LITHOFACIES AND GEOCHEMISTRY OF THE HOST SEQUENCE TO THE CURRAWONG MASSIVE SULPHIDE DEPOSIT BENAMBRA, VICTORIA

by

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Research project report submitted in part fulfilment of the requirements of the Master of Economic Geology degree within the Centre for Ore Deposit and Exploration Studies, University of Tasmania.

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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. To the best of the candidates knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text.

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Finally, I could not have undertaken this project without the constant support and encouragement of my wife Helen.

ABSTRACT

The Currawong massive sulphide deposit is one of two known deposits at Benambra, eastern Victoria. The deposit occurs near the base of the Gibsons Folly Formation which is a deep water, basin centre facies association of the Late Silurian Cowombat Rift (Allen, 1992).

Coherent volcanic units of the Gibsons Folly Formation comprise **andesite** and **plagioclase-phyric rhyodacite**. These are predominantly shallow sills with margins of sediment-matrix hyaloclastite. The rhyodacite also forms cryptodome-like intrusions which have penecontemporaneously deformed the sequence. These and the sills were emplaced into a relatively unlithified sequence of mudstone (interbedded with thin, fine sandstone turbidites) and andesitic volcaniclastic units prior to the mineralising event. Units of strongly flow-banded and/or brecciated rhyodacite in the footwall sequence may be lavas but textures are equivocal.
Quartz-plagioclase-phyric rhyolite (the Currawong Porphyry) is a sill which intruded relatively lithified rocks at the base of the Gibsons Folly Formation. Geochemical evidence indicates that it represents on-going silicic volcanism of the Middle-Upper Silurian Thorkidaan Volcanics.
A sequence of **andesitic scoriaceous breccia** and **plagioclase-quartz-bearing altered rocks** comprises several depositional units separated by thin mudstone units. These are ambiguous rocks but several features suggest that they are lava-derived mass-flow deposits. They are lithologically and geochemically distinctive and host the mineralisation at Currawong.

Ti, Zr, Nb and Y have behaved essentially in an immobile manner during hydrothermal alteration and subsequent metamorphism of the volcanic rocks at Currawong. Volcanic lithologies are best distinguished using the plots Zr/TiO_2 vs Nb/Y (after Winchester and Floyd, 1977) and Nb vs Zr. The coherent volcanic units of this sequence form a fairly continuous geochemical magmatic evolution trend but coherent **andesite** and andesitic volcaniclastic rocks show a broad range of compositions. Some of the andesitic units contain xenocrystic-quartz and volcaniclastic rocks of andesitic composition also contain silicic volcanic clasts. Together these suggest that the andesitic rocks are the result of magmatic differentiation combined with mixing of andesitic and quartz-phyric silicic magmas.

The Currawong deposit is interpreted as a subsea-floor replacement style volcanic hosted massive sulphide deposit. Massive pyritic mineralisation is intercalated with, and laterally equivalent to, strongly altered volcanic units which carry variable disseminated or vein mineralisation. Alteration and mineralisation show a strong stratigraphic control related to primary permeability of the host sequence. Quartz-xenocrystic, andesitic scoriaceous volcaniclastic rocks were the locus of the strongest mineralisation at Currawong, and possibly at the nearby Wilga deposit. These should be a primary target for future exploration at Benambra.

1. INTRODUCTION

The Benambra massive sulphide deposits are located in rugged mountainous country of the Limestone Creek area, near Benambra, eastern Victoria (Figure 1). The massive sulphide deposits do not outcrop and were discovered by Western Mining Corporation in May 1978 through geophysical testing (TEM) of geochemical anomalies in favourable geological terrain. Exploration history of the Benambra Project is summarised by Robbins and Chenoweth (1984).

The Currawong deposit is the subject of this study. It has an indicated resource of 9.5 Mt grading 1.65% Cu, 4.33% Zn, 0.86% Pb, 38 g/t Ag and 1.3 g/t Au (Macquarie Oil NL, 1987). The nearby Wilga deposit is a single lens of massive sulphide which includes pyritic Zn-Cu and Cu-rich ore types. The Wilga Cu-rich orebody is currently being mined by Denehurst Ltd, as operators of the Benambra Joint Venture Project, at the rate of 300,000 tonnes per annum.

The Benambra massive sulphide deposits occur within a structural relic of the Middle-Upper Silurian Cowombat rift within the Palaeozoic Lachlan fold belt (Allen, 1992; Figure 1). The stratigraphy and structure of the Limestone Creek area, which includes the Cowombat Rift sequence (Figure 2), were elucidated by the combined efforts of several workers particularly R.L.Allen in his PhD mapping and research, Western Mining Corporation geologists and the Victorian Geological Survey. The Ordovician-Silurian sequence between the Indi and Reedy Creek Faults has undergone three deformations with the strongest (D2) expressed as regionally northeast-trending F2 folds and associated axial planar cleavage (Allen, 1992; Figure 2).

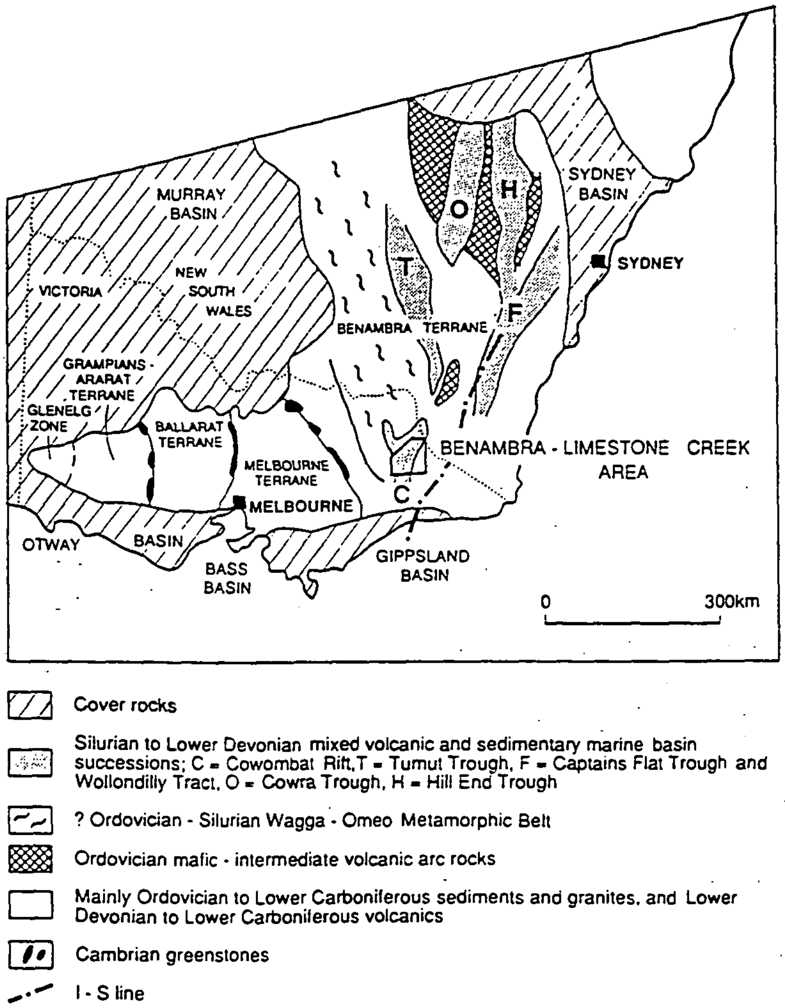

Figure 1. Main tectonic elements of the Lachlan Fold Belt (after Allen, 1987).

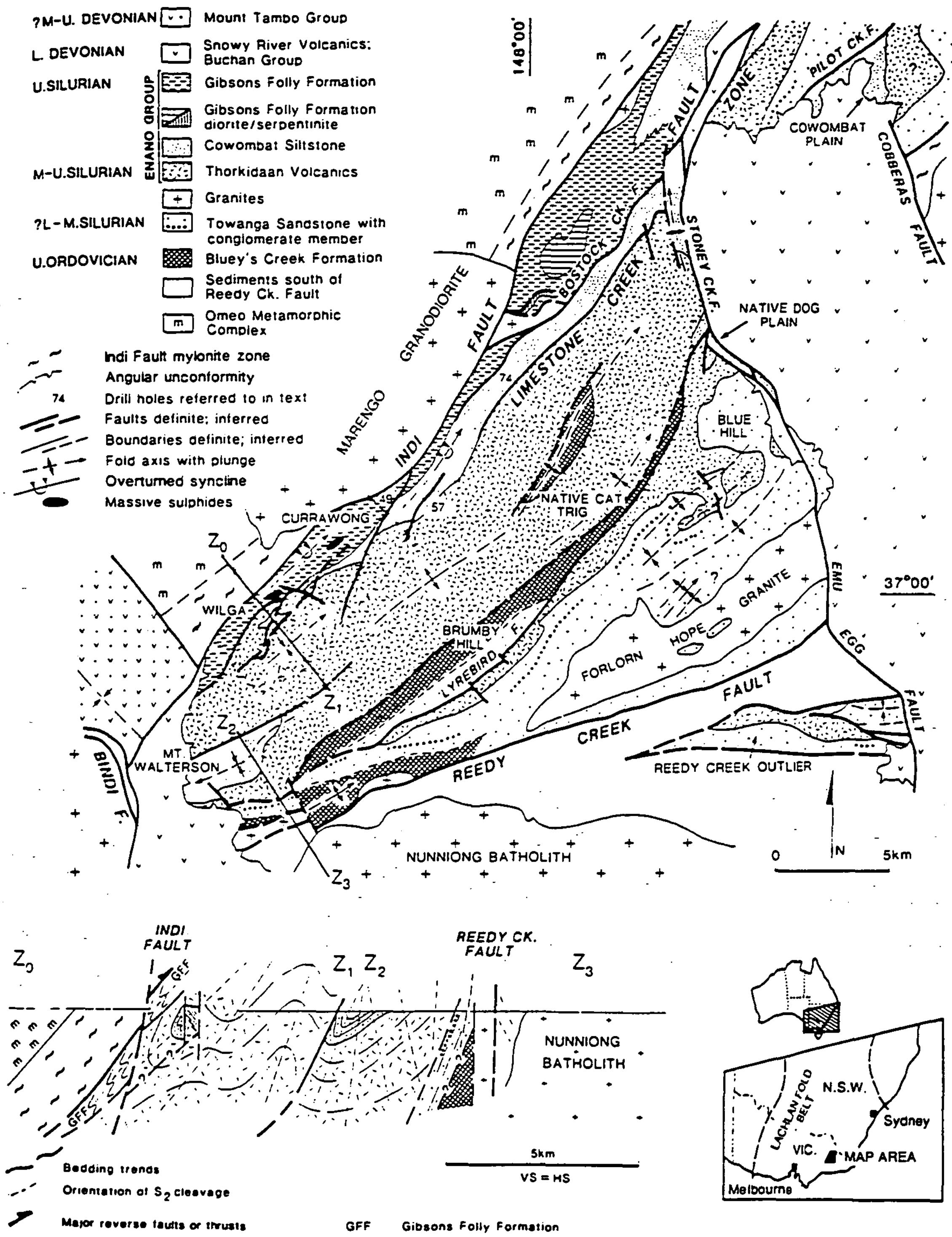

Figure 2. Geological map, cross-section and location of Limestone Creek area; including location of the Currawong deposit (after Allen, 1992).

2. RESEARCH AIMS AND METHODOLOGY

The aim of this research project was to clarify the lithofacies and geochemistry of the Currawong host sequence and its relationship to the massive sulphide mineralisation. The combination of strong hydrothermal alteration (associated with the mineralising event) plus subsequent deformation and lower greenschist facies metamorphism, makes recognition and correlation of stratigraphic units extremely difficult. Primary lithofacies variations expected in such volcano-sedimentary sequences (*cf* McPhie and Allen, 1992) are further complicated by textural modification which results from post-depositional processes (Allen, 1988).

The study focusses on a block of the complete host stratigraphy comprising 500 m of strike length by approximately 300 m down-dip from surface. The block incorporates part of the largest massive sulphide lens at Currawong (C lens) in its transition (up-dip) from thick massive sulphide to altered host rocks with minor thin massive sulphide bands, in the area south of the Currawong Fault Zone where structural complications were considered to be minimal (Figure 3).

Drill core of 14 holes from six cross-sections was re-logged in detail (Appendices I & II). During logging, macro- and mesoscopic textures of individual units were noted and particular attention given to the nature of contacts between all units. Where alteration and/or deformation did not mask the contacts, volcanic and sub-volcanic intrusive units were classified according to the criteria of Allen (1992; Table 1). In the cases where criteria critical to assessing the nature of emplacement were unavailable, inferences were made where possible, from adjoining cross-sections. This was done with a strong awareness of the lateral facies changes and highly irregular unit relationships typical of volcanic terrains (*cf* Cas and Wright, 1988; McPhie and Allen, 1992; McPhie *et al*, 1993).

Petrographic and geochemical studies were undertaken to identify the various lithologies, especially those with strong hydrothermal alteration. Variably altered coherent volcanic units were sampled for geochemical analysis of Ti, Zr, Sr, Rb, Y and Nb using XRF. Scattergram plots of these minor and trace elements and their ratios are most useful for demonstrating geochemical immobility during alteration and metamorphism and thus enabling classification of the coherent volcanic units (eg Zr/TiO_2 vs Nb/Y, Winchester and Floyd, 1977; Y vs Zr, MacLean and Barrett, 1993).

Volcaniclastic units and some more altered units (suspected of having either volcanic or sedimentary precursors) were also analysed to see if they could be geochemically correlated with the coherent volcanics.

A 3-dimensional interpretation on six cross-sections and three level plans was carried out combining the lithofacies logging, petrological and geochemical data. This approach improved the stratigraphic correlation, characterised the volcanic rocks and provided information about controls on the localisation of the mineralisation.

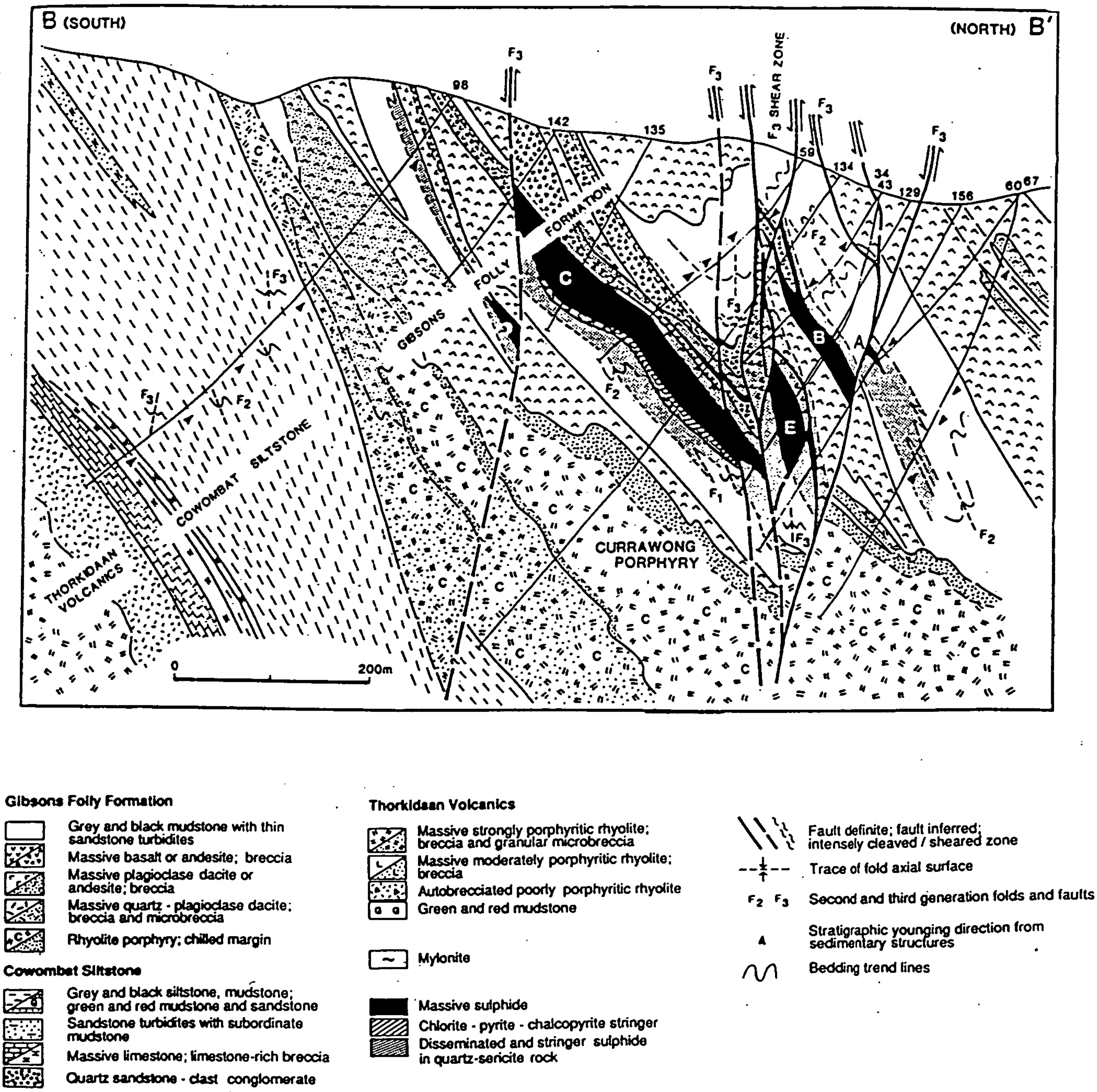

Figure 3. Cross-section 17550E of the Currawong deposit (after Allen, 1992).

Type of unit	Contacts with sediments or other volcaniclastics: Upper contact	Contacts with sediments or other volcaniclastics: Lower contact	Internal facies
Extrusive dome (rhyolite)	Mainly passive Lava top hyaloclastic Sediment not baked or bleached	Passive + disruptive Lava base coherent or hyaloclastic	Central facies: thick coherent (massive and flow-banded) core, thin in situ (massive, jigsaw-textured) hyaloclastite base, thick or thin in situ hyaloclastite top capped by thin or absent resedimented (stratified) hyaloclastite Lateral margin facies: mainly in situ + resedimented hyaloclastite
Extrusive tabular flow (rhyolite-basalt)			Central facies: mainly coherent (massive and flow-banded) core, thin in situ (massive, jigsaw-textured) ± resedimented (stratified) hyaloclastite top, ± pillow or minipillow fragments within hyaloclastite in basalt units; hyaloclastite very thin or absent at base Lateral margin facies: mainly in situ + resedimented hyaloclastite
Partially emergent cryptodome or sill (rhyolite-basalt)	Disruptive ± locally passive Top hyaloclastic Sediments locally baked and bleached Resedimented hyaloclastite within overlying sediment sequence	Disruptive ± locally passive Base hyaloclastic or coherent	Beds of resedimented (stratified) hyaloclastite, or resedimented-slumped mixed hyaloclastite-sediment, or mass-flow sediments with included rip-up clasts of hyaloclastite occur within overlying sediment sequence and locally directly on top of volcanic unit Central and lateral margin facies same as for shallow sill
Shallow sill (rhyolite-basalt)	Disruptive ± locally passive Top hyaloclastic or coherent Sediment baked and bleached		Central facies: coherent (massive or flow-banded) core ± thin hyaloclastite top and base, including sediment-matrix intrusive hyaloclastite Lateral margin facies: mainly sediment-matrix intrusive hyaloclastite + in situ (massive, jigsaw-textured) hyaloclastite; subordinate coherent intervals; multiple layers of the sill separated by thin sediment screens common No pillow or minipillow fragments in basalt units
Deeper sill (rhyolite-basalt)	Mainly passive, but locally transgressive, interfingering or slightly disruptive Top mainly coherent Sediment baked and bleached	Mainly passive ± locally slightly disruptive Base coherent	Coherent massive or faintly flow banded, ± coherent fine-grained chilled margin or very thin hyaloclastite margin; no pillow or minipillow fragments in basalt units
Pyroclastic debris (rhyolite)	Sharp sedimentary contacts		Entirely clastic, no gradations into in situ (jigsaw-textured) breccia, pyroclastic clast morphologies, shards, bed forms of subaqueous granular mass-flow deposits ± subaqueous suspension fallout

Table 1. Criteria for distinguishing submarine volcanic units in drill core and sparse outcrop at Benambra (after Allen, 1992).

3 REGIONAL GEOLOGY

3.1 Tectonic setting

The Middle-Upper Silurian Cowombat Rift is the southern-most of five Silurian to Lower Devonian marine basins within the Lachlan Fold Belt of southeastern Australia, some of which contain Zn-Cu-Pb volcanic hosted massive sulphide deposits (Cas, 1983; Powell, 1983; Allen, 1987, 1992).

The basins are built on the Benambra tectono-stratigraphic terrane (Figure 1) which was interpreted by Powell (1983) as the variably deformed and metamorphosed, Ordovician to Early Silurian plate margin terrane of the Gondwanan continent. During the Ordovician, an inferred subduction zone to the east produced north-south trending intermediate to mafic island arc volcanism. Marine back-arc and fore-arc basins received both continental and arc-derived sediment producing the characteristic Late Ordovician quartz sandstone and shale turbidite sequences of the Lachlan Fold Belt. (Cas *et al*, 1980; Powell, 1983). Wyborn (1992) demonstrated that the Ordovician volcanic rocks are shoshonites which in most modern examples are not associated with active subduction. He argued that the Ordovician magmatism was not accompanied by coeval subduction but was sourced from lithospheric mantle modified during an earlier (Cambrian) subduction event.

