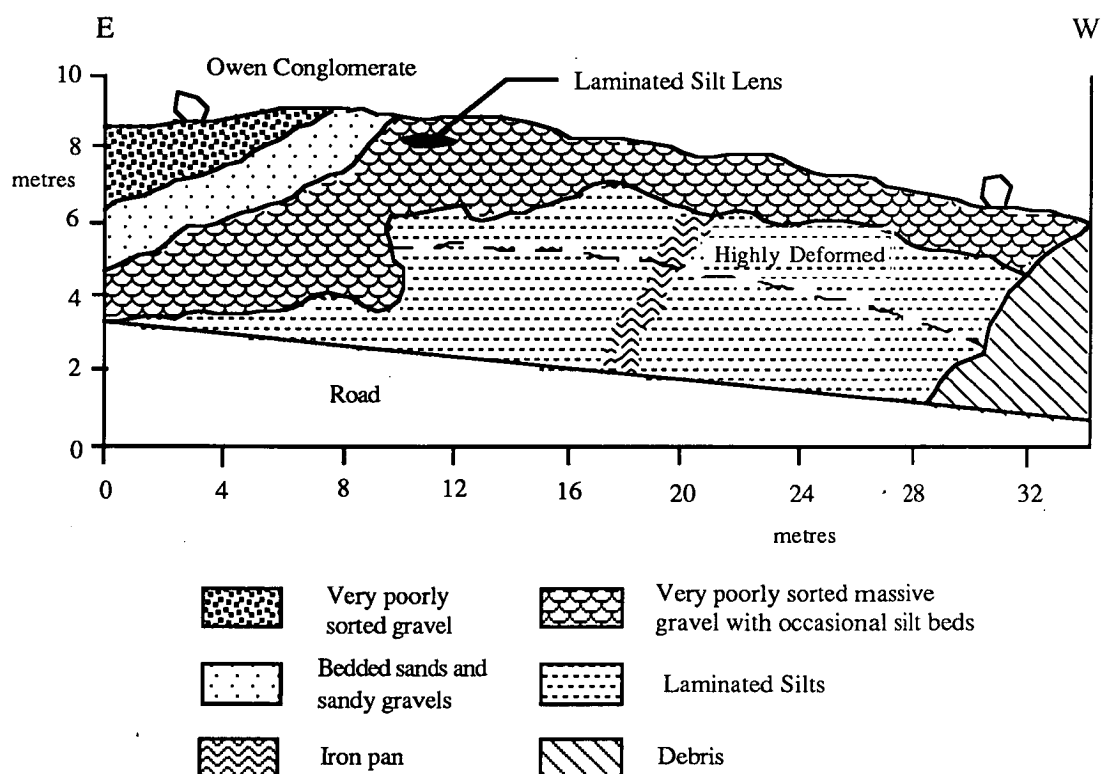


Fig. 4.5 Marionoak section (Fitzsimons, pers. comm. 1987).

The site occurs within the boundaries of the Bulgobac drift limit of Augustinus and Colhoun (1986) in the upper Marionoak Valley. They considered that this drift may be a correlative of the Linda drift of the southern part of the West Coast Range and was therefore at least of Early Pleistocene age.

Twenty one specimens were taken from this site. Several specimens were demagnetised over the normal range of values to 100 mT; the remainder of the specimens were accidentally cleaned at 50 mT and these values used for the stereoplot. However, this is unlikely to have significantly affected the final result. The results of the progressive demagnetisation of specimen M3, a typical specimen, are shown in Fig 4.6.

The Zijderveld plot shows two major components, the lower stability component being isolated during AF treatment to 15 mT. Thereafter, the plot shows some variations in direction with each demagnetisation step, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a soft overprint, total intensity increasing over the first three demagnetisation steps as the softer component is removed. The major component of magnetisation is very hard, MDF only being achieved at 76 mT.

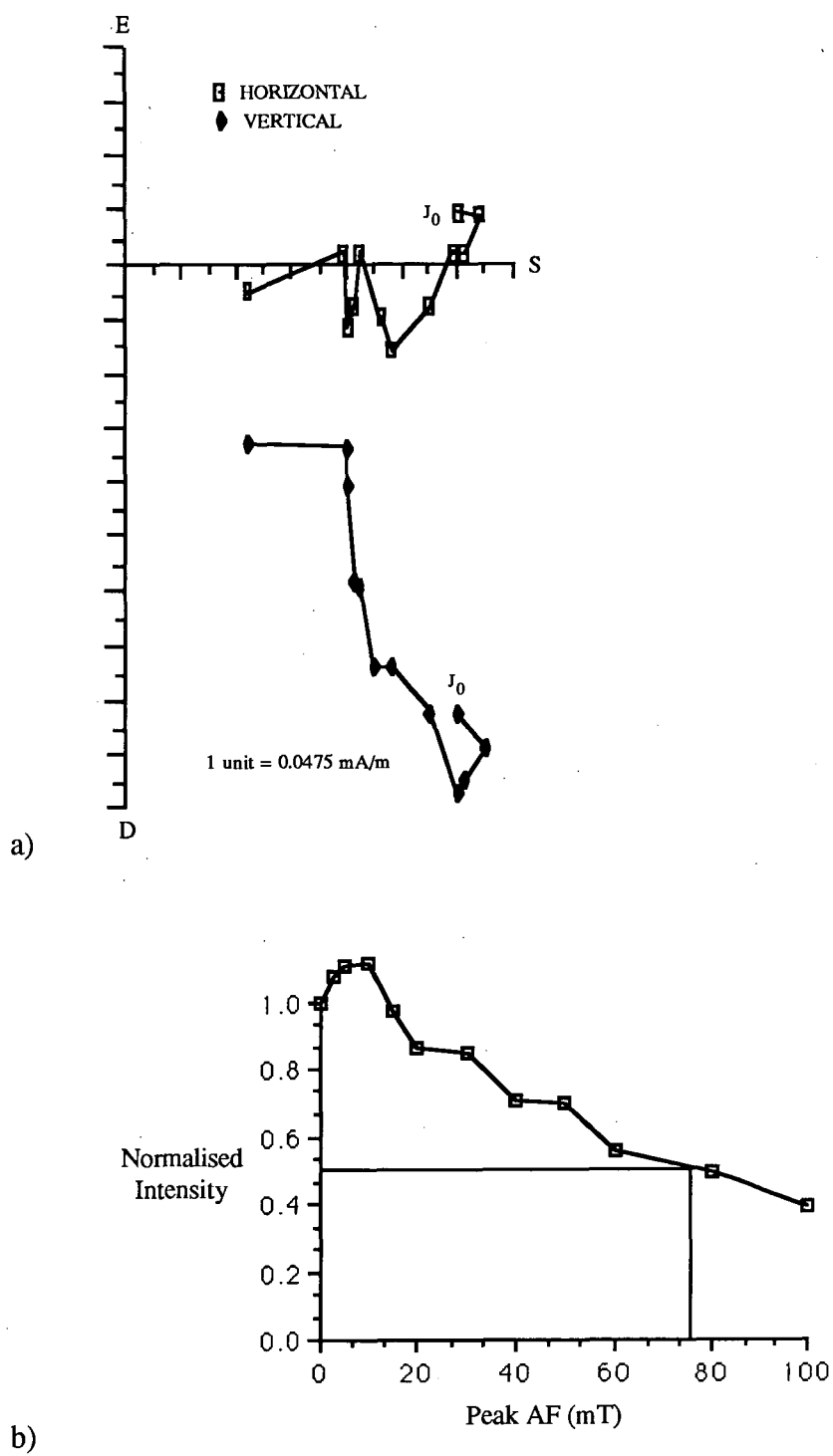


Fig. 4.6 a) Zijderveld plot, specimen M 3.
b) Normalised intensity plot, specimen M 3.

The specimens form a reasonably tight group on the stereoplot (Fig. 4.7), with 19 of the 21 specimens showing reversed polarity. The mean declination of the reversed specimens is 175° and the mean inclination is 36° .

The majority of these specimens were weakly magnetised, with NRM values ranging from 0.063 to 3.396 μG and with a mean value of 0.51 μG . Susceptibility values ranged from 1.31 to 4.08 $\mu\text{G}/\text{Oe}$, with a mean value of 2.52 $\mu\text{G}/\text{Oe}$.

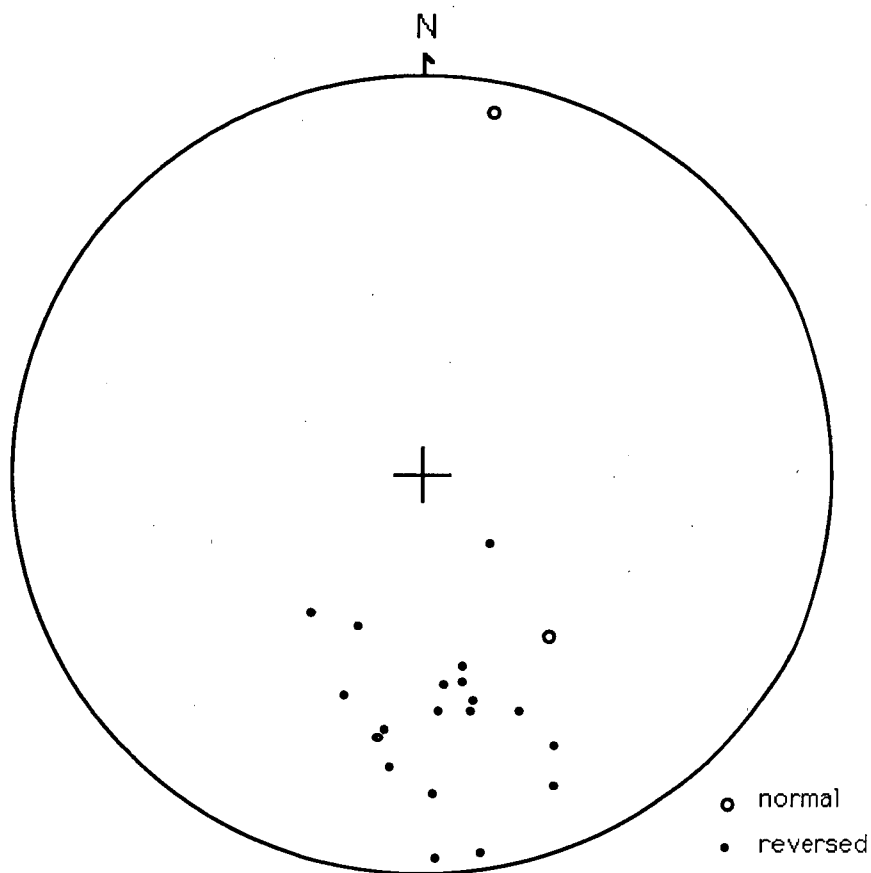


Fig. 4.7 Marionoak stereoplot (50 mT).

The Modified Königsberger Ratio ranged from 0.02 to 1.59, with a mean value of 0.21. Slightly more than half of the specimens have a fair to good capability of maintaining a stable remanence, with the remainder having only a poor capability.

This site has a reversed polarity and is therefore > 730 ka in age. The Bulgobac drift, within the boundary of which this site occurs, must therefore be at least of Early Pleistocene age.

Site 4: Boco

The Boco site is a large exposure located on the northern side of the forestry road west of Boco Siding, and is about 2 km from the railway siding (Block, Sheet 3838, 1:25000, GR 822858) (Figs. 2.1 and 3.1).

The section (Fig. 4. 8) is 50 m long, up to 15m high and is 390 m above sea level. The dominant material of the exposure is a fawn silty clay, with occasional dropstones, which becomes quite sandy in parts of the eastern end of the section. It is overlain in parts with gravels and contains some lenses of coarse-grained gravelly material (till?). Iron staining occurs throughout but becomes more pronounced towards the base of the section. An iron pan has developed in the gravelly material at the top of the section.

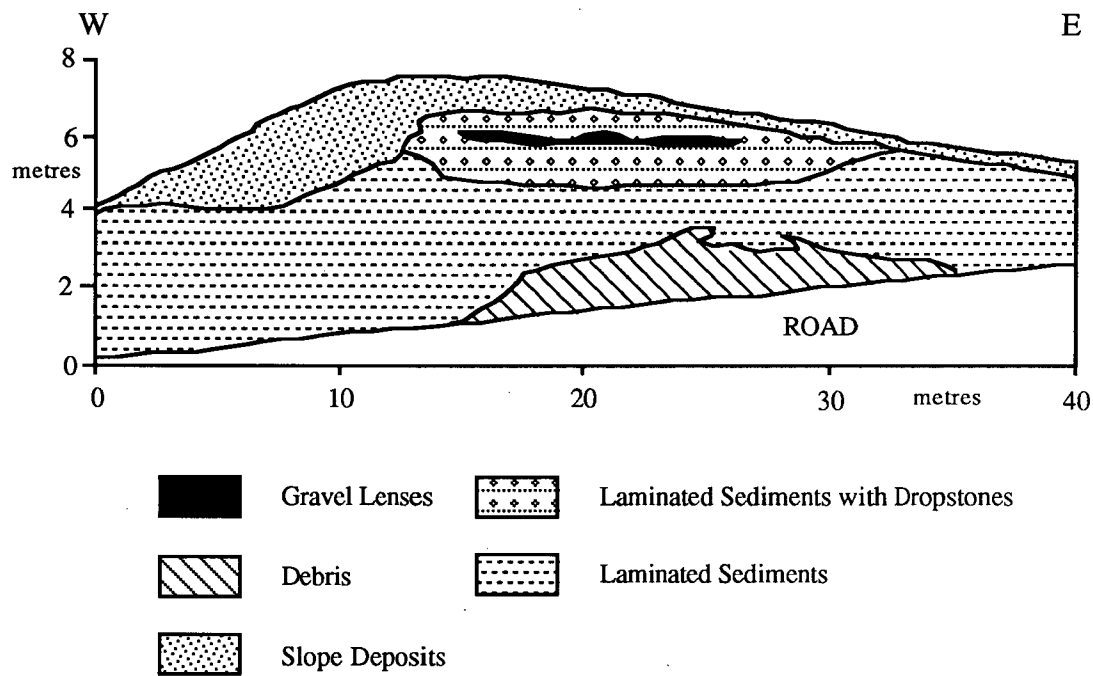


Fig. 4.8 Boco section.

This site occurs within the Boco I drift limit of Augustinus and Colhoun (1986) in the Boco Valley. They considered that this drift probably preceded the last interglacial and hence was > 130 ka in age.

Thirty four specimens were taken from this site. Six specimens were demagnetised over the normal range of values up to 100 mT (two to 150 mT). On the basis of these results the remaining specimens were cleaned at 25 mT. The results of the progressive demagnetisation of specimen B1.7, a typical specimen, are shown in Fig. 4.9.

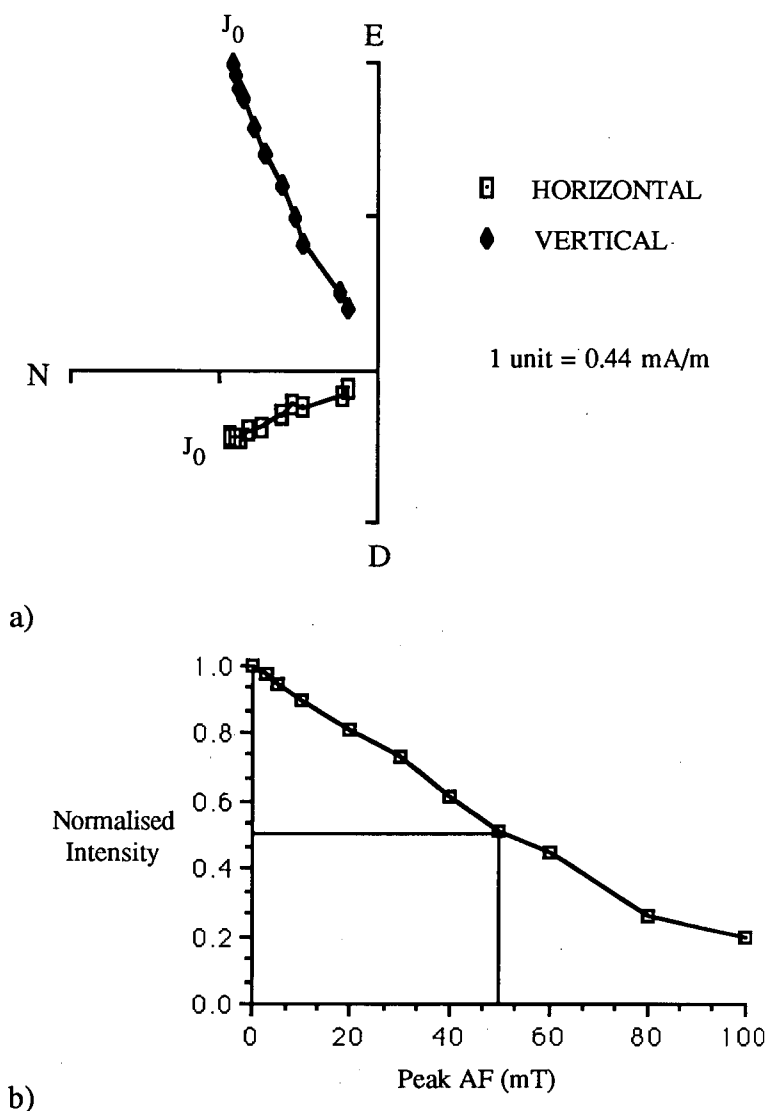


Fig. 4.9 a) Zijderveld plot, specimen B1.7.
b) Normalised intensity plot, specimen B1.7.

The Zijderveld plot shows one major component of magnetisation, with a strong and normal polarity. The direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component is being removed.

The normalised intensity plot shows that total intensity decreases only slowly with each demagnetisation step, MDF being achieved at 50 mT. This specimen therefore has one major hard component of magnetisation.

All the specimens have a normal polarity and form a tightly clustered group on the stereoplot (Fig. 4. 10), with a mean declination of 351° and a mean inclination of -55° .

These specimens varied from weakly magnetised to extremely strongly magnetised, with NRM values ranging from 0.838 to 369.146 μG and a mean value of 89.54 μG . The majority of the specimens were, however, strongly magnetised.

Susceptibility values ranged from 2.2 to 46.54 $\mu\text{G}/\text{Oe}$, with a mean value of 16.54 $\mu\text{G}/\text{Oe}$.

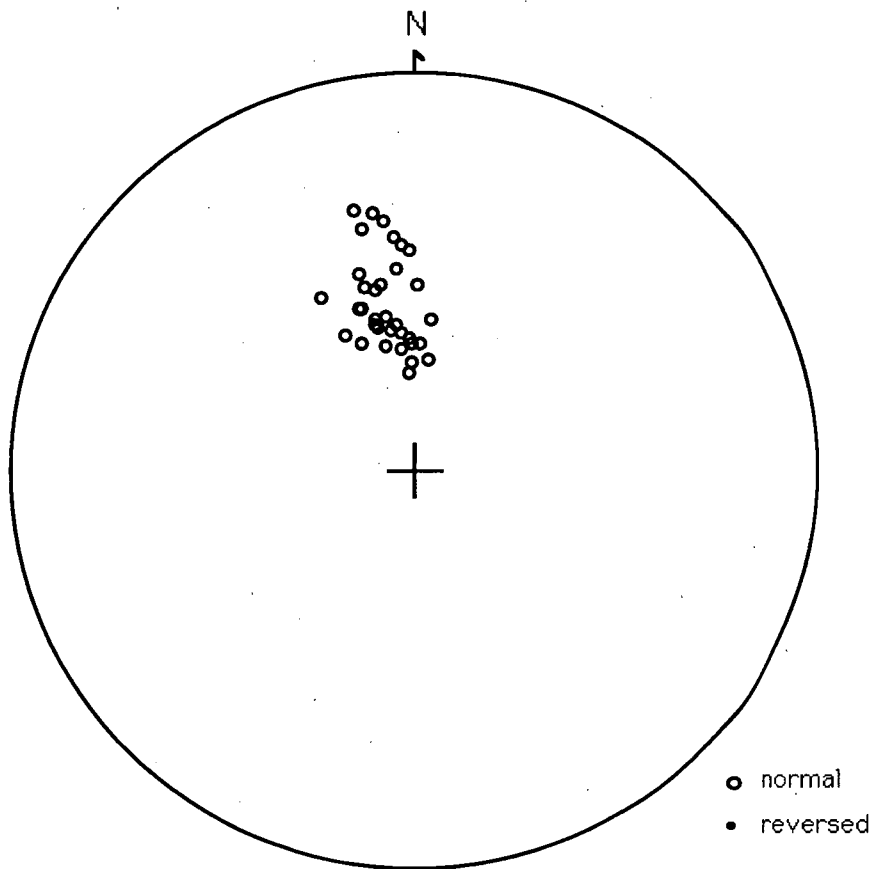


Fig. 4.10 Boco stereoplot (25 mT).

The Modified Königsberger Ratio ranged from 0.3 to 10.45 and had a mean value of 4.07; only five specimens had a mean value < 2 . The majority of these specimens thus have a good capability of maintaining a stable remanence.

This site has a normal polarity and is therefore < 730 ka in age. The Boco I drift, within the boundary of which this site occurs, cannot therefore be any older than Middle Pleistocene.

Site 5: Bulgobac

The Bulgobac site is a very large exposure located on the southern side of the forestry road west from Boco Siding, about 6 km from the railway siding (Parsons, Sheet 3638, 1:25000, GR 794852) (Figs. 2.1 and 3.1). Where sampled, on the eastern end of the exposure, the site is approximately 490 m above sea level, and is approximately 20 m high (Fig. 4.11). The site extends over several hundred metres west from here.

At the major sampling site (Site A) strongly weathered yellowish-brown till is overlain by laminated yellowish-fawn sandy silts. The contact is sharp and may represent a scoured surface. Over the majority of the section the sediments are distorted and wavy; only the lowermost metre of the laminated sediments is flat-lying, and hence suitable for sampling. Particle size in the sediments increases to the northeast, the sediment becoming distinctly sandy, suggesting a decreasing lake depth in this direction. The wavy structures in the laminated sandy silts may represent ripple marks. They have a wavelength of 15 - 25 cm and an amplitude of 5 cm.. Their asymmetric form suggests that they were formed by wave or current action from a northerly direction. At the eastern end of the section a large block of till occurs in the silts. It may represent a frozen block of ice rafted debris dropped into the lake. Small reverse faults in the lower silts probably result from compression associated with slumping of the sediments on the northern side of the schist outcrop. White laminated clay silts about this outcrop on the west (the adjoining sites B and C) and they are overlain by till. Augustinus and Colhoun (1986) suggested that these sediments were deposited in a shallow proglacial lake that was formed during ice melting or in kettle lakes formed by the melting of stagnant ice.

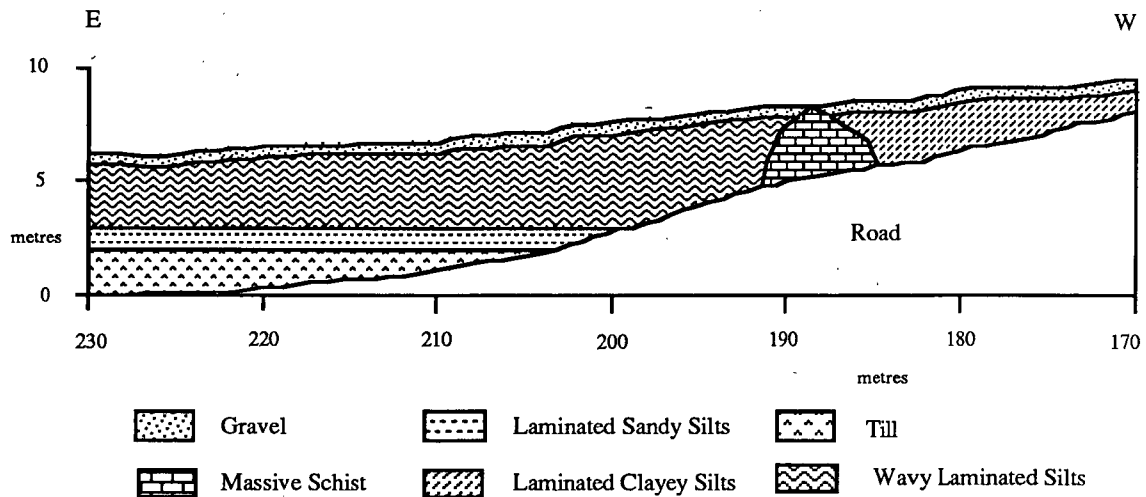


Fig. 4.11 Bulgobac section.

This site lies within the Bulgobac drift limit, in the Boco Valley, of Augustinus and Colhoun (1986). They considered that this drift was very much older than the Boco drifts,

was possibly a correlative of the Linda drift of the southern part of the West Coast Range, and was at least of Early Pleistocene age.

Thirty seven specimens were taken from this site, twenty eight from the major site and nine from the adjoining sites. In addition, a further ten specimens were taken from the adjoining site in resampling.

Four specimens from Site A were demagnetised over the normal range of values to 200 mT and on this basis the remainder of the specimens were cleaned at 20 mT. Two specimens from Site C were demagnetised over the same range to 100 mT and the remainder cleaned at 30 mT. All the specimens from Site B were demagnetised over the normal range of values to 50 mT and the values at 30 mT were chosen as representing the primary magnetisation and were used to prepare the stereoplot. The results of progressive demagnetisation of a typical specimen from Site A, B2.26, are shown in Fig. 4.12.

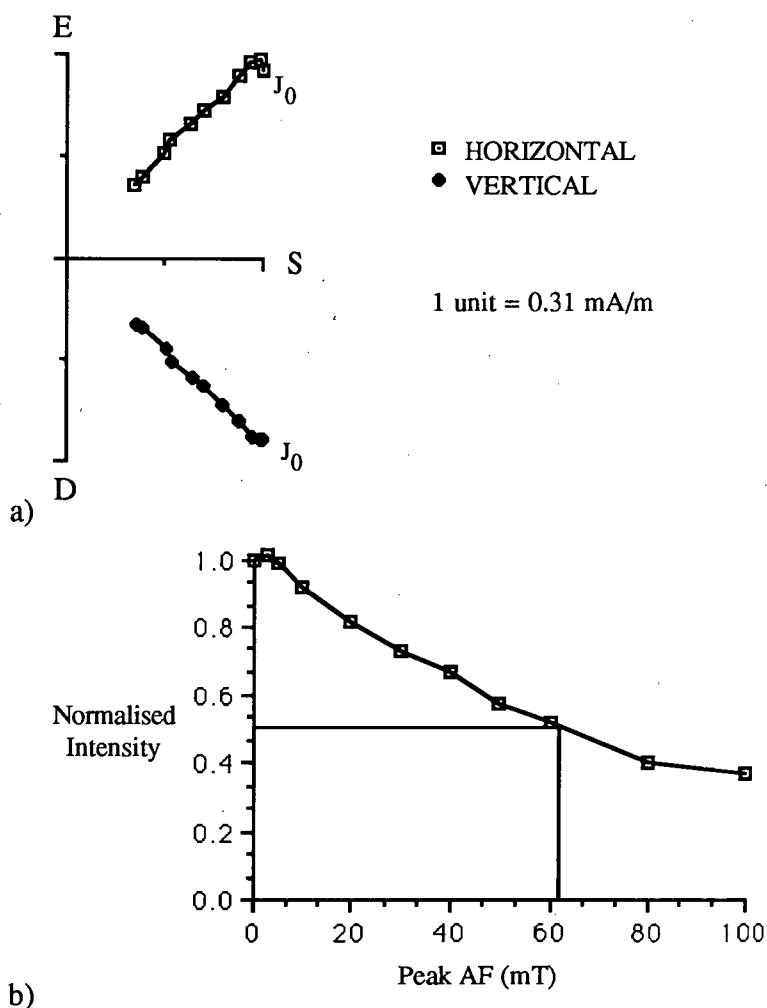


Fig. 4.12 a) Zijderveld plot, specimen B2.26.
b) Normalised intensity plot, specimen B2.26.

The Zijderveld plot shows essentially one major component of magnetisation, with a strong and reversed polarity. A low stability component is isolated during the first AF treatment (2.5 mT). Thereafter, with each successive demagnetisation step, the direction remains essentially unchanged towards the origin, a single component of magnetisation being removed.

The normalised intensity plot shows a very soft overprint and a very hard major component, MDF being achieved at 62 mT.

All the specimens from Site A had a reversed polarity and form a tight group on the stereoplot, with a mean declination of 150° and a mean inclination of 35° (Fig. 4.13 a).

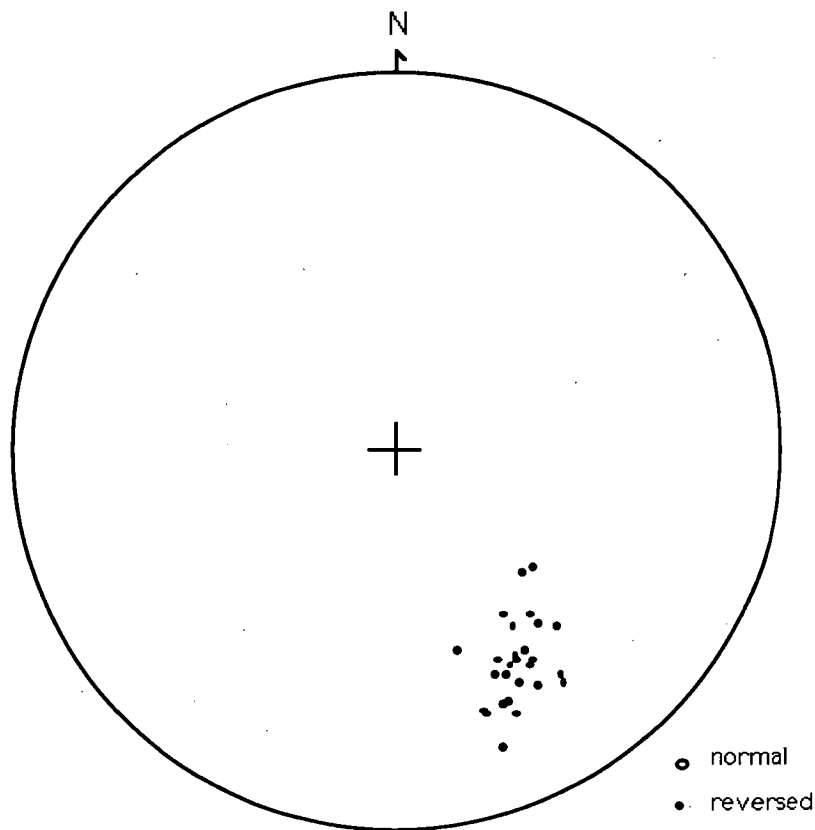


Fig. 4.13 a) Bulgobac A stereoplot (20 mT).

The specimens from Sites B and C have very shallow inclinations and a mixed polarity, although they are probably dominantly reversed (Fig.4.13b). However, the relatively scattered nature of this stereoplot, together with the mixed polarity of the specimens and the very low MDF (four specimens from these sites have an $MDF < 5$), suggests that these results are equivocal.

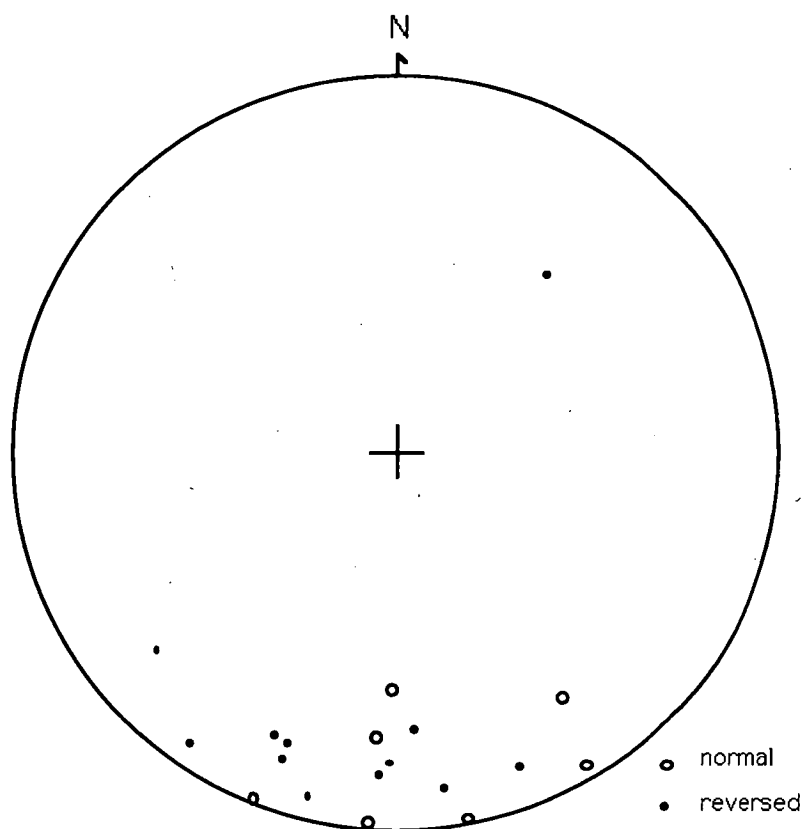


Fig. 4.13 b) Bulgobac B and C combined stereoplot (30 mT).

The majority of the specimens from Site A were strongly magnetised, NRM values ranging from 1.612 to 98.217 μG and with a mean value of 32.23 μG . Specimens from Sites B and C were weakly magnetised, with a range of 0.054 to 0.480 μG and a mean of 0.152 μG . Susceptibility values from site A ranged from 4.73 to 48.66 $\mu\text{G}/\text{Oe}$, with a mean value of 26.09 $\mu\text{G}/\text{Oe}$. Values from sites B and C ranged from 2.07 to 3.39 $\mu\text{G}/\text{Oe}$ with a mean value of 2.84 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio for site A had a range of 0.21 to 2.02, with a mean value of 1.15. Approximately 70% of these specimens had a good capability of maintaining a stable remanence, whilst the remainder had a fair to very fair capability. The Modified Königsberger Ratio for sites B and C ranged from 0.02 to 0.15 with a mean value of 0.05. These specimens therefore have a poor capability of maintaining a stable remanence.

All the specimens from Site A and the majority of the specimens from Site B have a reversed polarity. The Bulgobac site is therefore > 730 ka in age and provides further confirmation that the Bulgobac drift is at least of Early Pleistocene age.

Site 6: Que

The Que site is located in a road cutting on the western side of the Murchison Highway approximately 6 km north of Boco Siding (Sophia, Sheet 8014, 1:100000, GR 861901) (Figs. 2.1 and 3.1).

At this site rhythmites are underlain by a compact till with a fine sandy to coarse sandy matrix and clasts up to pebble size. This till is poorly sorted and diffusely iron stained. The rhythmites are finely laminated, silty, and diffusely iron stained. The top 25 cm contains white silty layers and lenses. At the southern end of the section the silts have been dragged up and faulted and the top of the silts truncated. At the northern end the silts have been gently warped. The top of the laminated sediments have been eroded prior to deposition of a very poorly sorted till with a silty matrix and cobbles up to 40 cm. This till is slightly cemented and diffusely iron stained and the clasts are subrounded to rounded (Fig. 4.14).

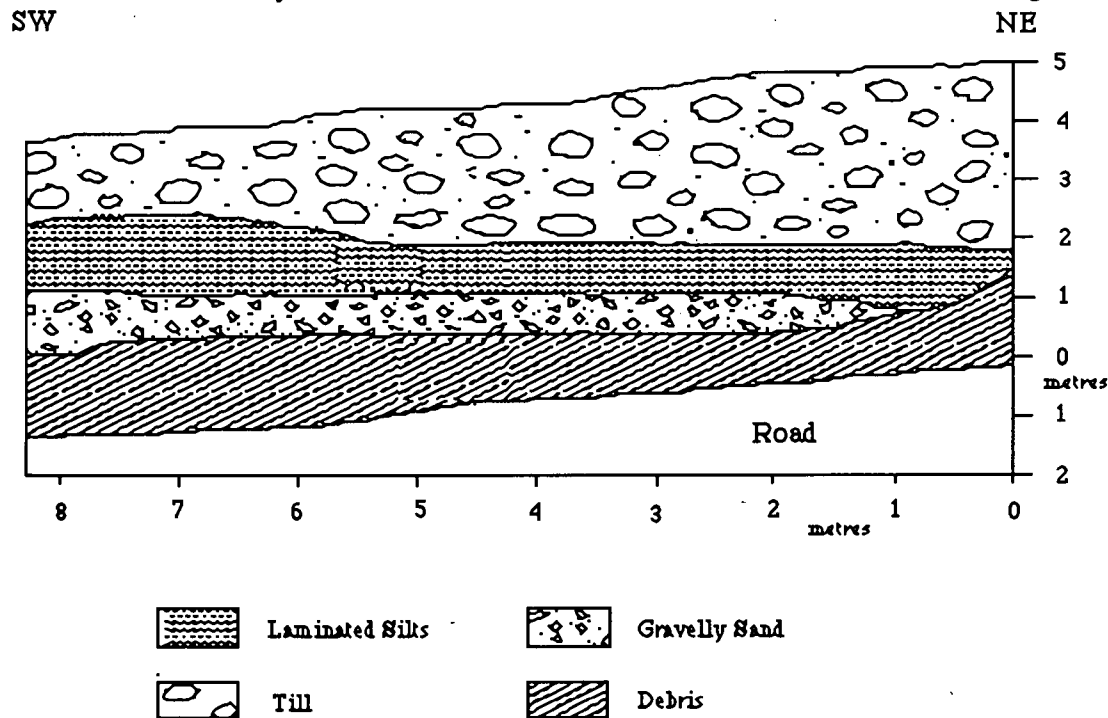


Fig. 4.14 Que section.

This site occurs within the Que drift but outside the Bulgobac drift limits of Augustinus and Colhoun (1986). They considered the Bulgobac drift to be a correlative of the Linda Glaciation and hence of at least Early Pleistocene age. On this basis the Que drift must also be at least of Early Pleistocene age.

Thirty specimens were taken from this site. Seventeen specimens were demagnetised over the normal range of values to 100 mT (two specimens to 200 mT) and on the basis of these

results the remaining specimens were cleaned at 30 mT. The results of progressive demagnetisation of specimen Q13, a typical specimen, are shown in Fig. 4.15.

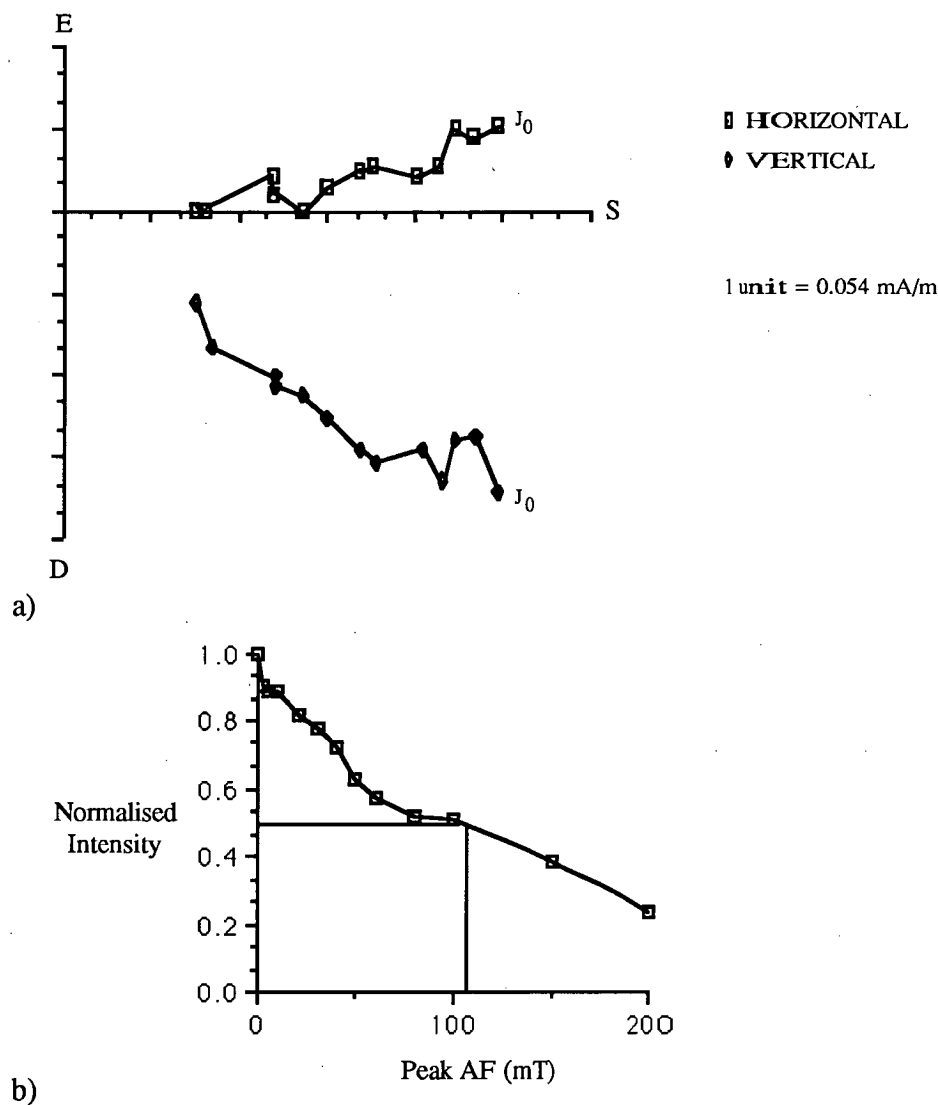


Fig. 4.15 a) Zijderveld plot, specimen Q13.
b) Normalised intensity plot, specimen Q13.