The Early Silurian was a period of uplift, compressional deformation and metamorphism (the Benambran Orogeny, eg Omeo Metamorphic complex, Figure 2). Arc volcanism appears to have ceased and sedimentation was more restricted, comprising shelf carbonate sedimentation and deposition of proximal quartz-rich turbidites from uplifted blocks into adjacent grabens (Crook *et al*, 1973; eg Towanga Sandstone, Section 3.3).

In the Middle to Late Silurian continued uplift was associated with the initiation of widespread silicic volcanism. Subsequently, a series of extensional basins with associated (dominantly silicic) volcanism developed (Cas, 1983; Powell, 1983). The extensional regime was interpreted by Powell (1983) as due to a change in the Middle Silurian from convergent to predominantly transcurrent movement between crustal plates. Localised basin development continued sporadically until the Early Carboniferous, punctuated by localised compressional events; *ie* the end-of-Silurian Bowning and Bindian deformations; Middle Devonian Tabberabberan deformation;

and early Carboniferous Kanimblan deformation (Cas, 1983; Powell, 1983; Allen, 1992). Glen (1992) suggested that the Bowning and Bindian deformations may not be compressional deformations but rather minor rotations on listric normal faults which accompanied renewed cycles of syn-rift basin extension.

In the area of the Cowombat Rift, the onset of extensional tectonics and silicic volcanism is represented by the Thorkidaan Volcanics which were deposited on the ?Lower to Middle Silurian Towanga Sandstone (Allen, 1987; Section 3.3).

Allen (1987, 1992) interpreted the Silurian-Carboniferous rift basins as back-arc or intra-arc basins which superseded the long-lived volcanic arc at an active margin of the Gondwana continent. By the time of rift basin initiation in the Middle Silurian, the underlying crust was substantially continental, as evidenced by the vast volume of Siluro-Devonian granites and silicic volcanic rocks in that part of the Lachlan Fold Belt (Allen, 1992). Thus the mineralised Silurian basins of southeastern Australia were probably ensialic basins of limited extensional origin, and had a similar tectonic and palaeogeographic setting to the Miocene Green Tuff basins of Japan, which contain the Kuroko VHMS deposits (Allen, 1986, 1987, 1992).

3.2 Regional structure

The Ordovician-Silurian sequence between the Indi and Reedy Creek Faults, which includes rocks of the Middle-Upper Silurian Cowombat Rift, has undergone three deformations (Allen and Barr, 1990; Valenta, 1990; Allen, 1987, 1992).

The earliest deformation (D1) is expressed by a bedding-parallel foliation (S1) and rare F1 folds.

D2 was the strongest deformation and is represented by regionally northeast-trending F2 folds and associated axial planar cleavage. The cleavage has a strong stretching lineation component and at some locations grades into shear zones and mylonites.

The third deformation (D3) is expressed by northwest- to northeast-trending upright open F3 folds, steep brittle-ductile faults and associated coarse, spaced S3 crenulations (Allen, 1992).

On a regional scale, the form surface of the Gibsons Folly Formation is a NW-dipping, overturned F2 syncline cut by late sub-vertical (D3) NE-trending faults (Allen 1987, 1992; Valenta, 1990). The latter are steep, strike-parallel faults and may be common between the Currawong deposit and the Indi Fault (Valenta, 1990; Figure 2).

At the Wilga deposit, Cox *et al* (1988) recognized sets of dip-parallel, steeply dipping faults which have displacements of generally less than a metre, but up to several metres at some locations. These are late faults probably related to D3 and are also probably present at Currawong (Section 6).

First and second generation structures are absent from overlying Lower Devonian rocks suggesting that D1 and D2 developed during the Bindian deformation, at the end of the Silurian (Allen, 1992). This deformation has been interpreted as a southeast-directed, oblique-compressional event involving thrusting, strike-slip fault movement and strong folding. The main focus of the deformation was along the Indi Fault mylonite zone (Allen, 1987; Vandenberg and Allen, 1988; Figure 2).

3.3 Regional stratigraphy

The regional stratigraphy of the Limestone Creek area was described in detail by Vandenberg *et al* (1984), Allen (1987) and Allen and Vandenberg (1988) and is summarised in Figure 2 (Allen, 1992). The succession comprises Ordovician to Silurian rocks which form several northeast to east-northeast striking fault-bounded blocks. Many contacts between stratigraphic units within the blocks are also faulted (Figure 2).

West of the Indi fault (Figure 2), the oldest units are metasedimentary rocks of the Upper Ordovician **Omeo Metamorphic Complex**. East of the Indi fault, Upper Ordovician rocks comprise the **Blueys Creek Formation** and unnamed sedimentary rocks south of the Reedy Creek fault. The ?Lower to Middle Silurian **Towanga Sandstone** overlies the Blueys Creek Formation and is (at least in part) disconformably overlain by the Middle-Upper Silurian ***Enano Group***. The ***Enano Group*** was interpreted by Allen (1992) as structural relics of the Cowombat rift and comprises (in ascending stratigraphic order) the **Thorkidaan Volcanics**, **Cowombat Siltstone** and **Gibsons Folly Formation**.

To the east and southwest a gently folded cover sequence of Lower Devonian silicic volcanics (**Snowy River Volcanics**) and limestone and mudstone (**Buchan Group**) unconformably overlies the Ordovician-Silurian sequence. Granite bodies of ?Middle Silurian age have intruded the sequence throughout the area (Allen, 1992).

Brief descriptions (after Allen and Barr,1990; and Allen, 1992) of the Ordovician to Silurian stratigraphic units between the Indi and Reedy Creek faults are given below.

Upper Ordovician

The **Blueys Creek Formation** consists of deep-marine sedimentary rocks (including Late Ordovician conodont-bearing cherts and andesitic-basaltic volcanogenic turbidites) and dacitic to andesitic sills and lavas. The formation has been interpreted as the southern continuation of the Benambra Terrane Ordovician volcanic arc system (Section 3.1).

?Lower-Middle Silurian

The **Towanga Sandstone** comprises mainly thick quartz sandstone turbidites and siltstone and has been interpreted as the proximal part of a submarine fan. Minor chert-pebble conglomerates and rhyolitic volcanics occur near the top of the formation. Late Ordovician conodonts in the chert pebbles suggest that they were derived from the Blueys Creek Formation and that the Towanga Sandstone is younger .

Middle-Upper Silurian

The Enano Group

The basal formation of the Enano Group is the **Thorkidaan Volcanics**. They form a 2-3 km-thick pile of porphyritic rhyolite lavas and shallow intrusions, with minor intercalated stratified volcaniclastic rocks, conglomerate and reworked pumiceous pyroclastic rocks. The Thorkidaan Volcanics are conformably to disconformably overlain by the Cowombat Siltstone.

The **Cowombat Siltstone** is up to 500 metres thick and comprises an upward-fining sequence. Limestone and thick-bedded coarse clastics occur in the lower parts of the formation and pass into siltstone and mudstone with thin sandstone turbidite units toward the top.

The **Gibsons Folly Formation** is 500 metres or more thick and conformably overlies the Cowombat Siltstone in the Currawong area. It comprises a sequence of interbedded mudstone and thin fine sandy turbidite units which encloses tabular to lenticular basaltic-dacitic volcanic units and tabular to cryptodome-like rhyolitic bodies. The Gibsons Folly Formation hosts the Wilga and Currawong massive sulphide deposits and the volcanics of the host sequence at Currawong are the subject of this study.

4. PETROLOGY: LITHOFACIES DESCRIPTIONS AND INTERPRETATIONS

4.1 Introduction

The primary purpose of the petrological study was to describe and classify the volcanic lithologies of the host sequence to the Currawong deposit. This assisted the stratigraphic interpretation, particularly when the precursors of altered units could be recognized. Also, the recognition of coherent volcanic units and visual assessment of their degree of alteration was necessary in selecting samples for the geochemical study.

For this study, a total of 52 representative drill core samples were taken during core logging and thin sections prepared for microscopic examination. Samples included both less altered, more easily interpreted lithologies plus more problematic strongly altered and deformed units.

It should be noted that throughout this study 'volcanic' is used in the broader sense of **volcanic deposits** as defined by McPhie *et al* (1993). In particular, 'volcanic units' include sub-volcanic intrusions and associated volcaniclastic facies.

4.2 Lithological descriptions

The following descriptions are based on the relatively small but representative group of samples from the study area. Additional features noted by previous researchers are appended.

Descriptive names for the rock-types are based on the results of the geochemical study (see Section 5) and in some cases these differ from those used by Allen (1987, 1989, 1992). For reference, Allen's descriptive names are given in parentheses.

4.2.1 Coherent volcanic rocks

Quartz-feldspar-phyric rhyolite

Description

Pink-green, fine to coarse grained porphyritic rocks consisting of 20-35%, 1-3 mm phenocrysts of quartz, K-feldspar, plagioclase and biotite in a siliceous, fine grained, poorly microlitic groundmass. Finer grained, sparsely porphyritic variants are also present. These units often have patchy or vein-like haematite alteration.

Discussion

In the study area this lithology forms a sill-like body known as the Currawong Porphyry with the finer grained variants noted above occurring as chilled margins. Contacts with other units are typically sharp and not disruptive, suggesting intrusion into a relatively lithified sequence. Allen (1992) observed that sedimentary units in contact with the sill exhibit narrow zones of bleaching or silicification .

Plagioclase-phyric rhyodacite *(plagioclase-dacite and andesite)*

Description

Brown to green-grey rocks with 10-20%, 0.5-3.0 mm plagioclase phenocrysts and/or glomerocrysts in a moderately to intensely plagioclase-microlitic groundmass. Mafic minerals and their alteration products are typically deficient and some units have rare quartz phenocrysts (Allen, 1989). Fine grained spherulitic or micropoikilitic textures are common indicating originally glassy units. Allen (1989) observed that the margins of the glassy units in places have perlitic cracks. Units are typically poorly to moderately amygdaloidal and are generally massive, although zones of flow-banding up to a few metres thick occur.

A variant of this lithology is shown in Plate 1. This forms a thick sequence of distinctive, strongly flow-banded and brecciated (Page, 1984) units tens of metres thick, in the footwall sequence of the Currawong deposit (Appendix II). It contains up to 10%, sparse, 0.5-1.0 mm euhedral to subhedral plagioclase phenocrysts which are saussuritized on their margins and cleavage planes. Flow-banding is defined by alternating, very fine (0.01-0.05 mm) phyllosilicate-rich versus thicker (up to 0.2 mm) siliceous laminae which wrap around the plagioclase phenocrysts. The siliceous laminae exhibit granophyric texture suggesting recrystallisation of devitrified glass (McPhie *et al*, 1993). Phyllosilicate-rich layers are mainly sericite and chlorite. Minor fine opaque minerals are concentrated in thin laminae which parallel the flow foliation. Bands of predominantly siliceous, granophyric texture up to several centimetres thick give the rock a brecciated appearance. Patchy carbonate alteration, sericite veining, disseminated- and vein-pyrite and microcrystalline quartz veining are common.

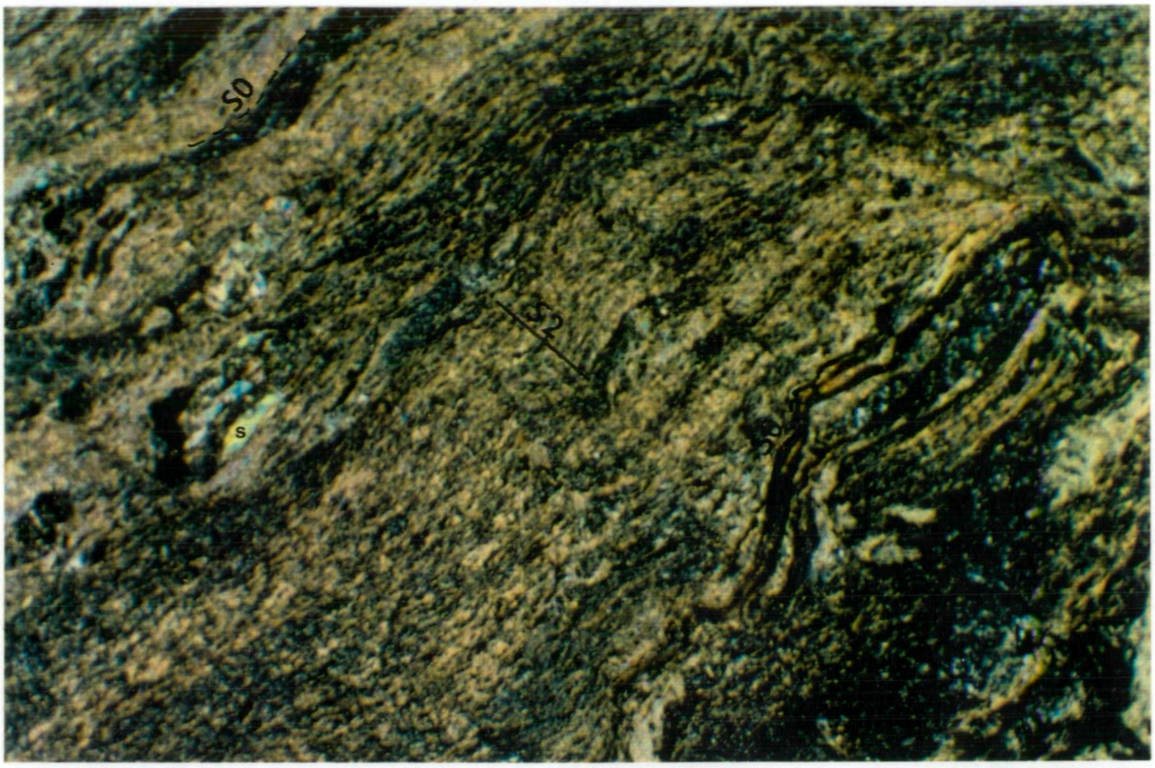

Plate 1. Flow-banded variant of **plagioclase-phyric rhyodacite** with saussuritized (**s**) plagioclase phenocysts. S 0 (& parallel S 1?)=flow banding; S 2=dominant cleavage, here weakly developed. Field of view 5.0 mm, crossed nicols.

Discussion

This is the most common lithology at Currawong, forming thick units in both the structural hangingwall and footwall sequences. Single units may be tens of metres to less than a metre thick, by hundreds to thousands of square metres in aerial extent. They form massive coherent to extensively brecciated bodies considered by Allen (1987, 1992) to include lavas and sills. Large cryptodome-like bodies tens of metres thick which thin very rapidly down-dip and along strike were also recognized in this study.

Unit margins may be either passive or disruptive with well-developed **massive volcanic breccia** and/or **massive volcanic breccia with sediment-matrix** (Section 4.2.2). Geochemically this lithology is predominantly rhyodacitic in composition but parts of individual dome-like bodies are more chloritic, less siliceous, finer grained and more strongly amygdaloidal. Some examples of the latter lithology are more dacitic in composition (Section 5) though contacts between the geochemical variants appear to be gradational.

The flow-banded lithological variant was interpreted by Allen (1992) as an extrusive phase of the Currawong Porphyry and by Fander (1988) as a welded ignimbrite. Strong alteration commonly masks contacts between units and with other lithologies, making interpretation difficult. However no convincing evidence of welded shards was found in this study and the presence of flow-banding is not definitive of lavas. Geochemically it is distinct from the **quartz-feldspar-phyric rhyolite** (Currawong porphyry; Section 5) and lithologically it is most like the **plagioclase-phyric rhyodacite.** The Currawong porphyry has intruded units of the flow-banded lithology.

Plagioclase-bearing altered rocks (Section 4.2.2) are possibly altered volcaniclastic equivalents of the **plagioclase-phyric rhyodacite**.

Andesite *(fine grained basalt and andesite)*

Description

These are green-grey, fine to medium grained, poorly to moderately amygdaloidal, poorly to moderately porphyritic rocks with generally less than 10%, but up to 20%, 0.5-1 mm plagioclase phenocrysts or 1-3 mm glomerocrysts; in a strongly plagioclase-microlitic, fine to medium grained groundmass. Pyroxene microphenocrysts form a minor component of fresher specimens (Allen, 1989). The groundmass has minor fine grained (0.05-0.1 mm) interstitial quartz and sericite and is rich in chlorite, disseminated Fe-oxides, epidote and carbonate. Fander (1988) noted ultrafine leucoxene throughout the groundmass and possible fine flow textures. In some cases the groundmass is hyalopilitic with spherulitic and micropoikilitic devitrification textures weakly developed. Several units of this lithology have rare to minor (in some cases up to 10%) 0.1-2 mm quartz phenocrysts. These have very strongly embayed and/or recrystallised rims and are interpreted as xenocrysts.

Discussion

Coherent units of this lithology are mainly sills which typically have either completely passive margins or contacts of **massive volcanic breccia with sediment matrix** grading into **massive volcanic breccia** (Plates 2 and 3; Section 4.2.2). Allen (1988) interpreted some lavas to be present but no coherent extrusive phases were recognized in the study area. Units show variations in grainsize and crystallinity which probably reflect differences in unit thickness and depth of intrusion. Geochemically the **andesite** shows a fairly continuous range of compositions from basaltic andesite almost to dacite. Units with abundant quartz xenocrysts are more dacitic although a medium grained, plagioclase-phyric example without quartz xenocrysts has a similar composition (Section 5).

Allen (1987, 1989) described 'plagioclase-quartz dacite' units in the Wilga sequence. They are grey-green, strongly porphyritic rocks with 20-25%, 1 mm phenocrysts of plagioclase and lesser quartz in a siliceous, plagioclase-microlitic groundmass. At Wilga this lithology forms possible domes, dykes and sills (sometimes with associated **massive volcanic breccia with sediment matrix**, see below) stratigraphically at the same horizon as the mineralisation. Although the Wilga 'plagioclase-quartz dacite' has a slightly greater quartz phenocryst component and more siliceous groundmass, it is otherwise very similar to the quartz xenocryst-rich units of the **andesite** at Currawong.

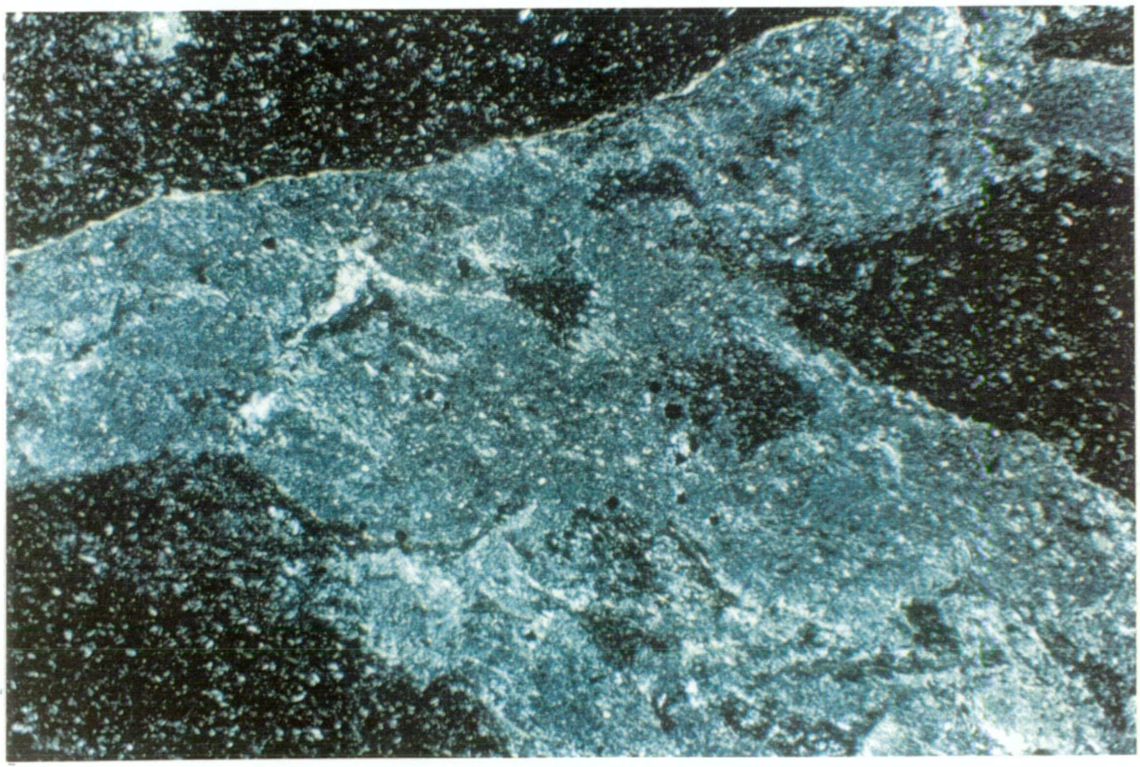

Plate 2. Sediment-matrix hyaloclastite of **andesite** and siltstone; DDH 98, 47.8 m. Blocky clasts of **andesite** (dark) with sharp, curviplanar contacts to sericitic and weakly silicified siltstone (light). Field of view 5.0 mm, crossed nicols.

4.2.2 Volcaniclastic Rocks

Allen (1992) described volcaniclastic facies associated with the coherent volcanic units of the Wilga and Currawong host sequences. These comprise *in situ* facies of (i) **massive volcanic breccia** and (ii) **massive volcanic breccia with sediment matrix** and resedimented facies of (iii) **stratified volcanic breccia and sandstone.** These are non-genetic terms (*cf* McPhie *et al*, 1993) but Allen convincingly demonstrated that the facies were *in situ* (i & ii) and resedimented (iii) hyaloclastites.

Volcaniclastic units recognized during this study were in most cases *in situ* facies which is consistent with the descriptions of Allen (1992). However several distinctive lithologies of ambiguous origin are described below. Of these, the **andesitic scoriaceous breccia** may represent a new volcaniclastic facies at Currawong. Otherwise Allen's terminology is adopted here for consistency.

Plate 3. Sediment-matrix hyaloclastite of quartz-xenocrystic **andesite** and silicified mudstone. DDH 133, 150 metres; Scale centimetres.

Andesitic scoriaceous breccia

Description

Grey-green, lenticular-mottled, matrix-supported breccia with 1-20%, rounded, often irregular, lobate- to amoeboid-shaped, 1-25 cm, poorly sorted, pink-grey-cream coloured clasts in a variably altered, clast supported, fine breccia matrix (Plate 4). The **framework clasts** are sometimes aphyric or have 1-5%, 0.5-0.75 mm, euhedral plagioclase phenocrysts and/or glomerocrysts; and in some examples, minor to rare 0.25-1.0 mm quartz phenocrysts with embayed or recrystallised margins. The clasts are moderately-strongly amygdaloidal (20-60%) with a size range of 0.1 to 5mm (Plate 6). Typically, smaller amygdules are nearly circular whereas larger (>1 mm) ones are slightly elongate. In most cases the amygdules coarsen towards the centre of the clast or band and strongly elongated amygdules or amygdales form central trails parallel to the long axis of larger clasts. The amygdules are most commonly filled with quartz aggregates (some exhibiting weak radial extinction), though many larger examples are zoned with a carbonate or chlorite core and quartz rim. The small (< 1mm) very circular structures are not easily distinguished from spherulites (*cf* Allen, 1988) however both types of structure are consistent with a coherent texture as suggested by the evenly distributed phenocrysts. If spherulites are present, the upper range of amygdule percentage would be lower. However spherulites are not common in andesites, or in pumice or scoria of any composition (J. McPhie, personal communication).

Clasts generally have sharp contacts with the matrix and have complete 1-3 mm rims of sericite-carbonate rich alteration (Plates 4 and 5) which also occupies thin (<1 mm) joints normal to the rim. The joints are typically best developed along the longer axis of elongate clasts. Most clasts are moderately silicified by fine grained polyhedral quartz associated with very fine grained disseminated pyrite, and have variable pervasive to patchy and/or vein-like carbonate alteration. Several units of this lithology have strongly haematite altered clasts which are overprinted by the quartz-carbonate alteration (Plate 7). In some units, bands up to several metres thick contain 10-30% sub-rounded, 5-50 mm clasts of fine silty mudstone which in some cases are silicified or haematite altered.

The **matrix** exhibits textural variations which mainly reflect differences in the degree of alteration and deformation. In less altered units it is a clast-rich fine breccia of predominantly 0.5-3 cm, weakly to strongly amygdaloidal, variably porphyritic clasts of **andesite;** plus minor, 2-10 mm lenticular chlorite wisps. The matrix breccia exhibits an apparent jigsaw-fit

texture of blocky, ragged to rounded clasts and wispy patches of dark chlorite in some clast interstices (Plate 8). In more deformed units strong S2 deformation has stretched the clasts and obscured finer textures. Fander (1988) described shards in the matrix breccia of this lithology. Shard-like structures were recognized in this study but alteration and deformation make interpretation difficult. Apparent shards could also be false textures (Allen, 1988).
In more altered and deformed units, the matrix is phyllosilicate-rich and comprises fine grained, lenticular, 1-5 cm domains of strongly foliated chloritic material and quartz-sericite-carbonate material (Plate 9). The chloritic domains contain minor, fine grained, disseminated opaques strung along the strong S2 cleavage. The sericite-quartz-carbonate domains appear to overprint the chloritic domains and are associated with minor fine disseminated pyrite. Carbonate is dominant over associated quartz-sericite alteration in some units. Both domains typically have minor 0.1-1.5 mm plagioclase phenocrysts or glomerocrysts and minor to rare, 0.25-1.0 mm euhedral to subhedral quartz phenocrysts. Mosaic quartz/feldspar-filled and/or zoned chlorite-quartz+albite-filled amygdules, typically 0.5-5 mm, occur in some units. The quartz phenocrysts typically have either strongly embayed or recrystallised margins. Lithologically both domains are very similar to the quartz-xenocrystic units of the **andesite.**
Units of the **andesitic scoriaceous breccia** are weakly stratified with intercalated bands of variable framework clast content, up to tens of metres thick. More altered units typically have a strong (S2) foliation. The uppermost parts of units in some examples appear to be normally graded from coarser to finer grained, altered scoriaceous breccia. The upper contacts are in some cases obscured by alteration but are typically very sharp to fine grained sedimentary rocks. Lower contacts are generally sharp but in some cases are sheared.
The immediately overlying sedimentary rocks in places (eg DDH 135, 88 m; Appendix I) have intercalated 0.5-1 metre thick, fine breccia units which consist of 0.5-2 cm, sub-angular, poorly sorted and variably silicified fine grained sedimentary clasts; plus minor, 2-15 mm, ragged, silica and carbonate altered scoria clasts; in a phyllosilicate-rich matrix.

Intercalated with the units of **andesitic scoriaceous breccia** are units of coherent **andesite** which are up to several metres thick and have sharp irregular contacts. Thinner (tens of centimetres) examples could be large clasts. The units are mostly coherent but some thinner examples are finely brecciated by a jigsaw-fit network of sericite-filled fractures. Both the coherent and brecciated examples are often more coarsely brecciated with 2-5 cm bands and patches of strongly amygdaloidal material, texturally identical to the strongly amygdaloidal clasts.

Discussion

This lithology is a distinctive stratigraphic marker and is one of only two rock types possibly associated with effusive volcanism in the study area. Both clasts and matrix in this lithology consist of variably altered, non-vesicular to scoriaceous **andesite** clasts. More altered and/or mineralised scoriaceous breccia is typically quartz-xenocrystic.

Texturally these breccias are comparable to **pillow breccias** (Carlisle, 1963) and more particularly **scoriaceous pillow breccias** (Dimroth *et al*, 1978, 1985; Staudigel and Schmincke, 1984; Schmincke and Sunkel, 1987; Dimroth and Yamagishi, 1987; Yamagishi, 1987, 1991; Dolozi and Ayres, 1991) both of which are typically associated with pillowed lava flows. The latter breccias contain shards and ragged clasts with relatively high vesicularities which are commonly considered to reflect 'relatively shallow' water depths (upward shoaling sequences) with a more explosive eruption style. However, the moderately to strongly vesiculated nature of clasts in the Currawong breccias may simply reflect a greater original magmatic volatile content which produced scoriaceous (hyaloclastite?) breccias in a deep marine setting (*cf* Cas, 1992).

Allen (1987, 1992) interpreted the Currawong breccias to be massive, *in situ* hyaloclastite containing small pillows or pillow fragments. Evidence supporting this interpretation included the sharp contacts of framework clasts to the supporting matrix; altered clast rims with 'tiny normal joints' (*cf* Yamagishi, 1987); plus the apparent jigsaw-fit textures and essentially monomict nature of the breccia matrix. Pillow lavas expected to be associated with such breccias have not been recognized at Currawong, though this may reflect the difficulty of their recognition in drill core and sparse outcrop.

Many textural features of the **andesitic scoriaceous breccia** are ambiguous and units of this lithology could also be resedimented, syn-eruptive volcaniclastic deposits. The strongest evidence for the latter interpretation is the weak stratification, defined by the variation in clast content of beds. Other features which support this interpretation include the presence of sedimentary intraclasts in some units and normally graded but strongly altered, finer grained tops of units. However, the latter textures may not be primary but rather the result of subsequent hydrothermal alteration and strong deformation. For example, the 'intraclasts' may be tectonically dismembered sedimentary interbeds or sediment-matrix hyaloclastite units, between *in situ* breccia units.

Thin, medium to fine grained breccias of scoria and mudstone clasts are intercalated with mudstone units immediately overlying **andesitic scoriaceous breccia** at some locations. These may be more distal equivalents of coarse grained resedimented scoriaceous breccia, or alternatively, reworked debris locally sourced from *in situ* scoriaceous breccia units (*cf* Allen, 1992).

The irregular, amoeboid shapes of larger framework clasts in the **andesitic scoriaceous breccia** suggest plastic deformation whilst still hot. This could have occurred during mixing and mass-flow deposition with (?hyaloclastic) debris (*cf* 'tuff-breccia with plastically deformed particles' of Dolozi and Ayres, 1991). Alternatively the clasts may be the products of mild subaqueous lava fountaining incorporated into *in situ* hyaloclastite (*cf* Schmincke and Sunkel, 1987; McPhie *et al*, 1993).

Coherent to quench brecciated volcanic units intercalated with units of the **andesitic scoriaceous breccia** may be slightly later intrusions eg sills or feeder dykes, or these may be analogous to the **lava lobe units** of Dolozi and Ayres (1991) ie thin lava flows extruded and incorporated into a debris flow near its depositional site, the **lobate basalt hyaloclastite breccia** of Bergh and Sigvaldason (1991), or the **scoria pillow breccias** with lava stringers of Schmincke and Sunkel (1987).

The vesicular but crystalline to slightly devitrified groundmass of clasts in the **andesitic scoriaceous breccia** would have been relatively impervious to the regionally extensive phyllosilicate alteration (Allen, 1992). In contrast, the thin glassy rims and radial cracks of the clasts; and the more porous, glassy, fine grained breccia matrix were altered to phyllosilicates. Very strongly altered parts of the scoriaceous breccia may reflect very fine brecciation with a greater glassy component. The clasts were, however, selectively altered by quartz-carbonate-pyrite alteration. During subsequent regional deformation the clasts and intercalated coherent units were relatively competent compared with the phyllosilicate-rich, hydrothermally altered breccia matrix, and thus have a less developed tectonic fabric.

Plate 4. Andesitic scoriaceous breccia. Quartz-carbonate altered, lobate, strongly amygdaloidal clasts; in scoriaceous, chloritised, fine-breccia matrix. DDH 144, 104 metres; Scale centimetres.

Plate 5. Andesitic scoriaceous breccia. Detail of strongly amygdaloidal clast in chloritised fine-breccia matrix. Clast margin has phyllosilicate-altered rim and 'tiny normal joints' (arrow). DDH 135, 88.25 metres.

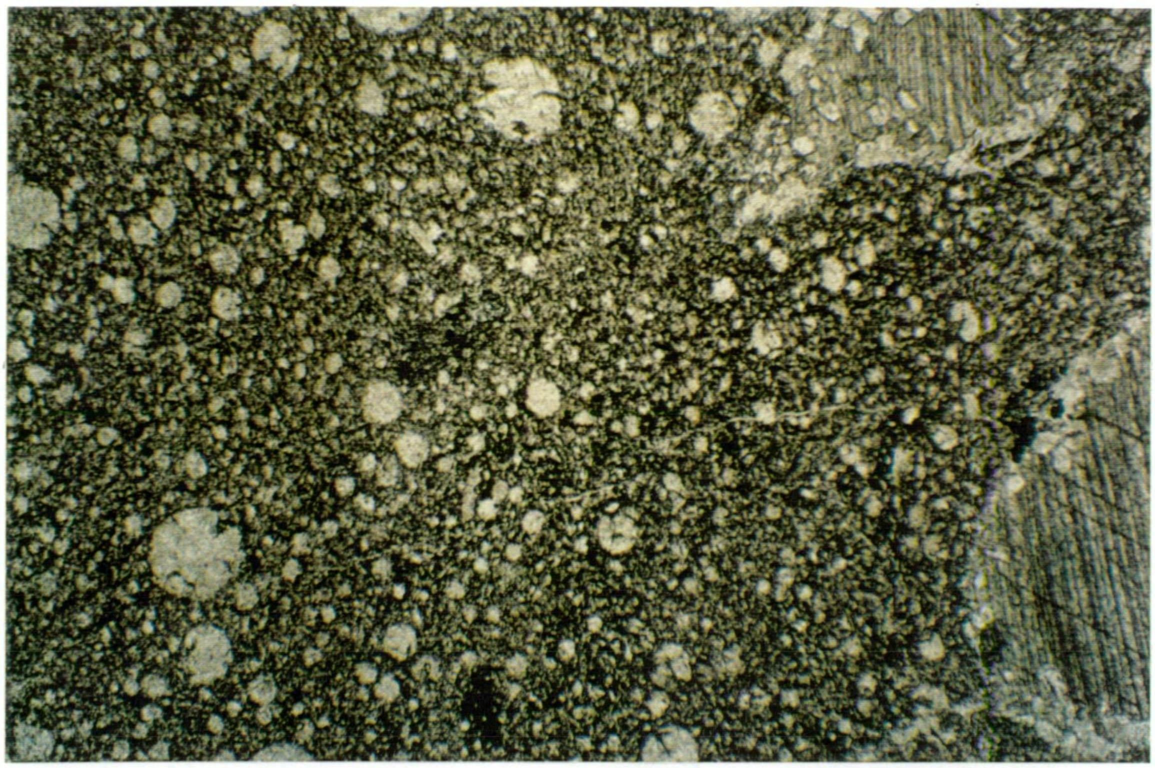

Plate 6. Detail of strongly amygdaloidal clast in andesitic scoriaceous breccia. DDH 142, 28.6 metres. Field of view 2.5 mm. Plane polarised light.

Plate 7. Andesitic scoriaceous breccia. Strongly amygdaloidal, haematite altered clasts in a chloritised matrix. Clasts and matrix are overprinted by quartz-carbonate alteration at top of photograph. DDH B240 (recent drilling), 217 metres. Scale centimetres.

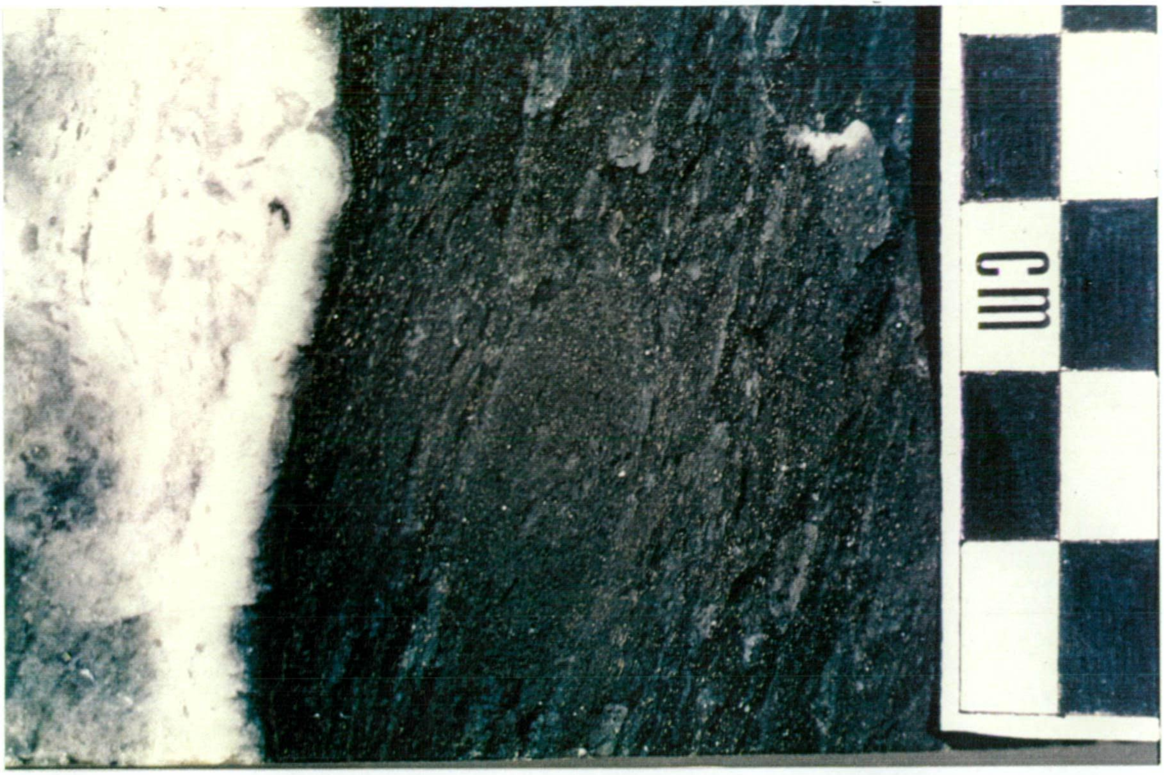

Plate 8. Detail of matrix in relatively unaltered andesitic scoriaceous breccia. Moderately amygdaloidal, poorly sorted clasts and thin, interstitial lenticular chlorite wisps (define strong S2 cleavage). Large white amygdaloidal clast at left. DDH 142, 89.2 metres.

Plate 9. Strongly quartz-sericite-carbonate-pyrite altered andesitic scoriaceous breccia. Clasts are selectively replaced by pyrite. Note increase in intensity of alteration and disseminated mineralisation towards bottom of photograph where unit grades into sub-massive pyritic sulphides. DDH 178, 36 metres. Scale centimetres.

Plagioclase-quartz-bearing altered rocks

Description

Several strongly hydrothermally altered and deformed units of variable thickness (up to 10 metres) superficially have the appearance of sandstones to fine breccias. Most units contain 5-10%, 0.25-1 mm quartz and lesser plagioclase ?crystals. A variety of clast-like patches include: fine-grained, very chloritic, microlitic-plagioclase textured lithology with remnants of amygdules; minor, variably amygdaloidal, often ragged, scoriaceous material; and minor silicic patches of fine grained, interlocking sericite-quartz-feldspar. The matrix consists of very fine-grained sericite-chlorite plus patchy to vein-like carbonate, quartz and pyrite. Minor ragged pumice clasts and possible shards were also noted by Fander (1988). The quartz crystals commonly have recrystallised or deeply embayed rims and are interpreted as xenocrysts (Plates 10 and 11), similar to those in the **andesite** (Section 4.2.1). Blocky, apparent clasts of very fine-grained, interlocking quartz and ?albite crystals are a minor component and are identical to the recrystallised rims of the quartz xenocrysts. These 'clasts' often contain minor, very small, deeply embayed quartz phenocryst remnants and are interpreted as completely recrystallised quartz xenocrysts. Plagioclase crystals are sometimes partly replaced by sericite giving them a rounded appearance. The plagioclase crystal component of this lithology is probably greater than it appears, with many now represented by blocky sericite patches. Quartz and plagioclase ?crystal fragments found in some units are grouped and exhibit similar optical orientation, suggesting *in situ* tectonic brecciation (*cf* Allen, 1988). Units of this lithology are massive to weakly stratified (0.1-1 m) and the latter appear to exhibit normal grading. In a few examples the lithology is intercalated with silty mudstone and contains possible intraclasts of the latter. Other samples have only minor silty mudstone clasts.

Discussion

These rocks are lithologically similar to the quartz-xenocrystic phase of **andesitic scoriaceous breccia** (see above) and are intercalated with it, and with mudstone and mudstone breccia. Some units occur in the immediate hangingwall of mineralisation and/or between thin ore lenses. The apparent grading, weak stratification and presence of possible silty mudstone intraclasts suggests that these may be subaqueous resedimented volcaniclastic units, possibly finer grained (distal facies?) equivalents of the **andesitic scoriaceous breccia** (*cf* Allen, 1987, 1992). However textures are ambiguous due to strong alteration and deformation and for reasons previously discussed (see **andesitic scoriaceous**

breccia above) these could be *in situ* volcaniclastic rocks.

This lithology forms a distinctive geochemical group at the dacitic end of the compositional range of the **andesite** (Section 5). The geochemistry and clast lithologies reflect a mixed provenance. Mixing of the contrasting volcaniclastic components (andesitic and silicic) may have been a mechanical process (ie during deposition) but another possibility is that magma mixing occurred prior to fragmentation and emplacement. The latter interpretation is discussed further in Section 5.

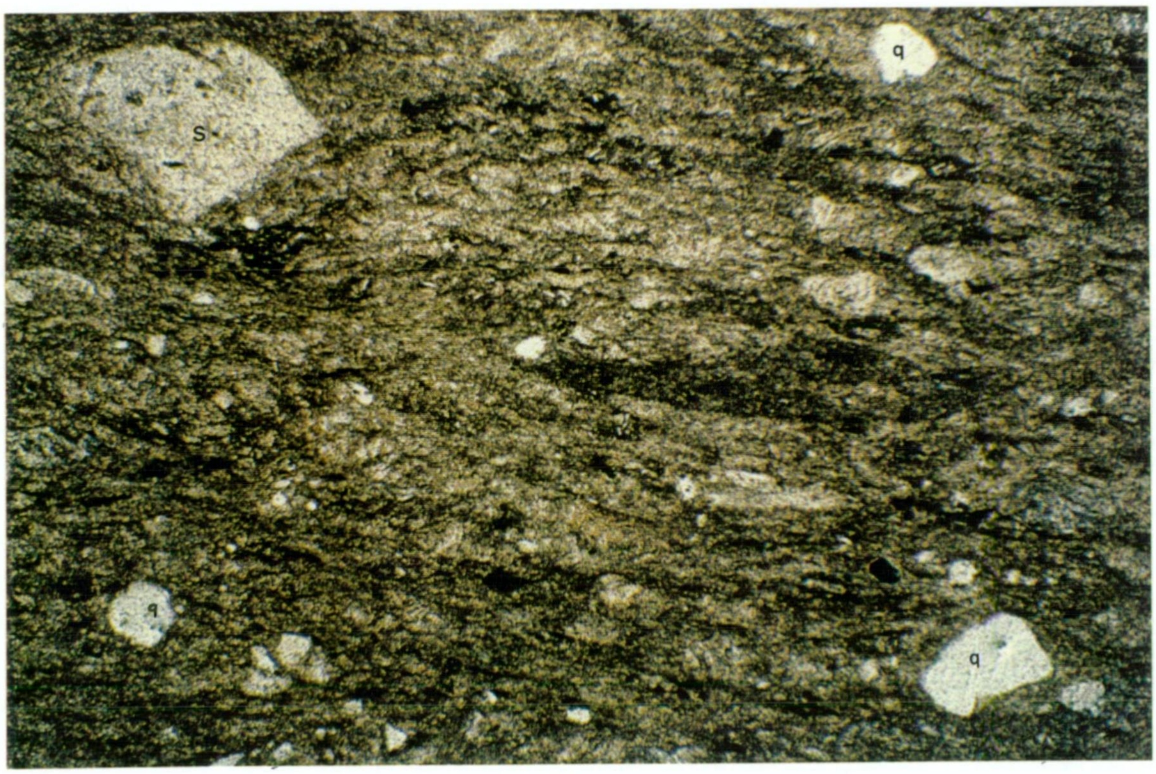

Plate 10

Plate 11

Plates 10 and 11. Plagioclase-quartz-bearing altered rock. Quartz xenocrysts (q) with embayed and recrystallised margins; and silicic lithic clasts (s) in a strongly chloritised matrix. DDH 180, 45.0 metres. Field of view 5 mm. Plate 10 plane polarised light; Plate 11 crossed nicols.