The Zijderveld plot shows essentially a two component system with low stability components being isolated during AF treatment up to 35 mT. Small variations in the direction with each demagnetisation step thereafter indicates that more than one component of magnetisation is being removed.

The normalised intensity plot shows that intensity decreases slowly with each step of demagnetisation treatment. This specimen has a very hard major component of magnetisation, MDF being achieved at a value > 100 mT.

Thirty-six of the thirty-eight specimens have a reversed polarity. The majority of the specimens form a reasonably close group on the stereoplot (Fig. 4.16), with a mean declination of 195° and a mean inclination of 40° for the reversed specimens. Two specimens have an MDF < 5 mT; these specimens are considered to be of no use and are therefore excluded from the stereoplot.

These specimens were weakly magnetised, NRM values ranging from 0.035 to 1.136 μG , with a mean value of 0.51 μG . Susceptibility values ranged from 3.07 to 10.44 $\mu\text{G}/\text{Oe}$ with a mean value of 4.99 $\mu\text{G}/\text{Oe}$.

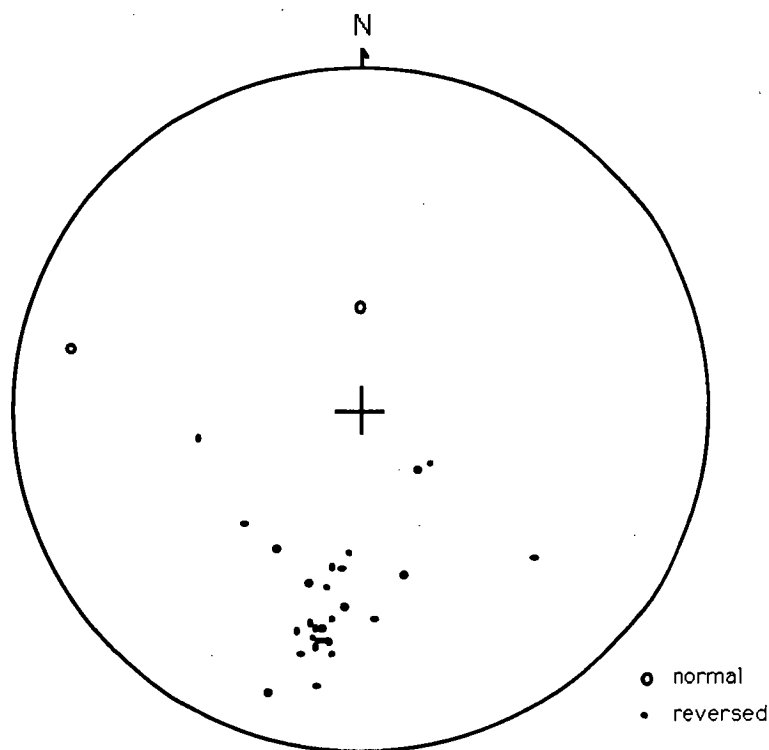


Fig. 4.16 Que stereoplot (30 mT).

The Modified Königsberger Ratio ranged from 0.01 to 0.28 with a mean value of 0.11. Twelve of these specimens have a poor capability of maintaining a stable remanence; the remainder have only a fair capability.

Almost all the specimens have a reversed polarity and so this site is > 730 ka in age. The Que drift, within the boundary of which this site occurs, is therefore at least of Early Pleistocene age.

Site 7: Rosebery Opencut

The Rosebery Opencut site is located in the northern face of the middle level of the old Rosebery Opencut Mine (Rosebery, Sheet 3637, 1:25000, GR 787746) (Fig. 3.1).

The site, which is approximately 230 m above sea level, has been described by Colhoun and van de Geer (1987). The deposit (Fig. 4.17) varies between 1 and 2.5 m in thickness and is about 8 metres long. It consists of glacial lake clays and silts resting on an erosion surface developed on Cambrian black slates and is overlain by compact basal till deposits of Boco Glaciation age. The clays contain abundant, small wood and charcoal fragments. Plant fossils from the site have been described by Colhoun and van de Geer (1987).

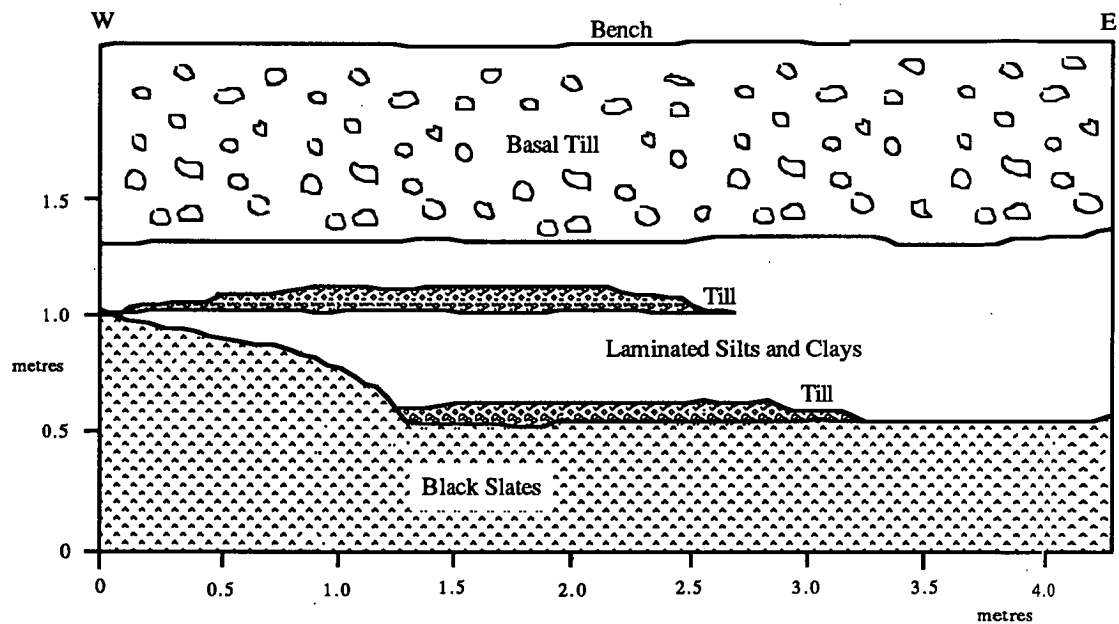


Fig. 4.17 Rosebery Opencut section.

Colhoun and van de Geer (1987) considered that the basal till deposits were formed during the Boco Glaciation, the Penultimate Glaciation of western Tasmania. Wood from this deposit has an amino-acid age of Isotope Stage 7 (Pillans pers. comm.). It is therefore considered to be of second last interglacial age (i.e. Langdon) and to have been incorporated into the till by the Boco ice during Isotope Stage 6 (Colhoun pers. comm., 1989).

Twenty three specimens were taken from this site. Six specimens were demagnetised over the normal range of values up to 80 mT and on the basis of these results the remainder of the specimens were cleaned at 25 mT. The results of progressive demagnetisation of specimen R5, a typical specimen, are shown in Fig. 4.18.

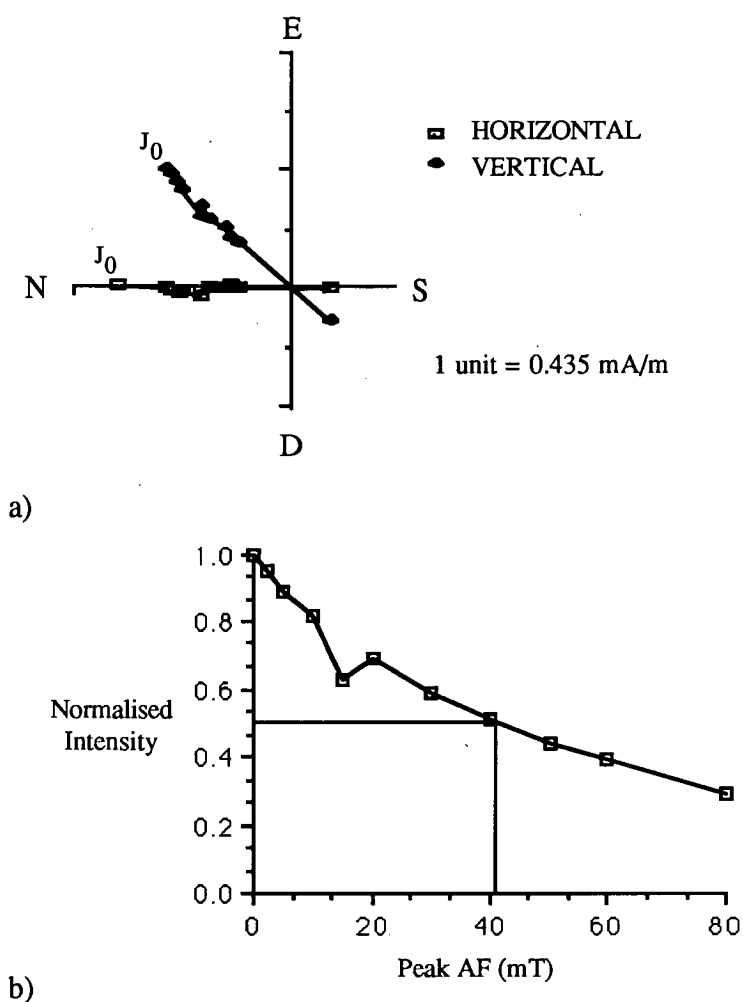


Fig. 4.18 a) Zijderveld plot, specimen R5.
b) Normalised intensity plot, specimen R5.

The Zijderveld plot shows a two component system, the first component being isolated during AF treatment up to 20 mT. Thereafter the the direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that intensity of magnetisation is reduced relatively slowly, MDF being achieved at 41 mT. This specimen thus has one relatively hard component of magnetisation.

All the specimens have normal polarity and form a fairly close group on the stereoplot, with a mean declination of 355° and a mean inclination of -54° (Fig. 4.19).

The strength of the magnetic signal ranged from 0.724 to 44.124 μG , with a mean value of 4.56 μG . However, twenty one of the specimens had values ranging from 0.724 to 2.873 μG ; the other two specimens had the much higher values of 26.624 and 44.124 μG respectively. Susceptibility values ranged from 3.41 to 26.38 $\mu\text{G}/\text{Oe}$, with a mean value of 6.77 $\mu\text{G}/\text{Oe}$.

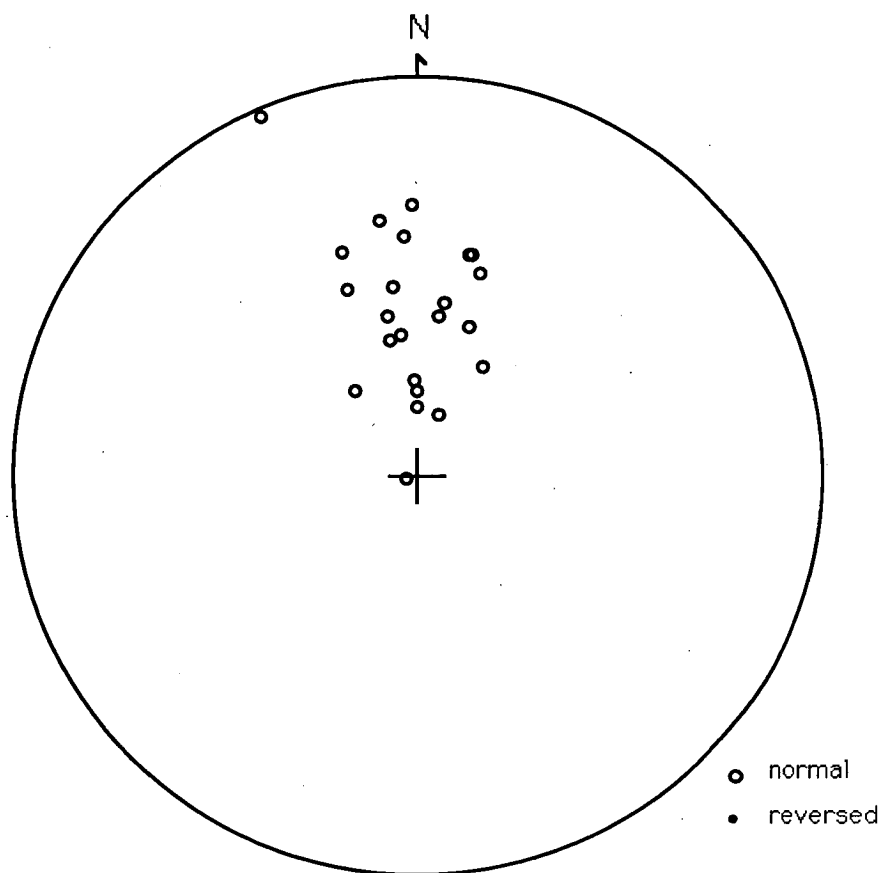


Fig. 4.19 Rosebery Opencut stereoplot (25 mT).

The Modified Königsberger Ratio ranged from 0.11 to 1.67, with a mean value of 0.43. Two specimens had a good capability of maintaining a stable remanence, whilst the remainder had only a fair capability.

All the specimens have a normal polarity and so this site is likely to be < 730 ka in age. These deposits are therefore unlikely to be any older than Middle Pleistocene.

Site 8: Williamsford Road

The Williamsford Road site is located in a cutting on the eastern side of the road into Williamsford (Dundas, Sheet 3636, 1:25000, GR 764689) (Fig. 3.1).

The site is at the highest point of the road, approximately 420 m above sea level, is up to 5 m high in parts and is approximately 45 m long (Fig. 4.20). It consists of light grey, horizontally bedded laminated muds and sands with minor convolute laminations. Some parts of the section are diffusely iron stained.

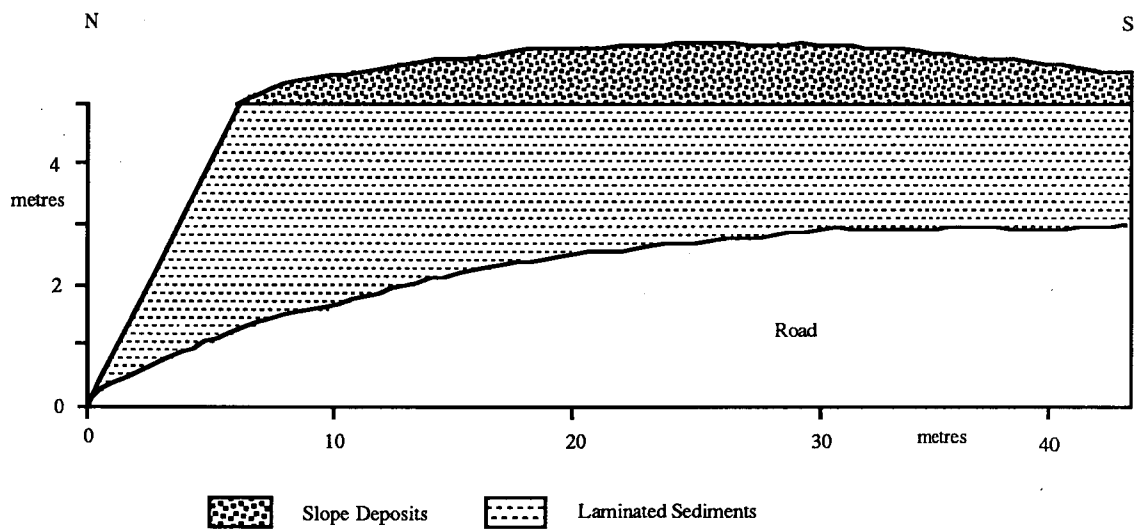


Fig. 4.20 Williamsford Road section.

These deposits, not studied in any detail by previous workers, were considered to have been deposited during the Boco Glaciation by Colhoun (pers. comm., 1987) and hence of Middle Pleistocene age.

Thirty specimens were taken from this site. All the specimens were demagnetised over the normal range of values up to 100 mT and on the basis of these results 30 mT was chosen as representing the primary magnetisation of the specimens. The results of progressive demagnetisation of specimen W27, a typical specimen, are shown in Fig. 4.21.

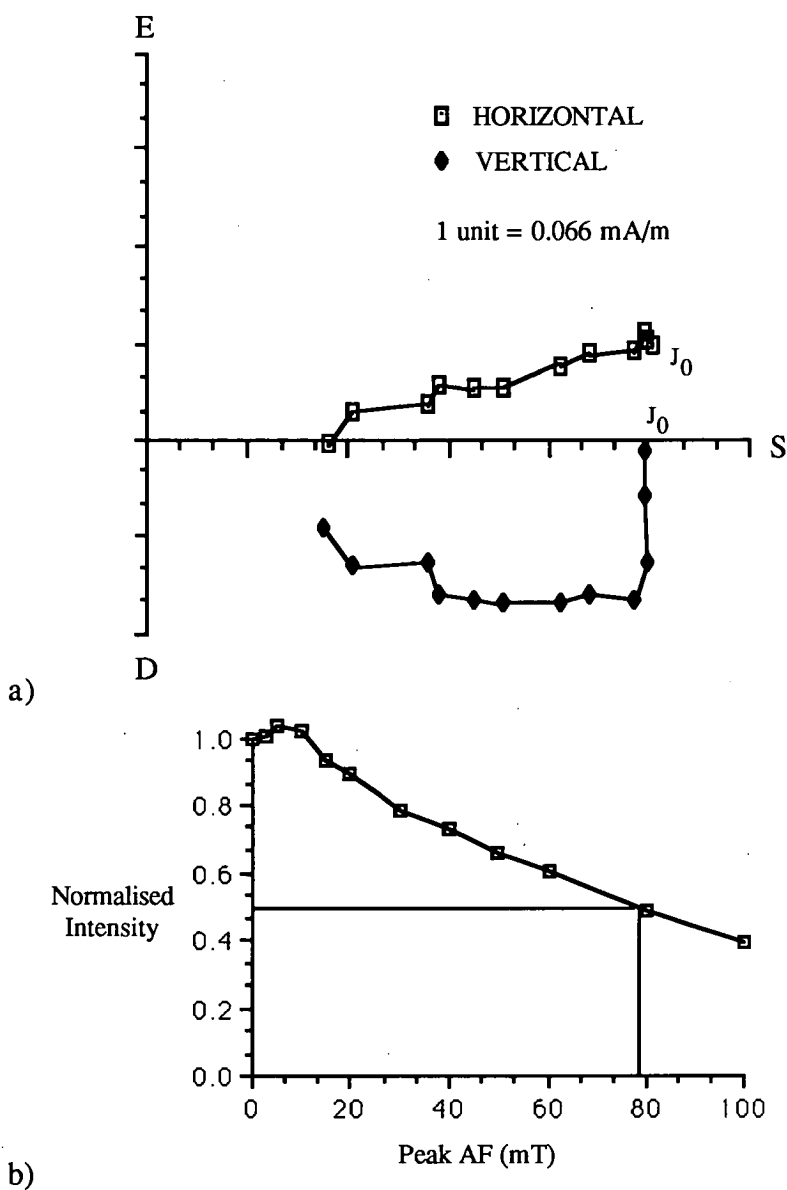


Fig. 4.21 a) Zijdeveld plot, specimen W27.
b) Normalised intensity plot, specimen W27.

The Zijdeveld plot shows a two component system, the first component being isolated during AF treatment up to 10 mT. Thereafter the plot is relatively stable but there are some small variations in direction with each successive demagnetisation step, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a soft overprint, total intensity increasing slightly during the first two demagnetisation steps as one component is preferentially removed. The major component of magnetisation is very hard, MDF being achieved at 77 mT.

Five of the specimens with an MDF <10 mT were discarded. Twenty-two of the remaining twenty-five specimens have reversed polarity. The specimens form a fairly open group on the stereoplot (Fig. 4.22), the reversed specimens having a mean declination of 163° and a mean inclination of 25° .

These specimens were weakly magnetised, NRM values ranging from 0.082 to 0.715 μG and with a mean value of 0.28 μG . Susceptibility values ranged from 1.17 to 2.92 $\mu\text{G}/\text{Oe}$, with a mean value of 1.82 $\mu\text{G}/\text{Oe}$.

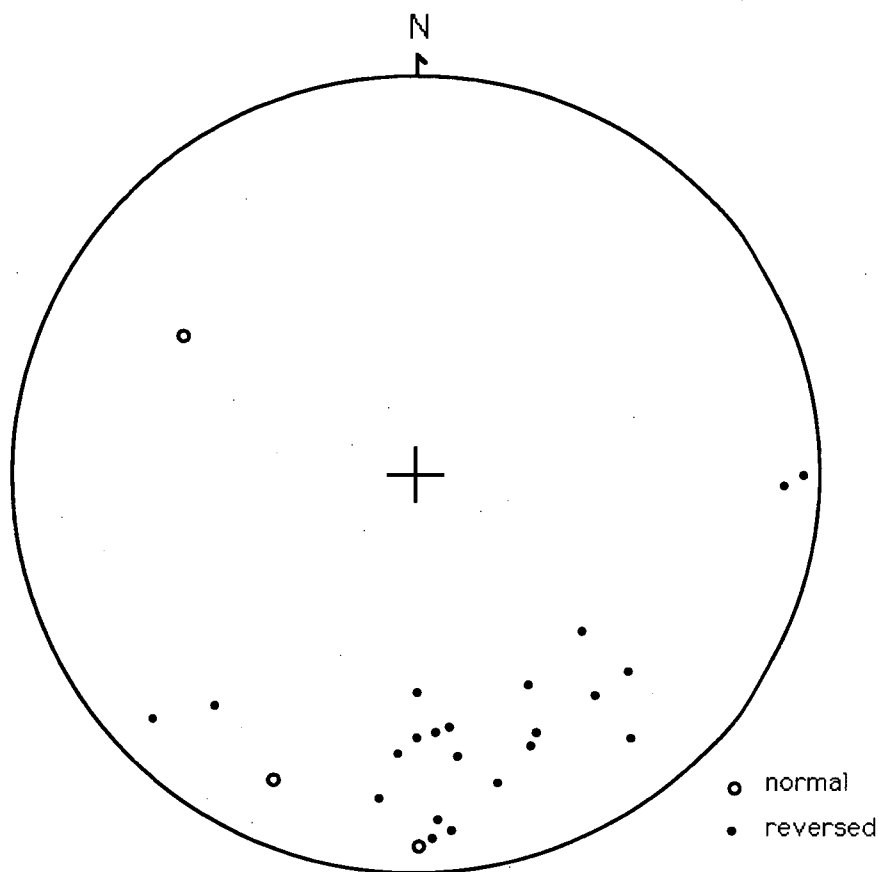


Fig. 4.22 Williamsford Road stereoplot (30 mT).

The Modified Königsberger Ratio ranged from 0.05 to 0.43, with a mean value of 0.16. Twenty of the specimens had a fair capability of maintaining a stable remanence whilst the remaining ten specimens had only a poor capability.

The majority of the specimens from this site have reversed polarity. The site is therefore likely to be > 730 ka old and so of Early Pleistocene rather than Middle Pleistocene age.

b) Henty Surface

Site 9: Tyndall Creek

The Tyndall Creek site is located in a road cutting on the eastern side of the Anthony Road (HEC Anthony Power Development sheet, 1:100000, GR 810570) (Fig. 2.2).

The site, which is approximately 500 m above sea level, has been described by Bowden (1974, S1 on his locality map) and Benger (1987). Only part of the large site described by Bowden (1974) is now open. This section is 18 m long and varies up to about 5 m high (Fig. 4.23). It consists of approximately 4 m of fine, laminated sediments and sands overlain by a green lodgement till. The laminated sediments consist of grey-white silt and clay laminations of variable thickness.

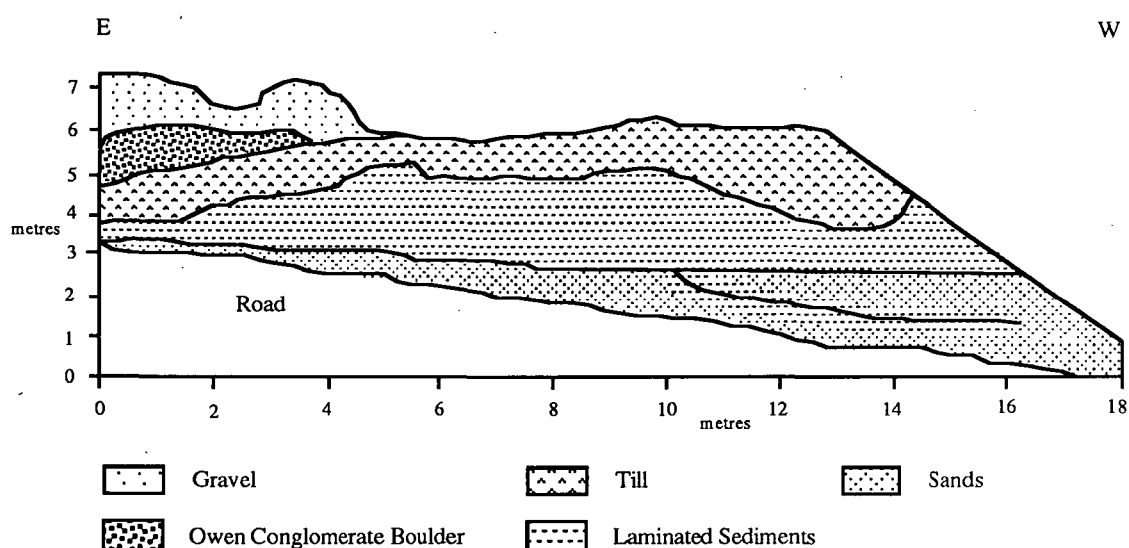


Fig. 4.23 Tyndall Creek section.

Bowden (1974) found no evidence to indicate that these silt and clay couplets represented annual events. He interpreted their variation in thickness as reflecting less regular phenomena such as periods of rapid melting followed by periods of little melting, resulting in different quantities and grade size of the laminated deposits. The laminated sediments have been folded and faulted and the upper layers show shearing with S-shaped drag folds and also some of the sediments are sheared into the till (Colhoun, pers. comm. 1990). Bowden (1974) interpreted the presence of faulting, rather than plastic flow, as indicating that the sediments were frozen at the time of deformation. The deformation was presumed to have resulted from ice pushing, as evidenced by the large Owen Conglomerate erratic (Bowden, 1974; Colhoun, pers. comm., 1990).

Bowden (1974) suggested that these sediments were deposited in a small proglacial lake that had been subsequently subjected to ice pushing as a result of a local readvance of the ice front. The readvancing ice spread a relatively thin layer of green lodgement till over these lake sediments. Subsequent fluctuations in the ice front resulted in deposition of silts, clays, and coarse gravels over the lodgement till. The sediments were thus deposited in an ice-proximal lake that was subsequently overridden by advancing ice.

Although the green till contains some strongly weathered clasts, it is very comparable with Henty Glaciation till exposed in other sections on the Anthony Road (Colhoun, pers. comm., 1990). In the section no longer visible a sequence of less well-bedded silts, clays, and coarse gravels overlies the till (Bowden, 1974).

In the next stream section to the south more than 2 m of very deeply weathered till, comparable with Linda age tills in the West Coast Range area, occurs at the base of the sequence. This till is very compact and cemented and contains highly weathered volcanics (Colhoun and Augustinus, pers. comm. 1990).

This site occurs geographically between the Margaret and Henty ice limits suggested by Colhoun (1985) and the deposits were originally considered to be of Henty Glaciation age. As a result of review of the deposits of the western side of the West Coast Range in 1990 by Colhoun and Augustinus (pers. comm.) it is now known that the till which underlies the laminated sediments compares with Linda age tills and the overlying green till is the Henty till. Stratigraphically, therefore, the deposits should be either of Middle Pleistocene Henty Glaciation age or of Lower Pleistocene Linda Glaciation age, depending on whether the rhythmites are associated with deglaciation events of Linda age or glacial advance of Henty age.

Twenty two specimens were taken originally from the Tyndall Creek site. A further twenty one specimens were taken subsequently in order to help clarify site results. These specimen groups are referred to as Tyndall Creek A and Tyndall Creek B.

All the specimens were demagnetised over the normal range of values up to 100 mT. The results of the progressive demagnetisation of specimens 059 and H1.2, typical specimens, are shown in Figs. 4.24 and 4.25. On the basis of this information, 30 mT was chosen as representing the primary magnetisation of the sediments and the values at this demagnetisation step were used for the stereoplots (Fig. 4.26).

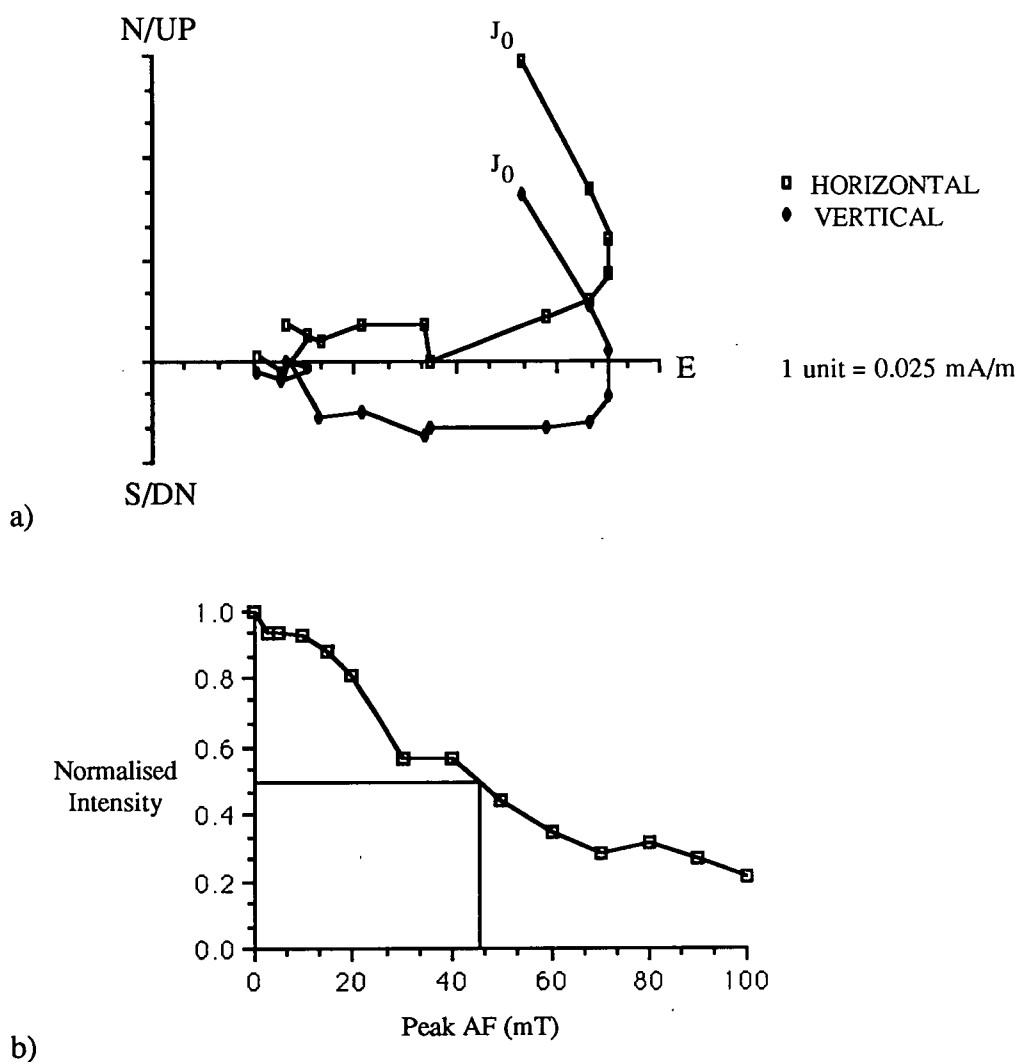


Fig. 4.24 a) Zijdeveld plot, specimen 059.
b) Normalised intensity plot, specimen 059.

The Zijdeveld plot for specimen 059 indicates that this specimen has two major components of magnetisation. The lower stability component is isolated during AF treatment to 15 mT. Thereafter the plot shows some variations in direction with each demagnetisation step, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a decrease in intensity of magnetisation with each step of AF treatment; MDF being achieved at 45 mT. This specimen therefore has a hard major component of magnetisation.

The Zijdeveld plot for specimen H 1.2 indicates that this specimen has two major components of magnetisation. The lower stability component is isolated during AF treatment to 15 mT. Thereafter the direction remains essentially unchanged towards the

origin with each demagnetisation step, indicating that a single component is being removed.

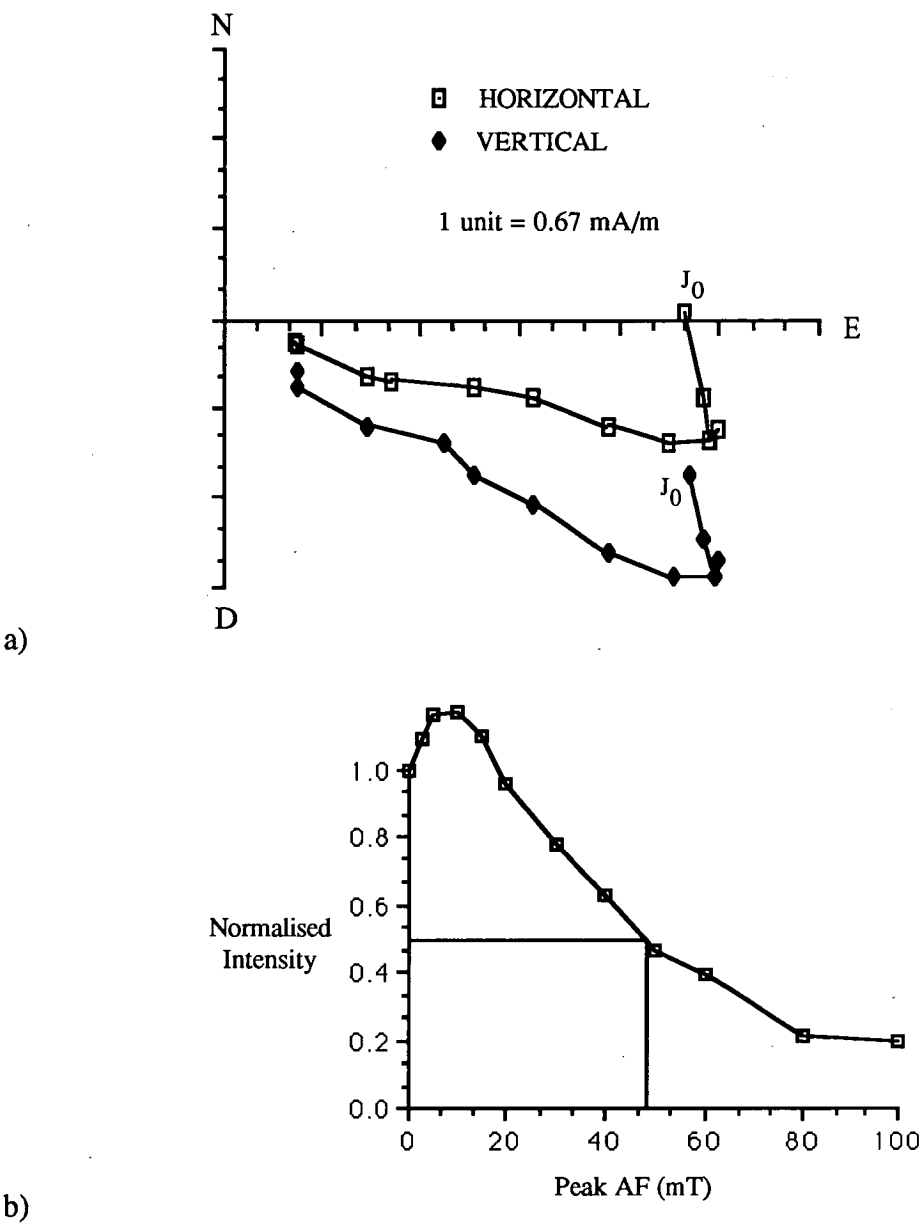


Fig. 4.25 a) Zijdeveld plot, specimen H1.2.
b) Normalised intensity plot, specimen H1.2.

The normalised intensity plot shows an overprint, the total intensity increasing as one component is preferentially removed. This increase occurs for the demagnetisation steps up to 10 mT. Thereafter it decreases relatively slowly, MDF being achieved at 47.8 mT. The major component of magnetisation is therefore hard.

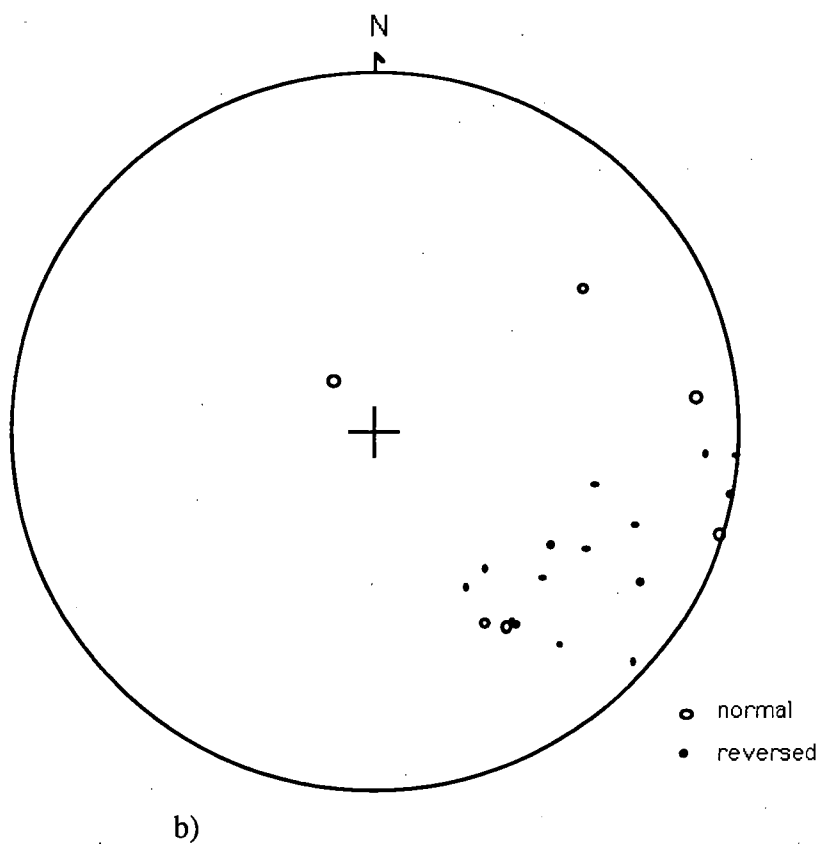
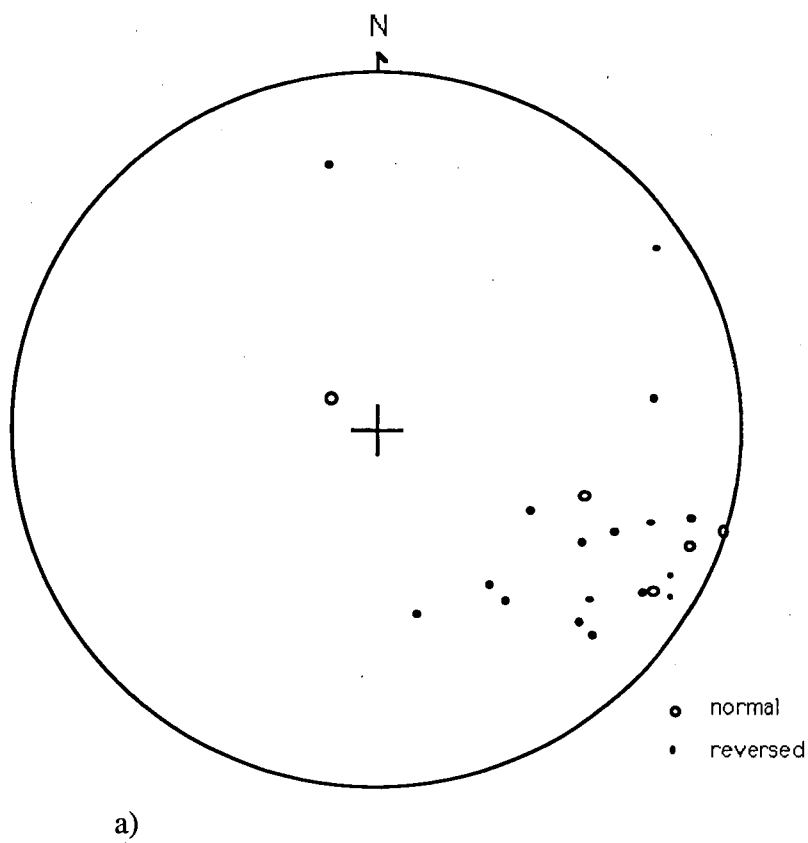


Fig. 4.26 a) Tyndall Creek A stereoplot.
b) Tyndall Creek B stereoplot.

Tyndall Creek A:

Seventeen of the twenty-two specimens had reversed polarity (Fig. 4.26 a). The reversed specimens had a mean declination of 133° and a mean inclination of 25° , and the normal samples a mean declination of 150° and a mean inclination of -27° .

Tyndall Creek B:

Fifteen of the twenty-one specimens had a reversed polarity with a mean declination of 123° and a mean inclination of 26° . The normal specimens had a mean declination of 144° and a mean inclination of -32° (Fig. 4.26b).