Plagioclase-bearing altered rocks

Description

This lithology consists of 5-10%, 0.25-0.5 mm euhedral to subhedral plagioclase and rare quartz phenocrysts or crystals, rare quartz-filled amygdules or their altered remnants, and minor patches or clasts of microlitic plagioclase-textured material, all in a strongly phyllosilicate-altered groundmass.

Discussion

This lithology forms units which are only a minor component of the Currawong sequence. Superficially it is similar to the **plagioclase-quartz-bearing altered rocks.** However it differs in the paucity of quartz phenocrysts or crystals and their lack of embayed or recrystallised rims (or completely recrystallised equivalents), the less chloritic nature of microlitic plagioclase patches or clasts and its more massive appearance. This lithology is rhyodacitic and is most probably the altered, possibly volcaniclastic, equivalent of **plagioclase-phyric rhyodacite.** The greater alteration suggests that these rocks had a large glassy component, now altered to phyllosilicates. Units of this lithology are intercalated with other variably altered and mineralised but andesitic volcaniclastic rocks. Other very similar lithologies (eg DDH 135 at 217 metres, Appendix I) appear to be the lateral equivalents of coherent rhyodacite sills .

4.3 Summary

Coherent volcanic rocks in the study area comprise basaltic to rhyolitic sills and domes (metres to tens of metres thick). These have intruded a dominantly fine grained sedimentary sequence intercalated with andesitic scoriaceous breccia and sandstone; and ?extrusive strongly flow-banded rhyodacitic units. Commonly associated with the margins of the coherent volcanic rocks are units of sediment-matrix hyaloclastite up to several metres thick . The andesitic volcaniclastic units include thick (typically tens of metres) andesitic scoriaceous breccia and thinner (metres or less thick) units of altered, finer grained scoriaceous rocks. These rocks have some ambiguous characteristics but several features suggest that they may be resedimented, lava-derived mass-flow deposits.
Strong alteration and deformation has made recognition of some volcanic units very difficult. However the results of the geochemical study, described in the next section, resolved some of these problems.

5. GEOCHEMISTRY

5.1 Sampling and analytical method

Samples of approximately 150 mm of HQ drill core (or its equivalent) were taken during logging of drill core for geochemical analysis.

Sample preparation comprised the following steps:

(i) Crush to pea size in a jaw crusher

(ii) Riffle split to approximately 100 grams of sample.

(iii) Pulverise 100 gram sample in a chrome-steel ring mill for approximately two minutes.

(iv) Prepare pressed pellet for XRF analysis.

Seventy three samples were analysed for TiO_2, Nb, Zr, Y, Sr, Rb and Pb using the automated Philips XRF spectrometer at the Department of Geology, University of Tasmania. Supplementary major and trace element analytical data for 17 samples from representative coherent, relatively unaltered volcanic units in the Currawong sequence were kindly provided by Dr J. Stolz for comparison and reference classification.

5.2 Data manipulation and presentation

MacLean and Kranidiotis (1987) postulated that apart from the primary compositional variation of volcanic units, Ti, Zr, Nb and Y were immobile in alteration zones around many Canadian greenstone belt hosted volcanic-hosted massive sulphide (VHMS) deposits. Other authors (eg Finlow-Bates and Stumpfl, 1981; Wynne and Strong, 1984; Gemmell and Large, 1992) argued that under the most intense alteration some of these elements eg Y and Nb show evidence of mobility.

Volcanic units of a single composition, which are associated with VHMS deposits, may be tested for element immobility using plots of pairs of these elements (MacLean and Kranidiotis, 1987; Whitford *et al*, 1989; MacLean and Barrett, 1993; Whitford and Ashley, 1992). Strong positive correlations, ideally passing through the origin, are considered to indicate a constant elemental ratio during the mass-loss or mass-gain effects of hydrothermal alteration or subsequent metamorphism.

Two data sets were used in this study. **Data set I** comprised units recognised as coherent volcanic rocks which displayed very little to moderate hydrothermal alteration. **Data set II** consisted of **data set I** plus all remaining samples ie units logged as volcaniclastic rocks and strongly altered units whose parent lithology could not be recognised with confidence.

The latter were further divided into units suspected of having either sedimentary or volcanic precursors.

Initially plots were made of all element pairs to test for immobility. To assess the effects of stronger alteration, separate plots were made for **data set I** and **data set II**. The ratios of Zr/TiO_2 vs Nb/Y were then plotted for **data set I** to classify the volcanic rock types using the scheme outlined by Winchester and Floyd (1977). A second plot was made using **data set II** to try and relate the volcaniclastic and strongly altered samples to the coherent units. The plot of Y vs Zr was also used to try and characterise the magmatic affinity of the coherent units using the approach of MacLean and Barrett (1993).

A check on the rock type groupings was carried out by comparing a plot of Ti/Zr vs SiO_2 (made for the data provided by Dr J Stolz) with the Winchester and Floyd plot for **data set I**.

5.3 Results

Nb vs Zr

Plots of Nb vs Zr for both data sets are shown in Figure 4 . The plot for **data set I** shows a strong positive correlation for the sample points with the line of best fit passing close to the origin. This suggests that these elements have not been fractionated with respect to each other and have been immobile during alteration. Samples from all units except the **quartz-feldspar-phyric rhyolite** (Currawong Porphyry) form groups with some overlap, spread along the linear trend.The spread of values within groups reflects both compositional variations within rock types and mass- loss or gain during alteration. Two of the three quartz-xenocrystic samples of **andesite** are grouped with its other samples but the third sample overlaps the rhyodacite group. Samples from the flow-banded lithological variant of the **plagioclase-phyric rhyodacite** overlap the main group at its upper end. The Currawong Porphyry samples form a distinct group on a different trend line. This suggests that the Currawong Porphyry is not genetically related to the other volcanic units.

The plot of **data set II** shows that with a few exceptions, most strongly altered volcanic and the volcaniclastic samples lie on the andesite-rhyolite trend line of **data set I**. The samples from strongly altered ?sedimentary rocks form two distinct groups, separate from the other data.

Nb vs Y

Figure 5 shows the plots for Nb vs Y. A positive correlation for both data sets is again evident but in this case the Currawong Porphyry samples appear to lie on the same trend as the other coherent silicic samples. For **data set II**, strongly altered ?sedimentary rocks are again grouped off the trend line whereas all but a few samples of the altered volcanic and volcaniclastic rocks lie within the main linear array of points. Overall, sample points on both plots show a slightly greater scatter compared to the Nb vs Zr plots. This may reflect some minor mobility of Nb and/or Y (*cf* Whitford *et al*, 1989).

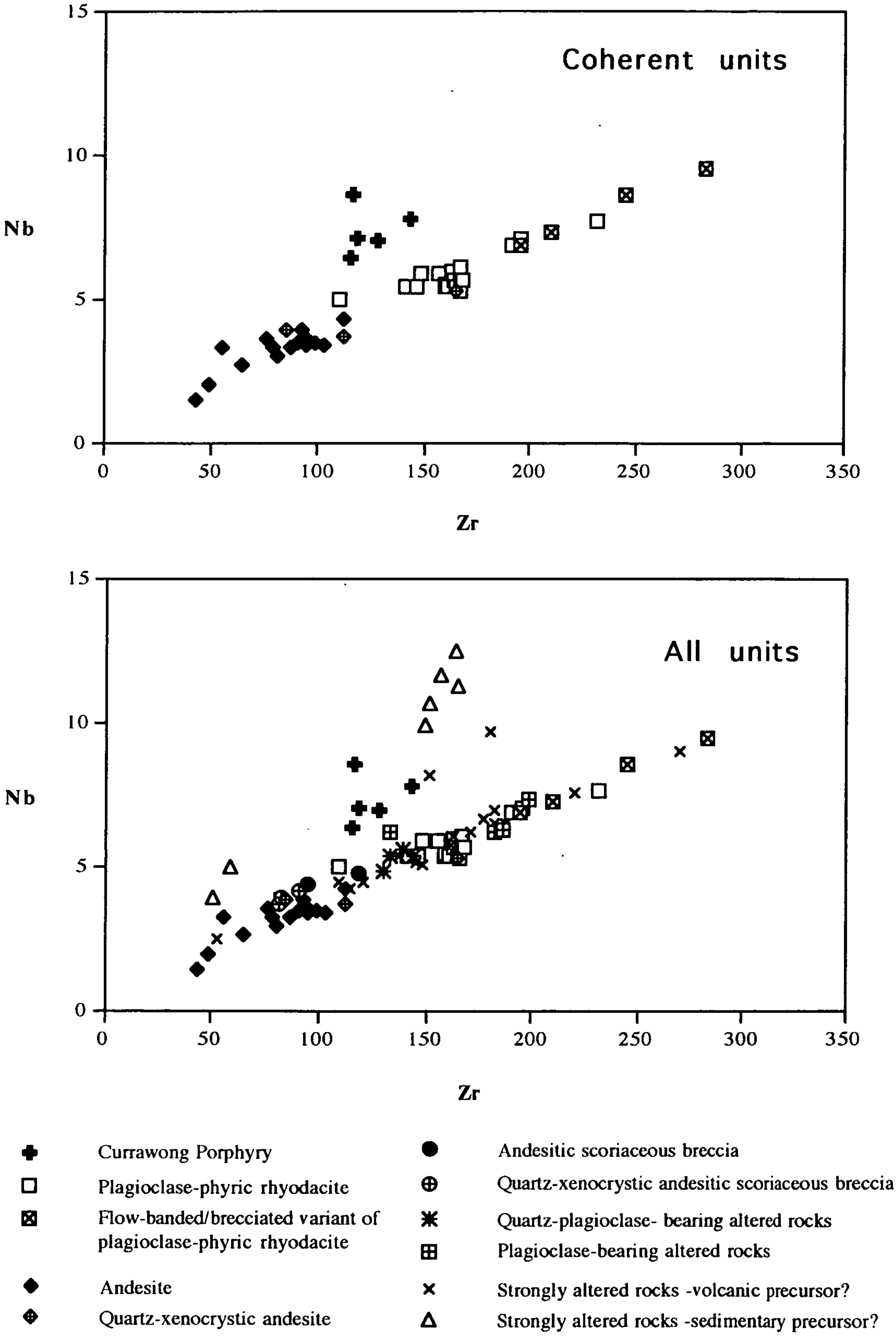

Figure 4. Nb vs Zr plots for analysed samples from Currawong.

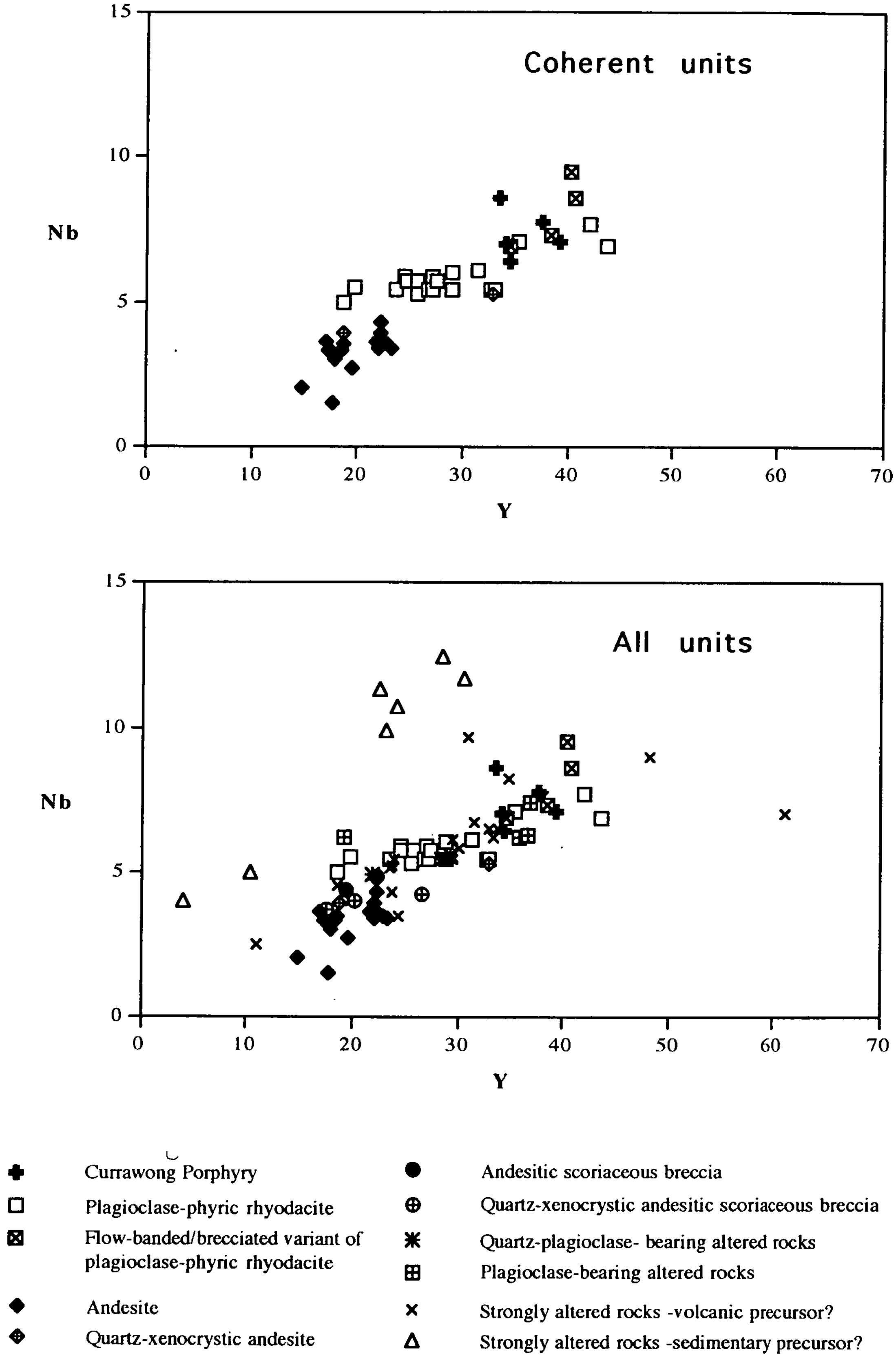

Figure 5. Nb vs Y plots for analysed samples from Currawong.

TiO_2 vs Zr, TiO_2 vs Nb & TiO_2 vs Y

Plots for these three pairs of elements are shown in Figures 6-8. In each case, the **data set I** plot shows reasonable correlations for fairly well defined groups of sample points which correspond with the **andesite, rhyodacite** and **rhyolite**. Each group lies on a linear alteration trend which passes towards the origin but overall the groups reflect the magmatic fractionation trend from andesite to rhyolite (MacLean and Barrett, 1993; Figure 6). On the **data set I** plot of TiO_2 vs Zr (Figure 6), the **quartz-feldspar-phyric rhyolite** (Currawong Porphyry) sample points lie on the same alteration trend as the **plagioclase-phyric rhyodacite** whereas samples from the flow-banded variant of the **plagioclase-phyric rhyodacite** lie just below the trend line. By contrast, on the plots for TiO_2 vs Nb and TiO_2 vs Y, both the Currawong Porphyry and flow-banded rhyodacite are grouped just below the rhyodacite trend line. On all three plots one quartz-xenocrystic **andesite** sample plots with the majority of other andesite samples whereas the other two (and one andesite sample which does not have quartz xenocrysts) have more dacitic compositions. The latter samples are difficult to distinguish from two more andesitic samples from the **plagioclase-phyric rhyodacite.** Similar trends are seen on the **data base II** plots with several of the altered samples loosely grouped between the andesite and rhyodacite groups. The strongly altered ?sedimentary rocks are also loosely grouped on each of the three plots but are best delineated on the TiO_2 vs Nb plot.

Y vs Zr

Figure 9 shows plots of Y vs Zr for **data set I and II**, with annotation after MacLean and Barrett (1993). For **data set I**, sample points are somewhat scattered although a positive correlation is evident for the **plagioclase-phyric rhyodacite** and its flow-banded variant with their sample points lying mainly in the *transitional* field of MacLean and Barrett (1993). The Currawong Porphyry samples lie on a steeper trend within the *tholeiitic* field of MacLean and Barrett. The **andesite** is more ambiguous and could lie in either the *tholeiitic* or *transitional* fields. The plot for **data set II** strengthens the correlation of data points in the *transitional* field and suggests that as on the other two-element plots, the **andesite** samples are part of that trend. In this case, the trend line passes through the Y axis just above the origin. It is also interesting to note that the strongly altered ?sedimentary rocks are not well delineated on this plot.

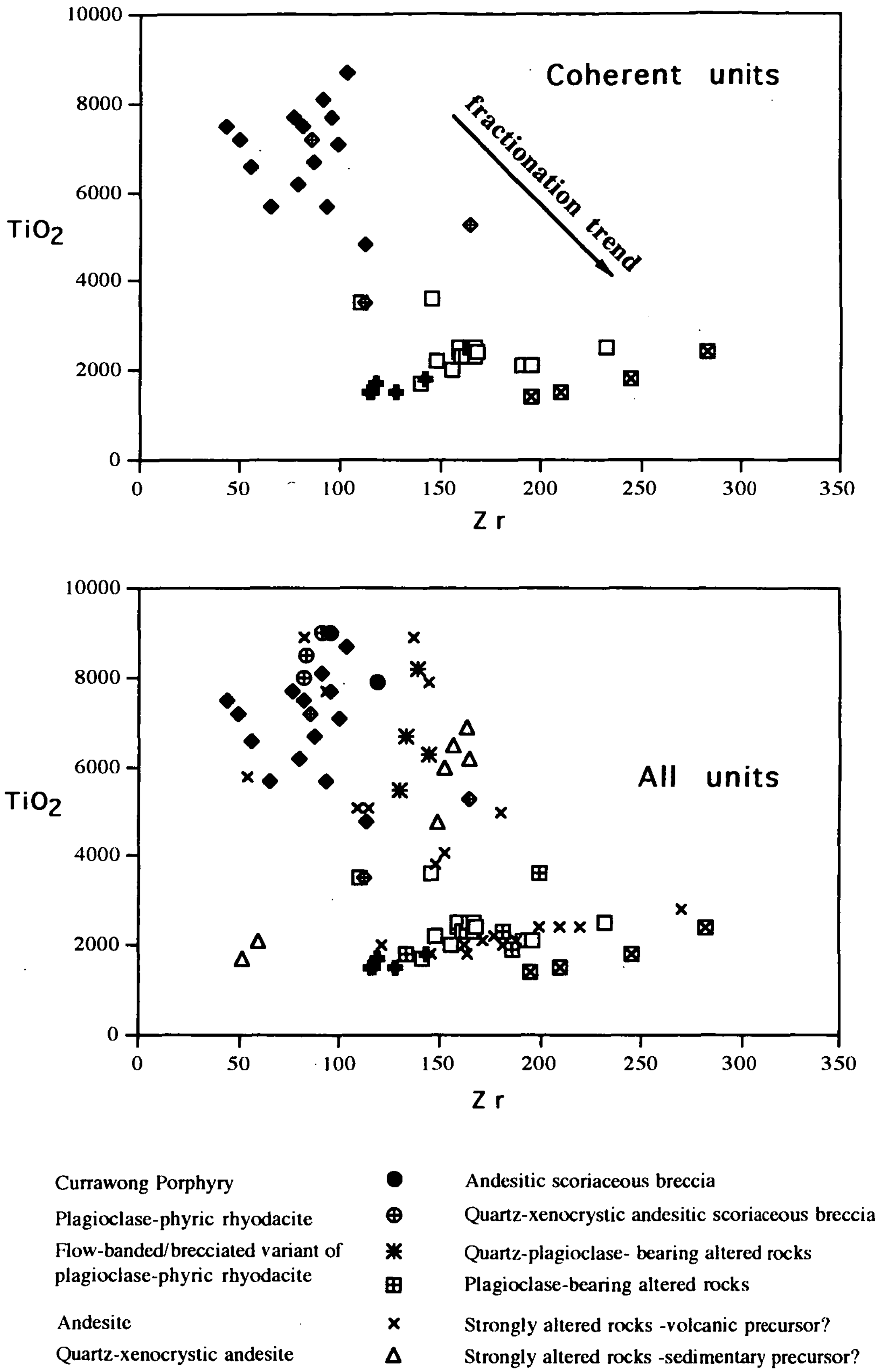

Figure 6. TiO_2 vs Zr plots for analysed samples from Currawong.