The specimens show some degree of scatter but the majority form a reasonably distinct group on the stereoplots, which strongly indicates a reversed polarity field at the time of deposition of the silts and clays.

Specimens from both sites were generally weakly magnetised. NRM values ranged from 0.194 to 5.971 μG , with a mean value of 1.11 μG for Henty Surface A; values for Henty Surface B ranged from 0.442 to 4.986 μG , with a mean value of 1.16 μG . Susceptibility values for Henty Surface A ranged from 3.57 to 4.84 $\mu\text{G}/\text{Oe}$, with a mean value of 4.05 $\mu\text{G}/\text{Oe}$. The values for Henty Surface B ranged from 3.04 to 4.39 $\mu\text{G}/\text{Oe}$, with a mean value of 3.86 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 0.05 to 1.31, with a mean value of 1.11, for the Henty Surface A site. The Henty Surface B site had a range of 0.11 to 1.17, with a mean value of 0.3. Thus, only two specimens have a good capability of maintaining a stable remanence; the remainder have a poor to very fair capability.

The Tyndall Creek site has a reversed polarity. This indicates that deposition of the laminated series of deposits occurred during the deglaciation of Linda age ice. These sediments are therefore of at least Early Pleistocene age. It can be inferred also from the overlying green till that the glacio-tectonic disturbance of this series resulted from the ice advance of the Henty Glaciation.

c) King River Area

Site 10: Thureau Hills Road

The Thureau Hills Road site is exposed in a road cutting at Thureau Hills (Franklin, Sheet 8013, 1:100000, GR 881355) (Figs. 2.3 and 3.1).

The exposure on the southern side of the road, 42 m long and up to 10 m high, is the type section for Unit 6 of the Thureau Formation (Fig.4.27). It consists of "...massive till overlain by a series of flow tills, massive sands, a thin sediment flow and laminated lake sediments." (Fitzsimons, 1988). The basal till is coarse, massive and matrix-supported and contains lenses of sands and gravels. It is overlain by an unsorted diamicton with some flow banding and a sharp sediment contact with the overlying sediment flows. The sediment flows are overlain by moderately well sorted coarse white sand that is horizontally laminated in the upper section. Sands exposed in the adjoining creek bed (Site 10A) are considered to be a northward extension of this unit. The sands are overlain by a thin diamicton interpreted as a sediment flow or an ice-rafted diamicton. Dark green and dark grey and green laminated sediments up to 3 m thick overlie the diamicton. These sediments contain numerous small-scale primary and secondary structures. The laminated sediments are unconformably overlain by poorly sorted slope deposits. This sequence has been interpreted by Fitzsimons (1988) as representing an ice-contact, deglacial environment, with the sediments being deposited in a supraglacial position on melting ice.

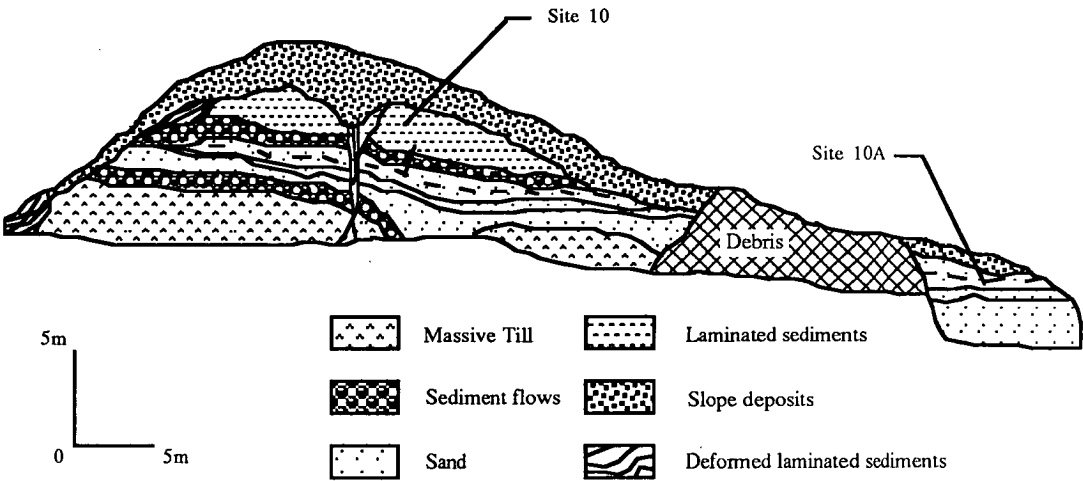


Fig. 4.27 Thureau Hills section (Fitzsimons, 1988).

Fitzsimons (1988) considered that the Thureau Formation was deposited during the Linda Glaciation, and hence was of Early Pleistocene age.

Twenty specimens were taken from this site. Twelve of the specimens were step-wise demagnetised over the normal range of values up to 100 mT; the remaining specimens were cleaned at 20 mT. The results of the progressive demagnetisation of specimen 037, a typical specimen, are shown in Fig. 4.28.

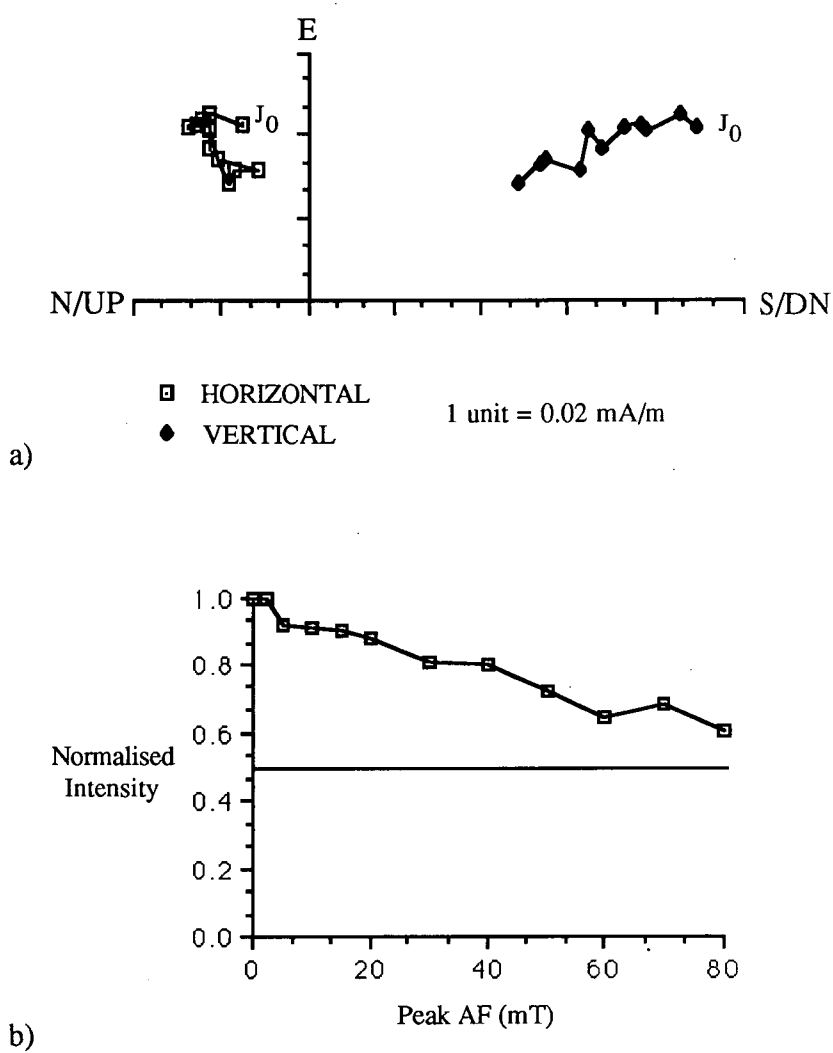


Fig. 4.28 a) Zijderveld plot, specimen 037.
b) Normalised intensity plot, specimen 037.

The Zijderveld plot shows essentially one major component of magnetisation. However the variation in direction with each demagnetisation step indicates that more than one component of magnetisation is being removed.

The normalised intensity plot shows that intensity of magnetisation decreases slowly with each demagnetisation step. The MDF was not achieved but is in excess of 80 mT. This specimen therefore has a hard major component of magnetisation.

All the specimens had reversed polarity. The majority of the specimens form a reasonably tight group on the stereoplot (Fig. 4.29), and have a mean declination of 185° and a mean inclination of $+37.5^{\circ}$.

These specimens were weakly magnetised, NRM values ranging from 0.15 to 1.22 μG , with a mean value of 0.4 μG . Susceptibility values ranged from 1.94 to 4.2 $\mu\text{G}/\text{Oe}$, with a mean value of 3.1 $\mu\text{G}/\text{Oe}$.

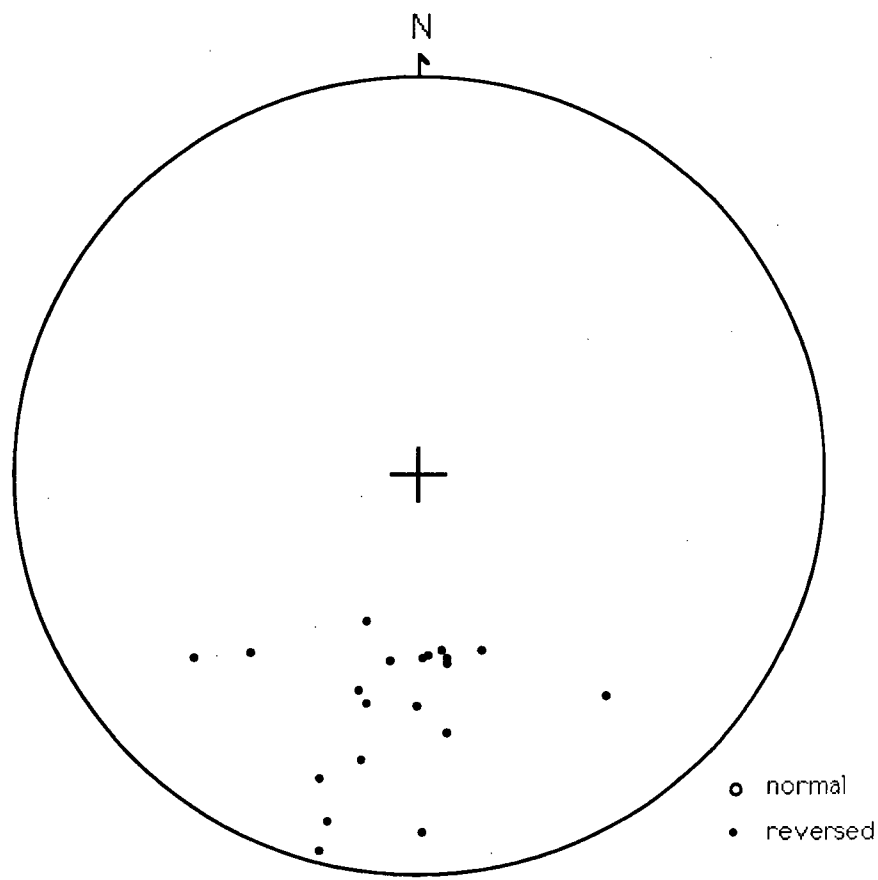


Fig. 4.29 Thureau Hills stereoplot (20 mT).

The Modified Konigsberger Ratio ranged from 0.05 to 0.29, with a mean value of 0.13. Slightly more than half the specimens thus have a fair capability of maintaining a stable remanence. The remainder of the specimens have only a poor capability of maintaining a stable remanence.

All the specimens from this site have a reversed polarity. This site is therefore likely to be > 730 ka old, and of at least Early Pleistocene age.

Site 10A: Thureau Hills Creek

The Thureau Hills Creek site occurs in a small creek 10 m north of the type section (Site 10) at Thureau Hills (Franklin, Sheet 8013, 1:100000, GR 881355) (Figs. 2.3 and 3.1).

In this exposure, which is 10 m long and up to 3 m high, laminated fine sand and silty sand is overlain by a very thin deposit of diamicton and a thin veneer of slope deposits (Fig. 4.27). The contact between the diamicton and the sands is sharp and eroded. Fitzsimons (1988) considered these sands to be a northward thickening of Unit 4 at the type section (ref. Site 10), but this has not been demonstrated.

Fitzsimons (1988) considered the Thureau Formation to have been deposited during the Linda Glaciation and to be at least Early Pleistocene in age.

Twenty five specimens were taken from this site. Five of the specimens were discarded because they had an MDF < 5 mT. Nineteen of the remaining specimens had a normal polarity. The specimens are extremely scattered on the stereoplot (Fig. 4.30).

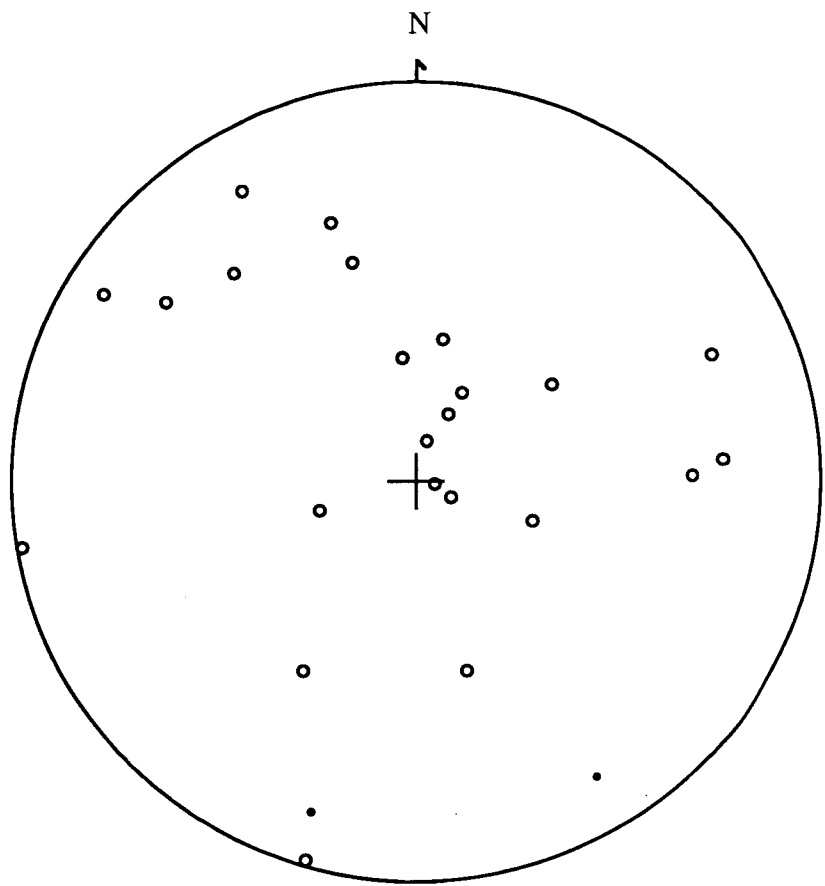


Fig. 4.30 Thureau Hills Creek stereoplot (35 mT).

Most specimens from this site were weakly magnetised, with NRM values ranging from 0.07 to 3.1 μG . Susceptibility values ranged from 0.2 to 3.2 $\mu\text{G}/\text{Oe}$, and the Modified Konigsberger Ratio from 0.07 to 2.8. Only four of the specimens have a good capability of maintaining a stable remanence, two have a poor capability and the remainder (the majority) have a fair to very fair capability.

Half the specimens were stepwise demagnetised over the normal range of values to 100 mT; the remaining specimens were cleaned at 35 mT.

Almost all the specimens have a normal polarity, but they are extremely scattered on the stereoplot. If this section represents part of the Thureau Formation, as suggested by Fitzsimons (1988), then it must have been deposited during a normal event in the Matuyama, such as the Jaramillo event (0.91 to 0.98 Ma) or the Olduvai event (1.66 to 1.88 Ma). On this assumption, this site is of at least Early Pleistocene age. However, it is also possible that the present polarity of the specimens may represent a chemical remanent magnetisation caused by groundwater flow rather than the original detrital remanent magnetisation.

Site 11: Baxter Rivulet

The Baxter Rivulet site is exposed in the eastern bank of Baxter Rivulet (Franklin, Sheet 8013, 1:100000, GR 875304) (Figs. 2.3 and 3.1).

A complex group of sediments consisting of coarse glaciofluvial gravels, white sand, organic silty sands, outwash gravel, boulder bed, outwash sands and gravels, and Holocene soil is exposed at this site (Fig.4.31). These sediments record "... the superposition of sediment bodies from different source areas." (Fitzsimons, 1988). The basal unit is the Traveller Formation which consists of well sorted and rounded outwash gravel. It is overlain by 1.2 m of organic silty sands which represent the type section of the Baxter Formation, an interstadial deposit. This is overlain by up to 1.7 m of massive, well sorted and rounded gravel of the Fish Formation. The Moore Formation, consisting of 1.6 m of coarse, poorly sorted gravel overlies the Fish Formation. Outwash sediments of the Cableway Formation, consisting of an upward-fining sequence of gravels interbedded with coarse and gravelly sands, overlie the Moore Formation (Fitzsimons, 1988).

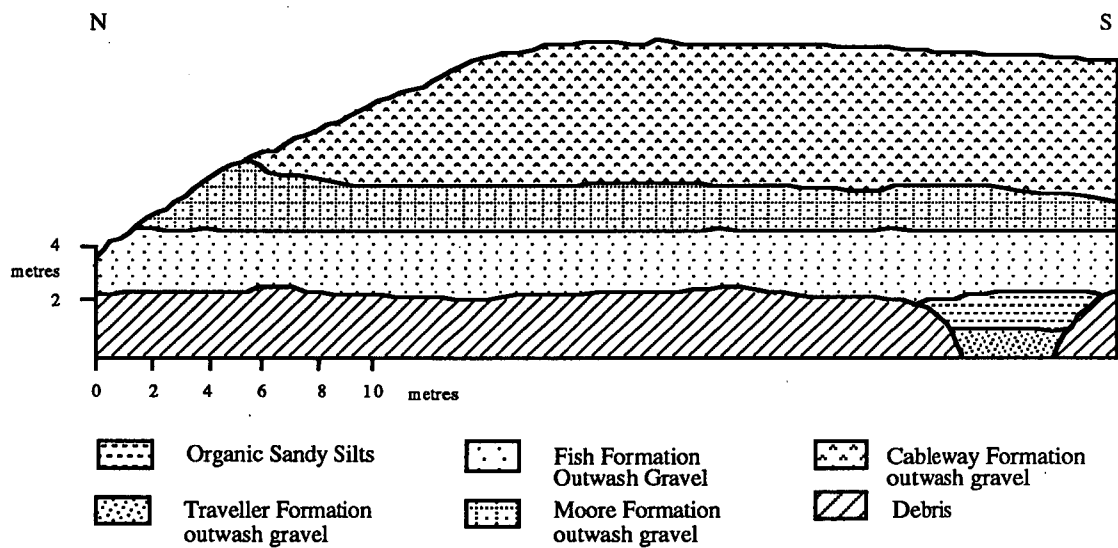


Fig. 4.31 Baxter Rivulet section (Fitzsimons, 1988).

Fitzsimons (1988) considered the Baxter Formation to be of probable Middle Pleistocene age because the radiocarbon dates from the overlying Cableway Formation were close to ^{14}C background. In addition, wood from the Baxter Formation gave an amino-acid age of Isotope Stage 10.

Twenty specimens were taken from the Baxter Formation for palaeomagnetic analysis. All the specimens were step-wise demagnetised over the normal range of values up to 50 mT

because of their weak magnetic signal and the very low MDF of many of the specimens. A value of 5 mT was chosen as being representative of the primary magnetisation, and so was used to produce the stereoplot. The results of progressive demagnetisation of specimen B17, a typical specimen, are shown in Fig. 4.32.

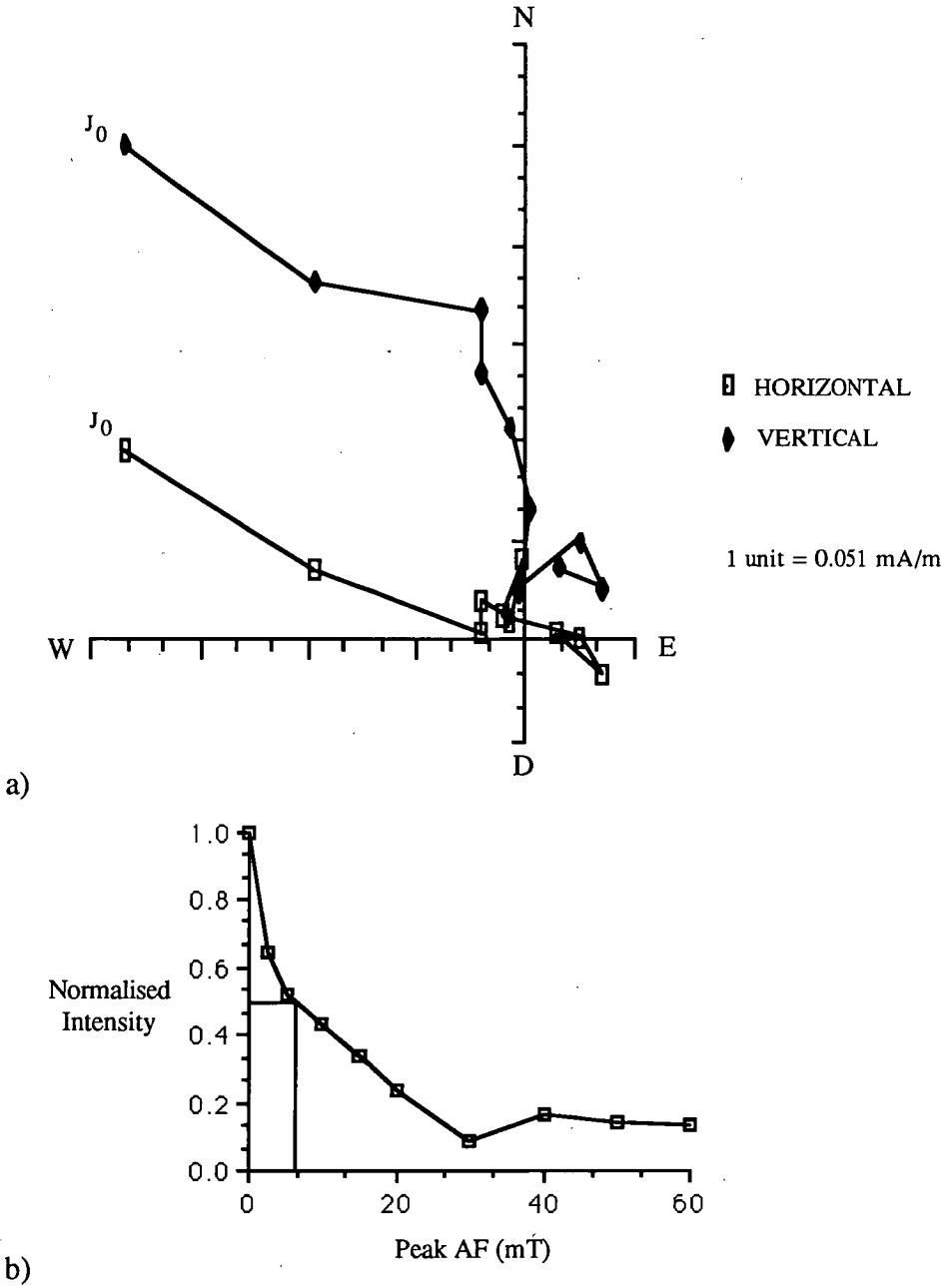


Fig. 4.32 a) Zijderveld plot, specimen B17.
b) Normalised intensity plot, specimen B17.

The Zijderveld plot shows a weak and possibly normal polarity. A lower stability component is isolated during AF treatment to 5 mT. Thereafter, the plot shows some variation in direction with each demagnetisation step, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a relatively rapid decrease in the intensity of magnetisation with each step of AF treatment, MDF being reached at 6 mT. The major component of magnetisation is relatively soft.

Five of the specimens were discarded because they had an MDF <5 mT. All the specimens had normal polarity, with a mean declination of 345° and a mean inclination of -51° (Fig. 4.33). The specimens are somewhat scattered, but the majority form a reasonable grouping on the stereoplot.

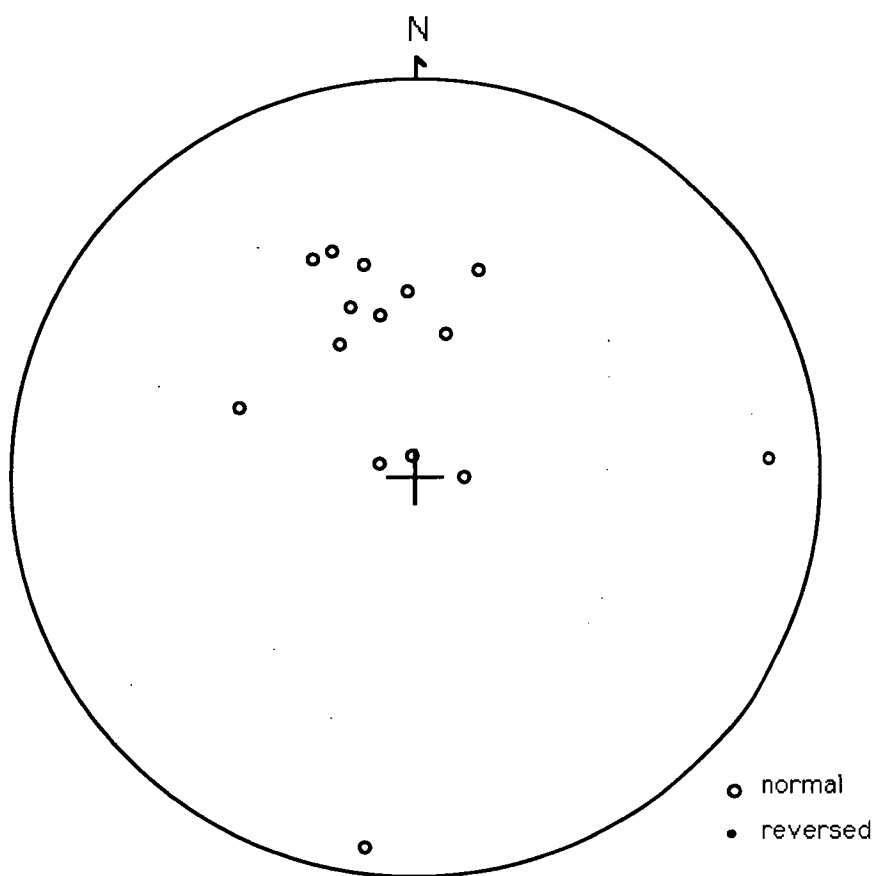


Fig. 4.33 Baxter Rivulet stereoplot (5mT).

All the specimens were weakly magnetised, NRM values ranging from 0.079 to 0.547 μG and with a mean value of 0.3 μG . Susceptibility values ranged from 1.44 to 3.95 $\mu\text{G}/\text{Oe}$, with a mean value of 2.6 $\mu\text{G}/\text{Oe}$. The Modified Königsberger Ratio ranged from 0.04 to 0.24, with a mean value of 0.12. Three quarters of the specimens had a fair capability of maintaining a stable remanence, whilst the remainder had a poor capability.

The normal polarity of all the specimens from this site suggests that it is < 730 ka in age and is therefore unlikely to be any older than Middle Pleistocene.

Site 12: King River Bridge

The King River Bridge site is located at the proposed King River Bridge site (Franklin, Sheet 8013, 1:100000, GR 893375) (Figs. 2.3 and 3.1).

At this site (Fig. 4.34) up to 40 m of laminated silts overlies gravels (till?) and are overlain by massive tills, outwash gravels, till, and peat (Fitzsimons, pers. comm. 1987). The basal unit, the Cableway Formation, is known only from drill cores and consists of fine gravels of mixed lithology. The laminated silts, the Nelson Formation, "... consist of pale green beds with multiple sublaminae less than 1 mm thick, and occasional dark grey laminae up to 40 mm in thickness." (Fitzsimons, 1988). Deformational structures occur only in the upper 4 m of the deposits; dropstones are absent throughout but numerous, flat, carbonate-cemented concretions occur in the middle section of the unit. These laminated sediments were probably deposited as turbidity currents settled out in a deep lake, possibly over a period of about 4500 years. Sedimentation rates in New Zealand proglacial lakes provide a basis for this estimation of the length of the depositional period. The overlying David Formation consists of a sequence of sediment flows, outwash gravels, massive diamictons and lodgement till deposits. (Fitzsimons, 1988).

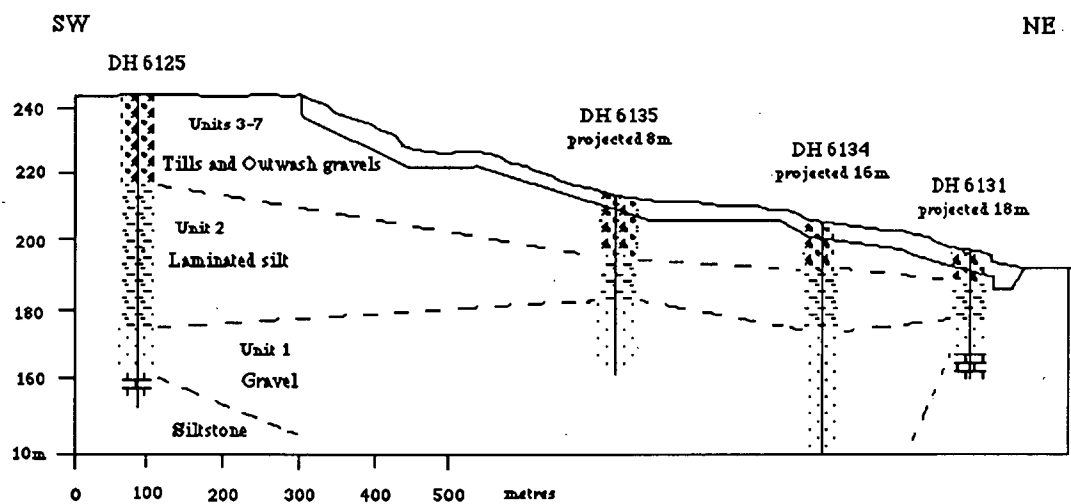


Fig. 4.34 King River Bridge section (Fitzsimons, 1988).

Fitzsimons (1988) considered that the Nelson Formation represented an interstadial period between the David and Cableway advances. He regarded this formation as being beyond the limits of conventional ^{14}C dating (ref. Site 13) and considered that weathering rinds on dolerite suggested a time gap of the order of 250 ka between it and the Late Pleistocene Chamouni advance. On this basis he considered that it was probably Middle Pleistocene in age.

Sixty five specimens were taken from the laminated silts and clays of the Nelson Formation, thirty eight from two drill cores and twenty seven from exploration trenches.

Representative specimens were step-wise demagnetised over the normal range of values to 100 mT; on the basis of this information, drill core specimens and trench specimens were cleaned at 30 mT and 35 mT respectively. The results of progressive demagnetisation of specimen K54, a typical specimen, are shown in Fig. 4.35.

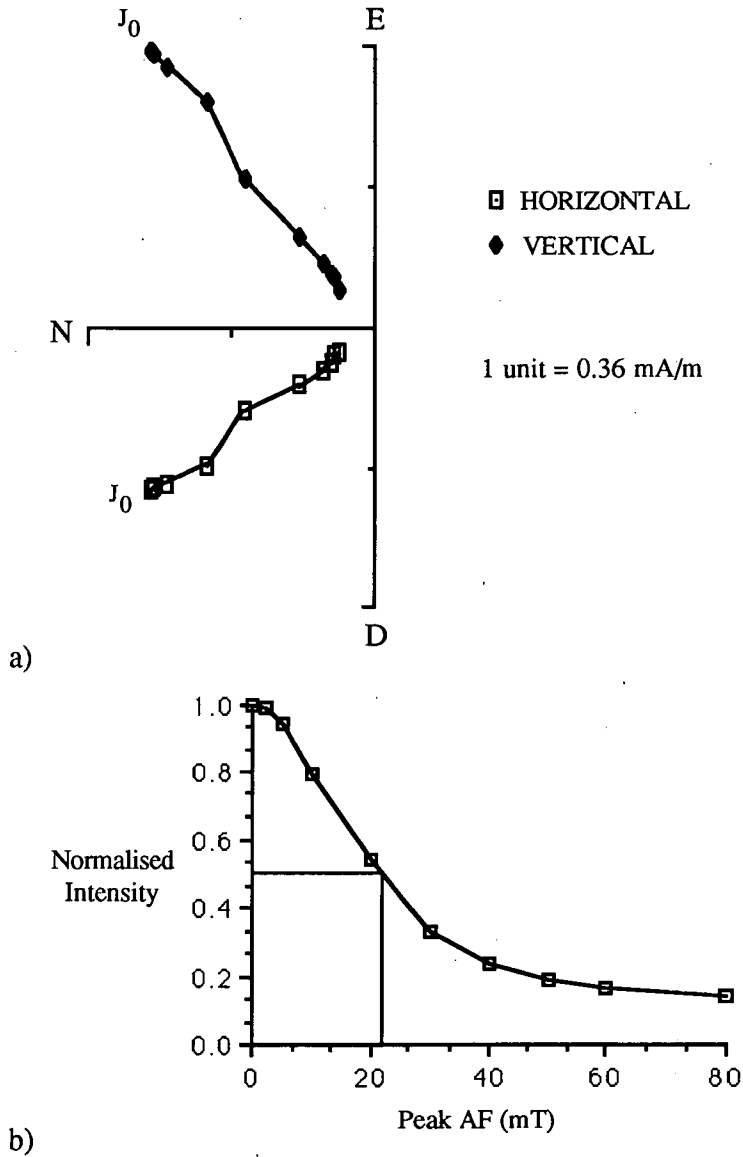


Fig. 4.35 a) Zijderfeld plot, specimen K54.
b) Normalised intensity plot, specimen K54.

The Zijderfeld plot shows a single component of magnetisation and a strong and normal polarity. The direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases reasonably slowly with each step of AF treatment. The magnetisation is relatively hard, MDF being achieved at 22 mT.

All specimens from the trenches (shown on the stereoplot, Fig. 4.36) had a normal polarity. They form a reasonably tight group on the stereoplot, with a mean declination of 336° and a mean inclination of -40° . Thirty-three of the thirty-eight specimens from the cores also had normal polarity. However, because the orientation of the core specimens in relation to north is not determinable, declination values for these specimens cannot be utilized and so a stereoplot cannot be prepared.

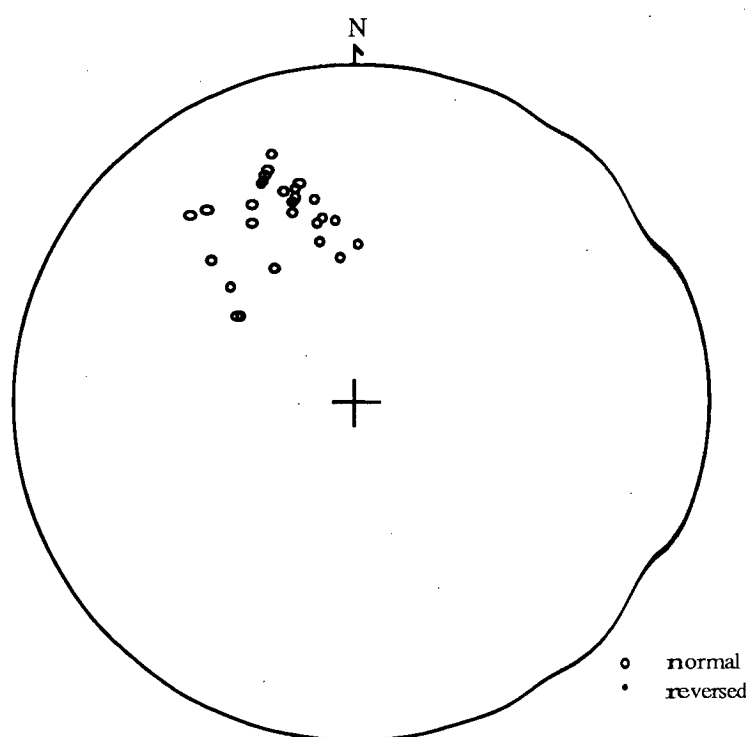


Fig. 4.36 King River Bridge stereoplot (35 mT).

These specimens were fairly strongly magnetised, NRM values ranging from 0.7 to 20.6 μG , with a mean value of 10.3 μG . Susceptibility values ranged from 6.8 to 17.3 $\mu\text{G}/\text{Oe}$, with a mean value of 12.8 $\mu\text{G}/\text{Oe}$. The Modified Königsberger Ratio ranged from 0.1 to 1.5, with a mean value of 0.8. Three quarters of the specimens thus had a fair capability of maintaining a stable remanence, whilst the remainder had a good capability.

All the specimens from this site have a normal polarity. This site is therefore likely to be <730 ka old and probably of Middle Pleistocene age.

Site 13: Linda Creek

The Linda Creek site is exposed on the western side of the Crotty Road, near the junction of Linda Creek and the King River (Franklin, Sheet 8013, 1:100000, GR 872405) (Figs. 2.3 and 3.1).

The section used is 24m long and up to 13m high (Fig. 4.37). At this site the David Formation (Fitzsimons, 1988) consists of laminated silty sands, sandy silts and silts underlain by water worked? gravel and overlain by till. Coarse diamicton is overlain along a scoured surface by 0.5 m of yellow laminated silt, which is overlain by a well sorted gravel with numerous voids, some partly filled with silt. Pale yellow, very finely laminated silt up to 3 m in thickness overlies the gravel. The upper 2 m of the laminated silt contains numerous deformation structures and is truncated at the top, possibly as a result of shearing by overriding ice. A highly consolidated diamicton consisting of pebbles in a silty matrix overlies the deformed laminated silts. This sequence of sediments was deposited in an ice-marginal lake that was overridden by ice (Fitzsimons, 1988).

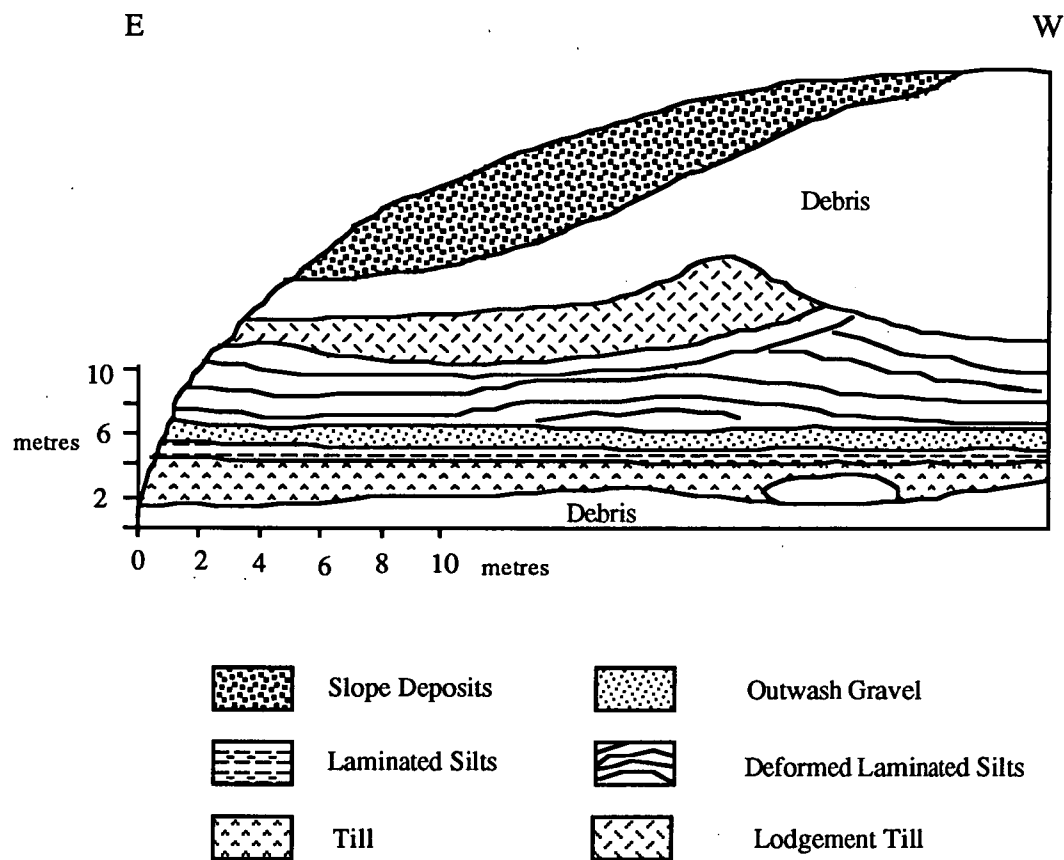


Fig. 4.37 Linda Creek section (after Fitzsimons, 1988).

The David Formation was regarded by Fitzsimons (1988) as being older than the limits of conventional ^{14}C dating. A basal date of 37,800 (+800, -700) years BP (SUA 2469) was obtained from an overlying organic deposit (Colhoun and van de Geer, 1987a) which appears to be separated from the David Formation by a considerable unconformity (Fitzsimons, 1988). On the basis of this information and the suggested time gap based on weathering rinds (ref. Site 12), Fitzsimons (1988) suggested that this formation was of probable Middle Pleistocene age.