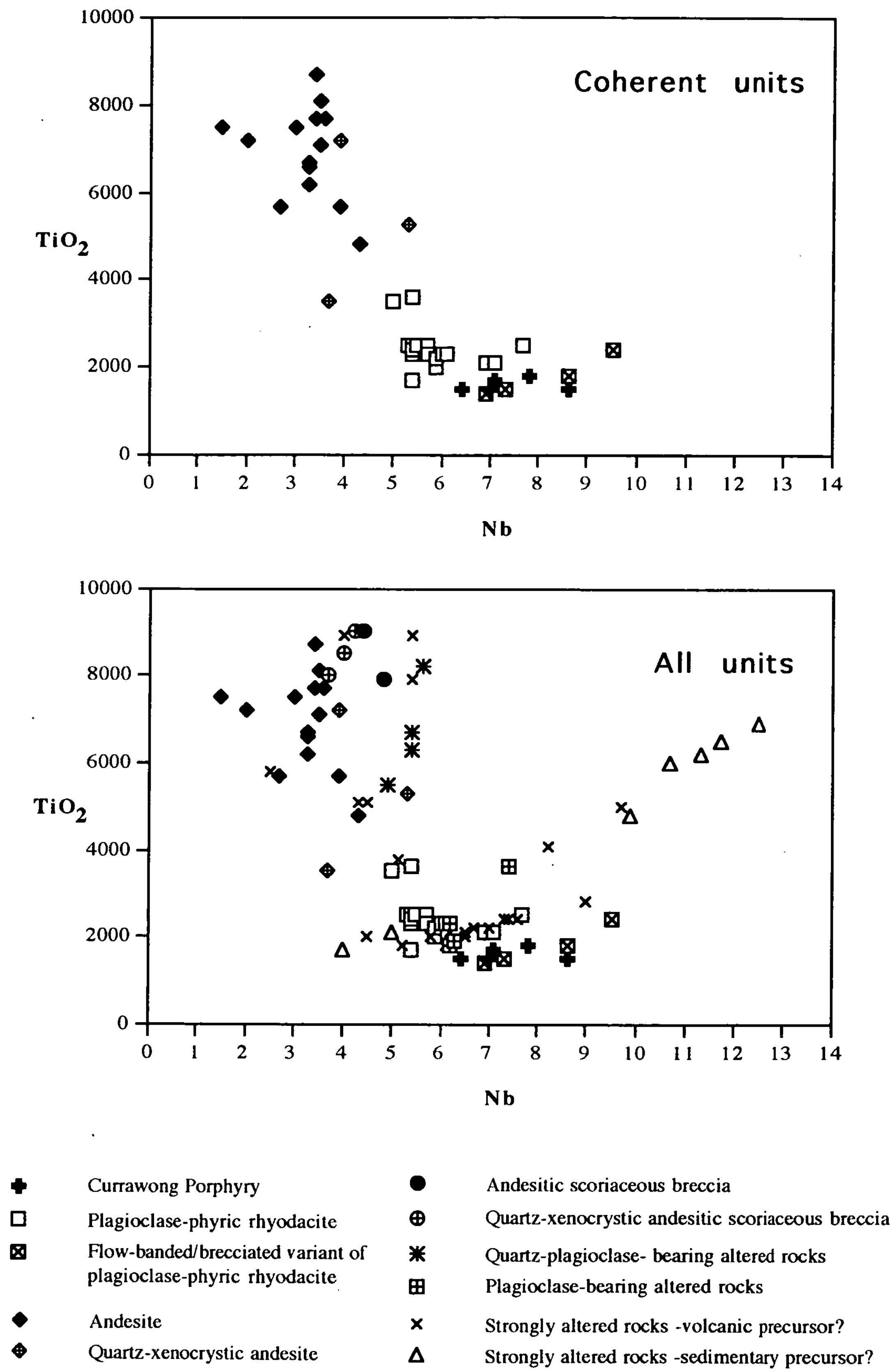

Figure 7. TiO_2 vs Nb plots for analysed samples from Currawong.

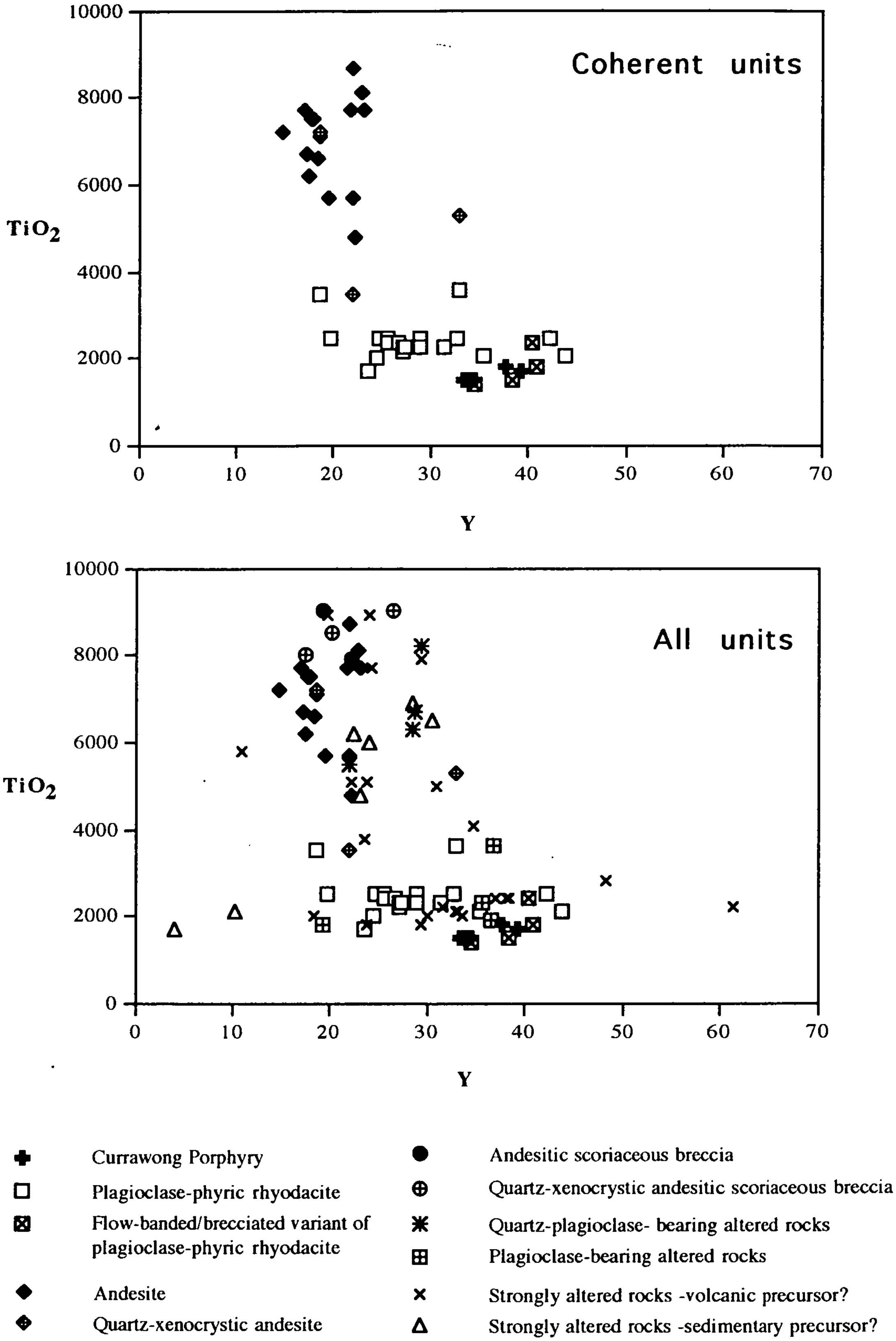

Figure 8. TiO_2 vs Y plots for analysed samples from Currawong.

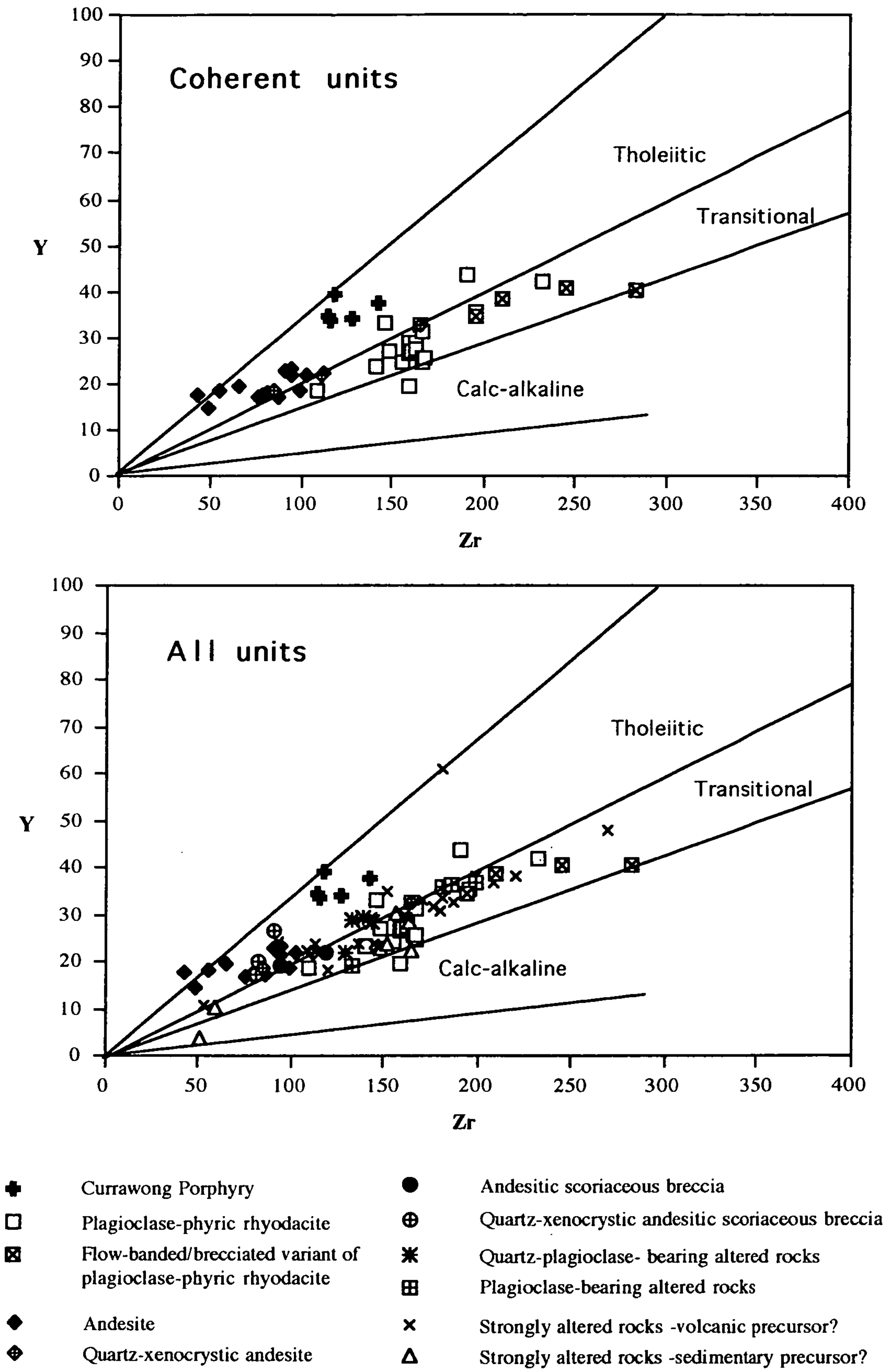

Figure 9. Y vs Zr plots for analysed samples from Currawong (annotation after MacLean and Barrett, 1993).

Zr/TiO_2 vs Nb/Y

Plots of Zr/TiO_2 vs Nb/Y with annotation after Winchester and Floyd (1977) for both data sets are shown in Figure 10. On the **data set I** plot the data points appear to form a fairly continuous series from basaltic andesite to rhyolite compositions. The majority of sample points form distinct groups ie andesites, rhyodacites and rhyolites but a few from the **andesite** (including two of the three quartz-xenocrystic samples) and two from the **plagioclase-phyric rhyodacite** have more dacitic, intermediate compositions. The flow-banded rhyodacite forms a group distinct from the overlapping **plagioclase-phyric rhyodacite** and **quartz-feldspar-phyric rhyolite** (Currawong Porphyry).
For **data set II**, the plot shows that most of the strongly altered ?volcanic rocks plot with the coherent end-member groups though a few have dacitic compositions. Samples from the **andesitic scoriaceous breccia**, including samples which are quartz-xenocrystic, are closely grouped with the more basaltic samples of the **andesite**. The **plagioclase-bearing altered rocks** are compositionally very similar to the **plagioclase-phyric rhyodacite** whereas the **plagioclase-quartz-bearing altered rocks** form a tight group with the more dacitic samples of the **andesite**. Samples from the strongly altered ?sedimentary rocks lie off the fractionation trend but are well constrained on this plot.

Ti/Zr vs SiO_2

The plot of Ti/Zr vs SiO_2 for the limited available data is shown in Figure 11. Samples from the **plagioclase-phyric rhyodacite** are well constrained except for a single sample which is anomalous in both SiO_2 and Ti. The Currawong Porphyry samples are also reasonably well grouped with similar Ti/Zr ratios to the **plagioclase-phyric rhyodacite** but generally higher silica contents. By contrast the samples from the **andesite** exhibit a wide range in silica content and Ti/Zr values.

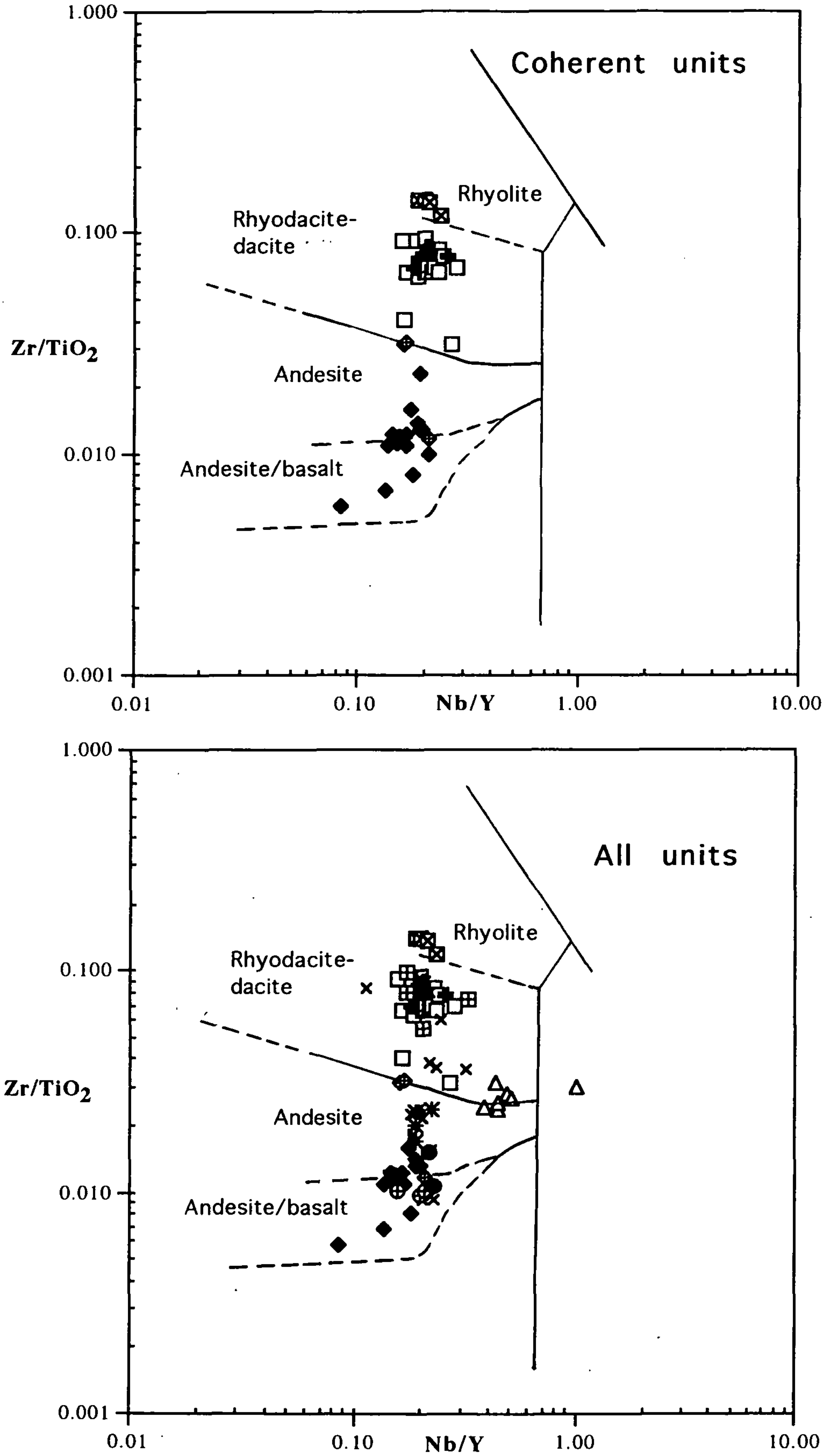

Figure 10. Zr/TiO_2 vs Nb/Y for analysed samples from Currawong. (after Winchester and Floyd, 1977). See Figure 9 for legend.

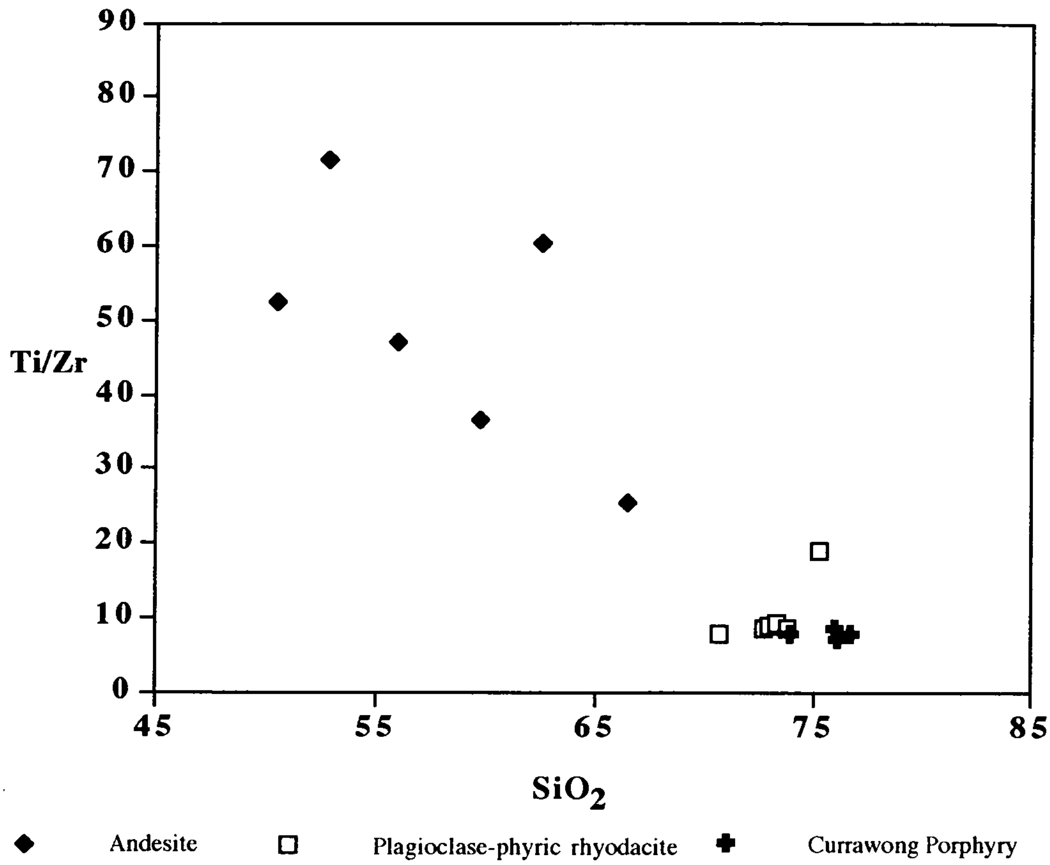

Figure 11. Ti/Zr vs SiO_2 plot for analysed samples of coherent, relatively unaltered volcanic rocks from Currawong (unpublished data of Dr J Stolz).

5.4 Discussion

The two-element plots described above indicate that Ti, Zr, Nb and Y have behaved essentially in an immobile manner during hydrothermal alteration and subsequent metamorphism of the volcanic units in the Currawong host sequence. A few altered samples are more scattered on plots involving Nb and Y suggesting some mobility of these elements during intense hydrothermal alteration.