Thirty one specimens were taken from this site. Four representative specimens were step-wise demagnetised over the normal range of values to 200 mT. The remaining specimens were cleaned at 25 mT on the basis of this information. The results of the progressive demagnetisation of specimen 014, a typical specimen, are shown in Fig. 4.38.

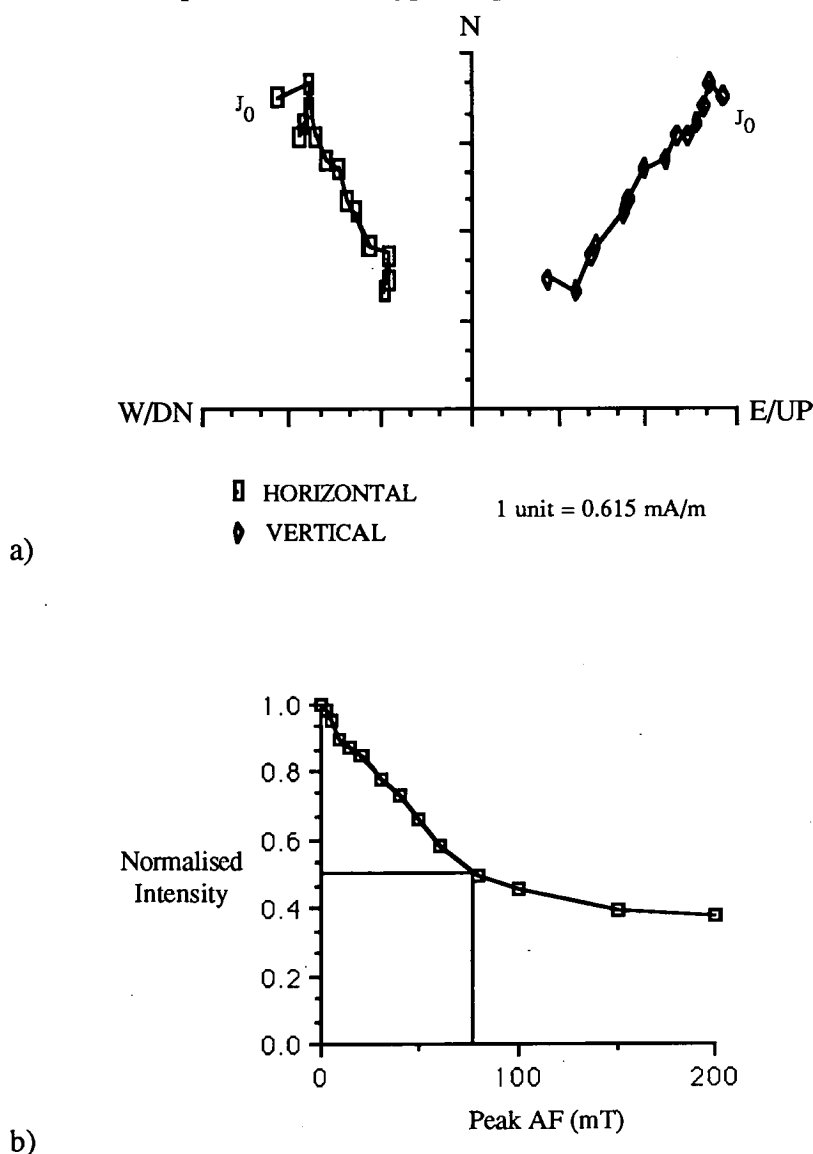


Fig. 4.38 a) Zijderveld plot, specimen 014.
 b) Normalised intensity plot, specimen 014.

The Zijderveld plot shows two components of magnetisation, the lower stability component being isolated during the first AF treatment (2.5 mT). Thereafter the direction remains relatively stable with each demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases relatively slowly with each step of AF treatment. The major component of magnetisation is hard, MDF being achieved at 90 mT.

Twenty nine of these specimens had normal polarity and they formed a distinct group with a mean declination of 19° and a mean inclination of -38° (Fig. 4.39). Two specimens had reversed polarity.

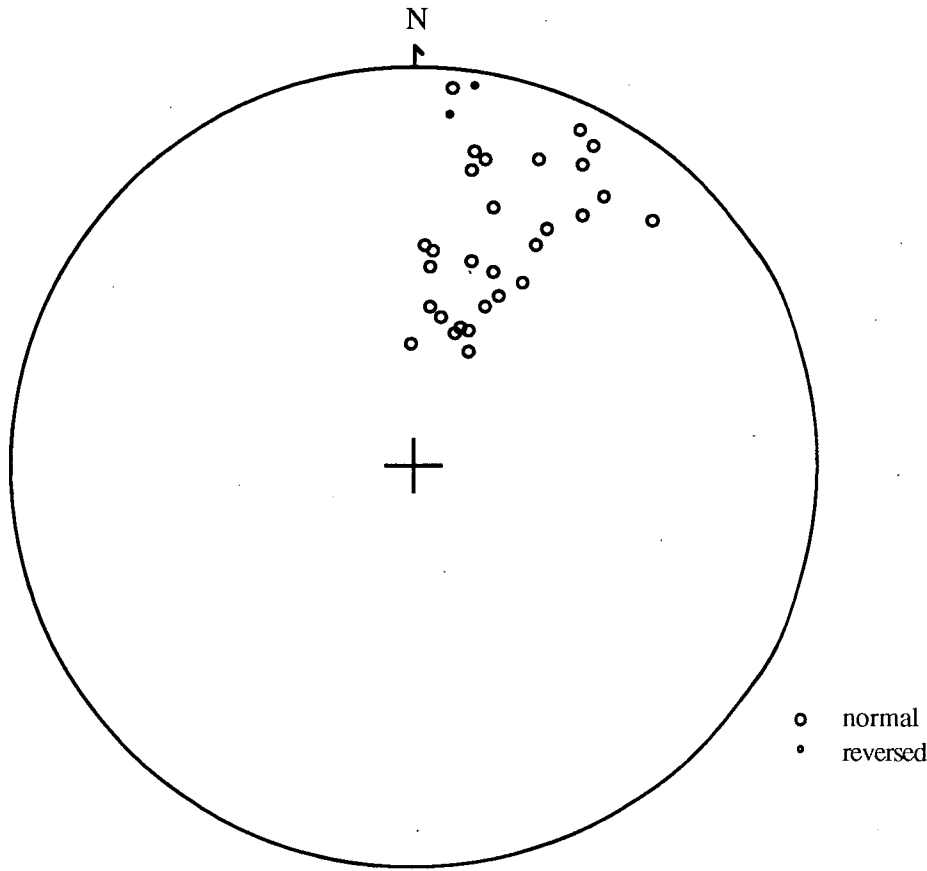


Fig. 4.39 Linda Creek stereoplot (25 mT).

NRM values of these specimens ranged from 1.0 to 21.8 μG , with a mean value of 7.1 μG , and susceptibility values ranged from 4.3 to 24.7 $\mu\text{G}/\text{Oe}$, with a mean value of 10.5 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 0.2 to 1.4, with a mean value of 0.7. The majority of the specimens thus had a fair capability of maintaining a stable remanence, with a few specimens having a good capability.

Almost all the specimens from this site have a normal polarity. This site is thus likely to be < 730 ka old and is therefore probably of Middle Pleistocene age.

Site 14: Gormanston Moraine

The Gormanston Moraine site is located in a road cutting in the Gormanston Moraine on the southern side of the Lyell Highway at Gormanston (Franklin, Sheet 8013, 1:100000, GR 834406) (Figs. 2.3 and 3.1).

At this site sandy laminated silts are exposed in a cutting, which is approximately three metres high by eight metres long, on the eastern margin of the Gormanston Moraine. These silts dip at 5° to the west. The presence of dropstones indicates that the sediments were deposited in a lake close to the ice front.

The Gormanston Moraine is located beyond the Linda Moraine in the Linda Valley. It was considered to be of at least Early Pleistocene age by Colhoun (pers. comm., 1987).

Six specimens were taken from the site for comparison with the nearby Gormanston Football Field site (Site 15) of Barbetti and Colhoun (1988). A representative specimen was demagnetised over the normal range of values to 150 mT; on the basis of this information the remaining specimens were cleaned at 35 mT. The results of progressive demagnetisation of specimen G2, a typical specimen, are shown in Fig. 4.40.

The Zijderveld plot shows a strong and reversed polarity. A low stability component is isolated during AF treatment to 5 mT. Thereafter the direction remains unchanged towards the origin with each successive demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases very slowly with each step of AF treatment. The major component of magnetisation is very hard, MDF being achieved at 128 mT.

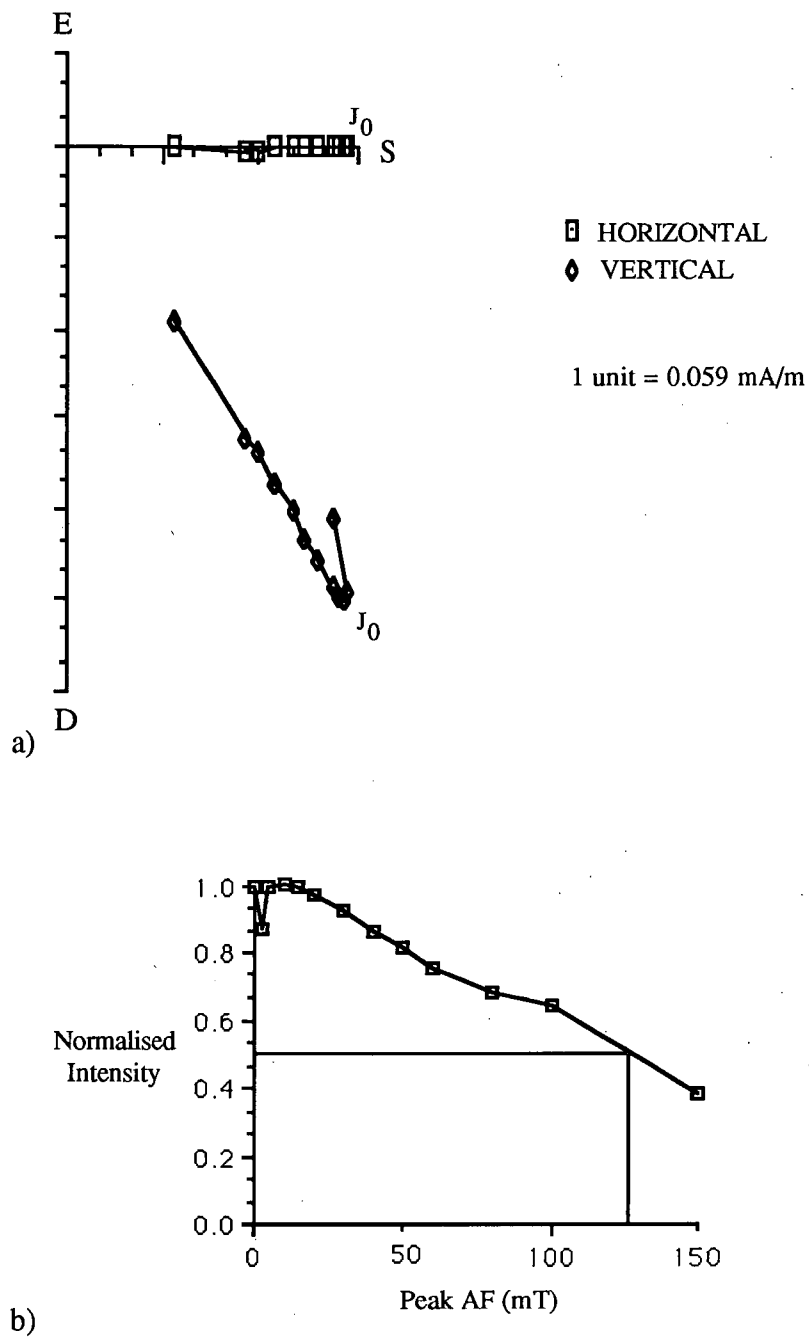


Fig. 4.40 a) Zijderveld plot, specimen G2.
 b) Normalised intensity plot, specimen G2.

All the specimens have reversed polarity. They have a mean declination of 198° and a mean inclination of $+60^{\circ}$ and form a compact group on the stereoplot (Fig. 4.41).

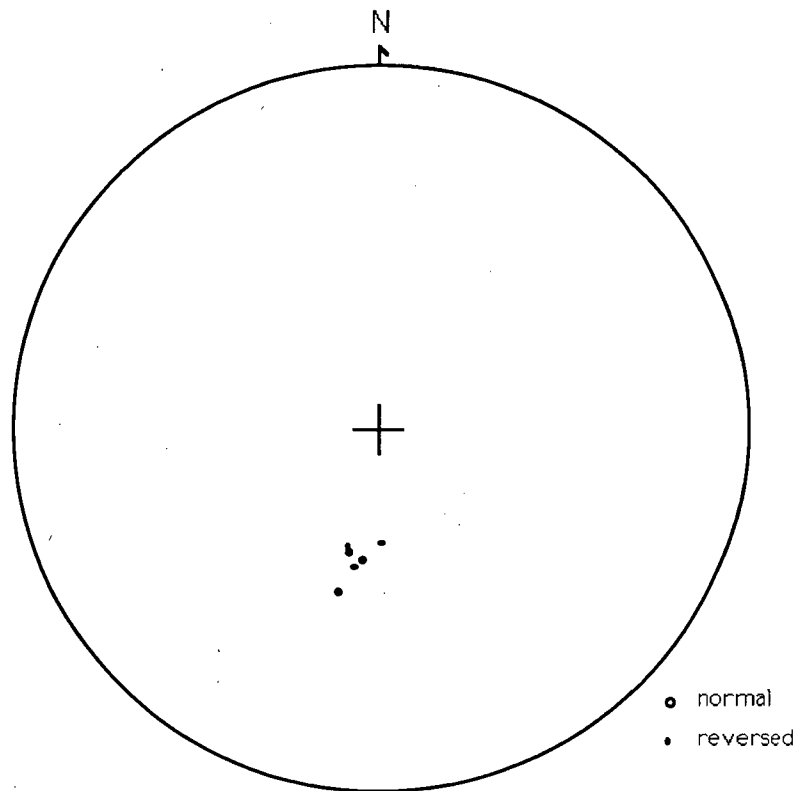


Fig. 4.41 Gormanston Moraine stereoplot (35 mT).

These specimens were quite strongly magnetised, NRM values ranging from 26.4 to 49.4 μG , with a mean value of 37.9 μG . Susceptibility ranged from 5.5 to 6.6 $\mu\text{G}/\text{Oe}$, with a mean value of 6.1 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 4.4 to 8.1, with a mean value of 6.2; all the specimens thus had an extremely good capability of maintaining a stable remanence.

All the specimens from this site have reversed polarity. The site is therefore likely to be >730 ka old and at least of Early Pleistocene age.

Site 15: Gormanston Football Field

The Gormanston Football Field site is exposed on the northern side of the old Gormanston Football Field (Franklin, Sheet 8013, 1:100000, GR 838413) (Figs. 2.3 and 3.1).

This site is 120 m long and 12-15 m high (Fig.4.42) and "... exposes basal till overlain by glacial lake silt and clay rhythmites that include several thin flow tills." (Barbetti and Colhoun, 1988). The basal till is composed of highly weathered Jurassic dolerite boulders in a silty matrix and is overlain by 1.5 m of grey laminated silts. The silts contain numerous dropstones and discrete beds of ice rafted pebbles. On the eastern end of the section the silt contains thick gravel lenses that are associated with intense deformation of the silt. These silts are overlain along a scoured surface by laminated brown silty sand (Fitzsimons, 1988). He interpreted the site as recording "... subaqueous deposition in a proglacial or supraglacial lake that was subject to ice rafting and occasional subaqueous sediment flows."

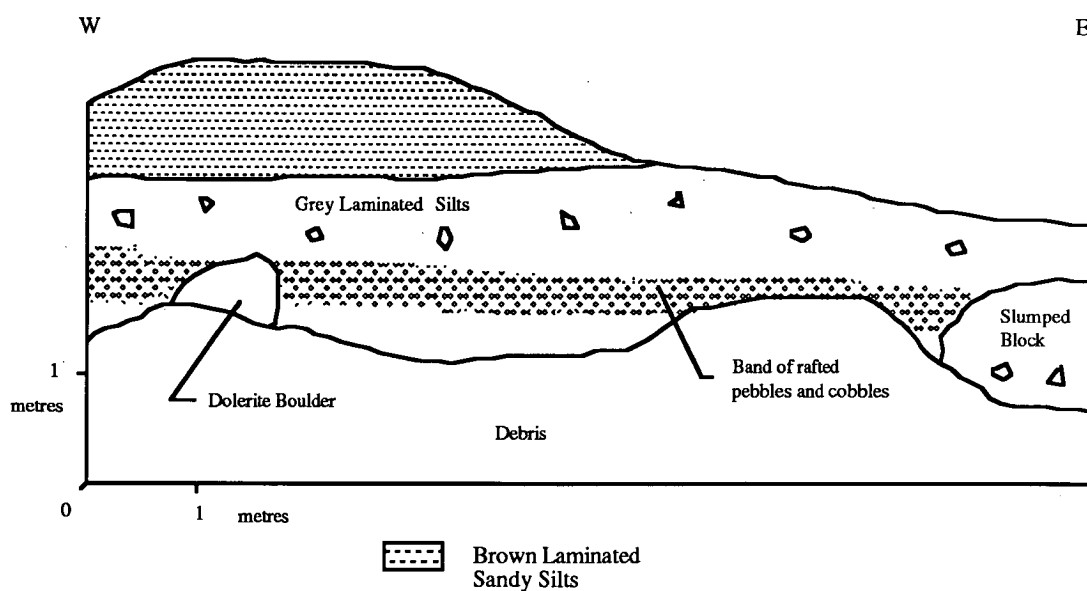


Fig. 4.42 Gormanston Football Field section (Fitzsimons, pers. comm. 1987).

This site is located between the Gormanston and Linda moraines in the Linda Valley and was considered by Colhoun (pers. comm. 1987) to be of at least Early Pleistocene age.

The stereoplot prepared by Barbetti and Colhoun (1988) is shown in Fig. 4.43. The specimens were demagnetised in steps to 15 mT and all have a reversed polarity; they form a tight group on the stereoplot.

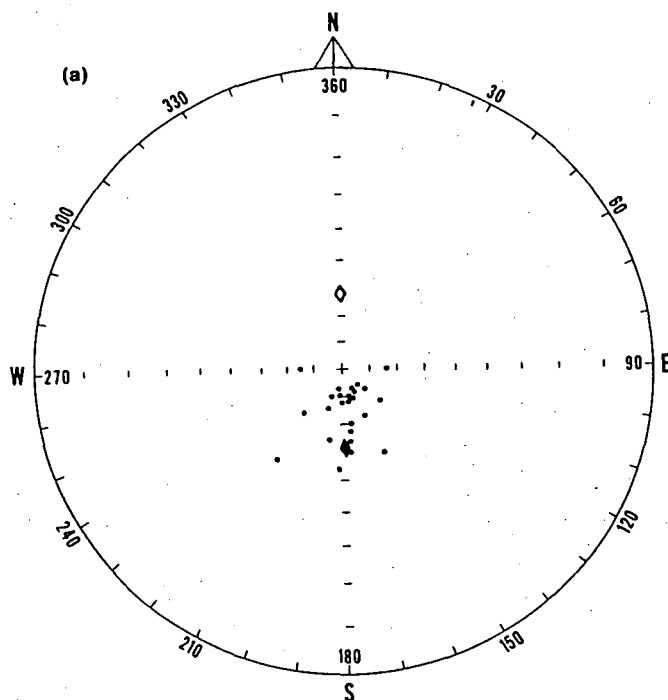


Fig. 4.43 Gormanston Football Field site stereoplot (Barbetti and Colhoun, 1988).

All the specimens from the site have a reversed polarity and so the site is likely to be > 730 ka old. It is therefore of at least Early Pleistocene age.

Site 16: King Gorge Exit

The King Gorge Exit site is located in a road cutting on the eastern side of the Mt. Jukes Road, just north of the King River, on the western side of the West Coast Range (Franklin, Sheet 8013, 1:100000, GR 785317) (Figs. 2.3 and 3.1).

The site is approximately 50 m long and up to 4 m high (Fig. 4.44). At this site coarse outwash sands are overlain by white clay and laminated sandy silts. The lowermost unit consists of coarse, poorly sorted, massive, iron-stained gravel. This unit grades into a laminated and very compact white silty clay with numerous granules and coarse sand particles. The clay grades upwards into light brown sandy silts (Fitzsimons, 1988). The silts were too sandy for palaeomagnetic determination and so the underlying white clay was sampled.

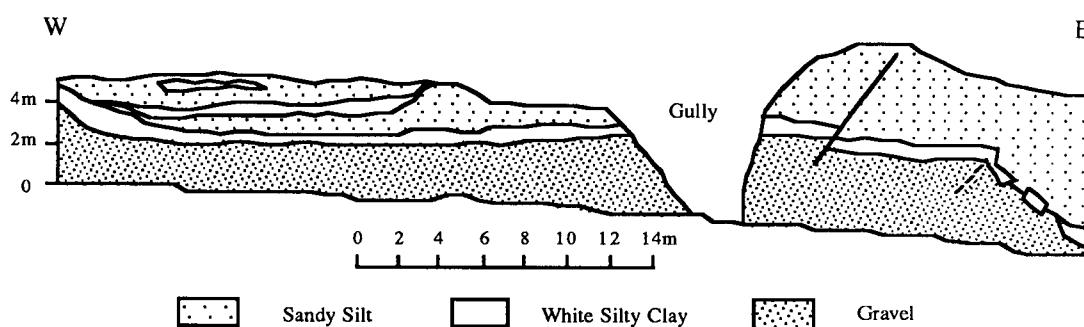


Fig. 4.44 King Gorge Exit section.

Fitzsimons (1988), on the basis of weathering evidence, suggested that these sediments may correlate with the Thureau Formation tills on the eastern side of the West Coast Range. He suggested that they were washed out through the King River Gorge during melting of the King River Valley glaciers. On this basis, they would be of at least Early Pleistocene age.

Twenty one specimens were taken from this site. All these specimens were demagnetised over the normal range of values to 100 mT because of the weak nature of the magnetic signal. A value of 10 mT was chosen as representing the primary magnetisation and was used for the stereoplot. The results of the progressive demagnetisation of specimen LQ12, a typical specimen, are shown in Fig. 4.45.

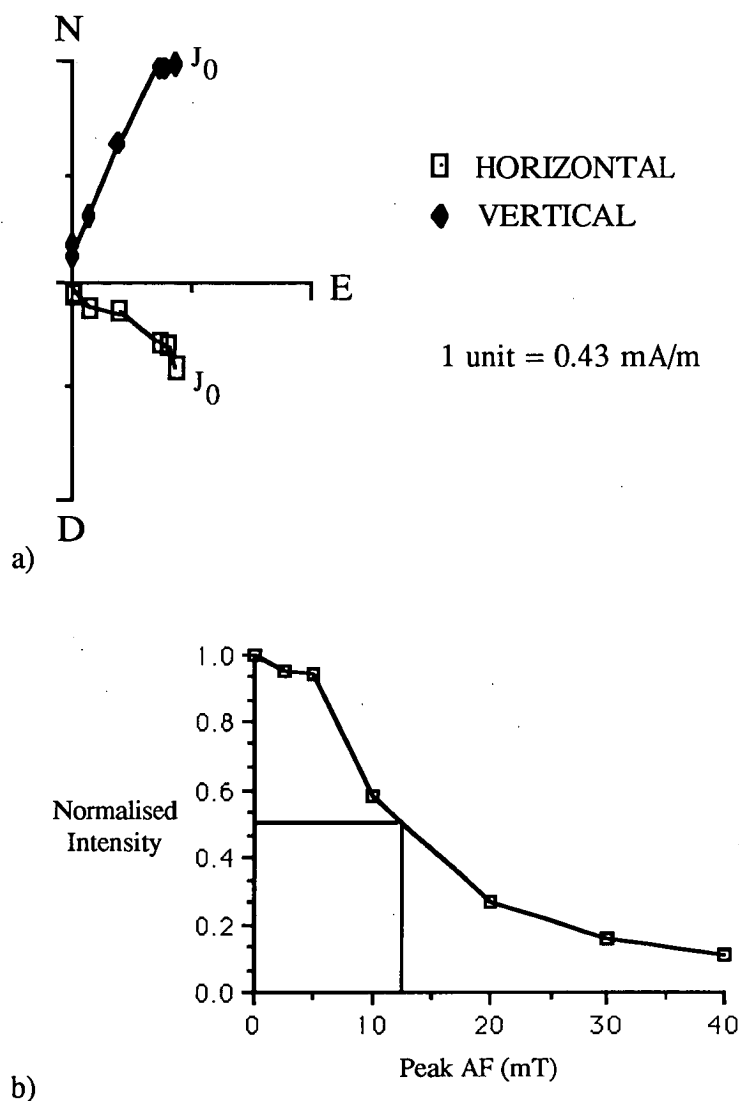


Fig. 4.45 a) Zijdeveld plot, specimen LQ12.
b) Normalised intensity plot, specimen LQ12.

The Zijdeveld plot shows a two component system, the low stability component being isolated in the AF treatment up to 5 mT. Thereafter the direction remains relatively unchanged towards the origin with each successive demagnetisation step, indicating that one component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases fairly rapidly with each step of AF treatment. The major component of magnetisation is soft, MDF being achieved at 12.5 mT.

Two of these specimens had an $MDF < 5 \text{ mT}$ and so were discarded. Sixteen specimens had normal polarity and three had reversed polarity. However, the specimens were very widely scattered on the stereoplot and did not form a distinct group (Fig. 4.46).

These specimens were very weakly magnetised with NRM values ranging from 0.03 to 0.97 μG , and with a mean value of 0.2 μG . Susceptibility values ranged from 2.3 to 3.4 $\mu\text{G/Oe}$, with a mean value of 2.6 $\mu\text{G/Oe}$.

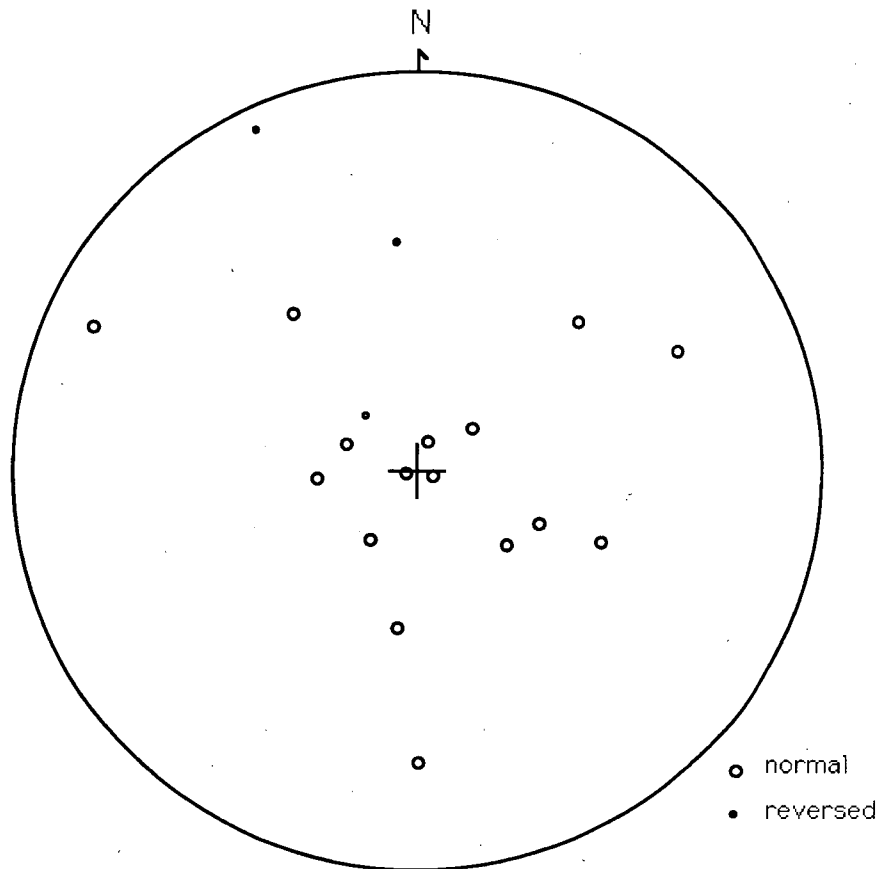


Fig. 4.46 King Gorge Exit stereoplot (10 mT).

The Modified Königsberger Ratio ranged from 0.01 to 0.4, with a mean value of 0.08. The majority of these specimens thus have a poor capability of maintaining a stable remanence.

Although there is no clear direction of magnetisation, almost all specimens have a normal polarity. If, as suggested by Fitzsimons (1988), these sediments correlate with the Thureau Formation in the King Valley they must have been deposited during a normal event in the Matuyama Chron, possibly the Jaramillo event (0.91 to 0.98 Ma) or the Olduvai event (1.66 to 1.88 Ma). On this basis, this site is of at least Early Pleistocene age.

4.2.2 NORTH CENTRAL SITES

Site 17: Fish River

The Fish River site, which is approximately 680 m above sea level, is located on the south bank of the Fish River, just below the beginning of the Walls of Jerusalem walking track (Rowallan, Sheet 4237, 1:25000, GR 363749) (Figs. 2.4 and 3.1).

Laminated silty clays are exposed in both banks of the river; on the southern side these exposures are only up to one metre above river level. On the northern bank exposures are up to 6 m high but are not accessible (Fig. 4.47). Approximately 100 m further downstream a large cutting up to 40 m high has exposed a reverse graded sequence of rhythmites, sand, gravel and till. The sand contains many small-scale deformational structures that have resulted from the overburden pressure of the till. The rhythmites are greyish olive in colour when fresh but brown when weathered. They consist of flexible laminae 1 - 5 mm in thickness that contain little or no water but are quite porous (Hannan, 1989).

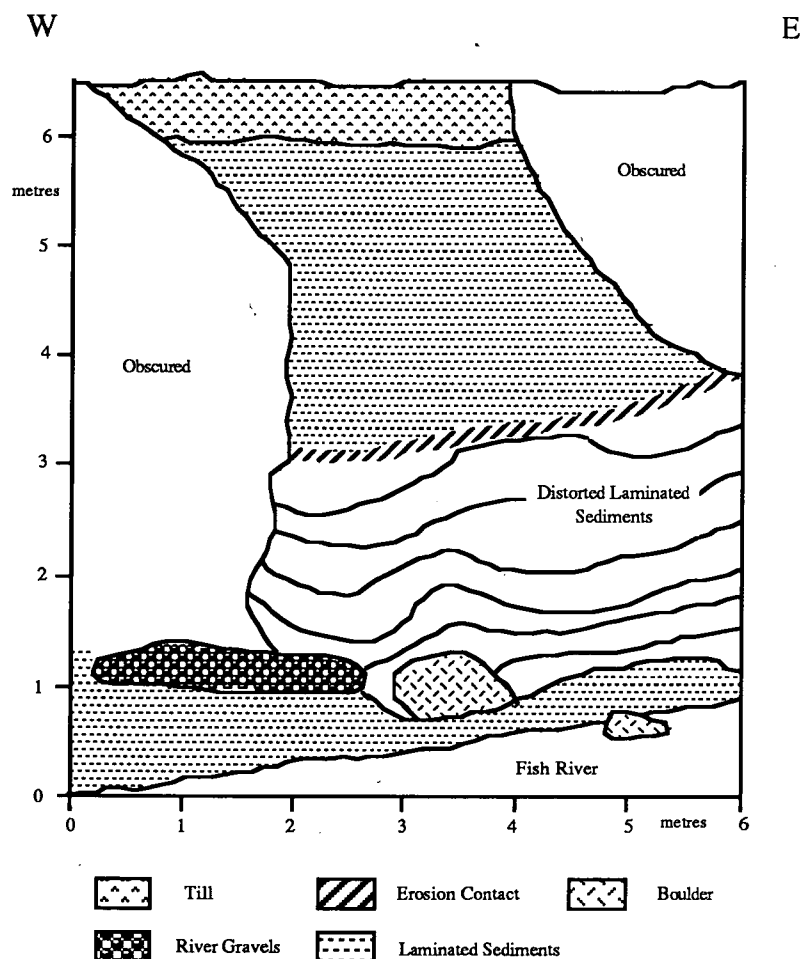


Fig. 4.47 Fish River section.

This site occurs well within the Rowallan drift limit of Hannan (1989) in the Mersey Valley. Hannan and Colhoun (1987) considered that the age of this glaciation, based on weathering rind analysis, was Late Pleistocene.

Twenty four specimens were taken from this site for analysis. Six specimens were demagnetised over the normal range of values to 100 mT and on the basis of these results the remaining specimens were cleaned at 20 mT. The results of progressive demagnetisation of specimen F11, a typical specimen, are shown in Fig. 4.48.

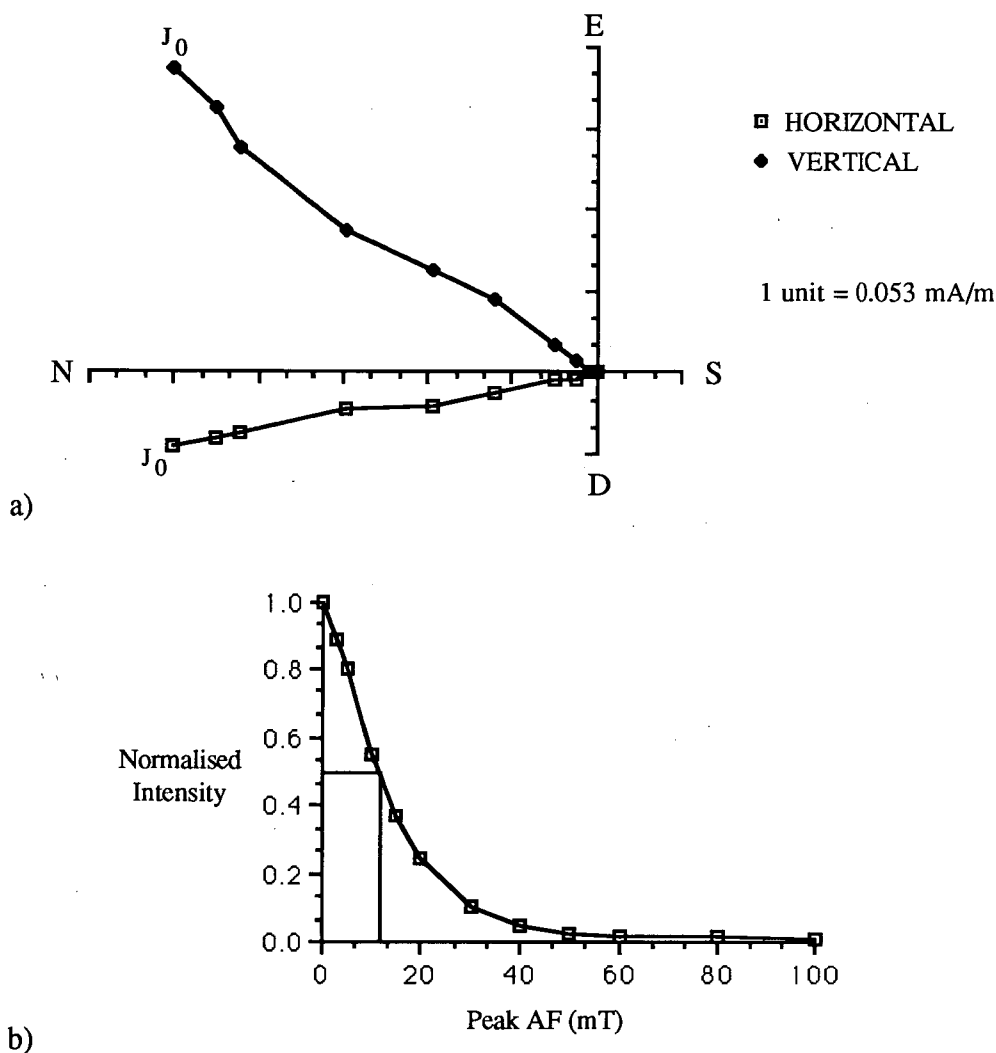


Fig. 4.48 a) Zijderveld plot, specimen F11.
b) Normalised intensity plot, specimen F11.

The Zijderveld plot shows a strong and normal polarity. The direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases with each step of demagnetisation treatment. The magnetisation is relatively soft, MDF being achieved at 11 mT.

All the specimens have a normal polarity and form a fairly tight group on the stereoplot (Fig. 4. 49). Declination values ranged from 350° to 21° , with a mean value of 3.5° , and inclination values ranged from -13° to -58° , with a mean value of -36° .

These specimens were very strongly magnetised. NRM values ranged from 69.25 to 357.87 μG , with a mean value of 195.1 μG and susceptibility values ranged from 111.04 to 259.37 $\mu\text{G}/\text{Oe}$, with a mean value of 191.1 $\mu\text{G}/\text{Oe}$.

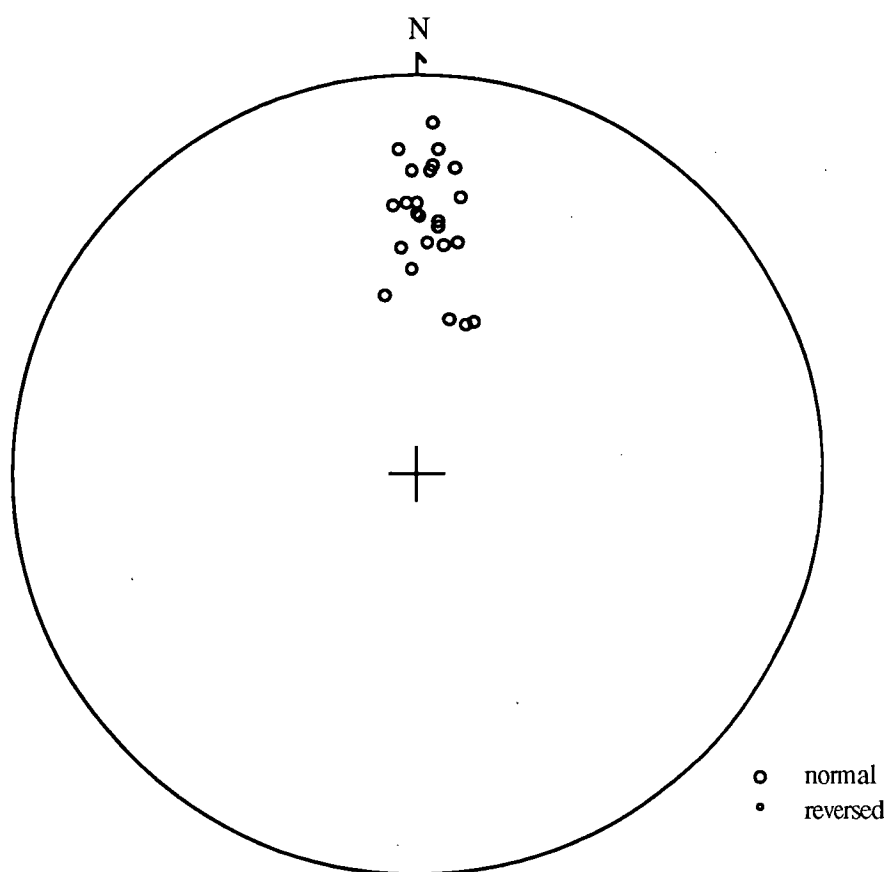


Fig. 4.49 Fish River stereoplot (20 mT).

The Modified Königsberger Ratio ranged from 0.46 to 1.83, with a mean value of 1.01. The specimens thus have a very fair to good capability of maintaining a stable remanence.

This site has a normal polarity. The Rowallan drift, within the boundaries of which this site occurs, is therefore no greater than Middle Pleistocene in age.

Site 18: Arm River Bridge

The Arm River Bridge site is located on the western bank of the Arm River, near the Arm River Bridge (Rowallan, Sheet 4237, 1:25000, GR 299799) (Figs. 2.4 and 3.1), and is 620 m above sea level.

Laminated clays are exposed over a distance of about 12 m in the river bank and up to about 4 m in height at the maximum (Fig. 4.50). The clays are also exposed in a drain along the side of the road back from the bridge towards the Arm Spur Road junction (Borradaile, Sheet 4238, 1:25000, GR 312835). These two sites have been treated as one site for the purposes of this study because of their proximity and because it is possible to trace the sediments from one site to the other.

These rhythmites are bright brown to reddish brown in colour, and are often sandy. They are usually very dry, quite brittle and unable to take up much water (Hannan, 1989).

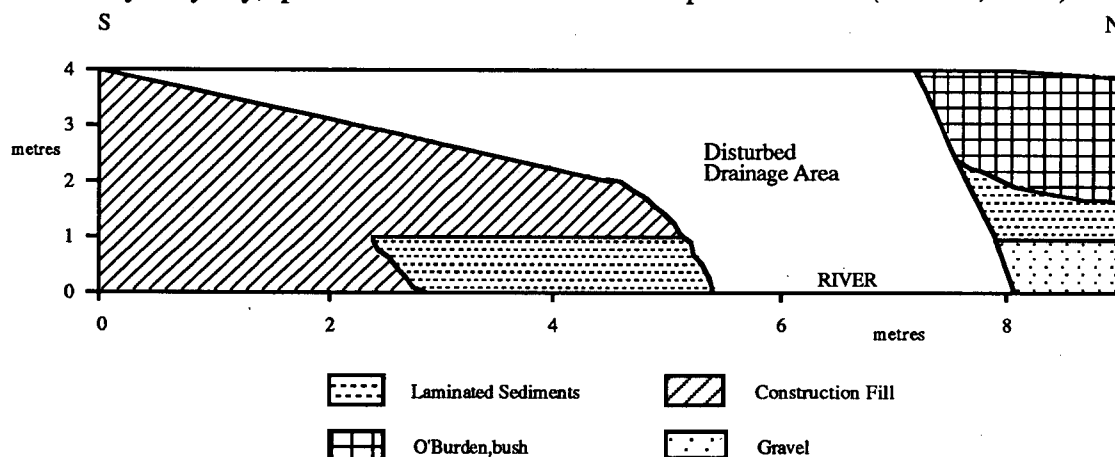


Fig. 4.50 Arm River Bridge section.

This site occurs between the Rowallan and Arm drifts of Hannan (1989) in the Mersey Valley. Hannan and Colhoun (1987) considered the Arm Glaciation to be at least 100 ka old, and hence of Middle Pleistocene age.

Twenty two specimens were taken from this site for analysis. Three specimens were demagnetised over the normal range of values to 200 mT and on the basis of these results the remaining specimens were cleaned at 25 mT. The results of the progressive demagnetisation of specimen 107, a typical specimen, are shown in Fig. 4.51.

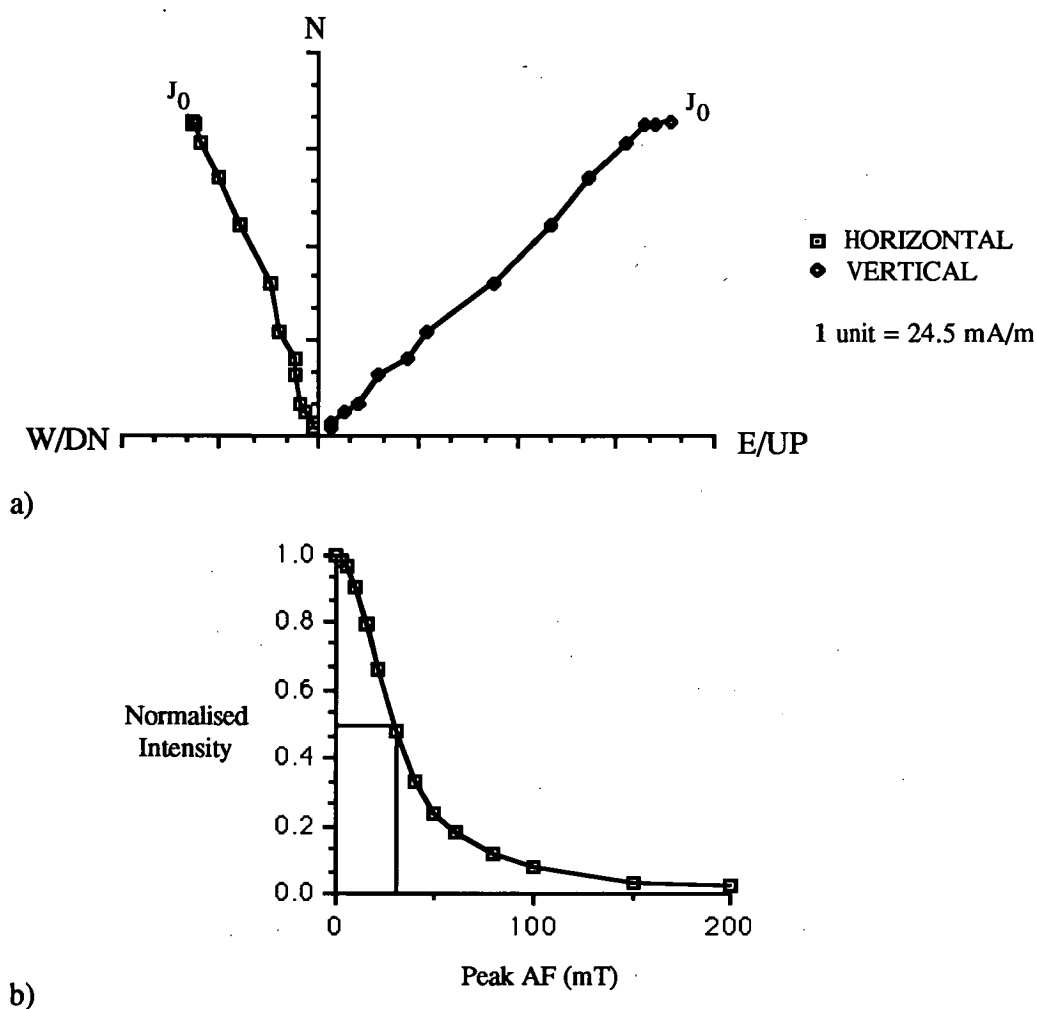


Fig. 4.51 a) Zijderfeld plot, specimen 107.
b) Normalised intensity plot, specimen 107.

The Zijderfeld plot shows a two component system and a strong and normal polarity. The lower stability component is isolated during AF treatment to 5 mT. Thereafter the direction of the plot remains essentially unchanged towards the origin with each demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases with each step of demagnetisation treatment. The major component is relatively hard, MDF being achieved at 30 mT.

All the specimens from this site have a normal polarity. Declination ranged from 332° to 21° , with a mean value of 358° . Inclination ranged from -4° to -58° , with a mean value of -34° . The specimens form a reasonably tight group on the stereoplot (Fig. 4.52).

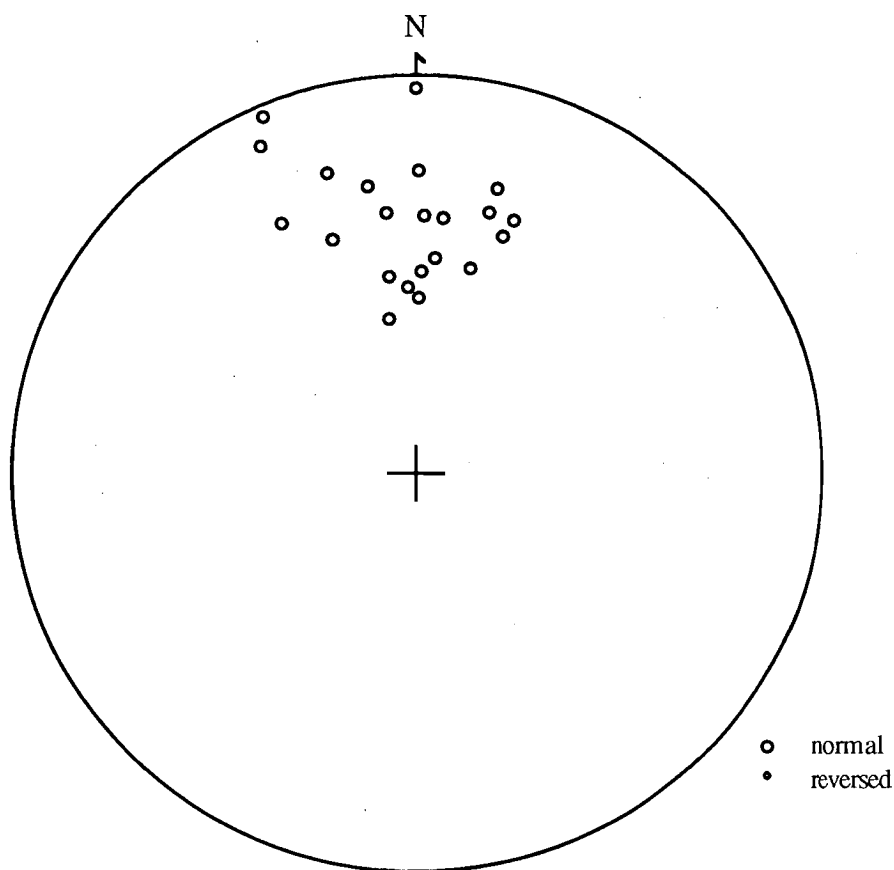


Fig. 4.52 Arm River Bridge stereoplot (25 mT).

These specimens were very strongly magnetised, with NRM values ranging from 96.68 to 466.81 μG and a mean NRM value of 261.1 μG . Values for susceptibility ranged from 55.11 to 135.91 $\mu\text{G}/\text{Oe}$ and the mean value was 91.8 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 1.33 to 4.04, with a mean value of 2.8. All the specimens thus had a very good capability of maintaining a stable remanence.

This site has a normal polarity and is therefore < 730 ka in age. The Arm drift, within the boundaries of which this site occurs, is therefore unlikely to be greater than Middle Pleistocene in age.

Site 19: Arm River Road

The Arm River Road site is located in the Arm River Valley, on Maggs Road, approximately one kilometre above its junction with the Mersey Forest Road (Borradaile, Sheet 4238, 1:25000, GR 332837) (Figs. 2.4 and 3.1), and is 500 m above sea level.

Rhythmites containing dropstones are exposed on both sides of the road. These rhythmites are brownish in colour, quite hard and very brittle and are overlain at the south-west end of the cutting by till (Fig. 4.53).

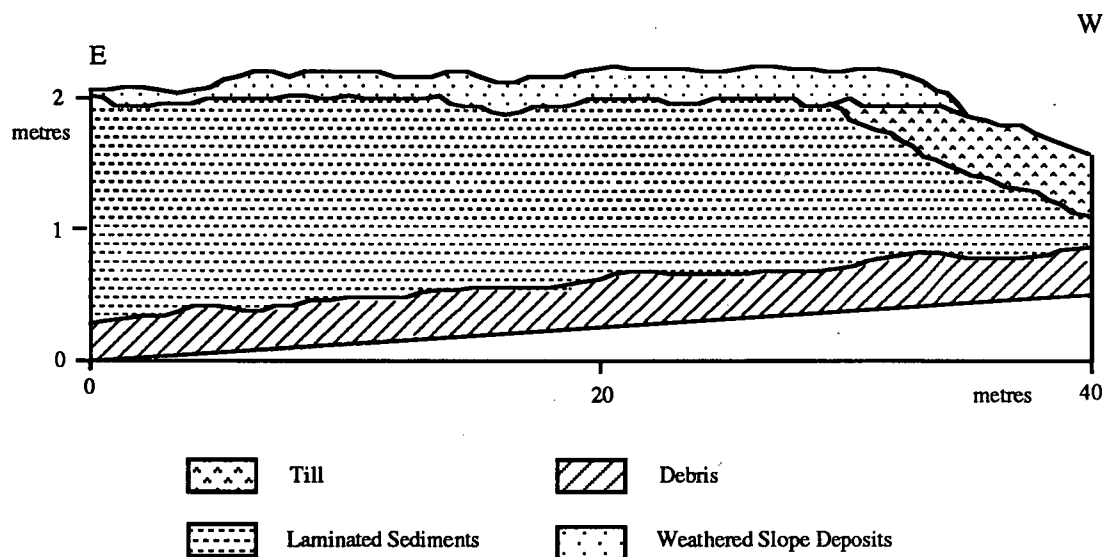


Fig. 4.53 Arm River Road (Maggs Road) section.

This site occurs between the Rowallan and Arm drifts of Hannan (1989) in the Mersey Valley. Hannan and Colhoun (1987) considered the Arm Glaciation to be at least 100 ka old, and hence of Middle Pleistocene age.

One sample was demagnetised over the normal range of values to 60 mT, and on the basis of these results the remaining specimens were cleaned at a value of 20 mT. The results of progressive demagnetisation of specimen AR2.3, a typical specimen, are shown in Fig. 4.54.

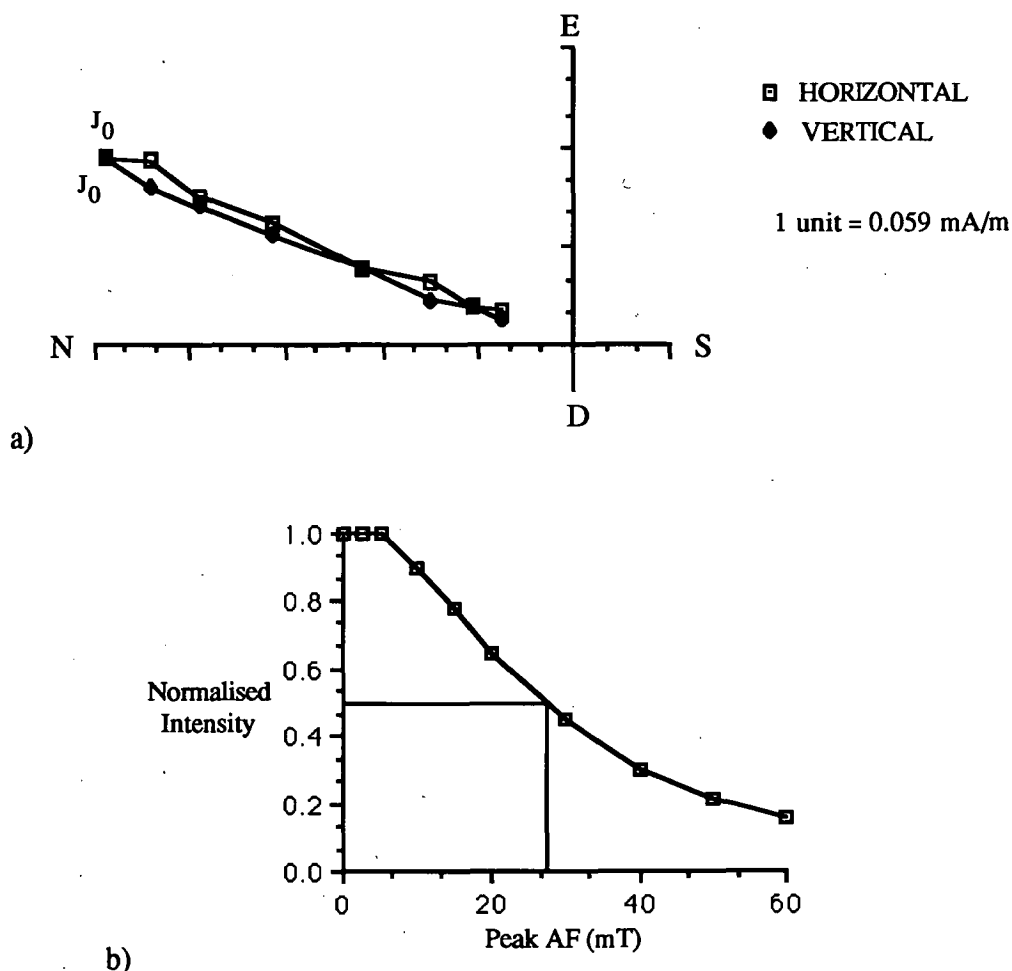


Fig. 4.54 a) Zijderveld plot, specimen AR2.3.
b) Normalised intensity plot, specimen AR2.3.

The Zijderveld plot shows a strong and normal polarity. There are some minor variations in direction with some of the demagnetisation steps, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows a stability in intensity of magnetisation during the first two demagnetisation steps (2.5 and 5 mT). Thereafter the intensity decreases relatively slowly with each step of demagnetisation treatment. The magnetisation is relatively hard, MDF being achieved at 27 mT.

All the specimens from this site had normal polarity and the declination values ranged from 31° to 38° , with a mean value of 33° . The inclination values ranged from -15° to -27° , with a mean value of -20° . The specimens formed a tight group on the stereoplot (Fig. 4.55).

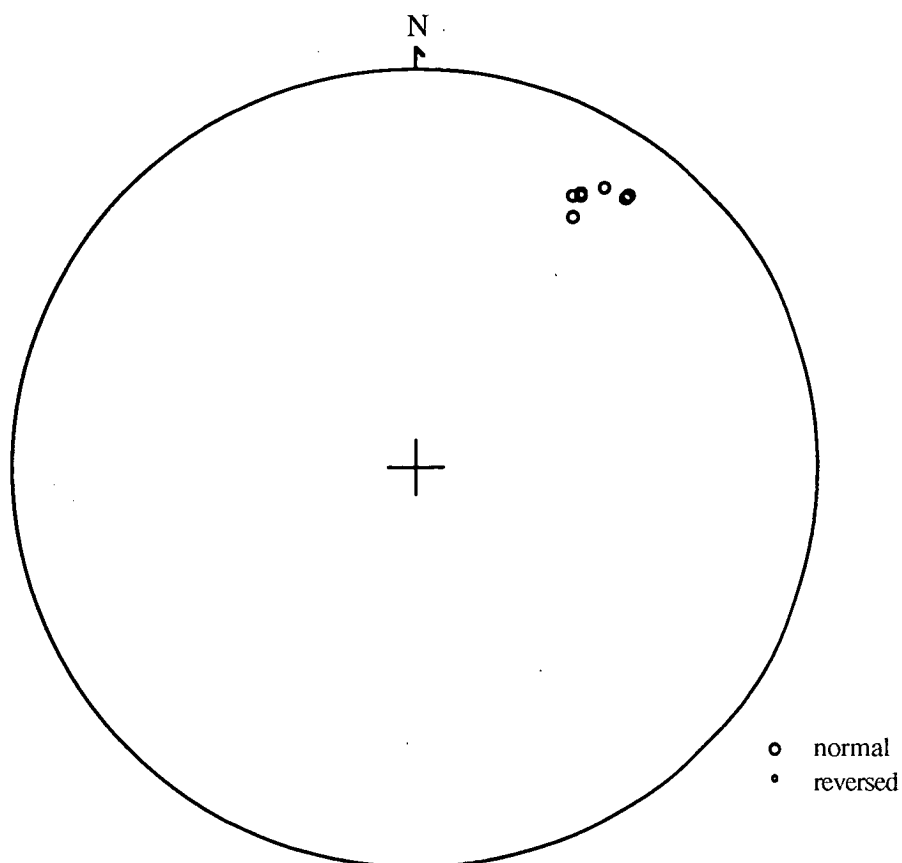


Fig. 4.55 Arm River Road (Maggs Road) stereoplot (20 mT).

These specimens were all extremely strongly magnetised, NRM values ranging from 234.5 to 683.5 μG and with a mean value of 547.0 μG . Susceptibility values ranged from 139.0 to 175.1 $\mu\text{G}/\text{Oe}$, with a mean value of 158 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio values ranged from 1.69 to 4.52, with a mean value of 3.1. These specimens thus had a very good capability of maintaining a stable remanence.

This site has a normal polarity. The Arm drift, within the boundaries of which this site occurs, is therefore unlikely to be greater than Middle Pleistocene in age.

Site 20: Lemonthyme Penstock

The Lemonthyme Penstock site is located at the intersection of Lemonthyme Road and the Lemonthyme penstock, in the Forth Valley (Liena, Sheet 4239, 1:25000, GR 282936) (Figs. 2.4 and 3.1), and is 250 m above sea level.

The site (Fig. 4.56) is approximately ten metres long and up to four metres high and consists of laminated silty clays overlain by till. These rhythmities are very weathered and have a bright reddish brown colour (Hannan, 1989).

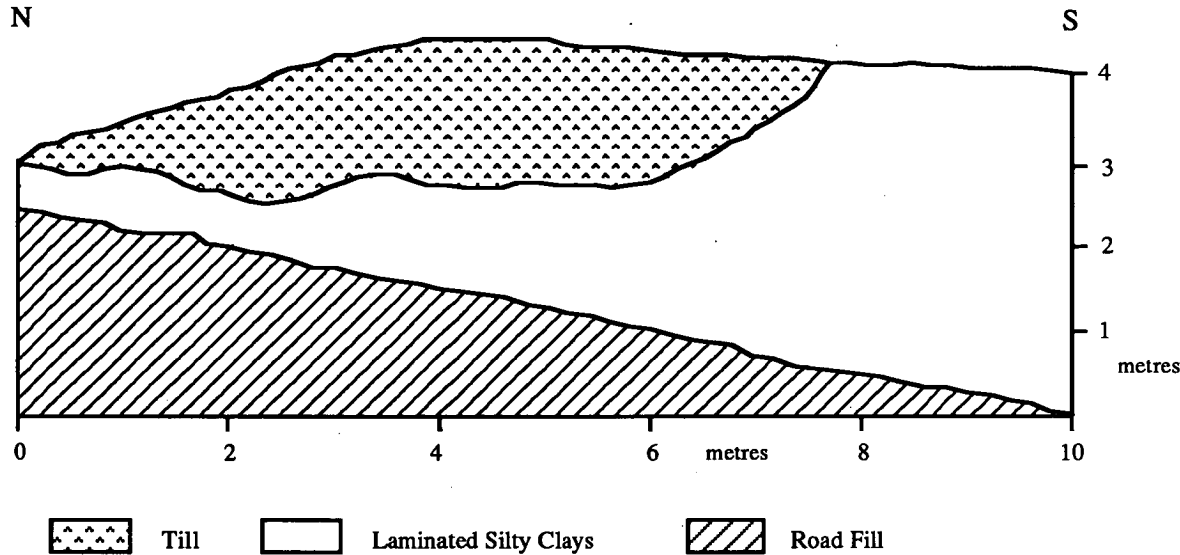


Fig. 4.56 Lemonthyme Penstock section.

This site occurs within the Patons drift limit of Kiernan and Hannan (1989) in the Forth Valley. On the basis of weathering rind analysis, they considered the Patons Glaciation to be a correlate of the Linda Glaciation of the West Coast Range and at least of Early Pleistocene age.

Fifteen specimens were taken from this site for analysis. Three specimens were demagnetised over the normal range of values up to 200 mT. On the basis of these results the remaining specimens were cleaned at 25 mT. The results of the progressive demagnetisation of specimen 124, a typical specimen, are shown in Fig. 4.57.

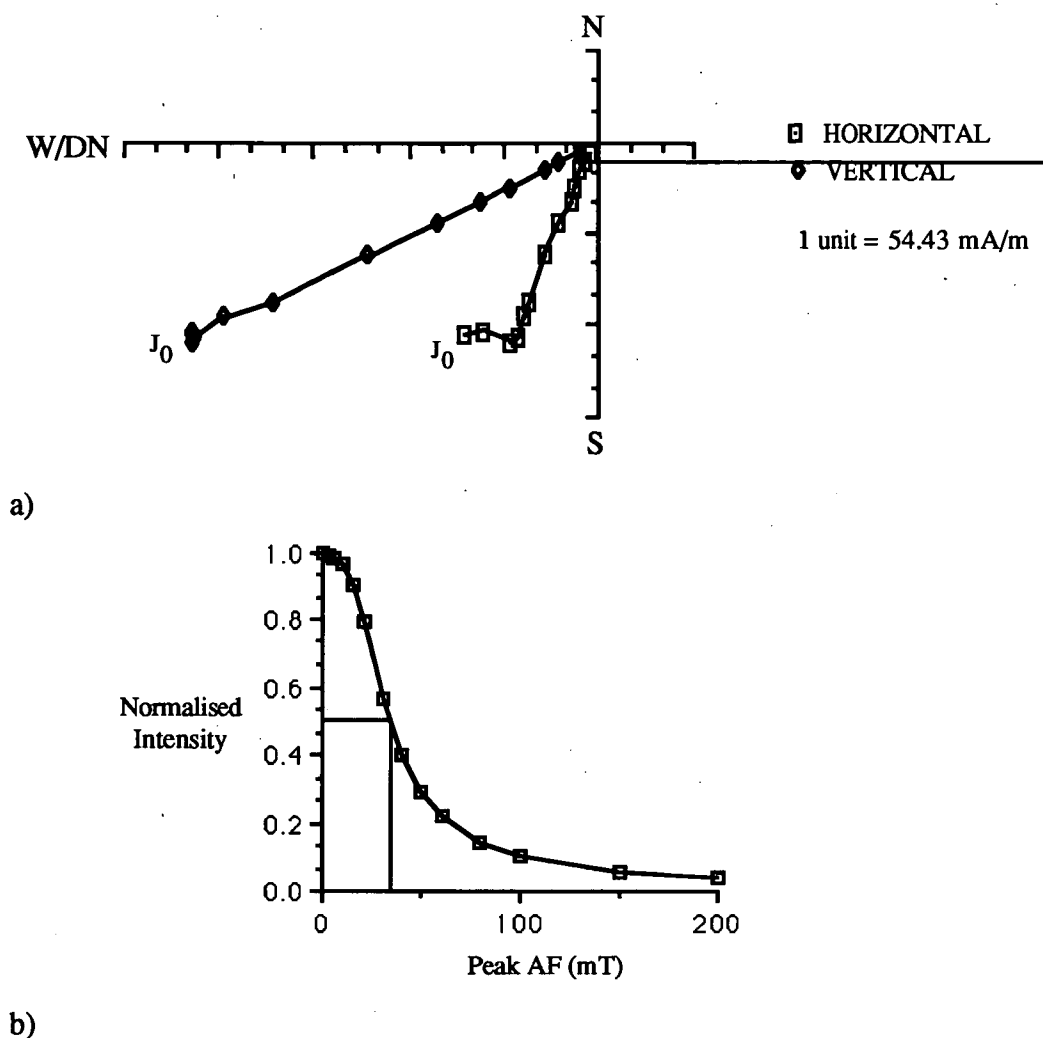


Fig. 4.57 a) Zijderfeld plot, specimen 124.
b) Normalised intensity plot, specimen 124.

The Zijderfeld plot shows two components of magnetisation, the lower stability component being isolated during AF treatment up to 10 mT. Thereafter, the direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases with each step of AF treatment. The major component is relatively hard, MDF being achieved at 35 mT.

Fourteen of the fifteen specimens from this site had a reversed polarity. Declination values ranged from 152° to 197° , with a mean value of 171° . Inclination values ranged from $+37^{\circ}$ to $+73^{\circ}$, with a mean value of $+53^{\circ}$. The specimens, with two exceptions, form a fairly tight group on the stereoplot (Fig. 4.58).

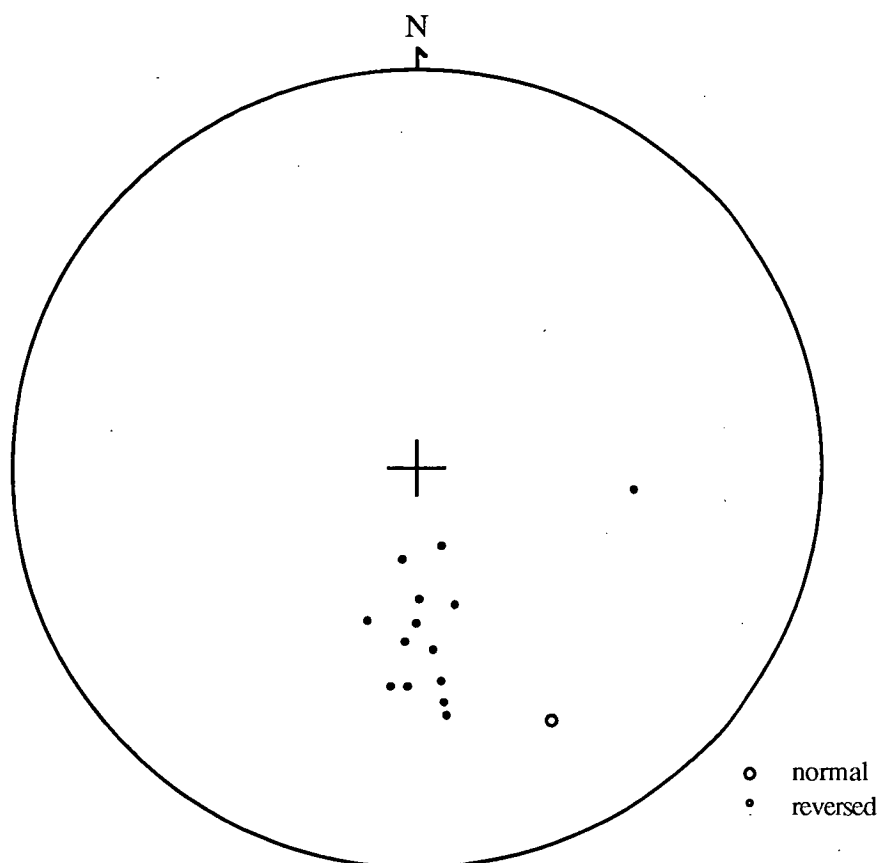


Fig. 4.58 Lemonthyme Penstock stereoplot (25 mT).

These specimens were extremely strongly magnetised, with NRM values ranging from 119.7 to 910.4 μG and a mean NRM value of 693.6 μG . Values for susceptibility ranged from 133.0 to 235.2 $\mu\text{G}/\text{Oe}$, with a mean value of 157.8 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 0.51 to 6.75, with a mean value of 4.5. Only the sample with normal polarity had a value of less than one. Thus, nearly all the specimens had a very good capability of maintaining a stable remanence.

The site has a dominantly reversed polarity. The Patons drift, within the boundaries of which this site occurs, is therefore at least of Early Pleistocene age.

4.2.3 WEST CENTRAL SITES

Site 21: King William Creek

The King William Creek site is located in a very shallow road cutting on the southern side of the Lyell Highway, 800 m east of King William Creek (Nive, Sheet 8113, 1:100000, GR 280263) (Figs. 2.5 and 3.1), and is 840 m above sea level.

Laminated sediments are exposed in a large ditch, the site being approx 30 m long and about one metre high (Fig.4.59). The rhythmites have been glaciotectonically deformed and "... are stiffly pliable to brittle, lightly oxidised, and fragment into small cubes when dried out." (Kiernan,1985). The upper layers have been eroded and are overlain with a peat layer at least 0.1 m thick. The lower contact is not exposed.

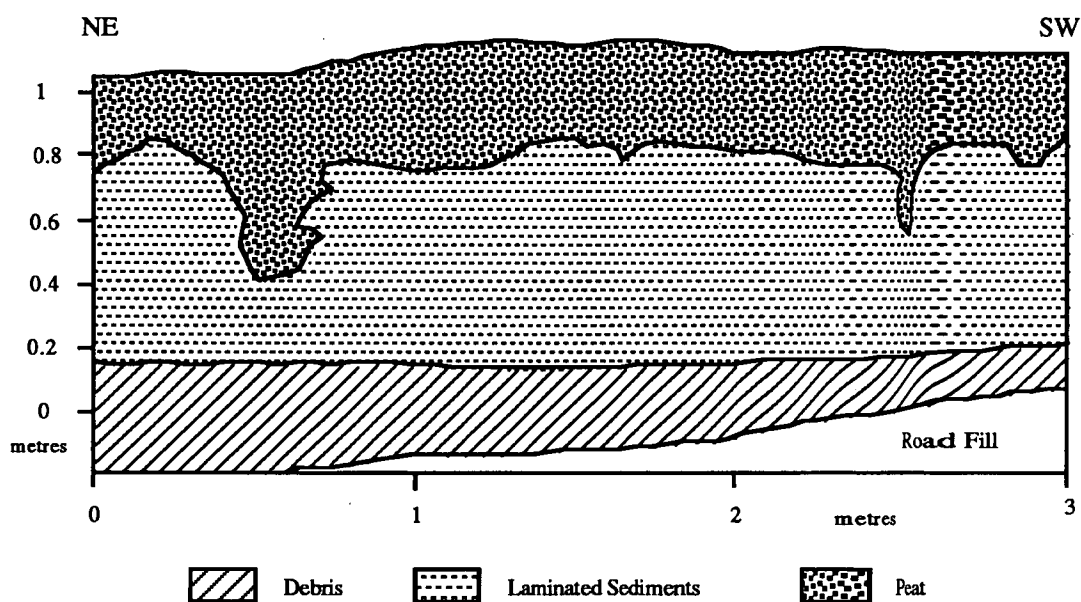


Fig. 4.59 King William Creek section.

This site occurs within the Sawmill Ridge drift limits of Kiernan (1985) in the Navarre Valley. He tentatively correlated this drift with the Taffys Creek drift of the Upper Franklin Valley area. On the basis of weathering rind analysis he considered the Taffys Creek drift to be at least 220 ka years old and hence of Middle Pleistocene age.

Fourteen specimens were taken from a section where the sediments were flat-lying. Two specimens were demagnetised over the normal range of values to 100 mT and on the basis of these results the remaining specimens were cleaned at 10 mT. The results of the progressive demagnetisation of specimen KW3, a typical specimen, are shown in Fig. 4.60.

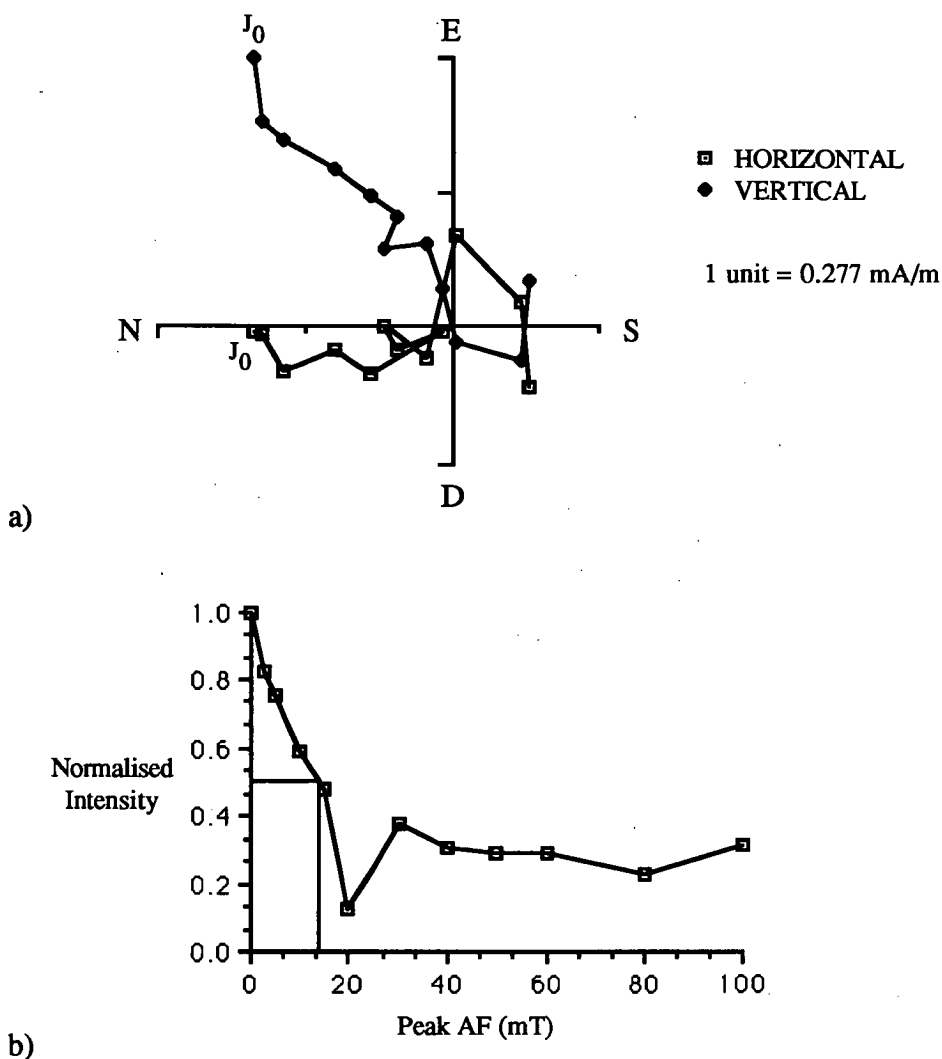


Fig. 4.60 a) Zijdeveld plot, specimen KW3.
b) Normalised intensity plot, specimen KW3.

The Zijdeveld plot shows a weak magnetisation and an indeterminate polarity. The magnetisation has several components, as indicated by the change in direction of the plot after many of the demagnetisation steps.

The normalised intensity plot shows that the intensity of magnetisation decreases fairly rapidly with each step of demagnetisation treatment up to 15 mT. Thereafter, the intensity decreases very slowly; the value at 20 mT is assumed to represent an error of measurement. The major component of magnetisation of this specimen is soft, MDF being achieved at 14 mT.

All the specimens from this site had a normal polarity. Declination values ranged from 320° to 68° , with a mean value of 8° . Inclination values ranged from -31° to -74° , with a

mean value of -53^0 . The specimens form a reasonably distinct group on the stereoplot (Fig. 4.61).

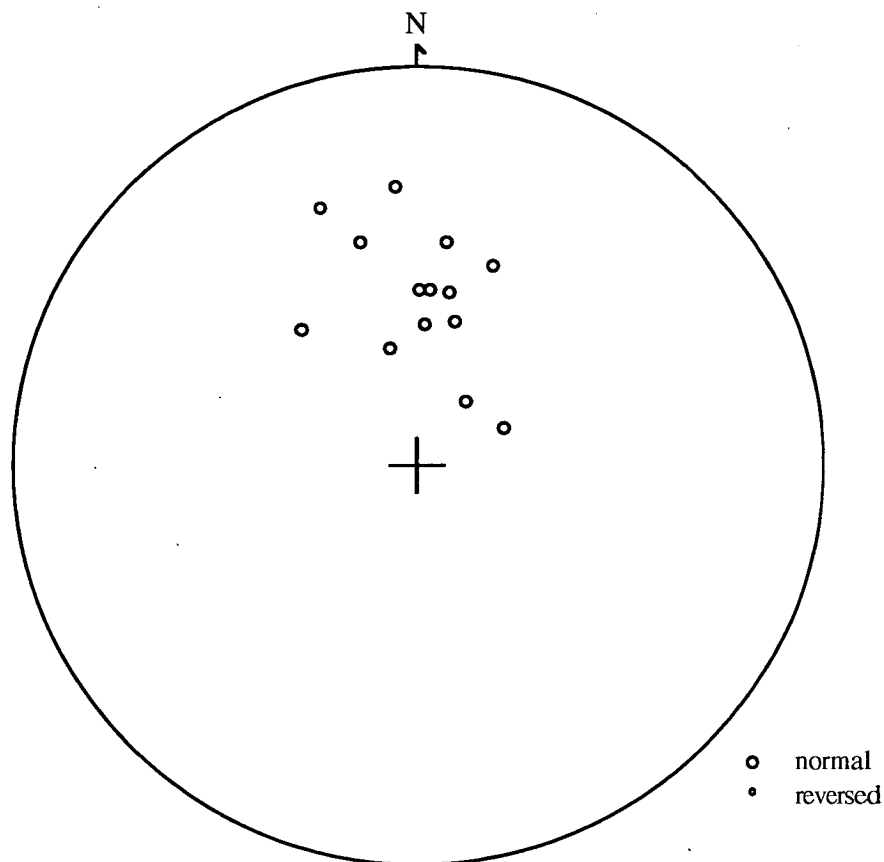


Fig. 4.61 King William Creek stereoplot (10 mT).

These specimens were extremely weakly magnetised, NRM values ranging from 0.137 to 0.3 μG and with a mean value of 0.229 μG . Susceptibility values ranged from 3.64 to 5.61 $\mu\text{G}/\text{Oe}$, with a mean value of 4.47 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio ranged from 0.03 to 0.07, with a mean value of 0.05. As all values are considerably less than 0.1, these specimens have a very poor capability of maintaining a stable remanence.

This site has a normal polarity. The Sawmill Ridge drift, within the boundaries of which this site occurs, is therefore unlikely to be greater than Middle Pleistocene in age.

Site 22: Stonehaven Creek

The Stonehaven Creek site is located on the northern side of the Lyell Highway, just west of Stonehaven Creek (Franklin, Sheet 8013, 1:100000, GR 154268) (Figs. 2.5 and 3.1), and is 400 m above sea level.

Thin beds of laminated silts, sandy in parts, occur in a small exposure approx 0.5 m high and about 5 m long (Fig. 4.62). The sediments are generally flat-lying, but show some warping on the western end of the section. The silts contain small dropstones and become very sandy towards the bottom of the section. The upper surface of the sediments has been eroded and is overlain by a peat layer approximately 0.1 m thick. An exposure in the Franklin River, just to the south of this site, "... reveals till, glaciofluvial gravels and rhythmites that contain dropstones." (Kiernan, 1985).

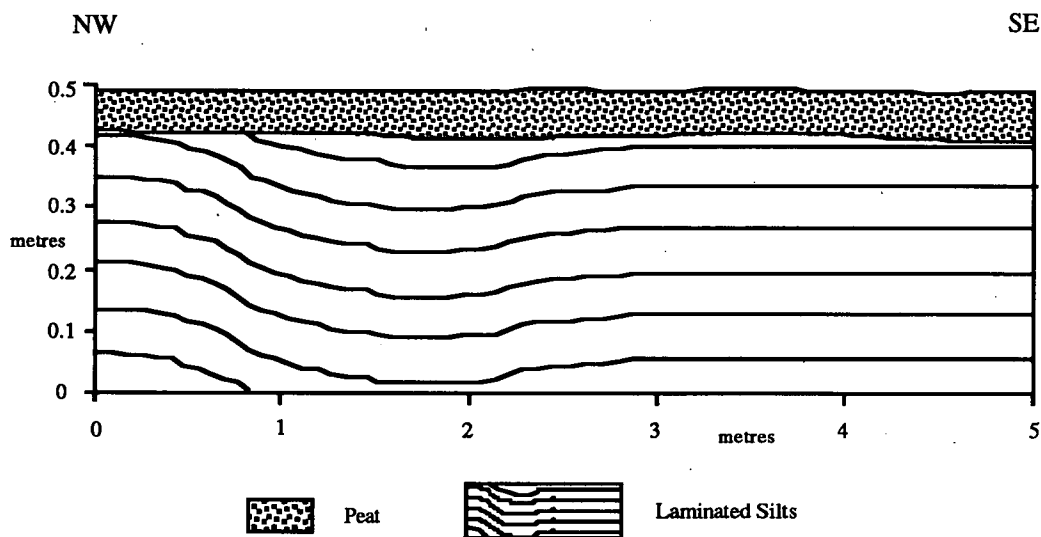


Fig. 4.62 Stonehaven Creek section.