The Zr/TiO_2 vs Nb/Y plot of **data set I** shows that coherent volcanic units in the Currawong sequence fall into two main groups ie andesitic and rhyodacitic-rhyolitic. The plot for **data set I** is useful for discriminating between most coherent volcanic rocks although a notable exception is the group containing the two lithologically distinctive but geochemically similar lithologies ie **plagioclase-phyric rhyodacite** and **quartz-feldspar-phyric rhyolite** (Currawong Porphyry). Apart from this case, the Zr/TiO_2 vs Nb/Y plot for both data sets enables recognition of precursors to the more strongly altered, lithologically unrecognisable volcanic units. Other plots of element-pairs, such as the Nb vs Zr and Y vs Zr, enable better discrimination of the rhyodacite from the Currawong Porphyry and suggest that the latter is not genetically related to the other volcanic units.
Volumetrically minor units, with compositions intermediate between the two end members, appear to represent variants emplaced during magmatic differentiation. However, these units include quartz-xenocrystic coherent **andesite** and may reflect mixing of andesitic magma, or its more dacitic differentiates, with a quartz-phyric silicic magma.
The Ti/Zr vs SiO_2 plot reflects the trends for coherent units identified in other plots. For the **andesite** in particular, the correlation of higher silica content with lower Ti/Zr is mirrored by its wide spread of Zr/TiO_2 values on the Zr/TiO_2 vs Nb/Y plot.
Comparison of the Zr/TiO_2 vs Nb/Y plots for the two data sets, together with lithological evidence presented in Section 4, indicate that the **andesitic scoriaceous breccia** (including units containing quartz xenocrysts) is a volcaniclastic facies of the **andesite**. Similarly, the **plagioclase-bearing altered rocks** are altered, possibly volcaniclastic, equivalents of the **plagioclase-phyric rhyodacite**. The **plagioclase-quartz-bearing altered rocks** are geochemically similar to the more evolved examples of the **andesite**. However, lithologically they appear to be polymict with xenocrystic-quartz and plagioclase crystal fragments plus clasts of **andesite**, a silicic lithology and minor scoria. They contain more quartz than the quartz-xenocrystic units of the **andesitic scoriaceous breccia** but are otherwise lithologically similar to them. The **plagioclase-quartz-bearing altered rocks** are interpreted as (?resedimented) volcaniclastic rocks of mixed provenance. Mixing of components was possibly mechanical during resedimentation. Alternatively, the polymict clastic components may reflect intermingling and mixing of andesitic and rhyodacitic magmas (*cf* Thompson and Dungan, 1985) **prior** to autoclastic fragmentation.

5.5 Summary

The volcanic lithologies at Currawong can be distinguished using minor and trace element geochemistry. This approach has proven useful for identifying altered volcanic units and relating volcaniclastic units to their coherent equivalents.

Basaltic to rhyolitic rocks of the Gibsons Folly Formation form a fairly continuous magmatic evolution trend. However the andesitic coherent and volcaniclastic rocks exhibit a wide range of Zr/TiO_2 values and SiO_2 content which appears to reflect the combined effects of magmatic differentiation and mixing with a quartz-phyric silicic magma. The latter mechanism is supported by the presence of xenocrystic quartz in some coherent andesitic units and silicic volcanic clasts in volcaniclastic rocks of andesitic composition.

A rhyolite intrusion at the base of the Gibsons Folly Formation (the Currawong Porphyry) is geochemically distinctive and unrelated to the other volcanic units. Nd isotope studies support this conclusion and indicate that the Currawong Porphyry is part of the Thorkidaan Volcanics (Dr J Stolz, unpublished data; *cf* Allen, 1992)

6. STRATIGRAPHY

6.1 Previous research

Several previous authors have presented interpretations of the Currawong deposit host stratigraphy. These include Western Mining Corporation (various authors in unpublished reports, 1979-1986 including a major relogging project by Page, 1984); Allen (1987, 1992); Cox et al (1988); Kennedy and Simopolous (1989); Allen and Barr (1990); and Bodon (1993).

Most interpretations have led to the conclusion that the Currawong deposit consists of at least five separate massive sulphide lenses within a sequence of intercalated fine sedimentary rocks and predominantly silicic volcanic units of the Gibsons Folly Formation (Section 3). The sulphide lenses appear to be arranged *en echelon* both in plan and section and are bounded by several sub-vertical faults.

Allen (1992) described the lithostratigraphy associated with the Currawong deposit as comprising a basal rhyolite breccia overlain by (in ascending stratigraphic order) mudstones and thin sandy turbidites; massive sulphide; basalt flows and sills; and again mudstones and turbidites. This sequence is intruded by several dacite sills in both the hangingwall and footwall. The basalts in part exhibit extrusive textures, whilst both the basalts and dacites include volcaniclastic facies comprising *in situ* massive and sediment matrix hyaloclastites and resedimented hyaloclastites. At Currawong, Allen (1992), assigned the footwall rhyolite to the Gibsons Folly Formation whereas at Wilga he considered the rhyolite to be part of the Thorkidaan Volcanics. However he concluded that the Wilga and Currawong mineralisation are at the same stratigraphic level ie within 100m of the last major extrusive rhyolites and within 50m below the first major basalt lava. Thus the Thorkidaan volcanism continued, albeit intermittently, until earliest Gibsons Folly Formation time (Section 3).

Bodon (1993) presented a stratigraphic interpretation though he did not carry out a detailed lithological study of the host sequence. His interpretation largely concurs with that of Allen (1992) except in the area north of the zone of multiple sub-vertical faulting (Figure 3). Bodon considered Lens 2 (=Allen's Lens B) to be within or above the highest andesitic to dacitic volcanic units of the sequence and about 50 metres stratigraphically higher than Lens 1 (=Lens C of Allen, 1992; and this study). He concluded that two horizons of mineralisation are present at Currawong, with Lens 2 at the stratigraphic position of the nearby Wilga deposit.

6.2 Results of this study

Data from the core logging is presented as graphic logs in Figure 12 and Appendix I. A stratigraphic interpretation is presented on cross-sections and level-plans in Appendix II. The stratigraphic relationships between the various rock types are summarised as a stratigraphic column in Figure 13.

6.2.1 Sedimentary rocks

Allen (1987, 1992) described the sedimentary rocks from the Currawong succession. Two facies are present, of which massive to finely laminated, grey and lesser black **mudstone and siltstone** are the most abundant. Repetitively interbedded with the finer grained units are thin, normally graded, **fine grained sandstone** units which have sharp basal contacts. Allen interpreted the sedimentary rocks as hemipelagic sediments which include thin turbidites and together represent a basin centre facies association. The sedimentary units are intercalated with and in part enclose both the volcanic units and massive sulphide mineralisation

6.2.2 Volcanic rocks

Intermediate composition

Volcanic rocks of intermediate composition at Currawong comprise two distinct but genetically related, andesitic lithologies ie **andesite** and quartz-xenocrystic **andesite.** Both form coherent intrusions which typically have margins of sediment-matrix hyaloclastite and are associated with thick, volcaniclastic units of **andesitic scoriaceous breccia** and **plagioclase-quartz bearing altered rocks**.

In the study area, the largest lens of massive sulphide mineralisation (C lens) is hosted by a sequence of variably altered andesitic rocks and intercalated sedimentary units. The andesitic rocks are predominantly **andesitic scoriaceous breccia** which have a variable quartz xenocryst component, and **plagioclase-quartz-bearing altered rocks**. The quartz-xenocrystic breccia units are generally more altered than those without quartz and in places are weakly mineralised, typically as selective pyrite replacement of clasts. They commonly occupy the up-dip and/or lateral stratigraphic position of C lens (Section 7). The scoriaceous breccias have minor intercalated **mudstone and siltstone** and **fine sandstone** which may represent hiatuses in eruptive activity and suggest that the breccias comprise several depositional units. The **plagioclase-quartz-bearing altered rocks** form (volumetrically) a minor component of the sequence and occur as thin (generally less than one metre, but up to 10 metres thick) units associated with the finer grained sedimentary facies, in the immediate structural hangingwall of C lens and/or between its component ore lenses. Stratigraphically these altered units are closely related to the quartz-xenocrystic phases of the **andesitic scoriaceous breccia** and may be their finer-grained equivalents.

Coherent **andesite** forms sills which have intruded the sedimentary units of both the footwall and hangingwall sequences and possibly the **andesitic scoriaceous breccia** units (Section 4). Strongly quartz-xenocrystic, more evolved coherent units of the **andesite** (Section 5) are found in the hangingwall sequence and in strongly altered rocks which occupy a stratigraphic position equivalent to C lens.
The sills intruded relatively unconsolidated sediments as their upper contacts are typically sediment-matrix hyaloclastites and lower contacts similar or relatively sharp and passive. The sediment matrix is always bleached or baked. Thus the criteria of Allen (1992, Table 1) suggest that these are shallow sills with right-way-up facing. The coherent andesitic units are interpreted as the shallow intrusive expression of the extrusive andesitic volcanism which generated the scoriaceous breccias.

Silicic composition

Silicic volcanic rocks in the Currawong sequence are rhyolitic to dacitic in composition (Section 5). The sequence of sedimentary and intermediate volcanic rocks is intruded throughout by sills and cryptodome-like bodies of **plagioclase-phyric rhyodacite.** Contacts are typically passive to disruptive and commonly include an interval of sediment-matrix hyaloclastite. In a few cases the matrix of the intrusive hyaloclastite is **andesitic scoriaceous breccia** indicating that that the scoriaceous breccia was unlithified at the time of intrusion. In places (eg DDH 98, 45m; Figure 12) rhyodacite intrusions have margins of sediment-matrix hyaloclastite within the same sedimentary unit that forms the matrix of underlying intrusive andesite hyaloclastite. This indicates that the rhyodacite was emplaced when the sediments were still relatively unlithified.

The silicic intrusions appear to have penecontemporaneously deformed the sequence. An example is the large rhyodacitic cryptodome-like body in the immediate footwall of mineralisation. The intrusion shows a marked variation in thickness (Appendix II) which appears to have produced local perturbations in the strike of underlying and overlying units. The units above the intrusion are most deformed suggesting predominantly upward doming. The present geometry of the C lens massive sulphide appears to be the result of penecontemponaneous deformation and subsequent tectonic deformation.
A distinctive lithology of the structural footwall is the flow-banded variant of the **plagioclase-phyric rhyodacite.** This forms a thick sequence of units tens of metres thick (eg Figures 12 and 14) which typically exhibit strong phyllosilicate alteration. Allen (1992) considered this lithology to be a compositionally identical, mainly autoclastic, earlier extrusive phase of the Currawong Porphyry (see below). Petrological and geochemical data from this study area (Sections 4 and 5) indicate that the lithology is marginally more silicic but otherwise similar to the **plagioclase-phyric rhyodacite.** Fander's (1988) interpretation of these more silicic rocks as ignimbrites was not supported by this study.

Lowest in the sequence of the study area is a large (tens of metres thick by square kilometres in areal extent) sill of variably brecciated, strongly porphyritic **quartz-feldspar-phyric rhyolite** (ie the Currawong Porphyry). The rhyolite has well developed chilled margins and in places (eg DDH 178, 253 m; Appendix II) has formed a coarse breccia with a matrix of altered, older flow-banded rhyodacite. Contacts with enclosing sedimentary rocks are generally passive, indicating intrusion into partly lithified sediments.

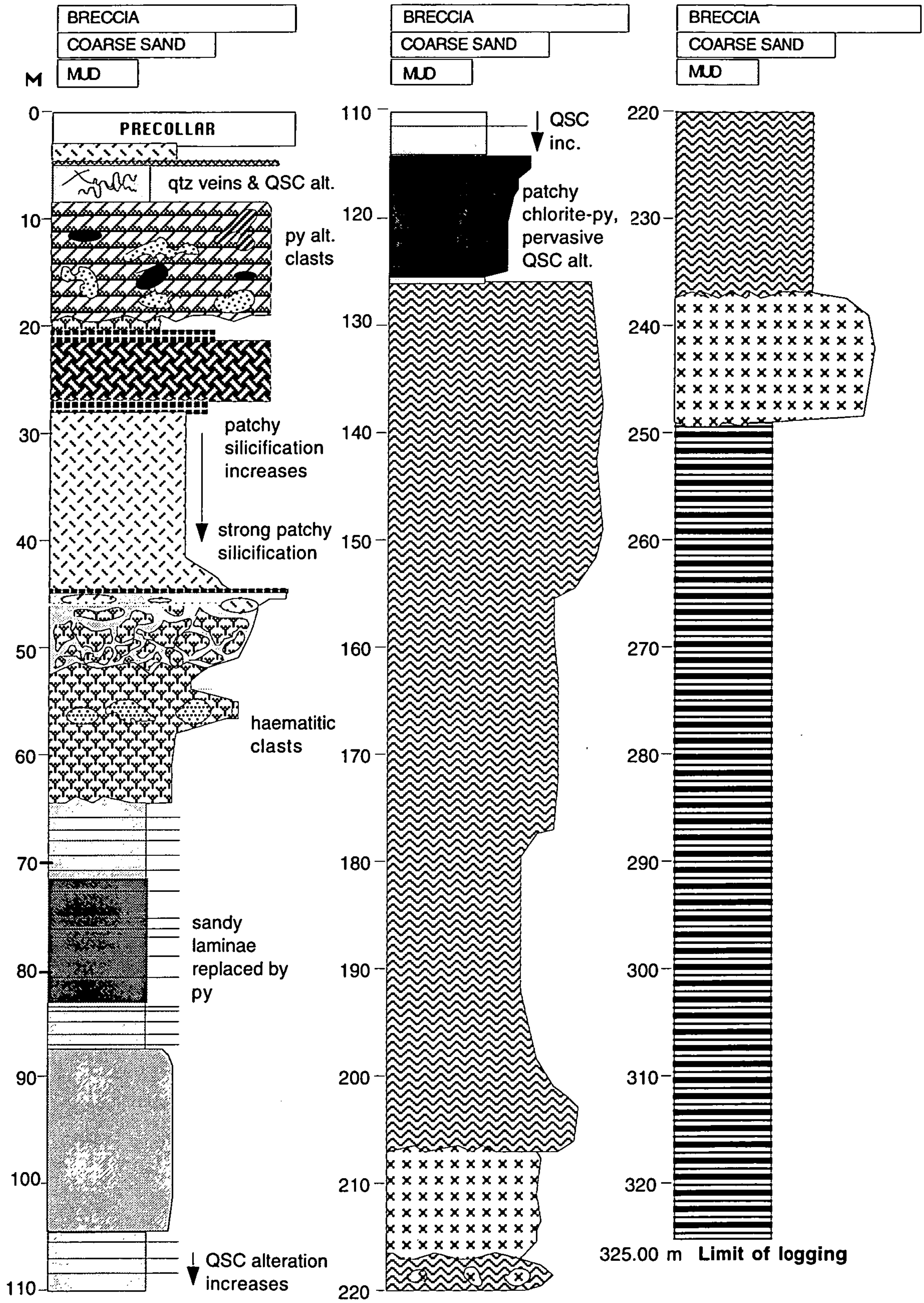

Figure 12. Graphic log of DDH 98. Fold out legend on next page.

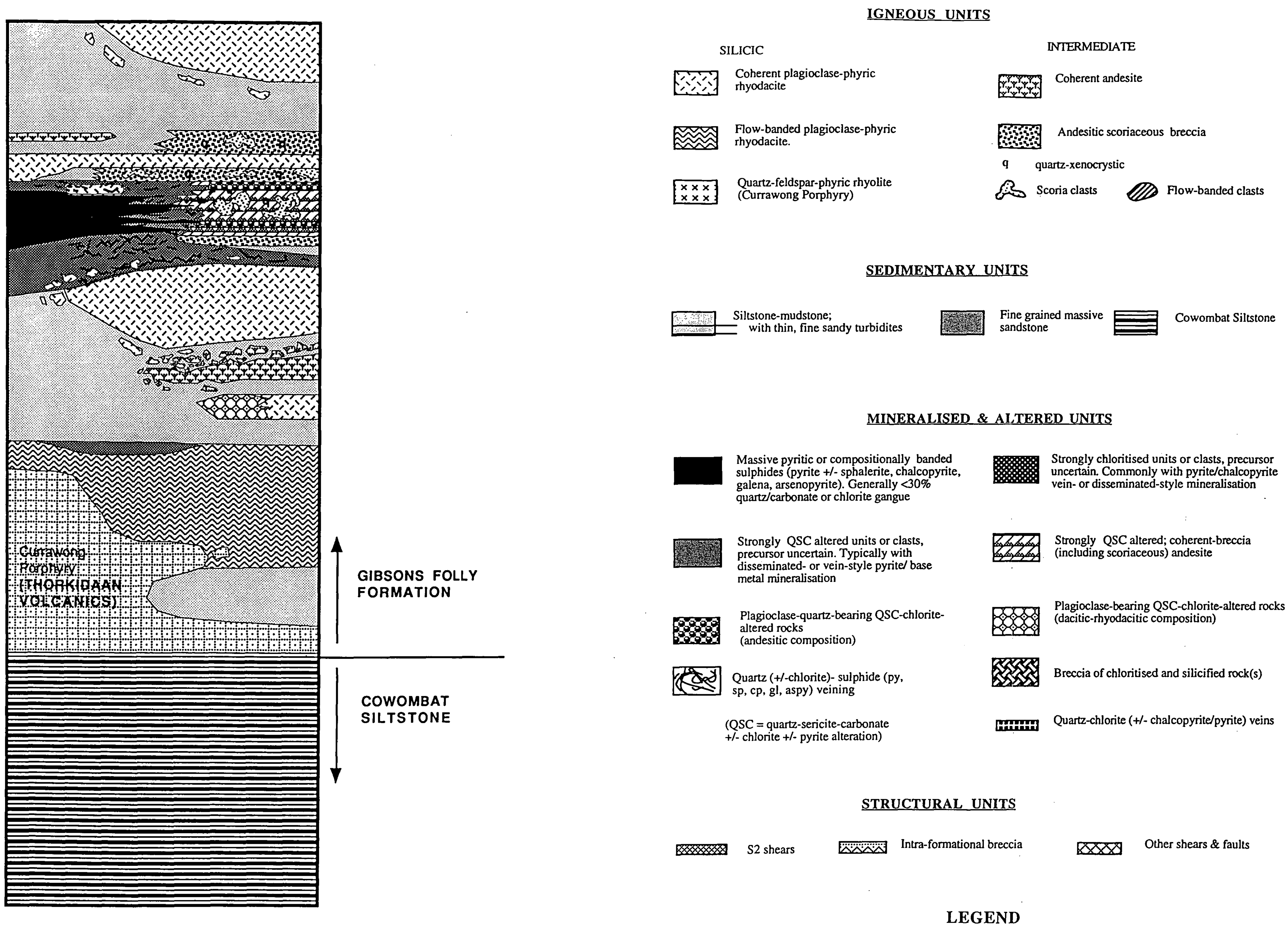

Figure 13. Idealised stratigraphic column for units in the study area.
Scale approximately 1:2500

6.3 Summary

Although in general the results of this study support the stratigraphic interpretation of Allen (1992), in detail some differences have emerged which have exploration implications. In particular, the stratigraphic position of the C lens massive sulphide mineralisation is interpreted differently. The important features of this interpretation are summarised below.

(i) Andesitic units are present both in the structural footwall and hangingwall.

(ii) Andesitic units of the footwall are predominantly shallow sills which have intruded unlithified sediments.

(iii) The massive sulphide mineralisation and stronger alteration show a close stratigraphic relationship with quartz-xenocrystic coherent and scoriaceous breccia facies of the **andesite** and more particularly, their intercalated units of fine grained sedimentary rocks and **plagioclase-quartz-bearing altered rocks.**

(iv) Comparison of this stratigraphic interpretation with those for the Wilga host sequence (eg Allen and Barr, 1990; Allen, 1992) suggest that the main lens of massive sulphide mineralisation in both deposits occurs at the same stratigraphic position. The strongest evidence for this conclusion is the stratigraphic equivalence of the Wilga mineralisation and variably altered 'quartz-plagioclase dacite' (Figure 4 of Allen, 1992). This rock type is lithologically most similar to quartz xenocryst-rich variants of the **andesite** which show a close stratigraphic association with the C lens massive sulphide mineralisation at Currawong. Other evidence for this interpretation is the presence of coherent **andesite** units in the footwall of the Wilga deposit (Allen, 1992).These were considered by Allen to be fault slices within his interpreted major F2 shear zone underlying the Wilga massive sulphide. The **andesite** units may be *in situ* sills, equivalent to those seen in the footwall at Currawong. Fine grained sedimentary units and rhyodacite units also occur between the Wilga massive sulphide and the footwall shear at some locations (Cox *et al*, 1988; Allen, 1992).

(v) In plan (Appendix II) a major dip-parallel fault is invoked for this interpretation, to explain the displacement of the stratigraphy apparent between 17500E and 17550E. Such faults are common in underground exposures at the nearby Wilga deposit. There, a major example dissects the orebody and displaces it several metres. At Currawong such faults may also be common but are difficult to define by the current drilling database. Such faulting may in some places offers an alternative explanation for apparent deformation of the sequence by rhyodacite cryptodome-like intrusions.

In conclusion, the differences in interpretation for Currawong are well illustrated on cross-section 17550E (Figure 14). No convincing evidence was found of the possible major fault in DDH 142 as shown on Allen's interpretation (Figure 3). This fault invokes a stratigraphic equivalence of the coherent andesite of DDH 98 (approximately 45-65 m) and the andesitic breccias of DDH 142 (approximately 25-70 m). Rather the coherent andesite unit of DDH 98 is interpreted by Allen's own criteria as a sill, rather than an extrusive unit. The scoriaceous breccia in DDH 98 (approximately 9-20 m), above the rhyodacite intrusion, is the strongly altered, variably mineralised up-dip equivalent of the C lens massive sulphide. The andesite sill occurs in the footwall of C lens at many other locations throughout the study area (Appendix II).

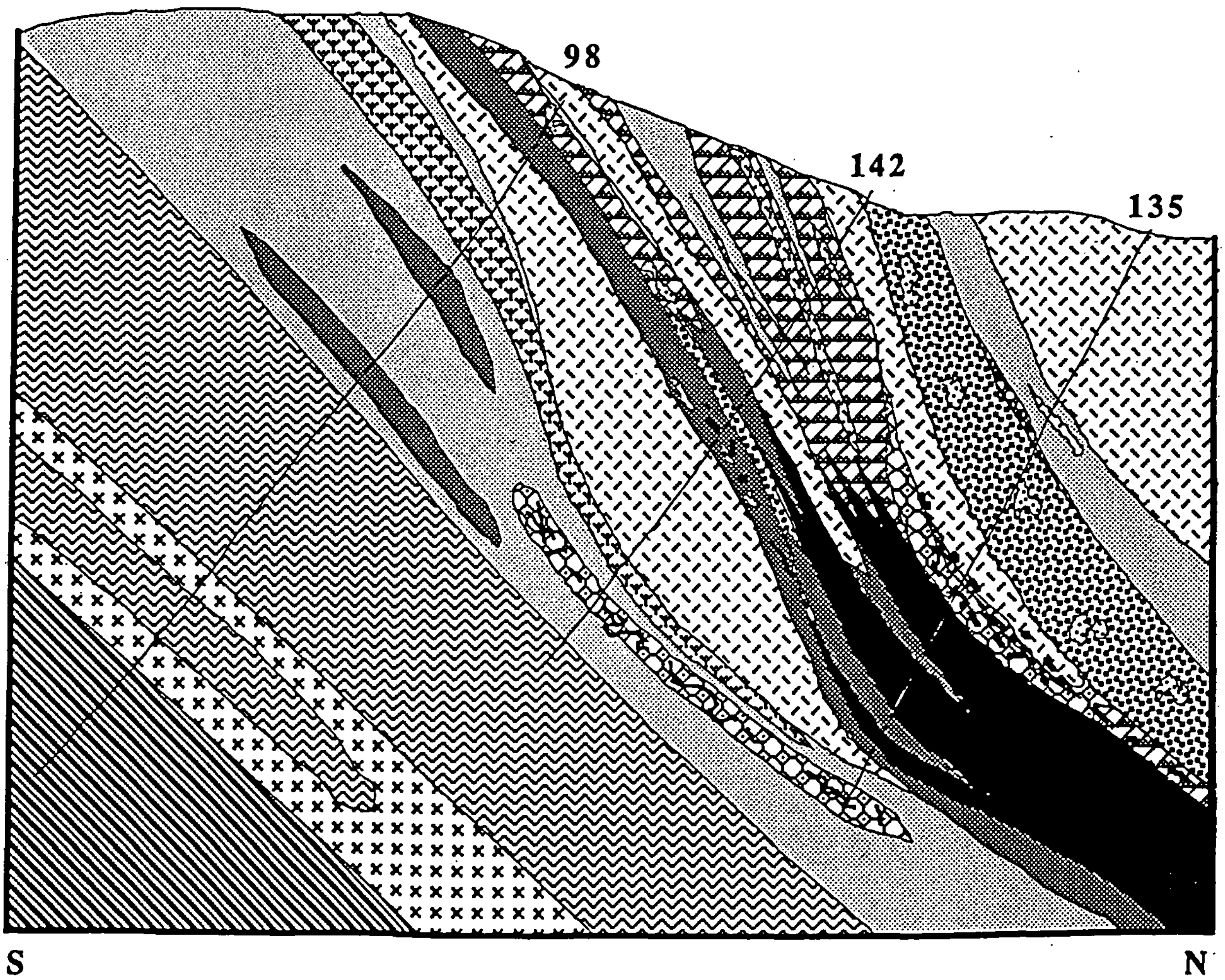

Figure 14. Cross-section 17550E. Scale 1:2500. See Figure 13 for legend.

7. ALTERATION AND MINERALISATION

7.1 Introduction

Ore-grade mineralisation within the study area of this research is part of the largest ore lens at Currawong (ie C lens of Cox *et al*, 1988 and Allen, 1992; Lens 1 of Bodon, 1993; Figure 3). The study area incorporated the up-dip and lateral margins of C lens. This enabled the relationship between mineralisation and the host-stratigraphy to be studied, albeit from the limited exposure of drill core.

7.2 Alteration

Hydrothermal alteration is a common feature of the volcanic and, to a lesser extent, sedimentary rocks at Benambra. Its presence is evidenced by mineral assemblages that cannot be explained by isochemical metamorphism of the volcanic rocks, such as chlorite in rhyolite and quartz-sericite alteration in andesitic to basaltic rocks (Allen, 1988, 1992). The unaltered basaltic to andesitic rocks of the Gibsons Folly Formation (Section 3) have mineral assemblages typical of lower greenschist facies metamorphism, that is chlorite-carbonate-epidote-quartz-Fe oxides. Thus in weakly altered rocks characterised by little addition of potassium, the distinction between hydrothermal alteration and metamorphic mineral assemblages may be unclear (Allen, 1988). The results of this study indicate that volcanic and sedimentary units, at several stratigraphic horizons throughout the sequence, have been altered by hydrothermal fluids including those associated with the base metal mineralisation. Only two types of alteration were recognised as hydrothermal in origin during this study: **quartz-sericite-carbonate alteration** and **chlorite alteration**. This is consistent with the results of a more detailed study of hydrothermal alteration assemblages and their distribution in the Currawong ore lenses and adjacent units, by Bodon (1993). The latter study recognised five types of hydrothermal alteration:

(i) Quartz-sericite-carbonate-(+/-chlorite, epidote).

(ii) Quartz-chlorite.

(iii) Chlorite.

(iv) Siliceous.

(v) Stilpnomelane-carbonate (chlorite) +/- talc, epidote.

Type (i) forms areally extensive (kilometre scale), semi-conformable alteration zones. The zones have a characteristic bleached appearance and associated disseminated pyrite and/or quartz-pyrite veins. Type (i) is dominant in the hangingwall sequence at Currawong and types (iii) and (iv) may also be locally developed; type (iii) often occurs in association with base metal sulphides. All alteration types occur in the Currawong footwall but typically types (iii) and (v) occur in the immediate footwall, grading down into types (ii) and (i) respectively (Bodon, 1993).

The results of this study show that **quartz-sericite-carbonate alteration** has a strong association with coarser grained (fine sand or coarser) units of both the structural hangingwall and footwall sequences of the study area. Units of **fine grained sandstone, andesitic scoriaceous breccia, plagioclase-quartz-bearing altered rocks, plagioclase-bearing altered rocks** and autoclastically brecciated margins of coherent volcanic rocks typically exhibit varying degrees of this alteration, often with associated pyrite as veins or disseminations. Contacts of altered, coarser grained sedimentary or volcaniclastic units with unaltered finer grained sedimentary units are always very sharp. In contrast, where margins of volcanic units exhibit autoclastic brecciation, a gradational decrease in quartz-sericite-carbonate alteration towards the coherent core of the unit is commonly observed.

The intensity of **quartz-sericite-carbonate alteration** generally increases as massive sulphide or higher grade vein and/or disseminated mineralisation is approached but strong **chlorite alteration** is commonly dominant adjacent to the strongest mineralisation. Similarly, units intercalated with massive sulphides are typically intensely chloritised. In lower grade disseminated and vein mineralised units, chlorite +/- quartz is associated with pyrite-chalcopyrite (+/- sphalerite-galena) mineralisation and clearly overprints quartz-sericite-carbonate alteration.

Observations made during this study also suggest that quartz-chlorite (type ii, see above) alteration is in some cases chlorite alteration overprinting sediment-matrix hyaloclastite breccia. The strongly silicified component is sediment altered and baked during peperitic mixing with hyaloclastite breccia of the intruding magma. The chloritic component was originally volcanic glass, subsequently altered to chlorite during the mineralising event. The combination of these two processes have produced a quartz-chlorite breccia.

In summary, hydrothermal alteration at Currawong is semi-conformable to stratabound and largely confined to coarser grained volcaniclastic and sedimentary units. This probably reflects a permeability control on the hydrothermal fluids throughout the volcano-sedimentary sequence. **Quartz-sericite-carbonate alteration** is extensively developed at several stratigraphic horizons and is pervasive within these units. It is overprinted by patchy- to vein-style **chlorite alteration**, commonly associated with base-metal mineralisation.

7.3 Mineralisation

A detailed study of the Currawong mineralisation and its paragenesis was outside the scope of this project but has previously been carried out by Bodon (1993).
In the following section the styles of mineralisation are first briefly described, followed by a summary of the key features of their distribution and relationship to the host stratigraphy. These are then integrated into a genetic interpretation for the Currawong C lens mineralisation followed by some thoughts on future exploration at Benambra.

7.3.1 Styles of mineralisation

Three distinctive styles of mineralisation were recognized in this study ie **massive pyritic, compositionally banded, vein** and **disseminated** mineralisation. These essentially concur with the 'ore-types' described by Bodon (1992; [1]).
Massive pyritic mineralisation is predominantly (up to 95%) pyrite with lesser sphalerite, chalcopyrite and rare galena. It typically has less than 30% siliceous and/or carbonate gangue and forms thick (tens of metres) massive bedded to very weakly foliated units with thin sphalerite wisps in places defining a diffuse (S2) cleavage-parallel foliation. These sometimes exhibit isoclinal folding and transposition onto S2.
A variant of massive pyritic mineralisation, **compositionally banded** sulphide mineralisation, consists of centimetre scale alternating pyrite-, sphalerite-, chalcopyrite- or (galena+arsenopyrite)-rich layers, often with chlorite gangue.
Vein sulphide mineralisation clearly cross-cuts and replaces volcanic or sedimentary units. Veins (typically centimetres thick) consist of pyrite and base metal sulphides in variable proportions associated with quartz-sericite-carbonate or chlorite alteration. Thicker veins (10's of centimetres) are difficult to distinguish from massive pyritic mineralisation. Chalcopyrite-pyrite veins are typically associated with strong chlorite

[1] 'Mineralisation' rather than 'ore-type' is the preferred term in this study as much of the mineralisation, including massive sulphide, is not of ore grade.

alteration

Disseminated mineralisation is associated with quartz-sericite-carbonate- or chlorite-altered volcanic or sedimentary units. Pyrite as millimetre to centimetre scale disseminations, isolated veinlets or replacements of clasts is most common; but base metal sulphides may also be present, especially in association with chlorite alteration. Where units exhibit a strong tectonic fabric, sulphide-replaced 'clasts' may be difficult to distinguish from boudinaged veins.

7.3.2 Relationship of mineralisation to the host sequence

The petrological and geochemical studies (Sections 4 and 5) enabled a consistent stratigraphy to be defined (Section 6). This showed that the thickest package of alteration and mineralisation in the study area (ie the C lens 'mineralised horizon' of Cox *et al*, 1988) is hosted by andesitic volcanic and volcaniclastic rocks at a consistent stratigraphic position. In plan and cross-section (Appendix II) the distribution of alteration and mineralisation clearly shows a stratigraphic control. Its geometry mirrors that of the host sequence, particularly the andesitic volcanic rocks.

C lens exhibits up-dip and lateral variations in its style of mineralisation such that **disseminated** and **vein** mineralisation are the stratigraphic equivalents of **massive pyritic** and **compositionally banded** sulphide mineralisation.

Within C lens **massive pyritic** and **compositionally banded** sulphide mineralisation is intercalated with units of variably altered and mineralised volcanic and sedimentary rocks. Some of the volcanic rocks are recognisable in hand-specimen or thin-section but most original textures are obliterated by strong hydrothermal alteration. The geochemical study (Section 5) enabled these volcanic units to be related to relatively unaltered equivalents in the host sequence. This showed that units of both the **andesite** and **plagioclase-phyric rhyodacite** occur within the massive pyritic mineralisation.

Similarly, **disseminated** and **vein** mineralisation stratigraphically equivalent to C lens occurs in strongly altered volcanic and sedimentary units. Thus in essence, the massive pyritic mineralisation of C lens is surrounded by a halo of disseminated and vein mineralised volcanic and sedimentary rocks.

Disseminated mineralisation is typical of fine-sand to fine-breccia clastic rocks *eg* sandstone and the matrix of scoriaceous breccia (Plate 9). In contrast, **vein**

mineralisation commonly replaces autoclastic volcanic breccias, on the margins of unaltered and unmineralised coherent volcanic units (Plate 12).

Vertical gradational increases in sulphide content, with an associated increase in the degree of alteration, are a common feature of **disseminated** mineralisation within altered units. This is expressed by an increase in the size and abundance of sulphide disseminations (eg in volcaniclastic units by an increase in the degree of selective clast replacement by sulphides) which in some cases grade into **massive pyritic** sulphides (Plate 9).

Contacts of relatively unaltered units to alteration/mineralisation of all styles are typically knife-edge sharp. The unaltered units appear to have been relatively impermeable to hydrothermal alteration eg coherent volcanic or massive mudstone units. Allen (1989) noted selective replacement of quartz grains by pyrite in altered psammitic units (turbidites) within unaltered mudstone and further suggested that lateral replacement fronts could be recognized.

In addition to the C lens mineralised horizon, several other horizons (up to several metres thick) of moderate to strong hydrothermal alteration with associated mineralisation are present in the study area. These occur throughout the sequence, from within the footwall flow-banded rhyodacite up to the base of the large cryptodome-like rhyodacite intrusion of the hangingwall sequence, and generally show only limited lateral continuity (eg Figure 14, Appendix II). **Quartz-sericite-carbonate alteration** is the most common style of alteration with associated **disseminated** and minor **massive pyritic** or **vein** mineralisation. At a few locations **chlorite alteration** is dominant and in some cases is associated with **vein** base-metal mineralisation (Plate 12). These minor mineralised horizons are thus very similar to the up-dip and lateral equivalent stratigraphic horizon of C lens.

The petrological study (Section 4) indicated that the **plagioclase-phyric rhyodacite** intrusions were emplaced into the partly lithified sedimentary sequence. As the intrusions commonly include altered and mineralised *in situ* volcaniclastic margins, it appears that the host sequence was in place at the time of the mineralising event.

Plate 12. Vein and disseminated mineralisation on the margin of a **plagioclase-phyric rhyodacite** sill. Strong chlorite alteration is associated with py-cp-sp mineralisation. The massive pyritic sulphide with sp wisps is interpreted as thick veins replacing the volcaniclastic (sediment-matrix hyaloclastite?) margin of the coherent rhyodacite.
DDH 181, 156 metres. Scale centimetres.

7.4 Genetic interpretation

Based upon the evidence presented above, the C lens at Currawong is interpreted as a subsea-floor replacement style volcanic hosted massive sulphide deposit (*cf* Large,1992).

In summary, the key features supporting this interpretation are:

(i) the strong association of alteration and lower grade mineralisation with clastic facies at various stratigraphic horizons;

(ii) the gradational increases in the degree of alteration and mineralisation within clastic units;

(iii) the sharp contacts of mineralisation to relatively impermeable, unmineralised units; and

(iv) the observed intercalation with, and stratigraphic equivalence of, massive pyritic mineralisation and altered/mineralised but geochemically recognisable volcanic units.

Together these observations suggest channelling of hydrothermal fluids through more porous horizons, with relatively impermeable units (eg mudstone or coherent volcanics) controlling fluid flow.

In this model, relatively porous units were mineralised as disseminated to massive pyritic or banded mineralisation whereas less porous units (eg autobrecciated volcanic units) were predominantly vein mineralised. Thus only the volcaniclastic margins of coherent volcanic units exposed to the mineralising fluids were mineralised. This effect is well illustrated on several cross-sections and level plans in Appendix II where the large cryptodome-like rhyodacite intrusion in the footwall of C lens is only vein mineralised on its brecciated margins nearer to C lens.

The C lens horizon was the locus of greatest fluid flow in very porous andesitic scoriaceous volcaniclastic rocks. Up-dip and along strike of the C lens massive sulphide mineralisation these comprise altered andesitic scoriaceous breccia with minor intercalated coherent andesite and mudstone.

The host of the strongest mineralisation was probably a finer-grained facies, equivalent to the breccia *ie* **plagioclase-quartz-bearing altered rocks**. The latter lithology shows a close spatial association with massive sulphide mineralisation.

Strongly altered but relatively unmineralised volcanic units within the C lens are coherent rhyodacite and andesite units. These were relatively impervious to hydrothermal fluids and produced the common vertical and lateral discontinuities of massive sulphide mineralisation seen in C lens.

Hydrothermal fluids were presumably vented simultaneously at the seafloor, at an indeterminate but higher stratigraphic position. Thus an anastomosing system of hydrothermal fluid channels is envisaged with the geometry of resultant massive sulphide mineralisation controlled by the original distribution of clastic units.

The above interpretation is consistent with that of Bodon (1993) who suggested a model of subsea-floor replacement of epiclastic units, based on paragenetic and metal zonation evidence. Similarly, Allen (1987, 1992) and Allen and Barr (1990) suggested that at least some massive sulphide mineralisation may have formed in this way. Their conclusion was based on observations that altered and mineralised rocks surrounding the massive sulphides, and some massive sulphide itself, had relict textures of, and graded into, sedimentary and volcaniclastic rocks.

7.5 Future exploration

The Currawong and Wilga massive sulphide deposits are essentially 'blind' in that massive sulphides do not outcrop. At surface the stratigraphic horizon equivalent to the massive sulphide consists of strongly altered volcanic units which contain limonitic veins and have anomalous base metal geochemistry (Robbins and Chenoweth, 1984; Cox *et al*, 1988).

These volcanic units have commonly been described by company geologists as 'quartz-eye tuffs'. At the Wilga deposit, Allen (1987, 1992) and Allen and Barr (1990) mapped this unit as 'plagioclase-quartz dacite'. The Wilga 'dacite' is lithologically very similar to the quartz-xenocrystic andesite at Currawong (Sections 4 and 6).

The results of this study suggest that altered, scoriaceous, quartz-xenocrystic volcaniclastic facies with andesitic compositions should be a primary target for further exploration at Benambra.

The target units have a distinctive range of Zr/TiO_2 ratios on the Zr/TiO_2 vs Nb/Y plot (after Winchester and Floyd, 1977; Figure 10, Section 5). Zr/TiO_2 ratio may thus be a cheap and useful tool during further exploration. This and the presence of xenocrystic-quartz should enable rapid definition of prospective horizons.

8. CONCLUSIONS

The main conclusions from the results of study are:

* Coherent volcanic rocks at Currawong are predominantly intrusions into a sequence of mudstone interbedded with thin, fine sandstone turbidite units. Coherent **andesite** and **plagioclase-phyric rhyodacite** units are mainly shallow sills but the rhyodacite also forms cryptodome-like bodies which appear to have penecontemporaneously deformed the sequence. Commonly associated with the margins of intrusions are units of sediment-matrix hyaloclastite which indicate intrusion into unlithified sediments.

* Units of strongly flow-banded and/or brecciated **plagioclase-phyric rhyodacite** in the footwall sequence may be lavas but textures are equivocal.

* **Andesitic scoriaceous breccia** and **plagioclase-quartz-bearing altered rocks** form a useful stratigraphic marker sequence (typically tens of metres thick) within the volcano-sedimentary succession. The breccia and finer grained altered rocks comprise several depositional units, separated by thin mudstone units. They are ambiguous lithologies, but several features suggest that they may be resedimented, lava-derived mass-flow deposits. These units are lithologically and geochemically distinctive and host the Currawong mineralisation.

* Ti, Zr, Nb and Y have behaved essentially in an immobile manner during hydrothermal alteration of the volcanic rocks of the Currawong host sequence. The various volcanic lithologies can best be distinguished using the plots Zr/TiO_2 vs Nb/Y (after Winchester and Floyd, 1977) and Nb vs Zr. The former plot is also useful for identifying petrographically unrecognisable altered volcanic units; and for relating volcaniclastic units to their coherent equivalents.

* The coherent volcanic units of this sequence form a fairly continuous geochemical magmatic evolution trend but coherent and volcaniclastic andesitic rocks exhibit a wide compositional range. The presence of xenocrystic-quartz in some andesitic units and silicic volcanic clasts in volcaniclastic rocks of andesitic composition suggest that these

were generated by the combination of magmatic differentiation and mixing of andesitic and quartz-phyric silicic magmas.

* Textural relationships indicate that the **plagioclase-phyric rhyodacite** intrusions were emplaced when the sediments and andesitic scoriaceous units were *in situ* but still relatively unlithified.

* The Currawong Porphyry (**quartz-plagioclase-phyric rhyolite**) is a sill-like body which has intruded relatively lithified rocks including flow-banded and brecciated units of the **plagioclase-phyric rhyodacite**. Geochemical and stratigraphic evidence indicates that the Currawong Porphyry represents a late phase of silicic volcanism of the Thorkidaan Volcanics, in the basal part of the Gibsons Folly Formation.

* Relationships of hydrothermal alteration and mineralisation to the host sequence suggest that the Currawong deposit is a subsea-floor replacement style volcanic hosted massive sulphide deposit. Massive pyritic mineralisation is intercalated with, and laterally equivalent to, strongly altered volcanic units which carry variable disseminated or vein mineralisation.

* Alteration and mineralisation show a strong stratigraphic control related to primary permeability of the host sequence. Quartz-xenocrystic, andesitic scoriaceous volcaniclastic rocks were the locus of the strongest mineralisation at Currawong, and possibly at the nearby Wilga deposit. **Plagioclase-phyric rhyodacite** intrusions were also weakly mineralised, suggesting that the whole host sequence was in place at the time of the mineralising event.

* Altered, scoriaceous, quartz-xenocrystic volcaniclastic facies with andesitic compositions should be a primary target for future exploration at Benambra. Trace element geochemistry, specifically Zr/TiO_2 ratio, may be a cheap and useful tool during exploration, as the andesitic host units have a distinctive range of values for this ratio. This, and the presence of xenocrystic-quartz, should enable rapid definition of prospective horizons.

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APPENDIX I

* Legend for all drill logs, cross-sections and level plans.

* Graphic drill logs, grouped on cross-sections (west to east).