This site occurs between the Stonehaven and Wombat Glen drift limits of Kiernan (1989) in the Upper Franklin Valley. On the basis of weathering rind analyses, he considered the Wombat Glen Glaciation to be at least 375 ka in age and the Stonehaven Glaciation at least 950 ka in age. This site is therefore likely to be of Early Pleistocene age.

Sixteen specimens were taken from this site. All specimens from this site were demagnetised over the normal range of values to 100 mT and on the basis of these results 20 mT was chosen as representing the primary magnetisation of the specimens. This value was used for the stereoplot. The results of the progressive demagnetisation of specimen S4, a typical specimen, are shown in Fig. 4.63.

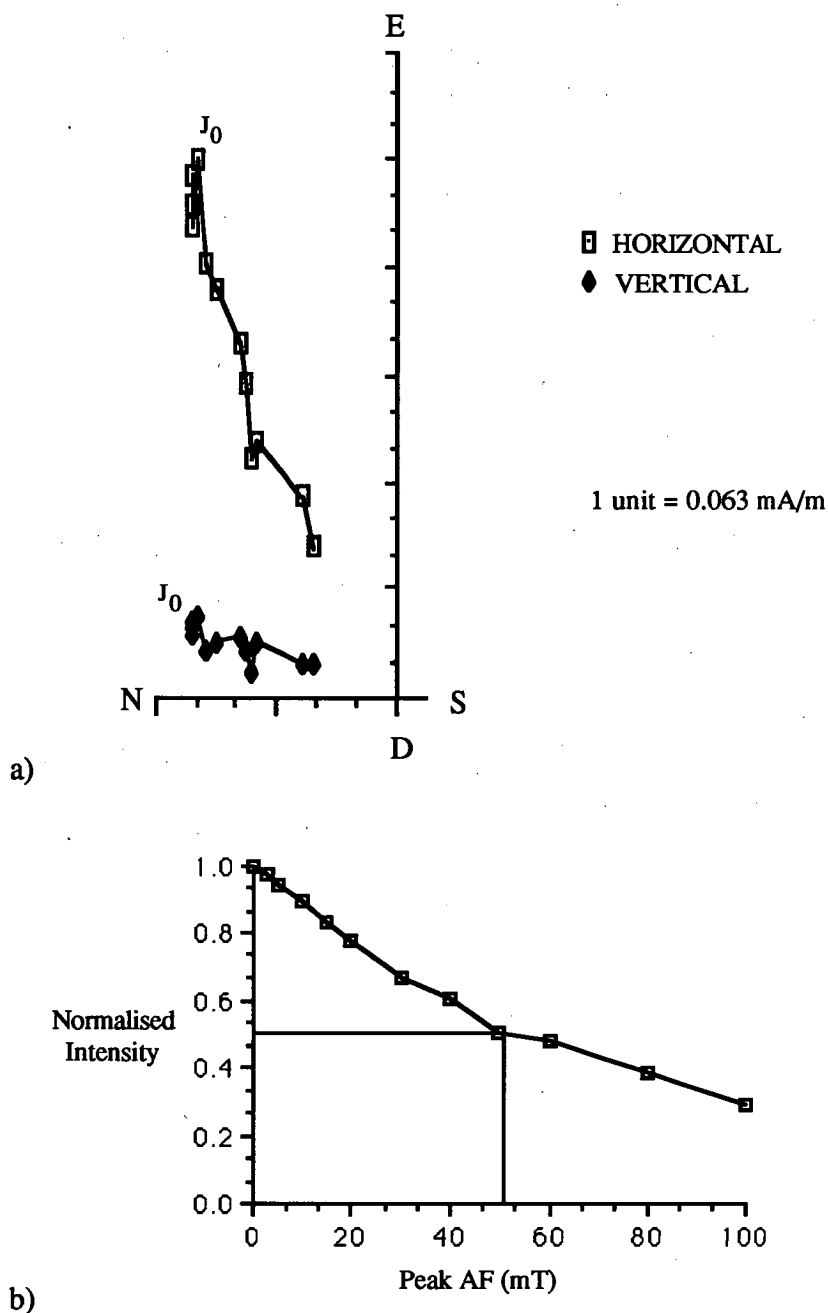


Fig. 4.63 a) Zijdeveld plot, specimen S4.
b) Normalised intensity plot, specimen S4.

Although the Zijdeveld plot shows a general consistency of trend towards the origin, there are some variations in direction with some of the demagnetisation steps, indicating that more than one component of magnetisation is being removed.

The normalised intensity plot shows that the intensity of magnetisation decreases very slowly and regularly with each step of AF treatment. The major component of magnetisation is hard, MDF being achieved at 49.9 mT.

The specimens from this site were of dominantly normal polarity; one sample was discarded because it had an MDF < 5 mT and two specimens had reversed polarity. Declination values ranged from 328° to 177° , with a mean value of 30° . Inclination values ranged from -13° to -83° , with a mean value of -63° . The specimens form a fairly close group on the stereoplot, with the exception of the two reversed specimens (Fig. 4.64).

The strength of the magnetic signal of these specimens varied somewhat, NRM values ranging from 0.942 to 40.909 μG and with a mean value of 9.09 μG . Susceptibility values ranged from 3.1 to 27.75 $\mu\text{G}/\text{Oe}$, with a mean value of 8.5 $\mu\text{G}/\text{Oe}$.

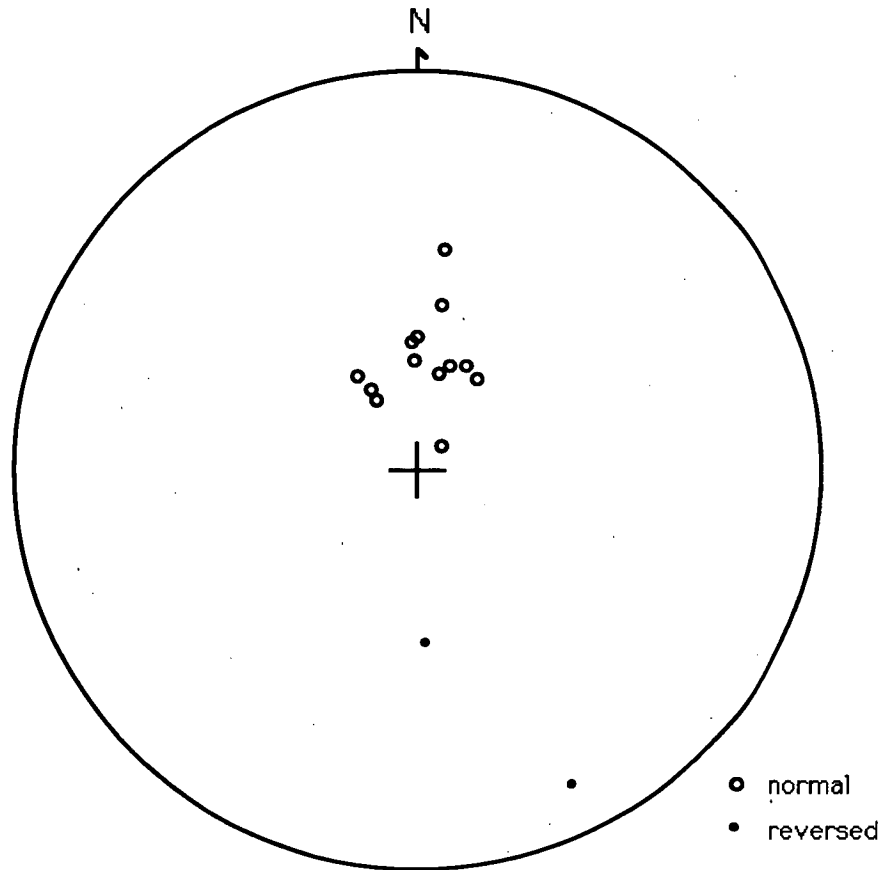


Fig. 4.64 Stonehaven Creek stereoplot (20 mT).

The Modified Königsberger Ratio ranged from 0.13 to 4.23, with a mean value of 1.11. Half the specimens had a value greater than one, indicating that these specimens had a good capability of maintaining a stable remanence whilst the remaining specimens had a fair capability.

This site has a dominantly normal polarity. The sediments of this site cannot therefore be of Early Pleistocene age, as indicated above, unless they were deposited during a period of normal polarity in the reversed Matuyama chron.

Site 23: Double Barrel Creek

The Double Barrel Creek site is located in a large cutting on the northern side of the Lyell Highway, just west of Double Barrel Creek (Franklin, Sheet 8013, 1:100000, GR 138275) (Figs. 2.5 and 3.1), and is approximately 400 m above sea level.

Flat-lying laminated silts form a relatively narrow band, generally less than half a metre thick, within sandy silts that overlie till. The sandy silts are overlain along an erosion surface by slope deposits (Fig. 4.65).

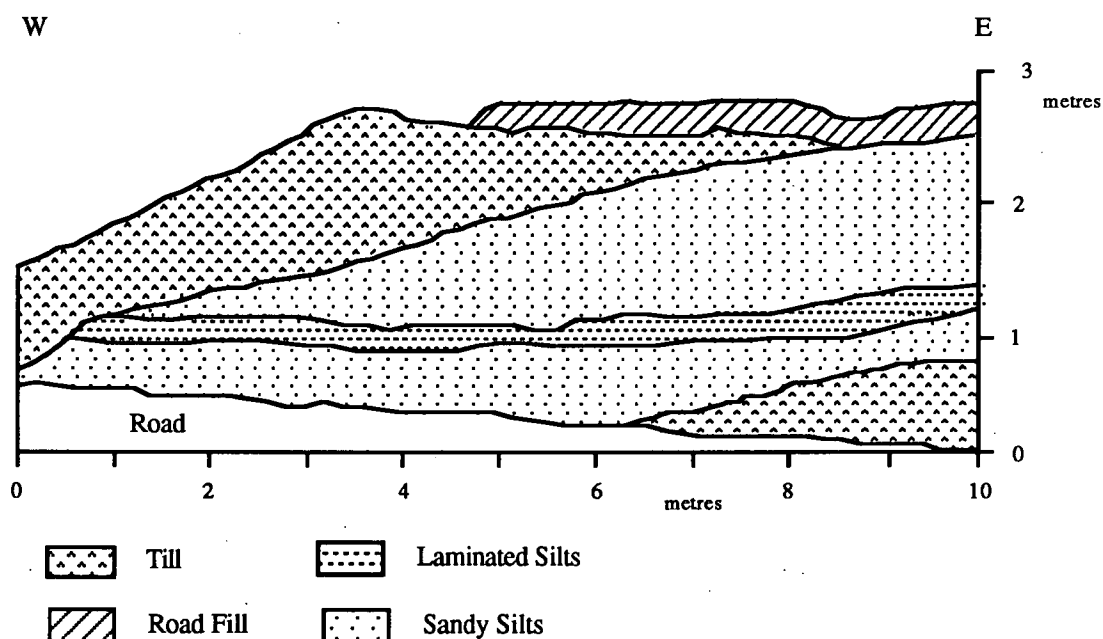


Fig. 4.65 Double Barrel Creek section.

This site occurs between the Stonehaven and Wombat Glen drift limits of Kiernan (1989) in the Upper Franklin Valley. On the basis of weathering rind analyses, he considered the Wombat Glen Glaciation to be at least 375 ka in age and the Stonehaven Glaciation at least 950 ka in age. This site is therefore likely to be of Early Pleistocene age.

Fifteen specimens were taken from this site. All the specimens from this site were demagnetised over the normal range of values to 100 mT. A value of 20 mT was chosen as representing the primary magnetisation of the specimens and hence was used for the stereoplot. The results of the progressive demagnetisation of specimen S29, a typical specimen, are shown in Fig. 4.66.

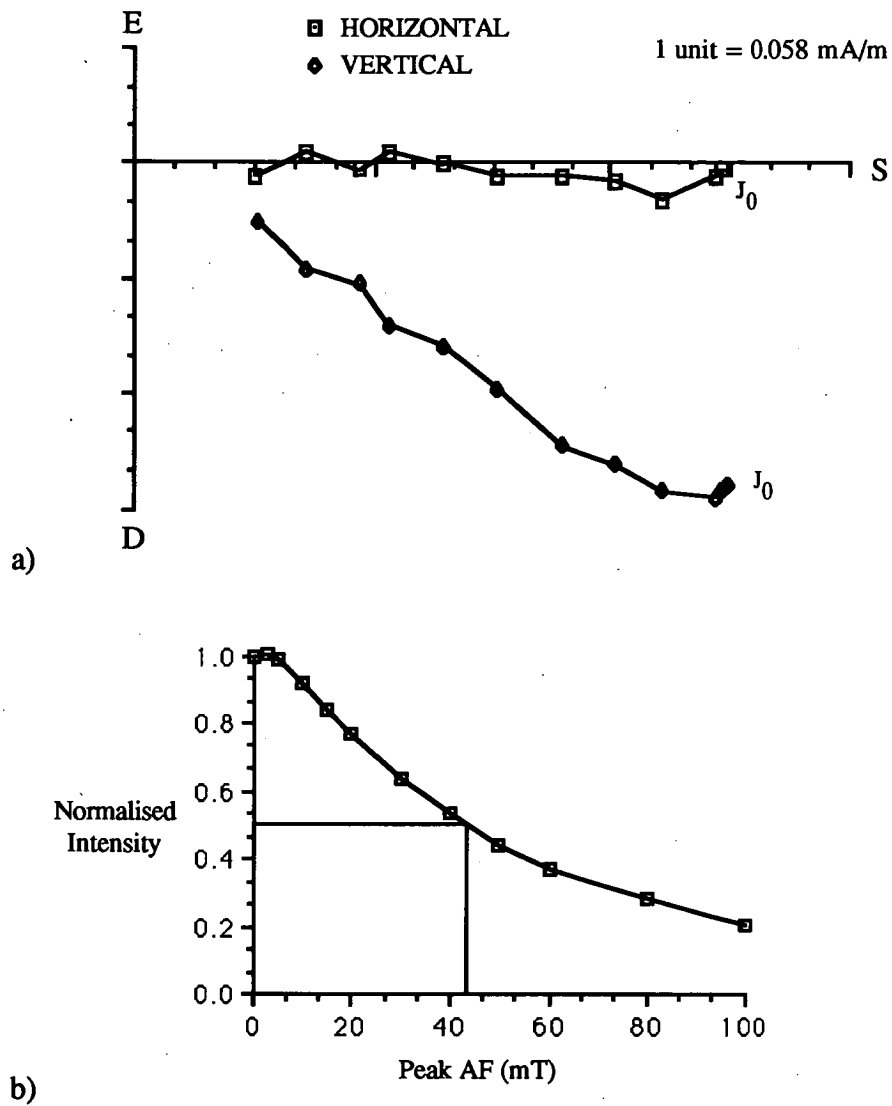


Fig. 4.66 a) Zijderveld plot, specimen S29.
b) Normalised intensity plot, specimen S29.

The Zijderveld plot shows a strong magnetisation and a reversed polarity. The specimen has two major components, the lower stability component being isolated during AF treatment to 15 mT. Thereafter the direction remains essentially unchanged towards the origin with each successive demagnetisation step, indicating that a single component of magnetisation is being removed.

The normalised intensity plot shows that the total intensity of magnetisation increases very slightly with the first step of AF treatment as one component is preferentially removed. Thereafter, the total intensity decreases relatively slowly with each step of AF treatment. The major component of magnetisation is hard, MDF being achieved at 43.9 mT.

The specimens from this site show a mixed polarity, with seven being reversed and five being normal. Three of the specimens were discarded, two because they were too heavily iron-stained and one because it had an MDF < 5 mT. The stereoplot of the specimens shows a very wide scatter (Fig. 4.67).

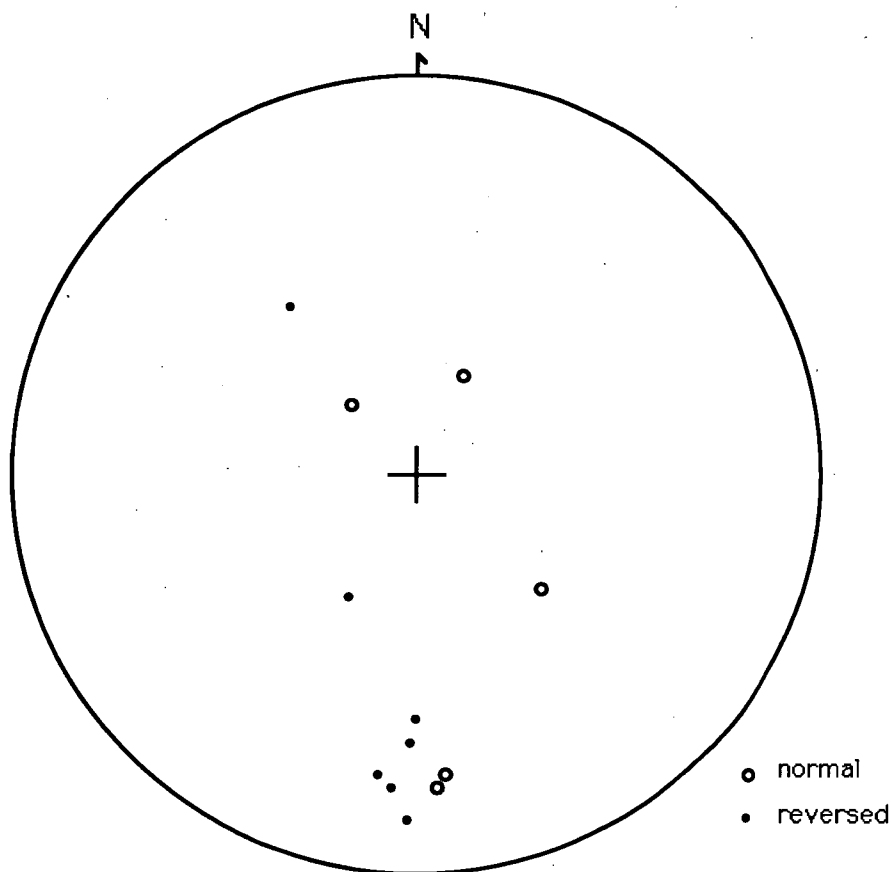


Fig. 4.67 Double Barrel Creek stereoplot (20 mT).

The strength of the magnetic signal also varied somewhat at this site. NRM values ranged from 0.193 to 36.899 μG , with a mean value of 5.85 μG . Values for susceptibility ranged from 1.32 to 40.65 $\mu\text{G}/\text{Oe}$, with a mean value of 13.75 $\mu\text{G}/\text{Oe}$.

The Modified Königsberger Ratio for these specimens ranged from 0.02 to 3.57, with a mean value of 0.6. Three of the specimens had a good capability of maintaining a stable remanence, eight had a fair capability and four had a poor capability.

This site has a mixed polarity. Therefore, the age of the Stonehaven drift, within the boundaries of which this site occurs, cannot be determined from the palaeomagnetic analysis of this site.

Ch. 5 ANALYSIS

5.1 Introduction

The purpose of this section is to analyse critically the results in Chapter 4 and to evaluate the model of Tasmanian glacial stratigraphy discussed in Chapter 2.1.

The data will be discussed in three broad categories - the West Coast sites, the North Central sites and the West Central sites. The main results obtained from each of these sites will then be interrelated in terms of similarities and differences. Broad and specific correlations will be drawn between areas and sites wherever possible.

In the majority of cases the palaeomagnetic results obtained were consistent with the age estimates based on morphostratigraphic and relative dating analyses. However, several sites considered to be of Early Pleistocene age, and hence >730 ka, produced results that were of normal polarity. These results are considered to be equivocal because they may be <730 ka BP or they may be from a normal event within the Matuyama reversed chron. The data from several other sites were inconclusive because of the mixed polarity of the results and no meaningful conclusions could be drawn. The palaeomagnetic information is compared to other evidence in Table 5.1.

The majority of sites showed a dominant polarity as indicated in Table 5.1. The significance of polarity to this study is that the Brunhes-Matuyama palaeomagnetic boundary occurred at 730 ka BP and so any sites with a reversed polarity are therefore likely to be > 730 ka old. Sites with a normal polarity will be usually < 730 ka in age or very much older.

Two major normal polarity periods occur in the Matuyama reversed chron, the Jaramillo normal event, 910 to 980 ka, and the Olduvai normal event, 1.66 to 1.88 Ma. These periods, together with the Reunion normal event, account for approximately twenty percent of the Matuyama reversed chron. Thus there is a twenty percent possibility of obtaining normal polarity results for deposits >730 ka in age. It is therefore important to assess the spatial patterns for all the sites in the context of the reconstructed drift limits because one apparently anomalous normal polarity result at a site may occur in an area where most results are reversed. Such an apparently anomalous result may in fact represent a normal event within the Matuyama Chron. Given the earlier comments on excursions, a reversed polarity result in the Brunhes Chron would be seen as an anomalous result.

Table 5.1 Comparison of palaeomagnetic age constraints with results obtained from other methods.

Site	Age ¹	Magneto- stratigraphy ²	Reliability Index	Comments
West Coast Sites				
a) Pieman Valley Area				
4. Boco	Mid. Pleist.	Normal, <730 ka	4.7	Confirmed
7. Rosebery Opencut	Mid. Pleist.	Normal, <730 ka	3.6	Confirmed
3. Marionoak	Early Pleist.	Reversed, >730 ka	3.6	Confirmed
5. Bulgobac A	Early Pleist.	Reversed, >730 ka	4.7	Confirmed
Bulgobac B&C	Early Pleist.	Mixed Rev. & Nor.	2.1	Inconclusive
8. Williamsford	Mid. Pleist.	Reversed, >730 ka	2.7	New data
2. Huskisson/ Marionoak	Early Pleist.	Mixed Rev. & Nor.	n.a.	Inconclusive
1. Lower Pieman	Early Pleist.	Mixed Rev. & Nor.	2.9	Inconclusive
6. Que	Early Pleist.	Reversed, >730 ka	3.3	Confirmed
b) Henty Surface				
9. Tyndall Creek A	Mid. Pleist.	Reversed, >730 ka	2.3	Different
Tyndall Creek B	Mid. Pleist.	Reversed, >730 ka	2.4	Different
c) King River Valley				
13. Linda Creek	Mid. Pleist.	Normal, <730 ka	3.9	Confirmed
12. King River Bridge	Mid. Pleist.	Normal, <730 ka	4.3	Confirmed
11. Baxter Rivulet	early Mid. Pleist.	Normal, <730 ka	2.7	Confirmed
10. Thureau Hills Road	Early Pleist.	Reversed, >730 ka	3.4	Confirmed
10A. Thureau Hills Ck.	Early Pleist.	dom. Normal, ? ka	2.6	Equivocal ³
16. King Gorge Exit	Early Pleist.	Normal, ? ka	2.0	Equivocal ³
15. Gormanston Football Field	Early Pleist.	Reversed, >730 ka	n.a.	Confirmed
14. Gormanston Moraine	Early Pleist.	Reversed, >730 ka	4.4	Confirmed
North Central Area				
17. Fish River	Late Pleist.	Normal, <730 ka	4.6	Confirmed
19. Arm River Road	Mid. Pleist.	Normal, <730 ka	4.4	Confirmed
18. Arm River Bridge	Mid. Pleist.	Normal, <730 ka	4.1	Confirmed
20. Lemonthyme P'stock	Early Pleist.	Reversed, >730 ka	4.1	Confirmed
continued....				

West Central Area

21. King William Creek	Mid. Pleist.	Normal, <730 ka	3.1	Confirmed
22. Stonehaven Creek	Early Pleist.	Normal, ? ka	3.1	Equivocal ³
23. Double Barrel Creek	Early Pleist.	Mixed Rev. & Nor.	1.9	Inconclusive

1 Interpretation of age based on evidence other than palaeomagnetism.

2 Result suggested by magnetostratigraphy.

3 Although these results are indicated as being equivocal, they are probably > 730 ka old as they may represent a Normal event in the Reversed Matuyama Chron.

n.a. Not available.

It is also possible that the reversed sites represent short excursions within the Brunhes normal period (e.g. the Blake or Biwa excursions). However, because of uncertainty regarding the validity and extent of some of these excursions (Tarling, 1983), this possibility has been disregarded in this study. Even though it has been the purpose of this study to test objectively the ages of the drift sequences, the other stratigraphic and relative dating methods that have been used to establish the stratigraphy for these areas of Tasmania should not be disregarded in favour of hypothetical short excursions which cannot be shown to apply to the area. These possibilities have been discussed in detail in Chapter 2.2.1.

In this chapter all combined stereoplots are equal-area stereographic projections, as are the individual stereoplots in Chapter 4. Equal-angle stereographic projections were used for the correlation plots, however, as the α_{95} cones of confidence project as circles on these projections. Comparison of the angle between individual mean site values and their combined α_{95} angles is shown in Table 5.2 for sites with normal polarity and Table 5.3. for sites with reversed polarity.

Table 5.2 Matrix showing the angle between the mean inclination of individual sites with normal polarity and their combined α_{95} angles.

	2	3	4	5	6	7	8	9	10	11	12	13
1	11.2 2.5	40.2 70.8	31.1 30.8	11.3 13.0	24.3 5.4	8.6 18.0	10.4 25.4	8.4 21.0	10.9 21.6	7.4 47.1	12.7 10.2	9.7 13.7
2		44.6 72.4	35.5 28.3	15.7 14.0	27.7 6.8	13.0 19.0	14.8 22.9	12.8 19.1	15.3 20.1	11.8 44.6	17.1 7.8	14.1 13.9
3			64.5 86.0	46.7 58.7	56.7 73.5	42.0 81.3	43.8 90.0	41.8 91.3	44.3 92.4	40.8 106.7	46.1 74.7	43.1 60.7
4				37.6 34.4	47.6 34.1	32.9 42.6	34.7 11.2	32.7 23.1	35.2 28.4	31.7 21.0	37.0 20.7	34.0 30.2
5					27.8 17.4	13.1 29.5	14.9 33.3	12.9 32.6	15.4 34.1	11.9 54.1	17.2 16.6	14.2 4.7
6						25.1 12.7	26.9 27.2	24.9 20.3	27.4 19.5	23.9 48.6	29.2 14.2	26.2 18.8
7							12.2 33.2	10.2 22.3	12.7 18.5	9.2 52.3	14.5 25.3	11.5 31.4
8								12.0 12.1	14.5 17.4	11.0 21.7	16.3 16.8	13.3 30.1
9									12.5 5.3	9.0 30.0	14.3 17.2	11.3 31.0
10										11.5 34.0	16.8 20.3	13.8 33.3
11											13.3 38.2	10.3 50.3
12												15.6 14.1

1 Boco	6 Baxter Rivulet	11 Arm River Road
2 Rosebery	7 King River Bridge	12 King William Creek
3 Thureau Hills Creek 1	8 Linda Creek	13 Stonehaven Creek
4 Thureau Hills Creek 2	9 Fish River	
5 Thureau Hills Creek 3	10 Arm River Bridge	

12.4 Combined α_{95} angles for the two sites.
13.8 Angle between the mean inclinations of the two sites.

Table 5.3 Matrix showing the angle between the mean inclination of individual sites with reversed polarity and their combined α_{95} angles.

	2	3	4	5	6	7	8	9	10
1 Lower Pieman Road	25.7 16.0	20.1 19.1	23.8 30.5	29.5 4.1	26.4 34.5	26.0 22.9	20.4 44.1	25.6 31.2	46.5 37.0
2 Marionoak		12.6 20.3	16.3 16.2	22.0 15.1	18.9 40.9	18.5 8.2	12.9 28.2	18.1 17.2	39.0 25.4
3 Bulgobac A			10.7 35.7	16.4 15.0	13.3 20.7	12.9 28.1	7.3 39.6	12.5 23.3	33.4 45.5
4 Que				20.1 30.6	17.0 56.4	16.6 8.0	11.0 20.0	16.2 20.9	37.1 10.6
5 Williamsford					22.7 31.2	22.3 22.7	16.7 42.5	21.9 28.6	42.8 38.2
6 Tyndall Creek						19.2 48.9	13.6 57.8	18.8 41.8	39.7 66.2
7 Thureau Hills Road							13.2 23.5	18.4 17.9	39.3 17.4
8 Gormanston Moraine								12.8 16.3	33.7 26.5
9 Lemonthyme Penstock									38.9 31.2

12.4 Combined α_{95} angles for the two sites.

13.8 Angle between the mean inclinations of the two sites.

5.2 West Coast Sites

As indicated earlier, the West Coast Region can be considered as a number of sub-areas; the Pieman and Boco valleys, the Henty Surface and the King and Linda valleys.

5.2.1 Pieman and Boco Valleys

The stratigraphy of the Pieman and Boco areas has been determined by Augustinus and Colhoun (1986); they identified four glaciations in this area, all of Penultimate and earlier age. This information is summarised in Chapter 2.1, Table 2.1 and Fig. 2.1.

One site has been analysed from the middle Pieman Valley at the Huskisson/Marionoak divide. An early analysis of this site by Barbetti and Colhoun (1988) suggested that the deposits had a reversed polarity. However, these specimens had a weak magnetic signal and the stereographic plot shows a wide dispersion of magnetic directions. To add to the

information from this area a further site was sampled at the 35 km peg on the Lower Pieman Dam site road. This site occurs in the end moraine complex of the Pieman Valley, 11 km downstream from the Huskisson/Marionoak divide. The palaeomagnetic data from this site are of mixed polarity (8 reversed and 6 normal specimens). These specimens also had a weak magnetic signal and a wide dispersion of magnetic directions (Fig. 4.1).

The weak magnetic signal of specimens from both these sites is possibly due to the siliceous nature of the bedrock over which the glacier passed in this area. The prospect of finding a more suitable site within this area therefore appears to be low. The palaeomagnetic results from these two sites are not convincing because of their weak magnetic signal and their scatter and mixed polarity. It is therefore not possible to conclude that the sediments have a reversed polarity, as suggested by Barbetti and Colhoun (1988), and the dating must therefore depend on the morphostratigraphic and relative dating evidence. These methods suggested an early Pleistocene age and correlation with the Bulgobac Glaciation, conclusions which cannot be denied or confirmed by the palaeomagnetic data.

The Marionoak site sediments belong to the Bulgobac drift of Augustinus and Colhoun (1986). They considered that the Bulgobac Glaciation may be a correlate of the Linda Glaciation and hence at least of early Pleistocene age. In addition, on the basis of weathering rind analysis, they suggested that the Bulgobac drift was at least ten times as old as the Boco II drift. As they considered the Boco II drift probably preceded the Last Interglacial (i.e. > 130 ka in age), the Bulgobac drift would therefore be at least 1.3 m.y. in age. The palaeomagnetic data from this site have a dominantly reversed polarity, and thus support their general contention.

However, comparison of the α_{95} cones of confidence for the mean directions of the Marionoak and Bulgobac sites (Fig. 5.1) shows that, at the 95% level of confidence, there is a significant difference between the mean directions of the two sites. This suggests that the Marionoak sediments may not belong to the Bulgobac drift of Augustinus and Colhoun (1986).

The Bulgobac drift in the Boco Valley also had palaeomagnetic values that undoubtedly indicate a reversed polarity. This drift therefore appears to have been deposited during the Matuyama Chron and is thus interpreted with considerable certainty as being > 730 ka in age. Augustinus and Colhoun (1986) suggested that this drift is at least 1.3 m.y. in age, as indicated above (Table 2.1). Acceptance of this as a minimum age would imply that these sediments are either between 1.3 and 1.66 m.y. of age or older than 1.88 m.y. as they would have a normal polarity if they were deposited during the Jaramillo or Olduvai

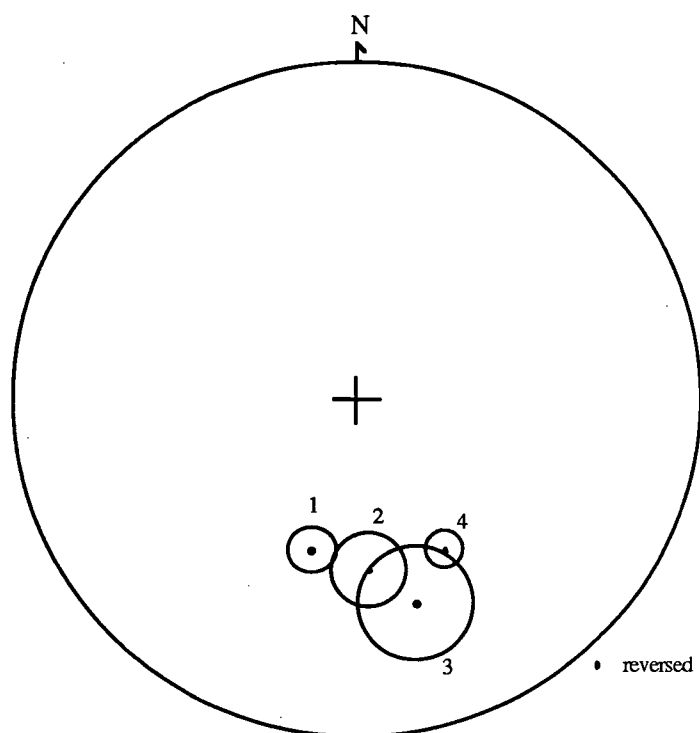


Fig. 5.1 Stereoplot showing mean directions and α_{95} cones of confidence for Que, Bulgobac, Marionoak and Williamsford.

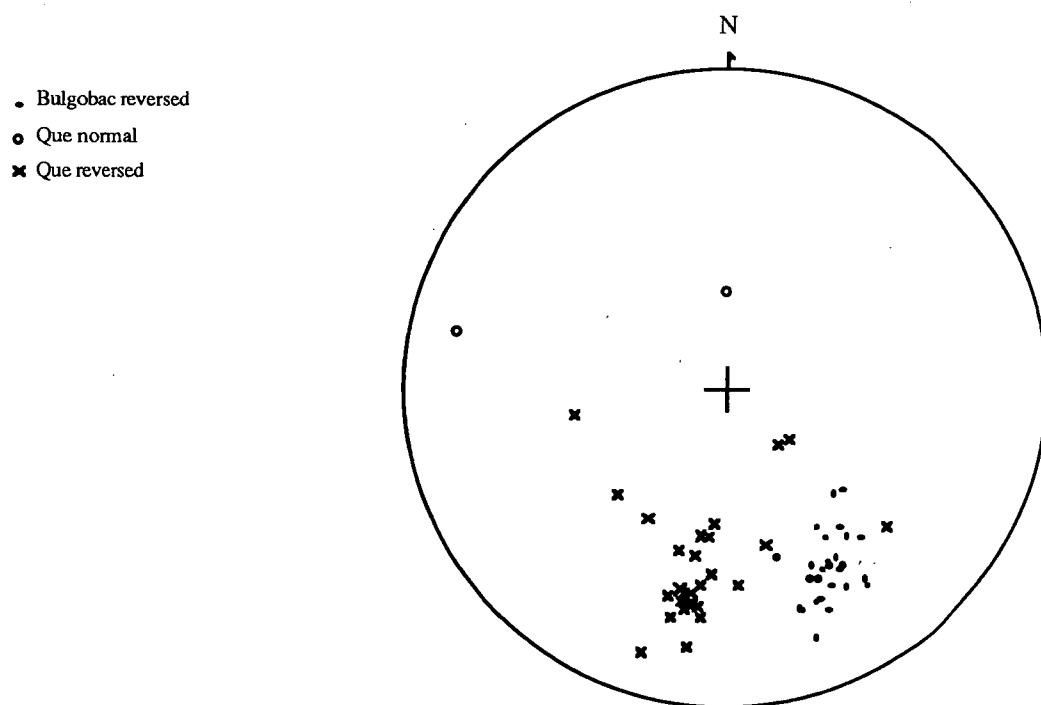


Fig. 5.2 Que and Bulgobac combined stereoplots.

events (refer Fig. 2.6, the polarity time scale). The present palaeomagnetic data can neither confirm nor deny these suggestions.

Beyond the limits of the Bulgobac drift Augustinus and Colhoun (1986) have recognised the Que drift. Specimens from the Que type site had very dominantly reversed polarity and hence are > 730 ka in age. In addition, magnetic directions from the Que site are significantly different from those at the Bulgobac site. Fig. 5.1 shows the plots of the Bulgobac and Que sample data superimposed on the same stereoplot and Fig 5.2 the mean directions and α_{95} cones of confidence. The discrete non-overlapping nature of the cones of confidence indicates that, at the 95% level of confidence, there is a significant difference between the mean directions of these two sites, suggesting that deposition at these sites was probably separated in time. This supports the idea that the Bulgobac drift and the Que drift may have been deposited during separate glacial events, as suggested by Augustinus and Colhoun (1986), not during the same event as suggested by Fitzsimons (1988). In addition, the cones of confidence for the Marionoak and Que sites marginally overlap, indicating that there is not a significant difference between the mean directions of these two sites.

Thus, the Marionoak and Que sediments may represent one glacial event and the Bulgobac sediments another, quite separate, event.

The Boco II drift of Augustinus and Colhoun (1986) was not sampled for this study. Therefore palaeomagnetic data cannot, at this stage, be used to establish whether the Boco I and Boco II drifts represent separate glacial events.

Palaeomagnetic data from the presumed older Boco I drift at the Boco Siding site had a normal polarity; this site is therefore < 730 ka in age. This supports the contention of Augustinus and Colhoun (1986) who regarded it as part of the Penultimate Glaciation and therefore of Middle Pleistocene age.

Drift that occurred further south in the Pieman catchment between Rosebery and Williamsford was considered to be of Boco age by Augustinus and Colhoun (1986). Colhoun and van de Geer (1987) considered the Rosebery Opencut deposit to be of Penultimate Glaciation age because the overlying till deposits of the Boco Glaciation have been radiocarbon dated to more than 43,800 yr BP (SUA 1047) old in the Mackintosh Valley and the pollen assemblage does not contain any ancient types with Tertiary affinities. In addition, wood from the deposits at Rosebery had an amino acid age that indicated Isotope Stage 6 (Colhoun, pers. comm. 1989).

Palaeomagnetic data from the Rosebery Opencut site is of normal polarity, suggesting an age of <730 ka. In addition, these data show a very similar distribution of magnetic directions to the Boco I site near Boco Siding. The combined stereoplots from these two sites are shown in Fig. 5.3 and the mean directions and α_{95} cones of confidence in Fig. 5.4). The cones of confidence show significant overlap, indicating that there is no significant difference in the mean directions of the two sites at the 95% level of confidence. This supports the contention of Colhoun (pers. comm., 1987) that the Rosebery Opencut site represents the Boco Glaciation (undifferentiated age), and suggests that it is of Boco I age.

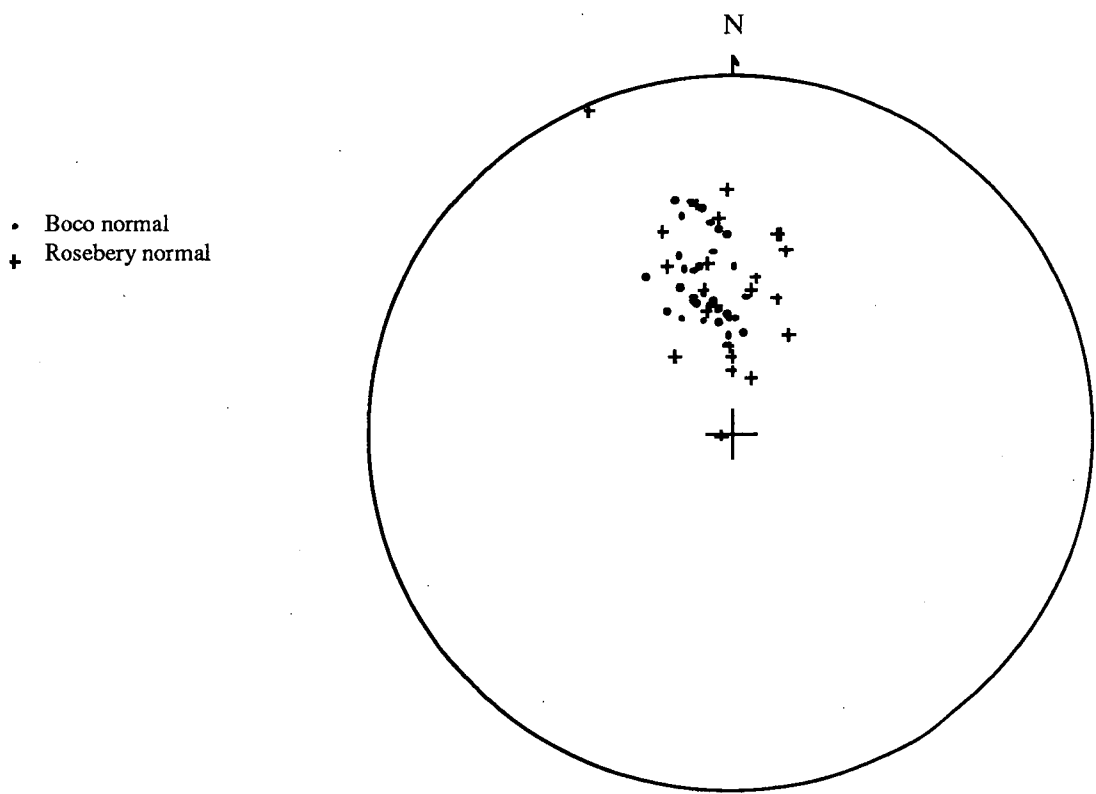
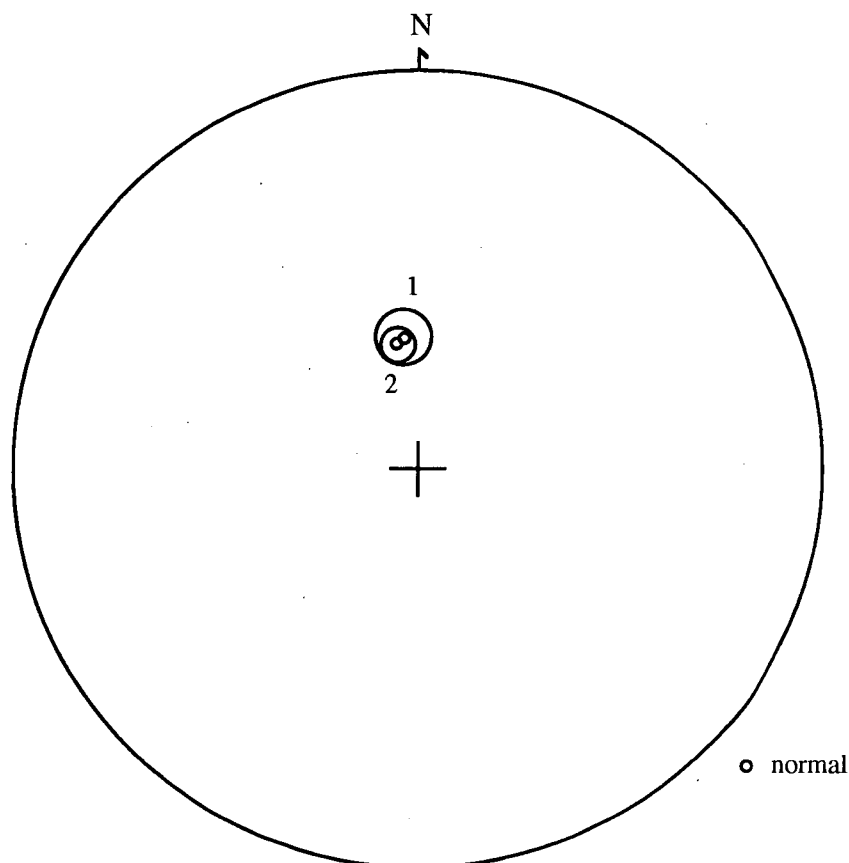


Fig. 5.3 Boco and Rosebery combined stereoplots.



1 Rosebery, α_{95} 7.8°

2 Boco, α_{95} 3.4°

Fig. 5.4 Stereoplot showing mean directions and α_{95} cones of confidence for Boco and Rosebery.

The data from the Williamsford Road site had a dominantly reversed polarity. This is an unexpected result (Colhoun, pers. comm. 1989) and suggests that the ice margin on Mount Read and the associated lateral moraine are of early Pleistocene age. In January 1990 Colhoun and Augustinus re-examined the drift sequence along a transect between Rosebery and Williamsford and determined two ice limits in the area. The outer limit is marked by the Williamsford Moraine which contains extremely weathered deposits that compare with other Bulgobac drift deposits; the inner limit is marked by a moraine at Rosebery Cemetery which contains much less weathered deposits that are comparable with Boco II age deposits. The stratigraphic contact between the deposits of both glaciations can be seen in the road section opposite Rosebery Cemetery entrance (Colhoun and Augustinus, pers. comm.). This new stratigraphic evidence supports the palaeomagnetic findings for the Williamsford Road site.

The mean direction and α_{95} cone of confidence for the Williamsford site are shown in Fig. 5.2, together with those for the Que, Marionoak and Bulgobac sites. Comparison of

the cones of confidence indicates that, at the 95% level of confidence, there is no significant difference between the mean directions of either the Williamsford and Marionoak sites or the Williamsford and Bulgobac sites .

5.2.2 Henty Surface

Laminated sediments from the Tyndall Creek site are dominantly of reversed polarity and hence are > 730 ka in age. These deposits are therefore not from the Penultimate Glaciation nor Henty Glaciation as suggested by Colhoun (1985). Review of the distribution of drifts of different ages on the Henty Surface and adjacent valleys by Colhoun and Augustinus during January - February 1990 showed that the occurrence of highly weathered drift comparable with Bulgobac/Linda drift occurred stratigraphically beneath the laminated sediments in an adjacent section to the south, and that the green Henty Till overlies the laminated series (Colhoun and Augustinus, pers. comm. 1990). The original proposition of Colhoun (1985; see Fig. 2.2) that the limit of maximum glaciation shown west of Henty Bridge is probably represented by deposits formed during glaciations of very different ages is confirmed by the palaeomagnetic data and the subsequent field data. In this regard, the Tyndall Creek section is a key site.

The combined stereoplot for the Que, Bulgobac and Tyndall Creek sites is shown in Fig. 5.5 and mean directions and α_{95} cones of confidence for the Que, Bulgobac, Marionoak, Williamsford and Tyndall Creek sites are shown in Fig. 5.6. Comparison of the cones of confidence for the mean directions for these sites indicates that, at the 95% level of confidence, there is a significant difference between the mean direction of the Tyndall Creek site and each of the other sites. In addition, it has already been shown in Section 5.2.1 that the mean directions of the Que and Bulgobac sites are significantly different. This evidence indicates that there may have been three glacial events in the Early Pleistocene of western Tasmania.

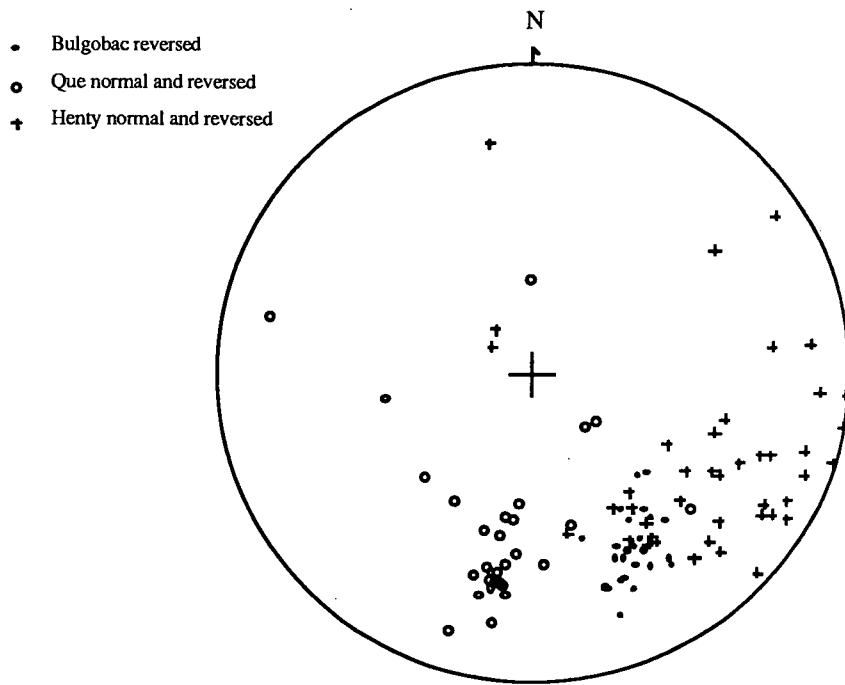
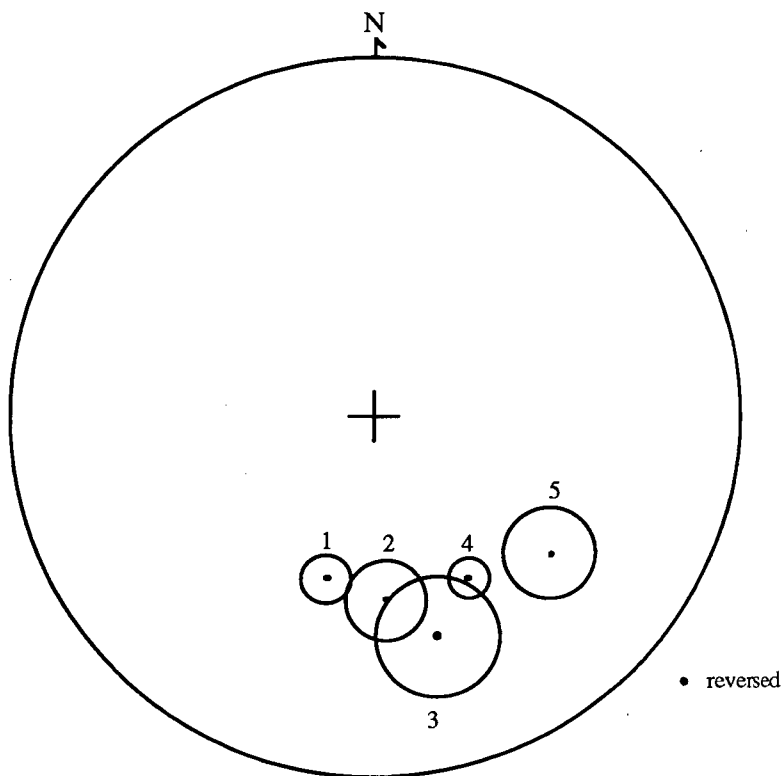


Fig. 5.5 Que, Bulgobac and Tyndall Creek combined stereoplot.



1 Que, $\alpha_{95} 7.2^0$ 2 Marionoak, $\alpha_{95} 9.1^0$ 3 Williamsford, $\alpha_{95} 12.9^0$
 4 Bulgobac A, $\alpha_{95} 3.5^0$ 5 Tyndall Creek, $\alpha_{95} 9.8^0$

Fig. 5.6 Que, Bulgobac, Marionoak, Williamsford and Tyndall Creek mean directions and α_{95} cones of confidence.

5.2.3 King and Linda Valleys

Deposits associated with the Linda Glaciation, called the Thureau Formation by Fitzsimons (1988), were sampled at Thureau Hills and at the Gormanston Moraine. Both these sites had reversed polarity. These results are in agreement with a previous palaeomagnetic result from the Gormanston site (Barbetti and Colhoun, 1988). The deposits assigned to the Linda Glaciation at Gormanston therefore precede the Brunhes-Matuyama boundary and are > 730 ka in age. This supports the contention of Colhoun (1985), Kiernan (1985) and Fitzsimons (1988) that the Linda Glaciation is old, and is of at least Early Pleistocene or possibly Late Tertiary age.

Although both the sites at Gormanston and the site at Thureau Hills have reversed polarity, the site at Thureau Hills, in the King Valley, appears to have a significantly different distribution of directions from the Gormanston Football Field site reported by Barbetti and Colhoun (1988). The magnetic directions of the Gormanston Moraine and Thureau Hills Road sites are shown in Fig. 5.7.

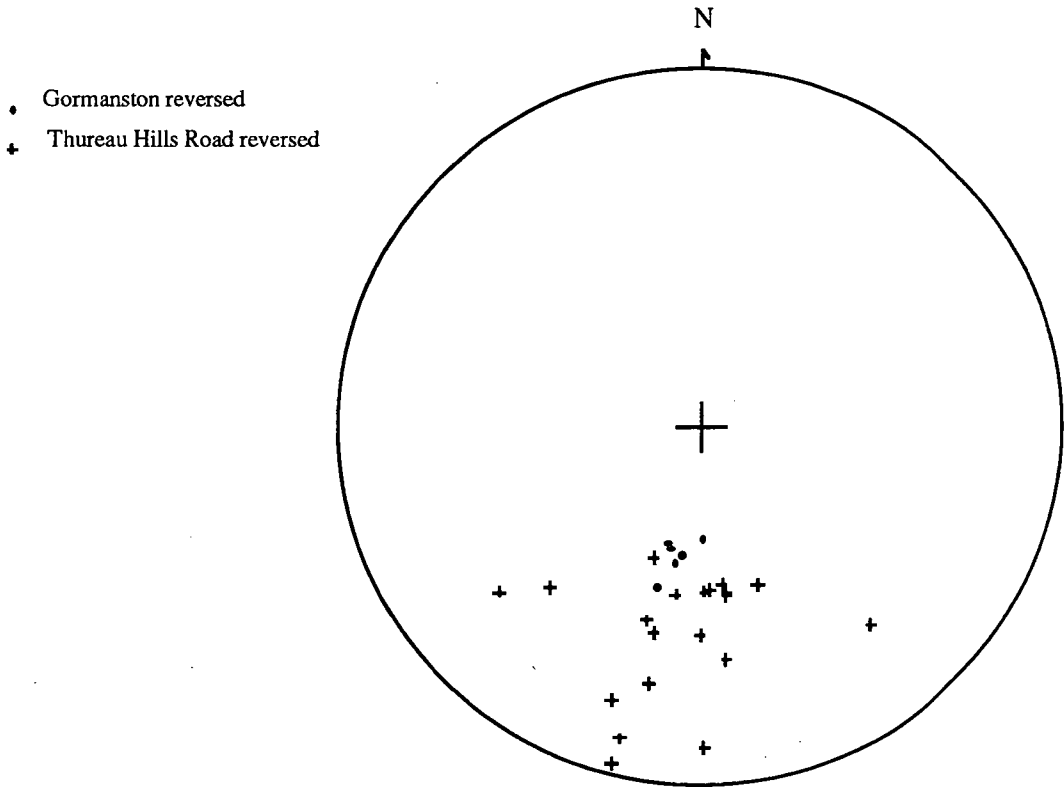
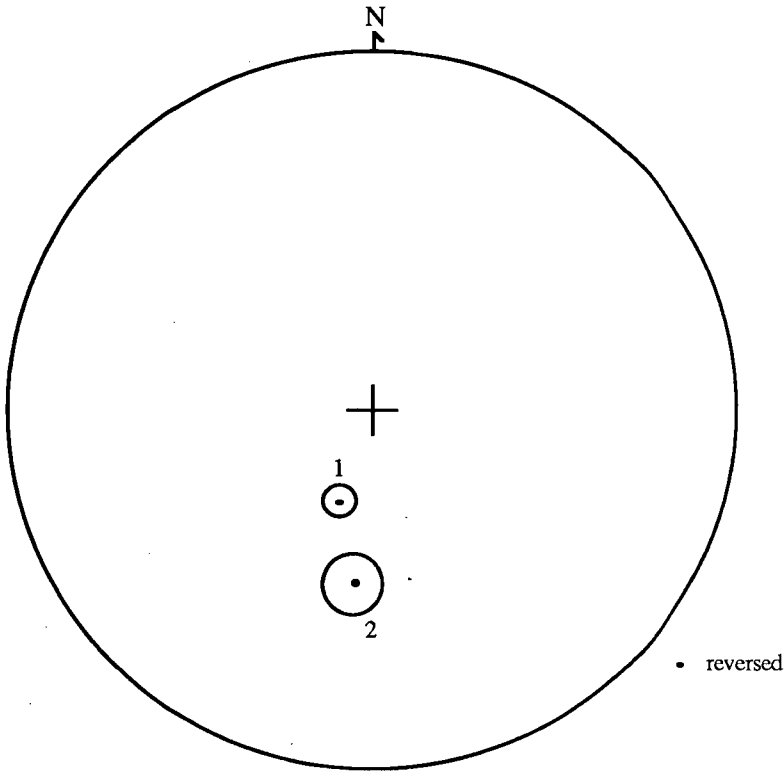


Fig. 5.7 Gormanston Moraine and Thureau Hills Road combined stereoplot.

However, comparison of the α_{95} cones of confidence for the mean directions for the Gormanston Moraine and the Thureau Hills Road sites (Fig. 5.8) shows that there is a significant difference between the mean directions of the two sites at the 95% level of

confidence, but this interpretation needs to be treated with some caution because of the very small number of specimens taken from the Gormanston Moraine site.



1 Gormanston Moraine, α_{95} 3.8⁰ 2 Thureau Hills Road, α_{95} 9.4⁰

Fig. 5.8 Gormanston Moraine and Thureau Hills Road mean directions and α_{95} cones of confidence.

Evidence from these three sites therefore indicates that the moraine at Thureau Hills was probably deposited by an ice advance that differed in age from that which deposited the moraines in the Linda Valley. This suggests that multiple phases of ice advance occurred during the Linda Glaciation, a suggestion which has also been made by Kiernan (1983).

Deposits exposed in a creek adjoining the Thureau Hills site had a very dominantly normal polarity. Fitzsimons (1988) interpreted this site as being a lower part of the deposit exposed at a higher level in the adjoining road cutting. The rhythmite clay deposits in the creek and road cutting cannot be separated stratigraphically or on the basis of weathering. The normal polarity of the lower deposits and the reversed polarity of the stratigraphically higher deposits suggest that the creek deposits may represent either the Jaramillo or Olduvai normal events in the Matuyama Chron. However, the boundary between the normally magnetised sediments and the sediments with reversed magnetisation was not able to be determined. It is also possible that the magnetisation in the creek site sediments

is a chemical remanent magnetisation derived from groundwater flow and therefore of more recent origin.

The Baxter Formation occurs at Baxter Rivulet and was considered to be of Middle Pleistocene age by Fitzsimons (1988), and Isotope Stage 10 (350,000 - 450,000 years BP) by Colhoun and Fitzsimons (in press). All the specimens from this site have normal polarity and so are < 730 ka in age, thus supporting this conclusion.

The David Formation is exposed on the northeastern flank of North Owen Peak near Linda Creek. This deposit was considered to be at least 150 ka in age by Fitzsimons (1988) and the Nelson Formation, exposed in excavations at the proposed bridge site in the King Valley, was considered to be slightly older. Virtually all specimens from the two sites have normal polarity and both sites have fairly tightly grouped, but quite distinct, sets of magnetisation directions (Fig 5.9). Comparison of the α_{95} cones of confidence for the Baxter, David and Nelson Formations (Fig. 5.10) shows that, at the 95% level of confidence, there is a significant difference between the mean directions of the David and Nelson Formations, and the David and Baxter Formations. There is not, however, a significant difference between the mean directions of the Nelson and Baxter Formations at the 95% level of confidence.

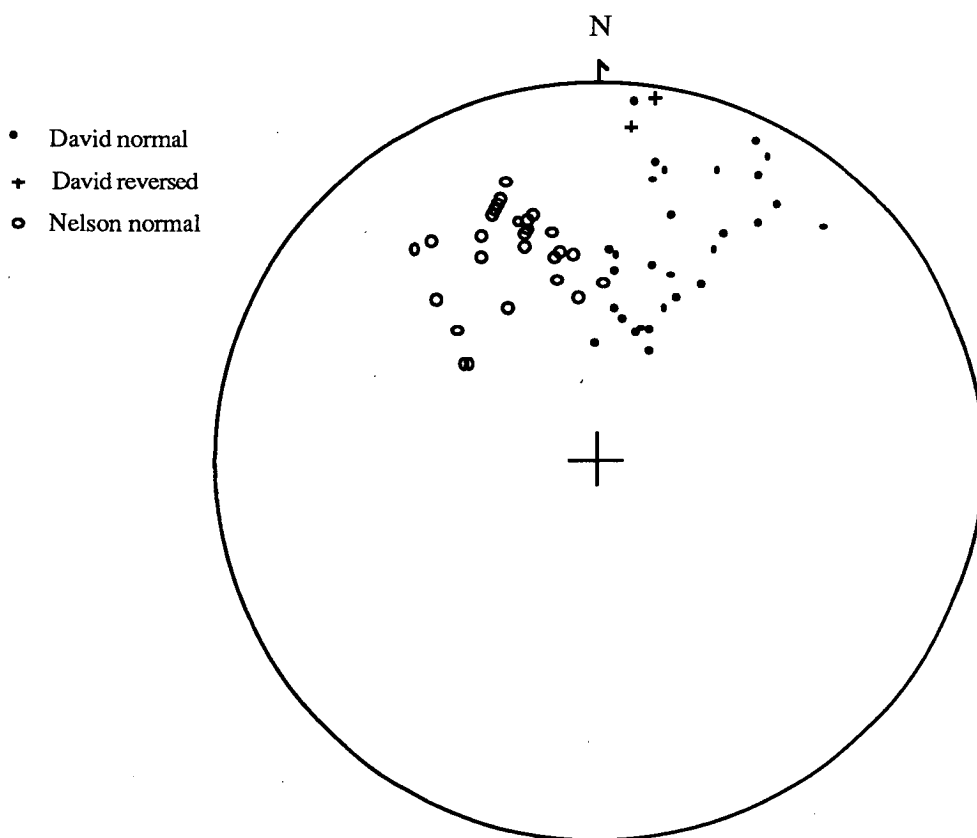
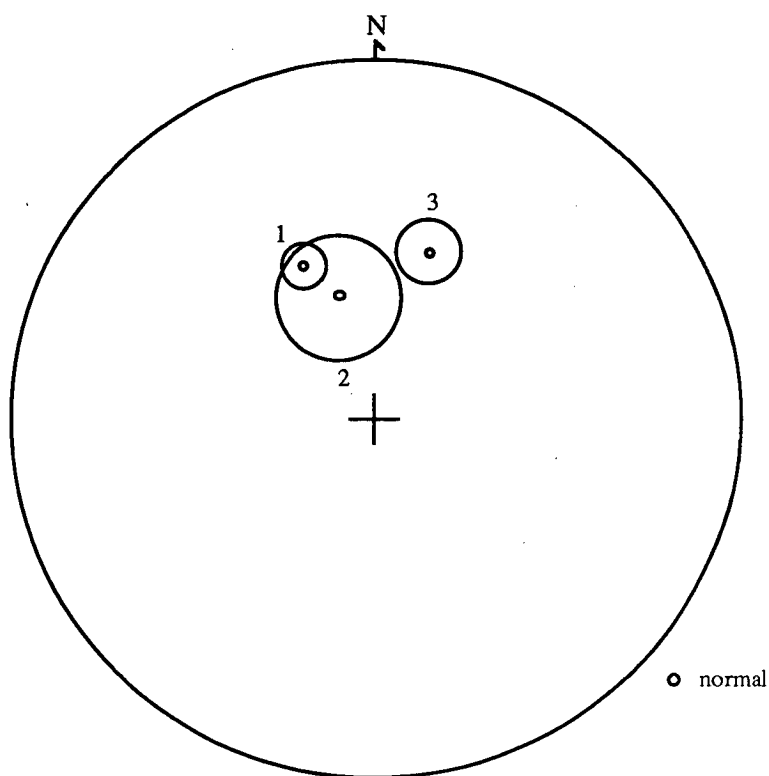


Fig. 5.9 David and Nelson Formations combined stereoplot.

The palaeomagnetic evidence therefore supports the allocation of the David and Nelson deposits to separate formations and a Middle Pleistocene age, and suggests that the Baxter and Nelson Formations may have been deposited at much the same time.



- 1 Nelson Formation, $\alpha_{95} 5.2^0$ 2 Baxter Formation, $\alpha_{95} 19.9^0$
 3 David Formation, $\alpha_{95} 7.0^0$

Fig. 5.10 David, Nelson and Baxter Formations mean directions and α_{95} cones of confidence.

There is a significant difference in strength of magnetisation between the Thureau and Baxter Formations on the one hand and the David and Nelson Formations on the other, the former group being one to two orders of magnitude weaker than the latter group. This difference probably reflects the differing source areas of the sediments. Sediments of the David and Nelson Formations have a much higher percentage of detritus derived from dolerite whereas quartz-rich materials were an important input to the Thureau and Baxter Formations (Fitzsimons, 1988).

Laminated clays within a sand and gravel deposit are also exposed at the King Gorge Exit site in the Lower King Valley. These deposits were correlated, on the basis of the

significant degree of weathering of the sediments, with Thureau Formation tills on the eastern side of the West Coast Range by Fitzsimons (1988). He considered them to be outwash material associated with the Thureau Formation tills of the King Valley. The very weak magnetic signal of these sediments, on average about half that of the Thureau Formation sediments in the King Valley, is in accordance with his suggestion.

Although the directions of magnetisation from this site are very scattered, almost all specimens have a normal polarity. This suggests that these sediments are either <730 ka in age, and hence not a correlate of the Thureau Formation, or are > 910 ka in age, should they belong to the Jaramillo normal event of the Matuyama Chron. However, they could also belong to one of the older normal events of the Matuyama Chron. Thus, they could be of either Middle or Early Pleistocene age.

The scattered nature of the directions and the extremely weak magnetic signal of the specimens make these results relatively unreliable. Therefore little significance should be read into these results which are probably best regarded as being inconclusive.

5.3 North Central Sites

The stratigraphy of the upper Mersey Valley, as determined by Hannan and Colhoun (1987) and Hannan (1988), has been discussed in Chapter 2.1, and illustrated in Table 2.3 and Fig. 2.4. As indicated, Hannan and Colhoun recognised three glaciations in the upper Mersey Valley, the Rowallan, the Arm and the Croesus Glaciations respectively; they regarded these glaciations to be the approximate correlates, respectively, of the Margaret, Henty and Linda Glaciations of the West Coast Range. A glaciation, presumed to be a correlate of the Linda Glaciation, and an older glaciation, the Lemonthyme Glaciation, have also been recognised in the upper Forth Valley by Colhoun (pers. comm. 1987).

The combined stereoplot for the North Central sites is shown in Fig. 5.11 and the mean directions and α_{95} cones of confidence for each of the sites in Fig. 5.12. Rhythmites in the Fish River, from within the limits of the Rowallan Glaciation, and from the Arm River, have normal polarities. Comparison of the α_{95} cones of confidence for the mean directions of the Fish River, Arm River Bridge and Arm River Road sites shows that, at the 95% level of confidence, there is no significant difference between the mean directions of the Fish River and Arm River Bridge sites. There is, however, a significant difference between the mean direction of the Arm River Road site and both the Fish River and Arm River Bridge sites. This tends to support the contention of Hannan and Colhoun (1987) that the Rowallan and Arm River Road deposits represent two glacial events within the

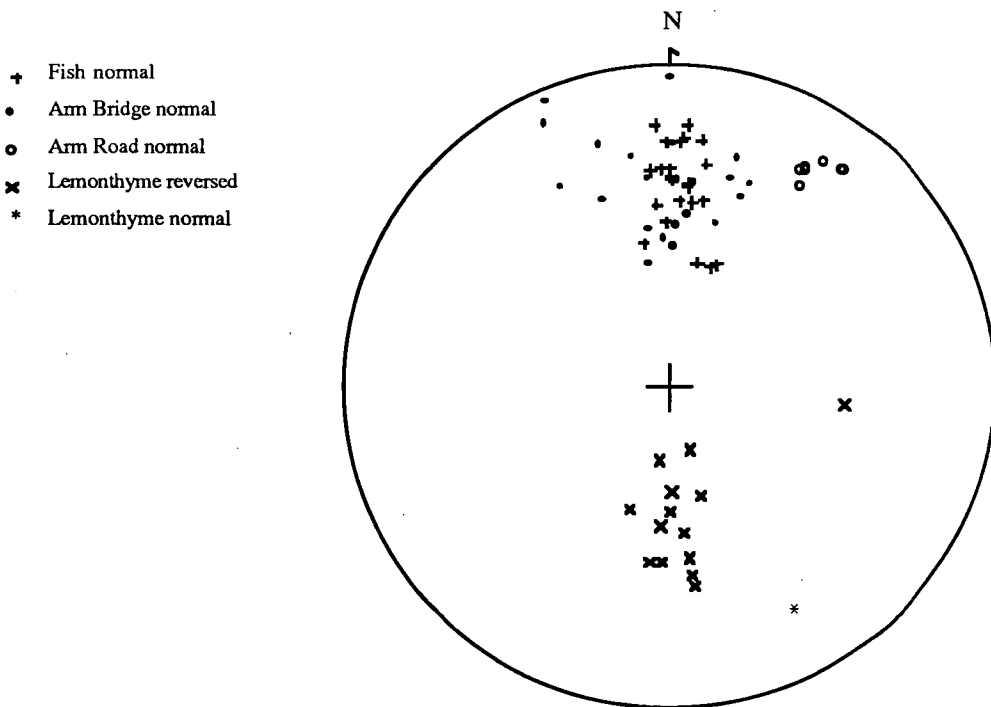
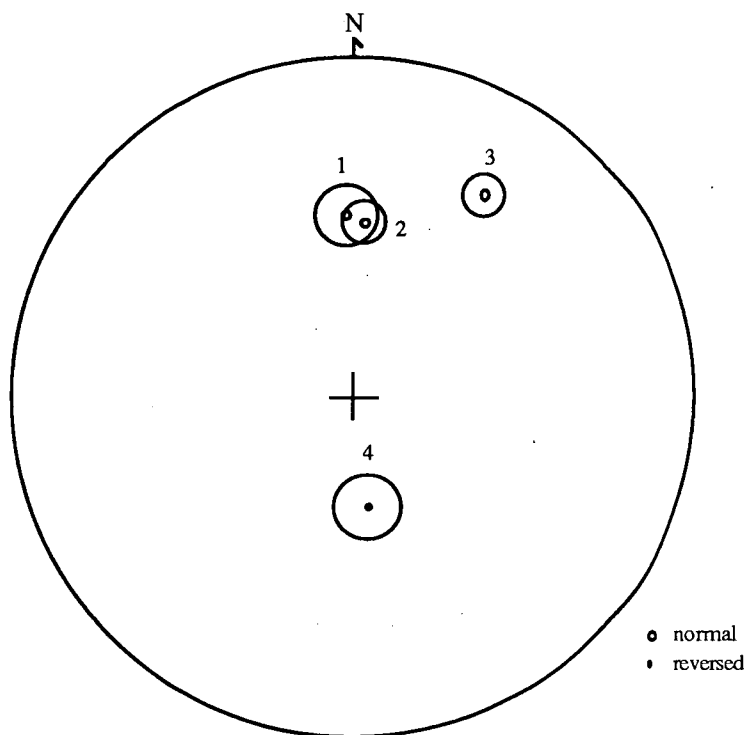


Fig. 5.11 Combined stereoplot for the North Central sites.



1 Arm River Bridge, $\alpha_{95} 7.5^0$ 2 Fish River, $\alpha_{95} 5.0^0$
 3 Arm River Road, $\alpha_{95} 4.0^0$ 4 Lemonthyme Penstock, $\alpha_{95} 9.0^0$

Fig. 5.12 Mean directions and α_{95} cones of confidence for the North Central sites.

Late and Middle Pleistocene respectively. This interpretation, however, needs to be treated with some caution because of the very small number of specimens taken from the Arm River Road site; a more extensive sampling of the Arm River Road site is needed to confirm this fully. This has not been possible in this study because of the extreme hardness of the Arm River Road sediments, which could not be sampled easily with plastic cubes.

Palaeomagnetic data could not be obtained from the Croesus Glaciation as there are no suitable exposures of rhythmites available. Rhythmites at Lemonthyme Penstock in the Forth Valley have been correlated with the Croesus Glaciation by Hannan and Colhoun (1987). These rhythmites are separate from those belonging to the Lemonthyme Glaciation, which is known only from drillholes and is regarded to be much older, possibly Tertiary in age (Colhoun, 1975).

The rhythmites at Lemonthyme Penstock in the Forth Valley have a reversed polarity. They therefore belong to the Matuyama Chron and hence are > 730 ka in age. These sediments are thus at least of Early Pleistocene age, supporting the contention of Hannan and Colhoun (1987). Their correlation of this deposit with the Croesus Glaciation suggests that the Croesus Glaciation is also of Early Pleistocene age. Hannan and Colhoun (1987), on the basis of weathering rind analysis, suggested that the Croesus Glaciation may be > 1.7 m y old. The palaeomagnetic data does not provide any direct evidence on this suggestion.

Palaeomagnetic data from the Mersey and Forth valleys thus lends support to the concept of three glaciations in this area, as suggested by Hannan and Colhoun (1987), and generally confirms the suggested dating of the stratigraphy. No attempt was made to determine the palaeomagnetic characteristics of the ancient Lemonthyme Glaciation.

5.4 West Central Sites

The stratigraphy of the upper Franklin Valley, as determined by Kiernan (1989), has been discussed in Chapter 2.1 and is illustrated in Table 2.4 and Fig. 2.5. He suggested that this area had experienced multiple glaciation, with as many as five or six separate glacial events.

Rhythmites associated with the Sawmill Ridge moraines (Taffys Creek Glaciation) east of King William Creek (referred to herein as the King William Creek site) have normal polarity. This supports the general age suggested by Kiernan (1989).

The palaeomagnetic data from the Stonehaven Creek site, however, indicates a dominantly normal polarity. Kiernan (1985) interpreted weathering rinds on dolerite with a mean thickness of 41.2 mm as indicating that the deposits were older than 950 ka. If this deposit is > 730 ka, it could be either 910 to 980 ka or 1.66 to 1.88 ka in age, and thus belong to one of the normal polarity events within the Matuyama Chron. The data, therefore, neither definitely confirm nor preclude an Early Pleistocene age for the Stonehaven Glaciation. However, taking into account the morphostratigraphic and weathering data of Kiernan, an older age seems much more likely to be correct. If this is so, then the palaeomagnetic data from Stonehaven Creek suggest that the deposit is at least 0.91 million years in age, assuming that the normal polarity represents the first of the normal events of the Matuyama Chron, the Jaramillo Event. This conclusion supports Kiernan's general stratigraphic framework (1985) and his minimum age for the Stonehaven Glaciation.

Data from Double Barrel Creek show a mixed polarity (8 specimens reversed and 5 specimens normal) and they are widely scattered on the stereoplot. The results from this site are therefore best regarded as inconclusive. However, since Double Barrel Creek is only one km west of Stonehaven Creek, the drift at this site probably represents the most westerly extent of the Stonehaven Drift deposited by ice flowing along the southeastern margin of Mt Alma. This evidence, together with the evidence from the Stonehaven Creek site, therefore favours a reversed magnetisation and an early Pleistocene age for the drift at Double Barrel Creek.

5.5 Summary of Palaeomagnetic Results

The palaeomagnetic results are in good general agreement with the chronostratigraphic framework established by other workers. The results from all the regions support, to a greater or lesser degree, the concept of multiple glacial events during the Quaternary in Tasmania. They also confirm the suspected considerable age of the 'oldest' glaciation, the Linda Glaciation; this glaciation is at least 730 ka years of age but may be very much older. The palaeomagnetic data also indicate that this glaciation may have been much more complex than previously thought, consisting of several major ice advances (three suggested) that could belong to separate glacial events.

The strength of the magnetic signal is quite variable between sites but this variation does not seem to be related to the ages of the deposits. Rather it appears to be related to the nature and distance of the deposits from particular source rock types. Thus lake sediments that have high quantities of detritals derived from Jurassic dolerite or Cambrian Mount Read Volcanics have a much stronger magnetic signal than those lake sediments with detritals derived mainly from the various siliceous conglomerates, sandstones, schists and quartzites of the areas.

The palaeomagnetic data have established that the rhythmites at the Tyndall Creek site, formerly thought to belong to the Henty Glaciation (the Penultimate Glaciation), are > 730 ka in age. They are therefore of Linda Glaciation age in the broadest sense.

The suggested relationships of the sites and the drift formations based on interpretation of the palaeomagnetic data are shown in Table 5.4.

5.6 Correlations

One of the major aims of this study was to separate glacial deposits in Tasmania that were older than 50 ka in age, and therefore beyond the range of radiocarbon dating, into those that exhibit normal and reversed polarity signals. Samples with a normal polarity are likely to belong to the Brunhes Chron, and hence would be < 730 ka old, and therefore of Late or Middle Pleistocene age. Samples with a reversed polarity belong to the Matuyama Chron, are > 730 ka old, and are therefore of Early Pleistocene or Late Tertiary age.

Table 5.4 Suggested relationships of sites based on the application of the palaeomagnetic data to the established stratigraphy.

CHRON	WEST COAST			NORTH CENTRAL	WEST CENTRAL
	Pieman	Henty	King		
B				Fish River ¹	
R				Arm River Bridge ¹	
U				Arm River Road (?) ²	
N			Linda Ck. ³		
H			King River Bridge ⁴		
E					
S	Boco ⁵ Rosebery Opencut ⁷		Baxter Riv. ⁶		King William Ck. ⁸
730ka					
M		Tyndall Creek ⁹			
A	Bulgobac ¹⁰				
T					
U	Williamsford ¹¹				
Y	Marionoak ¹² Que ¹⁵		Gormanston ¹³ Thureau Hills Rd. ¹⁶	Lemonthyme Penstock ¹⁴	Stonehaven(?) ¹⁷
A					
M					
A					

¹ Rowallan Glaciation, Hannan and Colhoun, 1987.

² Arm Glaciation, Hannan and Colhoun, 1987.

³ Blackwood Formation, Fitzsimons, 1988; David Formation, Colhoun and Fitzsimons, 1990.

⁴ Nelson Formation, Fitzsimons, 1988.

⁵ Boco I drift, Augustinus and Colhoun, 1986.

⁶ Baxter Formation, Fitzsimons, 1988.

⁷ Boco I drift, Colhoun and van de Geer, 1987.

⁸ Beehive phase, Kiernan, 1989.

⁹ Henty Glaciation, Bowden, 1974; Linda Glaciation, Colhoun, pers. comm. 1990.

¹⁰ Bulgobac drift, Augustinus and Colhoun, 1986.

¹¹ Linda Glaciation, Colhoun, pers. comm., 1987.

¹² Linda Glaciation, Colhoun, pers. comm., 1990.

¹³ Linda Glaciation, Colhoun, pers. comm., 1987.

¹⁴ Croesus Glaciation correlate, Hannan and Colhoun, 1987.

¹⁵ Que drift, Augustinus and Colhoun, 1986.

¹⁶ Thureau Formation, Fitzsimons, 1988.

¹⁷ Stonehaven drift, Kiernan, 1989.

In a very broad sense, therefore, all those sampled deposits < 730 ka in age but beyond the range of radiocarbon dating can be grouped together, with the exception of the Fish River and Arm River Road deposits which are of Last Glaciation age. Similarly, all those deposits > 730 ka in age can be grouped together. In the model based on three glacial episodes, the former group of deposits represent the Penultimate Glaciation and the latter group the earliest glaciation.

On this basis the Croesus Formation of the Mersey Valley, the Lemonthyme Formation of the Forth Valley, the Thureau Formation of the King Valley, the Bulgobac and Que Formations of the Pieman Valley, the Williamsford deposits and the Tyndall Creek deposits can be palaeomagnetically correlated. As some of these formations have been previously correlated with the Linda Glaciation of the West Coast Range they can all be considered to be 'Linda correlates'. Further consideration of the palaeomagnetic data allows this broad correlation to be considerably refined, as discussed below.

Similarly, the Boco, Rosebery Opencut, Linda Creek, King River Bridge, Baxter Rivulet, and Arm River Road deposits can all be loosely correlated. As some of these deposits have been previously correlated with the Henty Glaciation, they can be considered to be 'Henty correlates'. Further consideration of the palaeomagnetic data also allows considerable refinement of this broad correlation.

5.6.1 Regional Correlation

Comparison of the stereoplots for the Que and Thureau Hills Road sites (Fig. 5. 13) indicates that these sites have a similar spread of declinations and inclinations and so probably represent the same glacial event. Mean directions and α_{95} cones of confidence for the Que, Marionoak and Thureau Hills Road sites are shown in Fig. 5.14. The α_{95} cones of confidence for the Que and Thureau Hills Road sites show considerable overlap, as do those for the Marionoak and Thureau Hills Road sites. This indicates that, at the 95% level of confidence, there is no significant difference between the mean directions of the Que and Thureau Hills Road sites and the Marionoak and Thureau Hills sites. As already indicated in Section 5.2.1, the α_{95} cones of confidence for the Marionoak and Que sites, however, just touch, indicating that there is no significant difference between the mean directions of these two sites at the 95% level of confidence. This suggests that the deposits at these three sites probably represent the same glacial event, with the Thureau Hills Road deposits occurring temporally between the Que and Marionoak deposits. Accordingly, the Que and Marionoak deposits of the Pieman Valley area (Augustinus and Colhoun, 1986) can be correlated with the Thureau Formation deposits of the King River Valley (Fitzsimons, 1988).

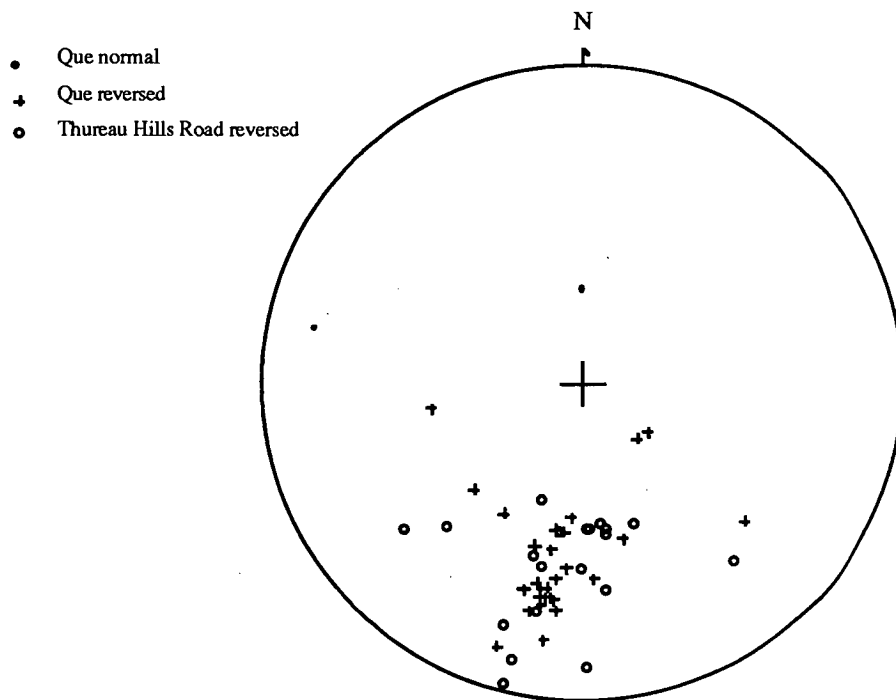
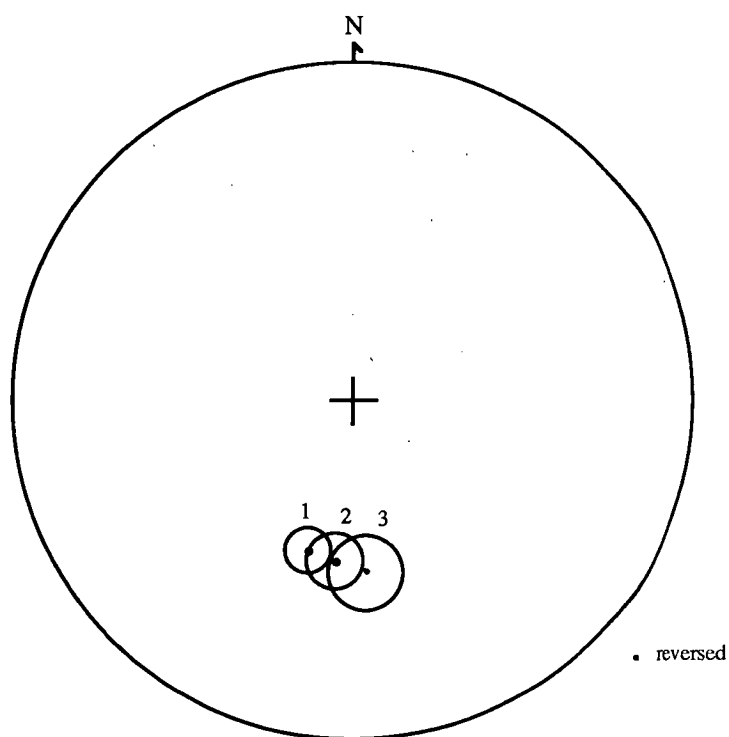


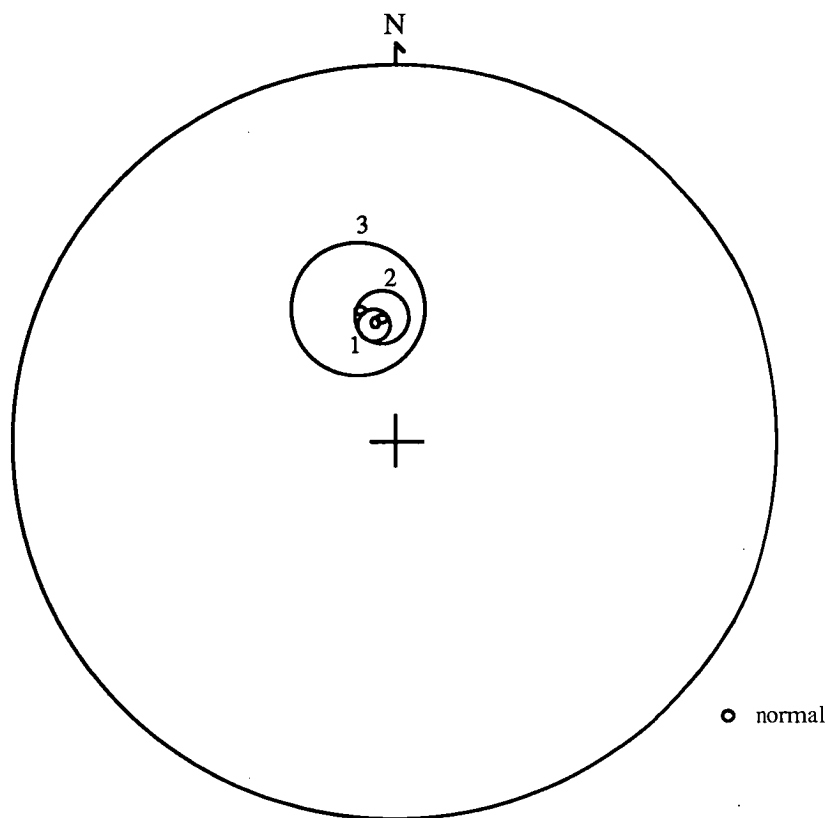
Fig. 5.13 Que and Thureau Hills Road combined stereoplot.



1 Que, α_{95} 7.20 2 Thureau Hills Road, α_{95} 9.40 3 Marionoak, α_{95} 9.10

Fig. 5.14 Que, Marionoak and Thureau Hills Road mean directions and α_{95} cones of confidence.

The mean directions and α_{95} cones of confidence for the Boco, Rosebery Opencut and Baxter sites are shown in Fig. 5.15. Comparison of the α_{95} cones of confidence for the mean directions shows that, at the 95% level of confidence, there is no significant difference between the mean directions of these sites. The Baxter Formation of the King Valley can therefore be correlated with the Boco I age deposits at Boco and Rosebery Opencut.



1 Boco, $\alpha_{95} 3.4^0$ 2 Rosebery Opencut, $\alpha_{95} 7.8^0$ 3 Baxter Rivulet, $\alpha_{95} 19.9^0$

Fig. 5.15 Boco, Rosebery Opencut and Baxter Rivulet mean directions and α_{95} cones of confidence.

5.6.2 Correlation within Tasmania

Fitzsimons (1988) addressed the problems of attempting to correlate glacial events within Tasmania. He pointed out that in order to be able to attempt such correlations the chronologies of other studies need to be assessed and compared. He also indicated that "such a comparison is beset by several problems that include a lack of relative dating data, absence of absolute dates for deposits older than the late part of the Last Glaciation, and lack of a consistent approach to field mapping and stratigraphic classification."

His suggested correlation of the major glacial sequences (Table 5.5) was based on two factors:

- a) radiocarbon dating for the late Last Glaciation.
- b) analysis of weathering rind data from Jurassic dolerite clasts for all other sediments.

Table 5.5 Correlation of Quaternary glacial sequences in Tasmania (after Fitzsimons, 1988).

Glaciations	Interglacials	King Valley (Fitzsimons, 1988)	Pieman Valley (Augustinus, 1982)	Lake St. Clair central plateau (Kiernan, 1985)	Mersey Valley (Hannan and Colhoun, 1987)
		Dante		Cynthia Bay	Rowallan
Margaret		Chamouni			
	Langdon?				
		Dunn		Beehive	
Henty		David	Boco 2	Powers Creek	Arm
		Cableway		Clarence	
Moore		Moore/ Fish	? Boco 1		
		Traveller			
	Regency	Regency			
Linda		Thureau	Bulgobac ? Que	Stonehaven	Croesus

Interpretation of the palaeomagnetic data only allows minor correlation of individual sites from various regions within Tasmania.

The combined stereoplot for Boco, Rosebery Opencut and King William Creek is shown in Fig. 5.16 and the mean directions and the α_{95} cones of confidence for these sites are shown in Fig. 5.17. Comparison of the α_{95} cones of confidence indicates that, at the 95% level of confidence, there are no significant differences between the mean directions of the sites. The Taffys Creek drift of the Central Plateau (Kiernan, 1989), exposed at the King William Creek site, can therefore be correlated with the Boco I Glaciation deposits of the Pieman Valley (Augustinus and Colhoun, 1986).

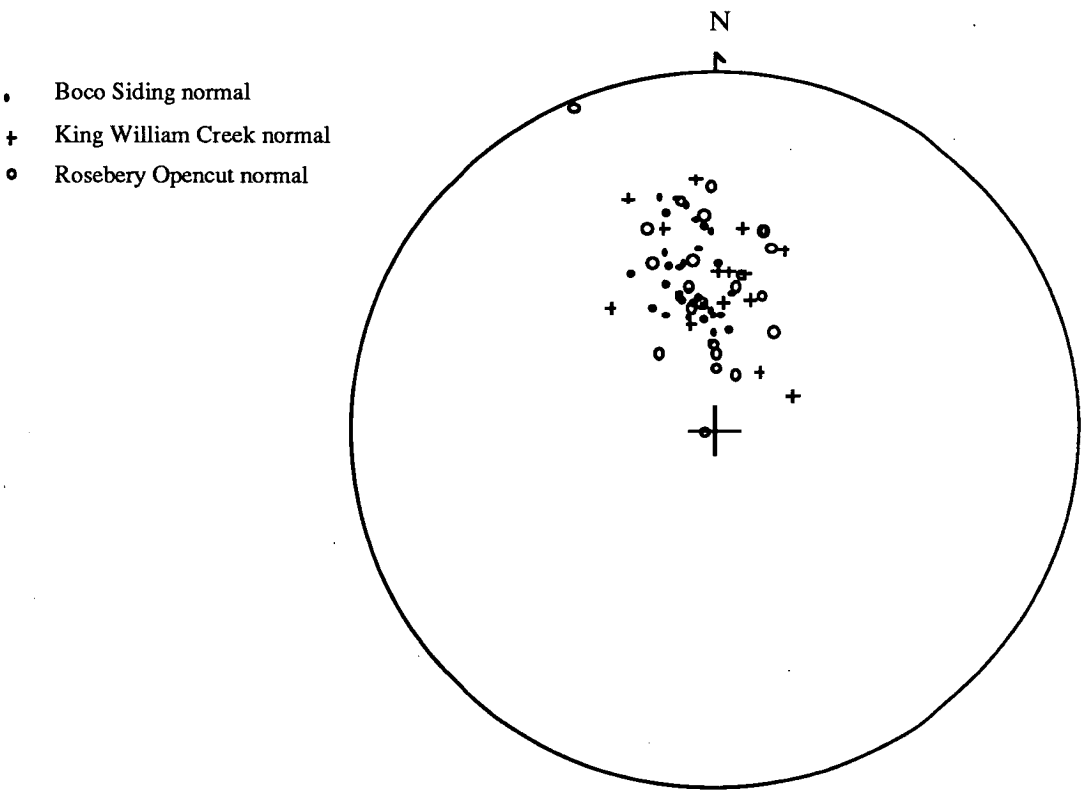
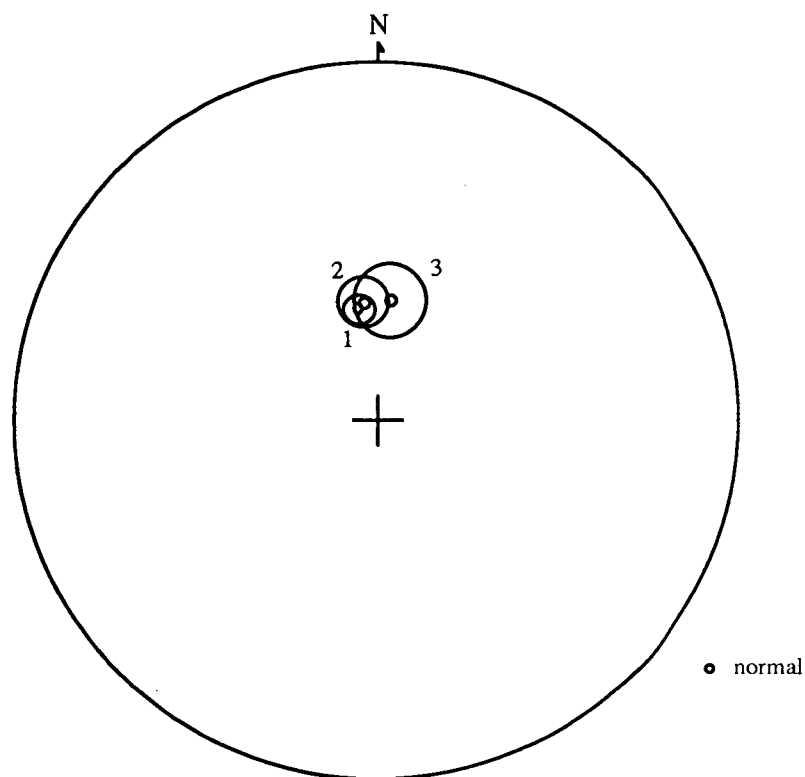


Fig. 5.16 Boco, Rosebery Opencut and King William Creek combined stereoplot.



1 Boco, $\alpha_{95} 3.4^0$

2 Rosebery Opencut, $\alpha_{95} 7.8^0$

3 King William Creek, $\alpha_{95} 9.3^0$

Fig. 5.17 Boco, Rosebery Opencut and King William Creek mean directions and α_{95} cones of confidence.

The combined stereoplot for the David Formation (Linda Creek site) of the King River Valley and the Arm River Road site of the Mersey Valley is shown in Fig. 5.18. Site mean directions and α_{95} cones of confidence are shown in Fig. 5.19. Comparison of the stereoplot of the David Formation with that from the Arm River Road deposits suggests that these two sites may be correlated. However, comparison of the α_{95} cones of confidence indicates that, at the 95% level of confidence, there is a significant difference between the mean directions of these two sites. The David Formation of the King River Valley cannot, therefore, be correlated with the Arm River Road deposits of the Mersey Valley. This result needs to be treated with some caution, however, because of the very small sample from the Arm River Road site.

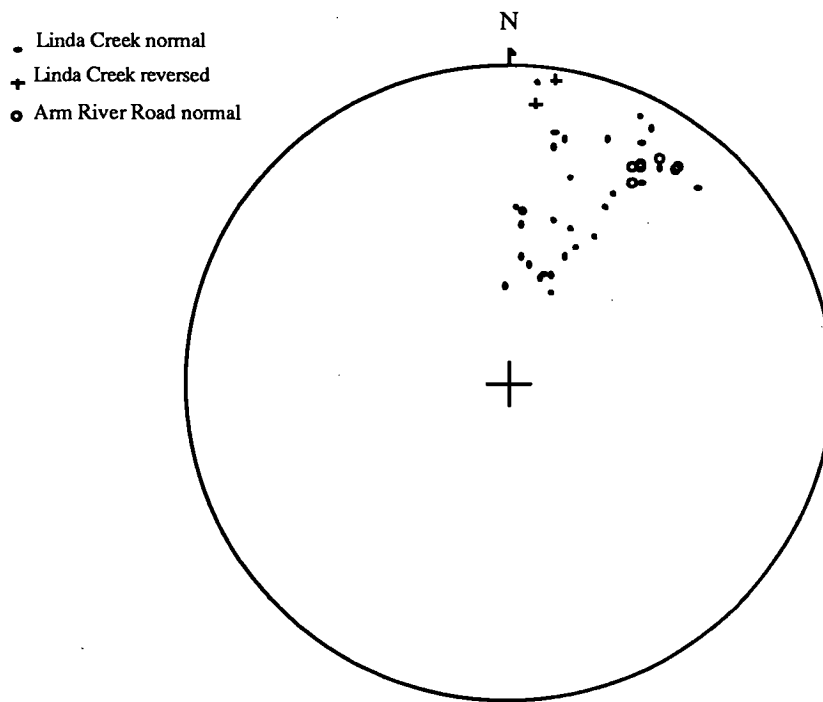
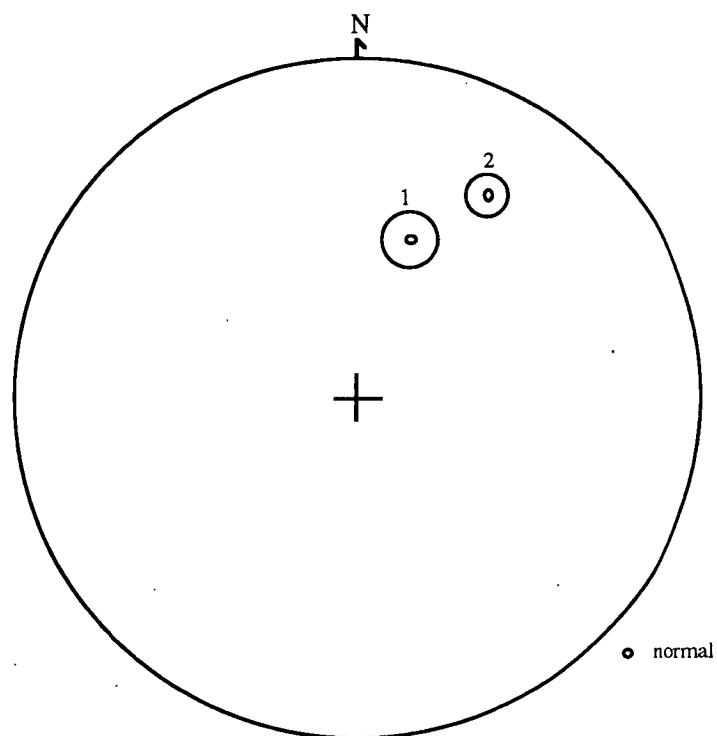


Fig. 5.18 David Formation (Linda Creek) and Arm River Road combined stereoplot.



1 David Formation, $\alpha_{95} 7.0^{\circ}$

2 Arm River Road, $\alpha_{95} 4.0^{\circ}$

Fig. 5.19 David Formation (Linda Creek) and Arm River Road mean directions and α_{95} cones of confidence.

The combined stereoplot for the Lemonthyme Penstock (Forth Valley), Marionoak (Pieman Valley) and Thureau Hills Road (King Valley) sites is shown in Fig. 5.20. The Lemonthyme Penstock specimens form a relatively tight group that shows some overlap with the more dispersed Marionoak and Thureau Hills Road specimens, suggesting a possible correlation. The site mean directions and α_{95} cones of confidence for these sites are shown in Fig. 5.21. Comparison of the α_{95} cones of confidence shows that, at the 95% level of confidence, there is no significant difference in the mean directions of either the Marionoak and Lemonthyme Penstock sites or the Thureau Hills Road and Lemonthyme Penstock sites. Furthermore, as shown in Section 5.6.1, the Marionoak and Thureau Hills Road sites can be correlated. Therefore, the Lemonthyme Penstock deposits in the Forth Valley can be correlated with the Thureau Formation in the King Valley and the Marionoak deposits in the Pieman Valley.

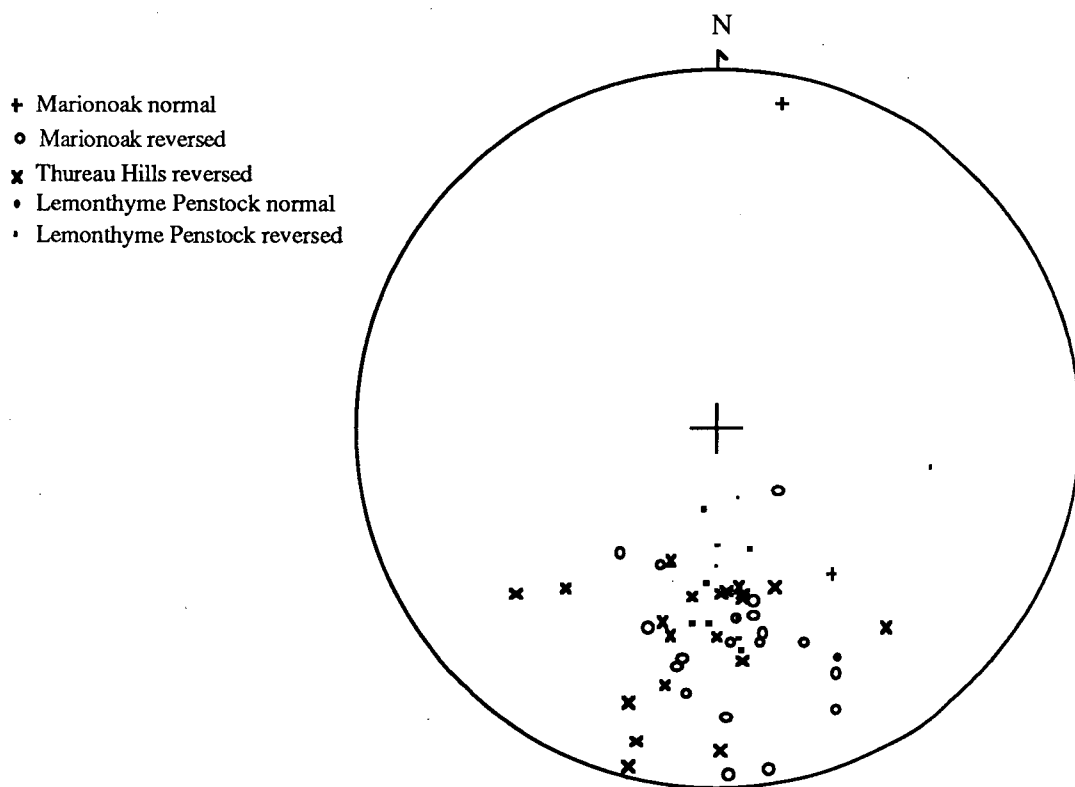
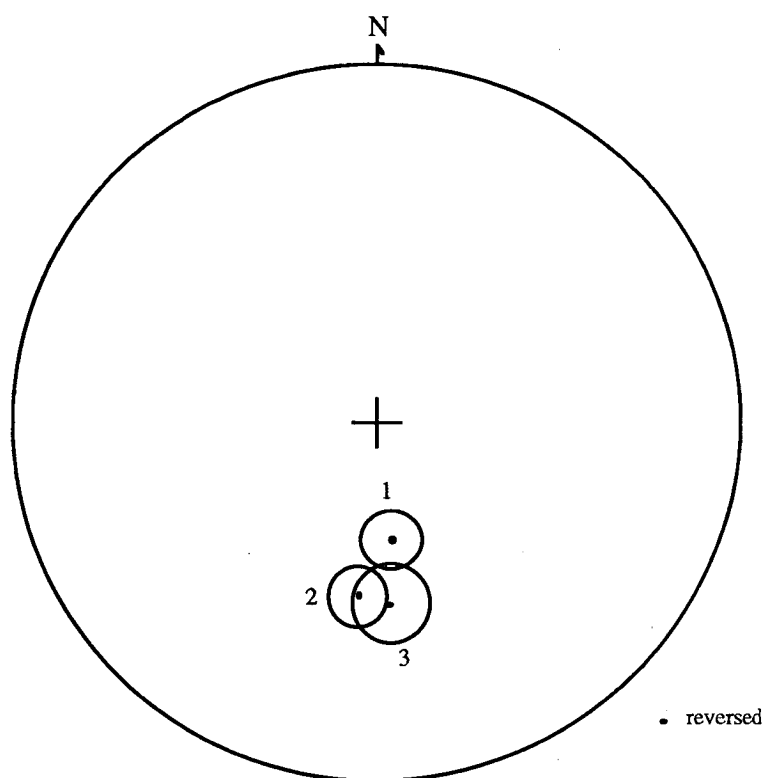


Fig. 5.20 Lemonthyme Penstock, Marionoak and Thureau Hills Road combined stereoplot.



1 Lemonthyme Penstock, α_{95} 9.0⁰
3 Marionoak, α_{95} 9.1⁰

2 Thureau Hills Road, α_{95} 9.4⁰

Fig. 5.21 Lemonthyme Penstock, Marionoak and Thureau Hills Road mean directions and α_{95} cones of confidence.

5.6.3 Correlations with Glacial Events in the Southern Hemisphere

Various earlier workers, e.g. Colhoun (1985), Hannan and Colhoun (1987), and Fitzsimons (1988), have made tentative correlations with some of the other Southern Hemisphere glacial sequences. Much of this correlation is speculative and Fitzsimons (1988) has emphasised the dangers of correlating without dating (discussed in Section 5.6.2).

No attempt has been made in this study to correlate the glacial events of Tasmania with the glacial events that occurred elsewhere in the Southern Hemisphere, including south eastern mainland Australia. The reason for this is that, because of the lack of available palaeomagnetic data for these areas, no magnetostratigraphy has been developed at this stage.¹

1. The author is aware that N.A. Morner has divided a sequence of moraine stages east of Lago Buenos Aires in Argentina using palaeomagnetism but has been unable as yet to obtain the publication.

Accordingly, it does not seem a valid exercise to attempt any such correlations until a magnetostratigraphy has been developed for these areas or until the magnetostratigraphic framework developed for Tasmania can be linked with other dating methods.

5.7 Conclusions

Interpretation of the palaeomagnetic data provides confirmation of much of the existing stratigraphic framework as well as allowing some refinement of it; in two cases, the Williamsford and Tyndall Creek sites, interpretation of the palaeomagnetic data refines the existing framework (see Colhoun, 1985). The data also allow correlations to be made, some within local areas and some between the regions studied. Some of these correlations can be made with considerable confidence while others are only tentative (Table 5.4).

The suspected considerable age of the Linda Glaciation and its correlates is confirmed, all such deposits being > 730 ka in age. These deposits are therefore at least Early Pleistocene in age. In addition, the palaeomagnetic data suggest that this 'glaciation' consisted of three, or possibly even four, glacial advances and, in particular, they support the contention that the Bulgobac and Que deposits represent two glacial advances or events.

The conclusions are listed by area and site below:

West Coast Sites

a) Pieman Area:

Polarity of the lowermost deposits in the Pieman Valley is equivocal.

The Bulgobac and Que drifts are both > 730 ka in age.

The Bulgobac and Que drifts may represent different glacial events because:

a) sediments from the two sites have very different magnetic signal strengths.

b) magnetic directions from the two sites are significantly different.

The Williamsford Road deposits are > 730 ka in age.

The Boco I Glaciation is < 730 ka in age.

The Rosebery Opencut deposits are < 730 ka in age and are the equivalent of the Boco I Glaciation of the Pieman Valley area.

b) Henty Surface:

The Tyndall Creek deposits are > 730 ka in age and therefore do not represent the Penultimate Glaciation.

c) King River Area:

The Thureau Formation is > 730 ka in age and can be correlated with the Que deposits of the Pieman Valley area.

The deposits at King Gorge Exit site in the Queen Valley may or may not be of Linda age and therefore may or may not be part of the Thureau Formation.

The David, Nelson and Baxter formations are all < 730 ka in age.

North Central Area:

There were three major phases of glaciation in the Mersey-Forth area.

The Croesus Glaciation is > 730 ka in age.

The Rowallan and Arm glaciations are < 730 ka in age.

West Central Area:

The Stonehaven Glaciation may or may not be > 730 ka in age, and hence may or may not be Linda equivalent.

The deposits at Double Barrel Creek probably belong to the Stonehaven Glaciation.

The Taffys Creek Glaciation is < 730 ka in age.

General Conclusions:

The Linda Glaciation is >730 ka in age and is therefore of at least Early Pleistocene age.

The Linda Glaciation had at least two phases of ice advance.

There may have been at least three glacial events prior to 730 ka in Western Tasmania.

The Thureau Formation of the King River Valley and the Que deposits of the Pieman Valley area probably represent the earliest known ice advance of the Quaternary in Tasmania.

The Henty Surface was glaciated during both the Henty and Linda Glaciations. Deposits of the Linda Glaciation stratigraphically underlie Henty till at Tyndall Creek.

Ch. 6 CONCLUSIONS

6.1 Introduction

Three major conclusions can be drawn from the application of palaeomagnetic techniques to this study. These conclusions are stated briefly below and each is treated in greater detail in the following sections.

Glacial lake clays and associated fine-grained sediments, given certain restrictions discussed in greater detail in Section 6.2, are very suitable media to use for the application of palaeomagnetic techniques.

Palaeomagnetic dating is a useful tool for the dating of Middle/Early Pleistocene glacial events in Tasmania. However, its potential is not restricted to the Middle/Early Pleistocene; the technique can provide useful support for other dating methods over the entire period of Quaternary glaciation. This is discussed in Section 6.3.

Finally, the application of palaeomagnetic techniques to glacial lake clays and associated sediments in Tasmania has confirmed most aspects of the broad stratigraphic framework established for the Quaternary glacial events in Tasmania by earlier workers using other methods, whilst enabling some refinement of the framework. This study has thus confirmed both the multiple glaciation model and the very significant age of the earlier Quaternary glacial events in Tasmania. This material is covered in greater detail in Sections 6.4 and 6.5.

Future research directions that might consolidate the findings of this research and help to clarify some of the problems that have arisen are discussed in Section 6.6.

6.2 Validity of Method for Glacial Lake Clays and Associated Sediments

The glacial lake clays and associated sediments used in this study appear to be quite suitable materials to utilize for palaeomagnetic studies, particularly if they are undisturbed and flat-lying. Generally such materials are easily obtained and, in most cases, can be collected by simply pressing or very lightly tapping the cube-shaped sampling pots into an horizontal surface.

In most cases the glacial lake clays and sediments provide a good record of the magnetic directions that prevailed at the time of deposition of the sediments (c.f. Section 2.3.7), although some sediments are much more suitable for palaeomagnetic studies than others.

Those sediments derived from dolerite or volcanic material have a strong magnetic signal, whereas sediments derived from sandstones, quartzites, conglomerates and schists usually have a weak to very weak signal. Thus the Mersey-Forth sediments (derived from Jurassic dolerite) and the Boco sediments (derived from Cambrian volcanics) produced very strong magnetic signals. On the other hand, the King Gorge Exit site sediments and the Williamsford Road sediments (both derived from Precambrian quartzites, conglomerates and schists) had very much weaker magnetic signals.

These significant variations in signal strength of sediments derived from different materials can be utilized to identify or confirm the source areas of material carried by a glacier. Furthermore, they can be particularly useful for identifying and interpreting multiple source area deposits where the source areas were quite different. Thus, where a site contains sediments derived from two or more quite different source areas, these variations can help to distinguish the source areas of the glacier ice.

6.3 Validity of Method for Dating Middle/Early Pleistocene Events in Tasmania.

Sites with a normal polarity can usually be regarded as being < 730 ka in age and hence as belonging to the Brunhes Chron. They may, of course, have been deposited during one of the normal events of the Matuyama Chron, but this is likely to be evident from other stratigraphic evidence from the area. Sites with a normal polarity can be differentiated further on the basis of those sites that are within the range of radiocarbon dating and those sites that are beyond the range of radiocarbon dating.

It should, of course, be pointed out that sediments of < 730 ka in age could have been deposited during an excursion, in which case they will have a direction more than 40° away from the normal direction but not a reversed polarity. The probability of deposition during an excursion is considered to be certainly less than 5%, and probably less than 3% (refer Ch. 2.2.1). All samples with a reversed polarity have been considered to be >730 ka in age.

Stratigraphic evidence from various areas, based on weathering rind analysis and pollen analysis, has indicated that in Tasmania there were at least three major glacial events, one within the range of radiocarbon dating, an older one, and another very much older event. This study has confirmed the validity of the basic model, consisting of three major glacial advances, whilst indicating that the events were probably rather more complex.

Thus, if this method is applied to those sites in Tasmania beyond the range of radiocarbon dating, then the sites with normal polarity can be identified as belonging to the Penultimate Glaciation and those sites with reversed polarity as belonging to earlier glacial events. The Brunhes/Matuyama boundary, at 730 ka, is therefore a very convenient 'breaking point' between the earlier and later glacial events. The method is therefore a valid one for differentiating the Penultimate Glaciation from any significantly older glacial events in Tasmania, assuming that there were only two glacial events before 730 ka. Such an assumption, however, has been shown to be incorrect in the King Valley area where two glacial events beyond the range of radiocarbon dating, but less than 730 ka in age, have been identified (Fitzsimons, 1988).

Application of palaeomagnetic studies, however, is not restricted to simply determining whether a deposit is reversed or normally magnetised; that is, whether the sediments were deposited > or < 730 ka years ago. The information obtained can also be used to separate any events that have a significant temporal difference, as such events are likely to have significantly different mean directions. Such studies can therefore serve a much more useful purpose than just separating the Penultimate and earlier glaciations in Tasmania.

Declination and inclination values for each specimen can be used to plot up the position of each specimen on a stereoplot. If a sufficiently large number of specimens is taken from each site, and the specimens for the site form a distinct group, then the site mean directions for sites deposited at different times will be different. Superimposition of plots from two or more sites and statistical comparison of their mean directions can then be used to demonstrate whether those sites were deposited at significantly different times. As sediments deposited in glacial lakes may record the secular variation of the geomagnetic field, such time differences may be as short a period as one hundred years.

The palaeomagnetic data have been applied in a number of ways to the dating of Quaternary glacial sediments in Tasmania in this study. The data have been used to verify that the Linda Glaciation and its equivalents, the 'earliest' glacial event in Tasmania, are quite old. The suggestion of a number of previous workers (e.g. Colhoun, 1985; Hannan and Colhoun, 1988; Fitzsimons, 1988) that this glacial event was Early Pleistocene in age has been confirmed by this study.

The data have also been used to subdivide, or support the subdivision of, glacial events. Augustinus and Colhoun (1986) suggested that the Early Pleistocene glaciation in the Pieman area was represented by two distinct glacial phases, rather than by one. They based their conclusion on weathering rind analysis, percentage absorption of water, specific gravity of rock clasts, degree of till matrix weathering and post-depositional

modification of glacial landforms. The palaeomagnetic data support this contention, the Bulgobac and Que samples having quite distinct groupings on the stereoplot and statistically different mean directions. In addition, the data from the Tyndall Creek site on the Henty Surface, although more scattered, form a group that is quite distinct from either the Bulgobac or Que groupings and also have a statistically different mean direction. This suggests that there may have been at least three phases of Early Pleistocene glaciation on the West Coast.

Similarly, the stereoplots of site data from the Mersey-Forth area and the King Valley have been used to support the Late and Middle Pleistocene stratigraphy, as well as the Early Pleistocene stratigraphy, established for these areas by Hannan and Colhoun (1987) and Fitzsimons (1988) respectively. For example, comparison of the stereoplots from the Fish River, Arm River Bridge, and Arm River Road sites confirms that the Rowallan and Arm glacial events were quite distinct in time.

The age of a deposit can also be determined by the comparison of its site mean direction with that of a deposit of known age. Thus, the age of the Rosebery Opencut site, thought to be Boco undifferentiated, was established to be Boco I because of the similarity of its site mean direction with that from the Boco I sediments at the Boco Siding site.

The validity of this method for dating glacial events is also dependent on the time of the deposition of the sediments. In order to use the method as a means of dating glacial events it must be quite certain that the sediments were deposited either during the presence of the glacier ice or very soon after. It is invalid to use the method for dating if this is not the case, unless it is being used to date an Interglacial. Fine grained interglacial lake or alluvial deposits could be dated by this method but this was not undertaken in this study.

6.4 Major Confirmations

As indicated in Table 5.1, Section 5.1, the palaeomagnetic data confirmed most of the stratigraphy established from other data. More specifically it has confirmed the multiple glaciation model for Tasmania in the Quaternary.

The data have demonstrated that the Croesus Glaciation in the Mersey-Forth area and the Linda Glaciation of the West Coast are time equivalent in a broad sense and, in particular, they have established the very considerable age of the Linda Glaciation and its equivalents by demonstrating that they are >730 ka in age. Hence the Linda and Croesus Glaciations must be of Early Pleistocene age.

The palaeomagnetic data also suggest that the Bulgobac and Que glacial drifts probably do represent separate glacial events as suggested by Augustinus and Colhoun, 1986, and not the same event as suggested by Fitzsimons, 1988.

6.5 Major Differences

The palaeomagnetic data indicate two significant differences from the established stratigraphy. The sediments from the Tyndall Creek site on the Henty Surface were considered by Colhoun (pers. comm., 1987) to belong to the Middle Pleistocene Penultimate Glaciation. However, the samples from this site have a very dominantly reversed polarity and so are >730 ka in age. They must therefore be of Early Pleistocene age.

The Williamsford site also has a dominantly reversed polarity, contrary to expectations (Colhoun, pers. comm., 1989). This suggests that the ice margin on Mount Read and the associated lateral moraine, considered to be of Middle Pleistocene age, must be of Early Pleistocene age. As discussed in section 5.2.1 the stratigraphic data have been re-examined in the field by Colhoun and Augustinus (1990); in the light of the palaeomagnetic evidence, and the palaeomagnetic results have helped to pinpoint ice limits of different ages in both areas.

6.6 Suggestions for Future Research

The following suggested areas for future research could be used to clarify, consolidate and extend the findings of this study:

A more extensive study of the Central North area to determine whether the stratigraphy in this area is more complex than currently thought;

Location and systematic study of suitable sites in the Central West area to link it more closely with the Central North and West Coast areas;

Sampling of other sites on the Henty Surface and at Henty Bridge to define further the two ice limits;

Detailed work on specific suitable sites to relate more closely the ages determined by aminoacid dating techniques and weathering rind analysis and the relative ages determined by the application of palaeomagnetic techniques (ref. Colhoun and Fitzsimons, 1990);

Utilization of glacial lake sediments in New Zealand and South America, particularly Chile, to establish a magnetostratigraphic framework for these areas that can be used to facilitate the correlation of some of the glacial events of the Southern Hemisphere.

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APPENDIX 1

RELIABILITY OF RESULTS

As indicated in Chapter 4.1, a reliability index was developed in an attempt to establish the relative reliability of the varying results. The reliability index was seen as a means by which the results from the various sites could be compared with each other in terms of reliability. The reliability index therefore indicates the degree of confidence that can be placed in each of the individual site results.

A reliability matrix was constructed for each site on the basis of the following seven criteria:

- a) percentage of inclinations of the one type, north or south.
- b) mean Modified Konigsberger Ratio.
- c) spread of declinations in degrees.
- d) spread of inclinations in degrees.
- e) number of samples.
- f) α_{95} value.
- g) K value.

Data for each of these criteria were divided into five groups to form a scale from one (considered to be the least reliable) to five (the most reliable) and each site was allocated to a position on this scale for each of the seven criteria. Each of the seven criteria were given equal weight and the seven ratings were numerically averaged to obtain an overall rating for the site. This rating was then rounded to one decimal place to produce the Reliability Index for each site as shown in Tables 5.1 and A1.2. In constructing the index no one criteria was seen as more important than any other and so no attempt was made to weight the seven criteria.

Groupings for each of the seven criteria used are shown in Table A 1.1 and the reliability indices for each of the sites are shown in Table A 1.2.

Table A1.1. Reliability Index criteria.

	1	2	3	4	5
a) percentage of inclinations of the one type					
	50 - 59 %	60 - 69 %	70 - 79 %	80 - 89 %	90 - 100%
b) mean Modified Konigsberger Ratio, Q					
	< 0.1	0.1 - 0.33	0.34 - 0.66	0.67 - 1.0	>1
c) spread of declinations in degrees					
	> 269 ⁰	180 - 269 ⁰	90 - 179 ⁰	30 - 89 ⁰	< 30 ⁰
d) spread of inclinations in degrees					
	> 150 ⁰	116 - 150 ⁰	65 - 115 ⁰	30 - 64 ⁰	< 30 ⁰
e) number of samples					
	< 8	8 - 14	15 - 21	22 - 29	> 29
f) α_{95}					
	>40	>20 - 40	>10 - 20	>5 - 10	5 or less
g) K					
	5 or less	>5 - 10	>10 - 20	>20 - 50	>50

Table A1.2 Reliability indices by criteria and reliability index for individual sites.

Site	Criteria						Total	Reliability Index	
	a	b	c	d	e	f			g
West Coast Sites									
a) Pieman Area									
1. Lower Pieman Rd	1	3	4	1	2	4	5	20	2.9
3. Marionoak	5	2	4	4	3	4	3	25	3.6
4. Boco	5	5	4	4	5	5	5	33	4.7
5. Bulgobac A	5	5	4	5	4	5	5	33	4.7
5. Bulgobac B	3	1	2	1	2	2	4	15	2.1
5. Bulgobac C	1	1	4	1	2	2	4	15	2.1
6. Que	5	2	2	2	5	4	3	23	3.3
7. Rosebery Opencut	5	3	3	3	4	4	3	25	3.6
8. Williamsford Rd	4	2	2	1	5	3	2	19	2.7
b) Henty Surface									
9. Tyndall Ck A	3	2	1	1	3	4	2	16	2.3
Tyndall Ck B	3	2	2	1	3	4	2	17	2.4

continued...

Site	Criteria							Total	Reliability Index
	a	b	c	d	e	f	g		
c) King River Area									
10.Thureau Hills Rd	5	2	3	4	3	4	3	24	3.4
Thureau Hills Ck.1	4	4	1	3	2	2	2	18	2.6
Thureau Hills Ck. 2	5	3	1	4	2	2	2	19	2.7
Thureau Hills Ck. 3	5	4	4	5	2	4	4	28	4.0
11. Baxter Rivulet	5	2	2	3	3	3	1	19	2.7
12. King River									
Bridge C & D	5	4	4	5	4	4	4	30	4.3
13. Linda Creek	5	3	4	3	5	4	3	27	3.9
14. Gormanston Moraine	5	5	5	5	1	5	5	31	4.4
16. King Gorge Exit	4	1	1	1	3	3	1	14	2.0
North Central Sites									
17. Fish River	5	5	5	4	4	5	4	32	4.6
18. Arm River Bridge	5	5	4	4	4	4	3	29	4.1
19. Arm River Road	5	5	5	5	1	5	5	31	4.4
20. Lemonthyme									
Penstock	5	5	4	4	3	4	4	29	4.1
West Central Sites									
21. King William Ck.	5	1	3	4	2	4	3	22	3.1
22. Stonehaven Ck.	4	5	2	1	3	4	3	22	3.1
23. Double Barrel Ck.	1	3	1	2	3	2	1	13	1.9