IGNEOUS UNITS

SILICIC

- Coherent plagioclase-phyric rhyodacite
- Flow-banded plagioclase-phyric rhyodacite.
- Quartz-feldspar-phyric rhyolite (Currawong Porphyry)

INTERMEDIATE

- Coherent andesite
- Andesitic scoriaceous breccia
- q quartz-xenocrystic
- Scoria clasts
- Flow-banded clasts

SEDIMENTARY UNITS

- Siltstone-mudstone; with thin, fine sandy turbidites
- Fine grained massive sandstone
- Cowombat Siltstone

MINERALISED & ALTERED UNITS

- Massive pyritic or compositionally banded sulphides (pyrite +/- sphalerite, chalcopyrite, galena, arsenopyrite). Generally <30% quartz/carbonate or chlorite gangue
- Strongly chloritised units or clasts, precursor uncertain. Commonly with pyrite/chalcopyrite vein- or disseminated-style mineralisation
- Strongly QSC altered units or clasts, precursor uncertain. Typically with disseminated- or vein-style pyrite/ base metal mineralisation
- Strongly QSC altered; coherent-breccia (including scoriaceous) andesite
- Plagioclase-quartz-bearing QSC-chlorite-altered rocks (andesitic composition)
- Plagioclase-bearing QSC-chlorite-altered rocks (dacitic-rhyodacitic composition)
- Quartz (+/-chlorite)- sulphide (py, sp, cp, gl, aspy) veining
- Breccia of chloritised and silicified rock(s)
- Quartz-chlorite (+/- chalcopyrite/pyrite) veins

(QSC = quartz-sericite-carbonate +/- chlorite +/- pyrite alteration)

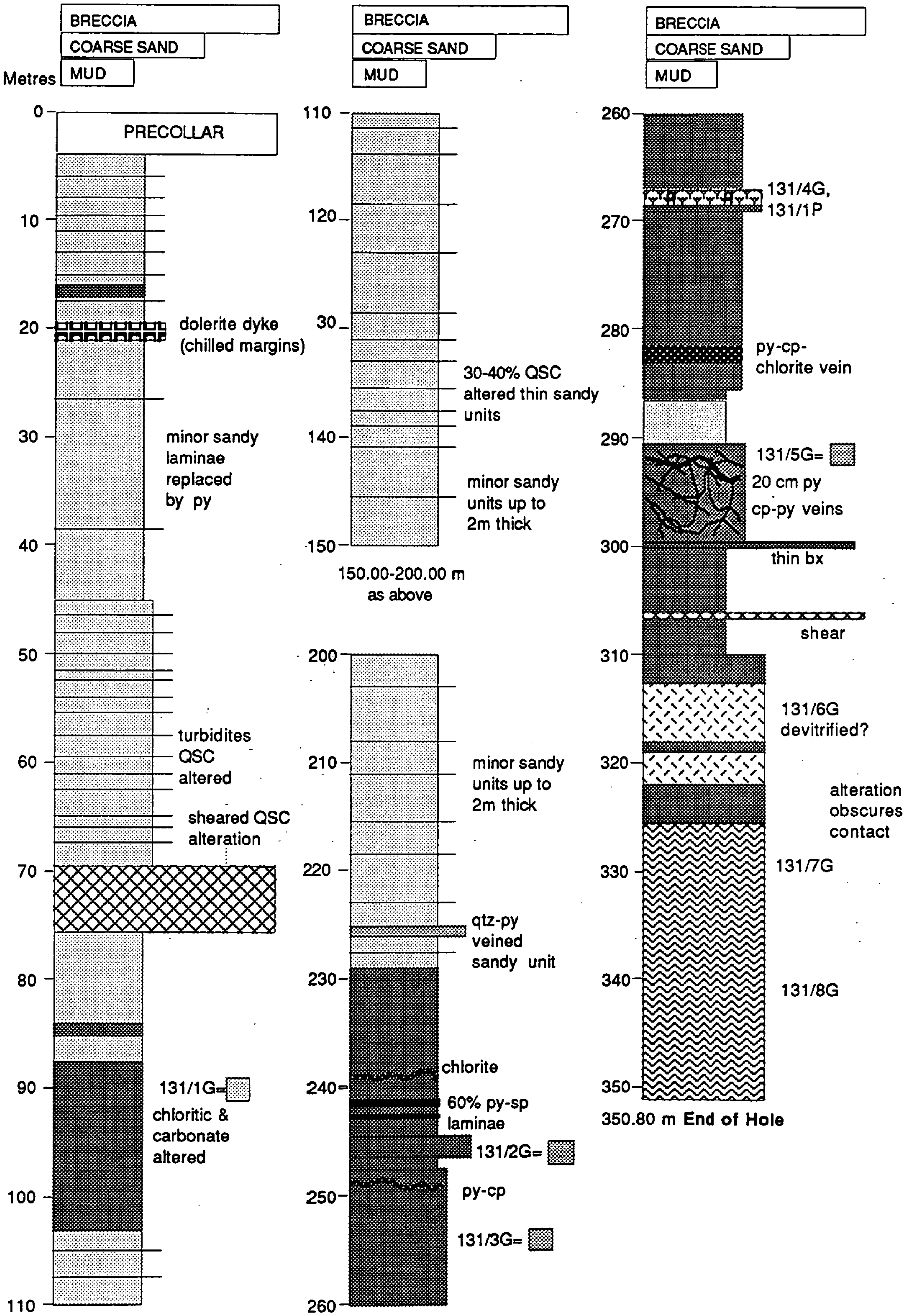
STRUCTURAL UNITS

- S2 shears
- Intra-formational breccia
- Other shears & faults

SAMPLING: 98/4P Petrological sample 98/6G Geochemical sample

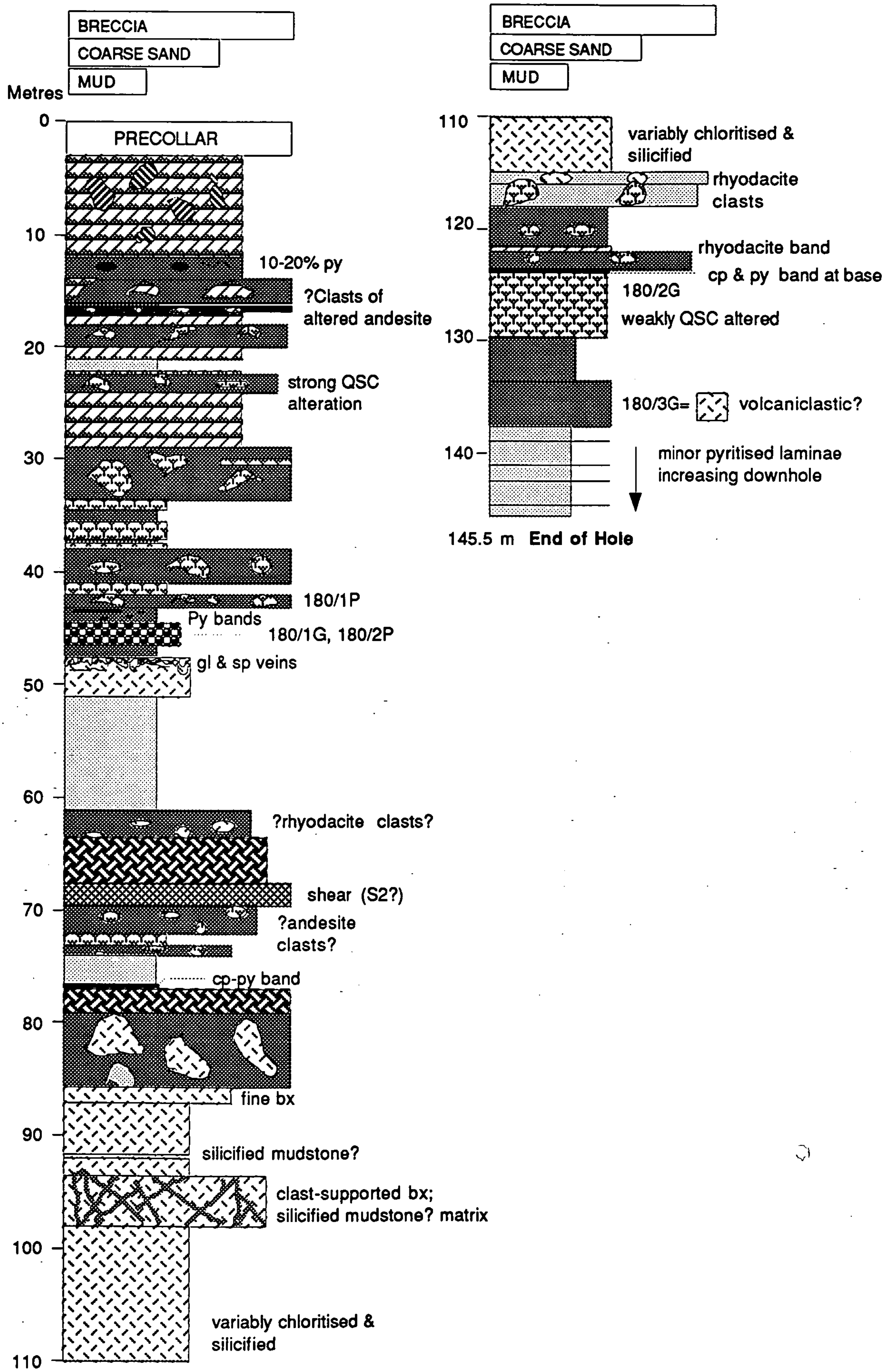
LEGEND for drill logs, cross-sections and level plans

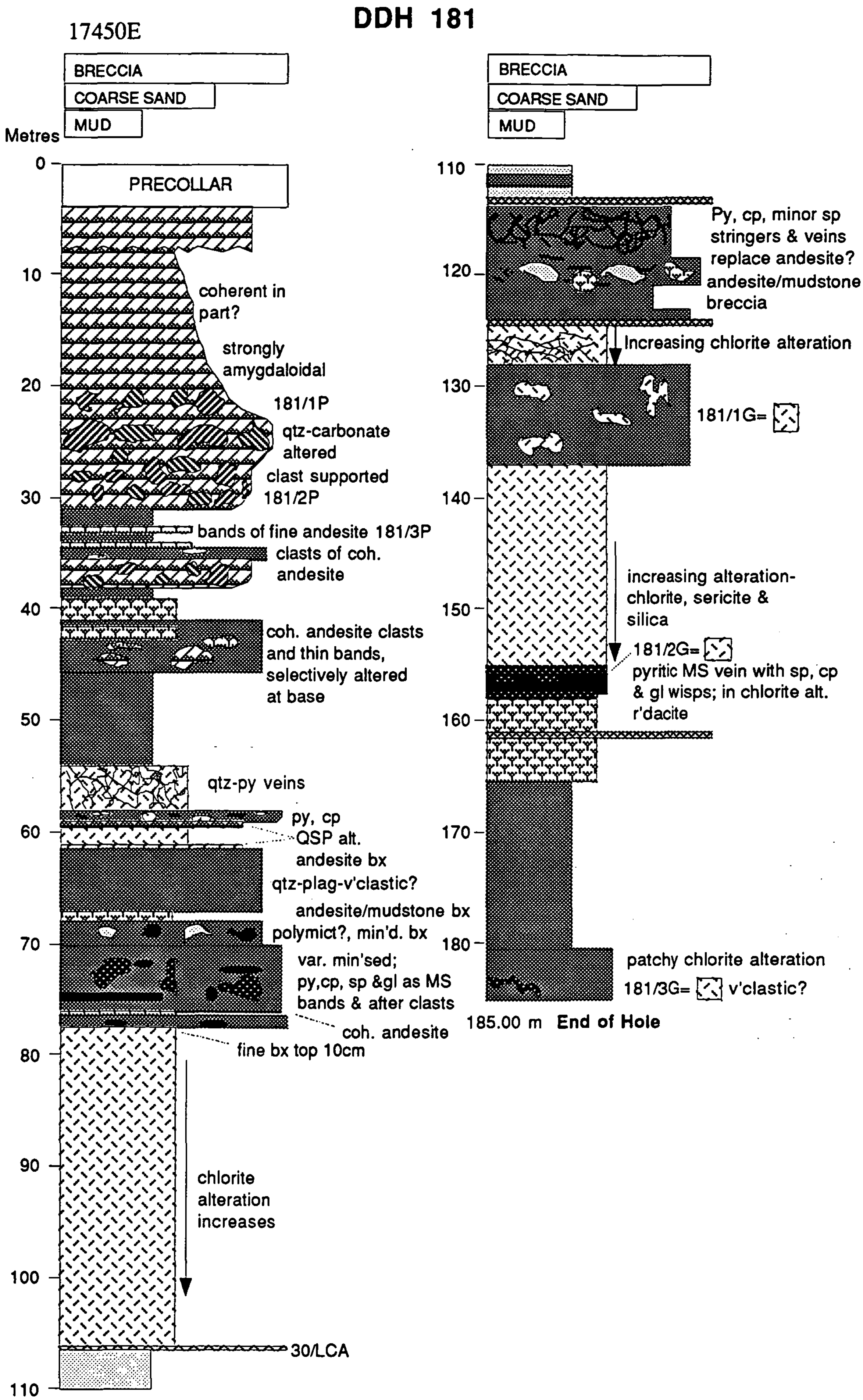
17400E **DDH 131**



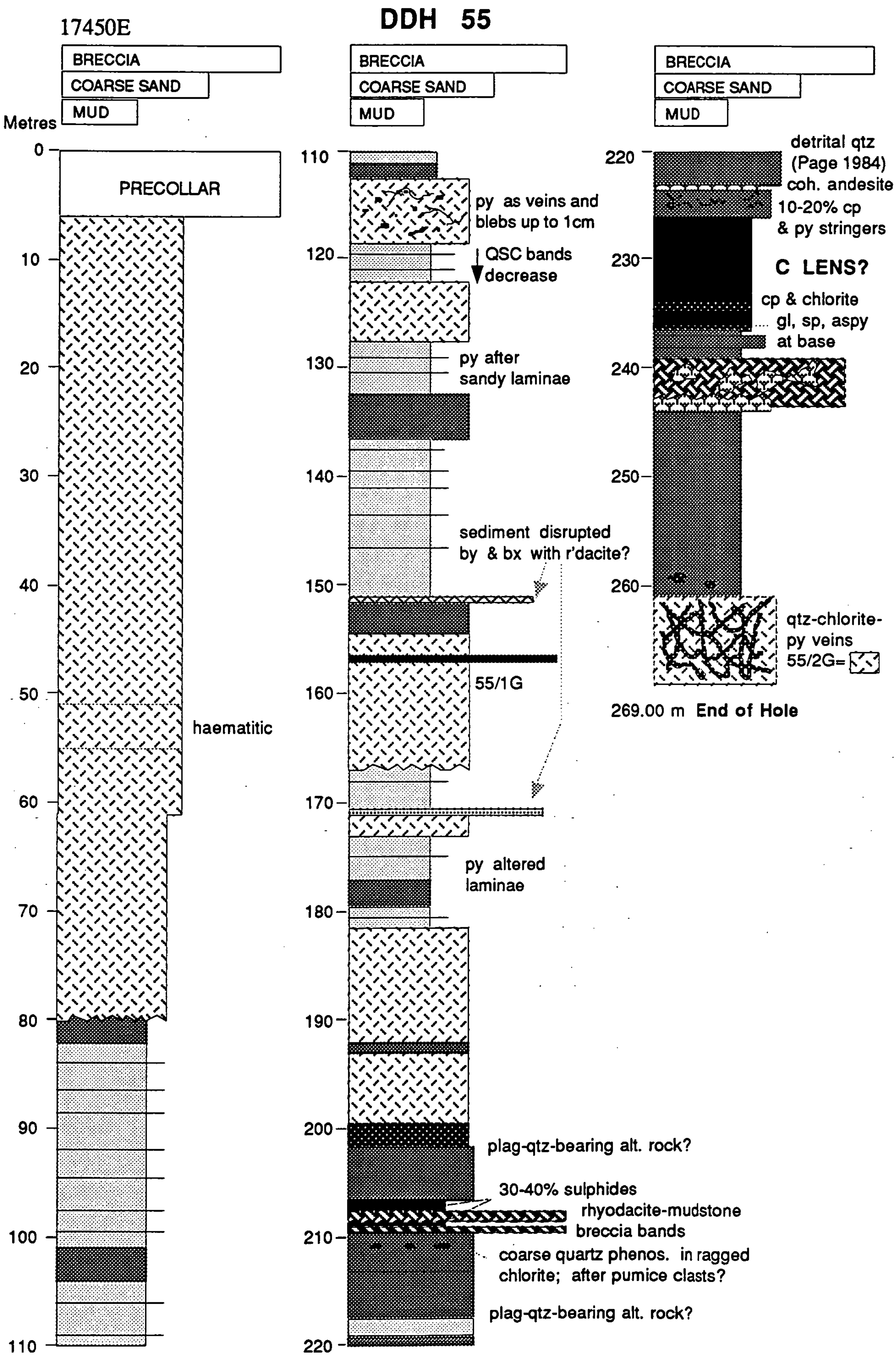
17450E

DDH 180



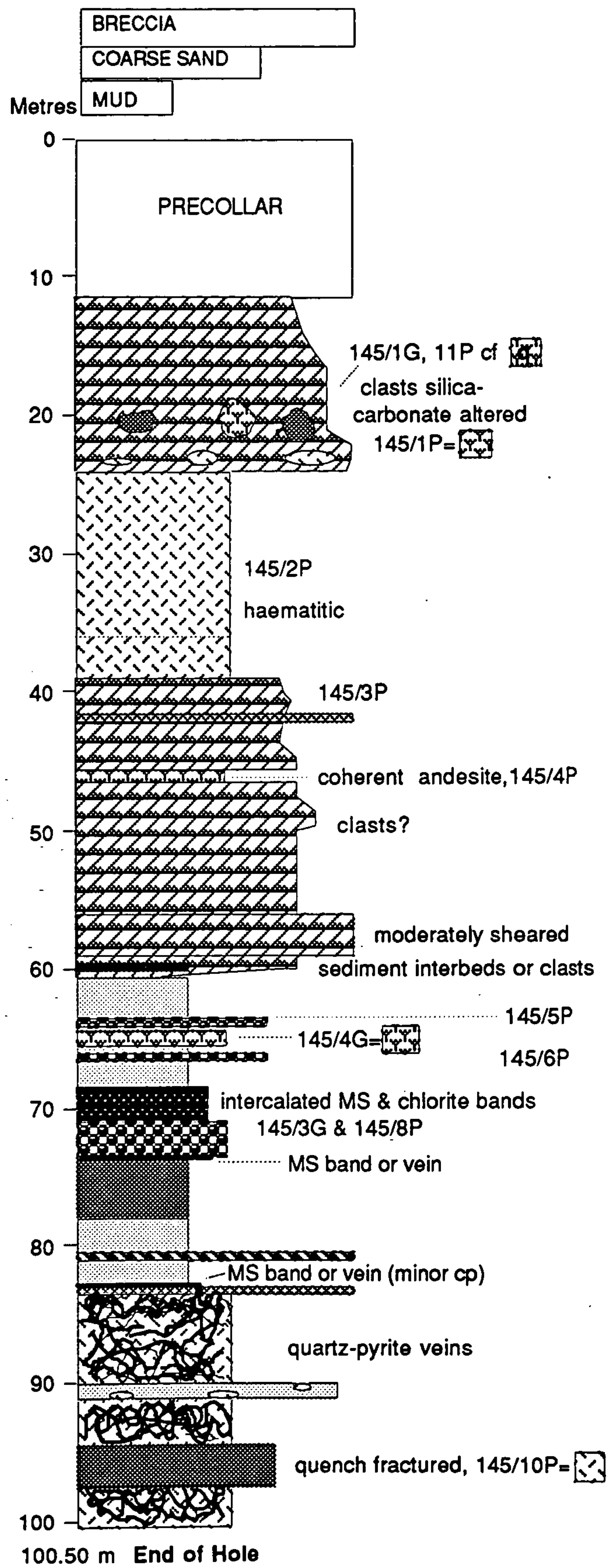


DDH 181
17450E
BRECCIA
COARSE SAND
MUD
Metres
PRECOLLAR
0
10
20
30
40
50
60
70
80
90
100
110
coherent in part?
strongly amygdaloidal
181/1P
qtz-carbonate altered
clast supported
181/2P
bands of fine andesite 181/3P
clasts of coh. andesite
coh. andesite clasts and thin bands, selectively altered at base
qtz-py veins
py, cp
QSP alt.
andesite bx
qtz-plag-v'clastic?
andesite/mudstone bx
polymict?, min'd. bx
var. min'sed;
py,cp, sp &gl as MS bands & after clasts
coh. andesite
fine bx top 10cm
chlorite alteration increases
30/LCA
BRECCIA
COARSE SAND
MUD
110
120
130
140
150
160
170
180
Py, cp, minor sp stringers & veins replace andesite?
andesite/mudstone breccia
Increasing chlorite alteration
181/1G=
increasing alteration- chlorite, sericite & silica
181/2G=
pyritic MS vein with sp, cp & gl wisps; in chlorite alt. r'dacite
patchy chlorite alteration
181/3G= v'clastic?
185.00 m End of Hole


17450E
DDH 55
BRECCIA
COARSE SAND
MUD
Metres
PRECOLLAR
haematitic
0
10
20
30
40
50
60
70
80
90
100
110
py as veins and blebs up to 1cm
QSC bands decrease
py after sandy laminae
sediment disrupted by & bx with r'dacite?
55/1G
py altered laminae
plag-qtz-bearing alt. rock?
30-40% sulphides
rhyodacite-mudstone breccia bands
coarse quartz phenos. in ragged chlorite; after pumice clasts?
plag-qtz-bearing alt. rock?
120
130
140
150
160
170
180
190
200
210
220
detrital qtz (Page 1984)
coh. andesite
10-20% cp & py stringers
C LENS?
cp & chlorite
gl, sp, aspy at base
qtz-chlorite-py veins
55/2G=
269.00 m End of Hole
230
240
250
260

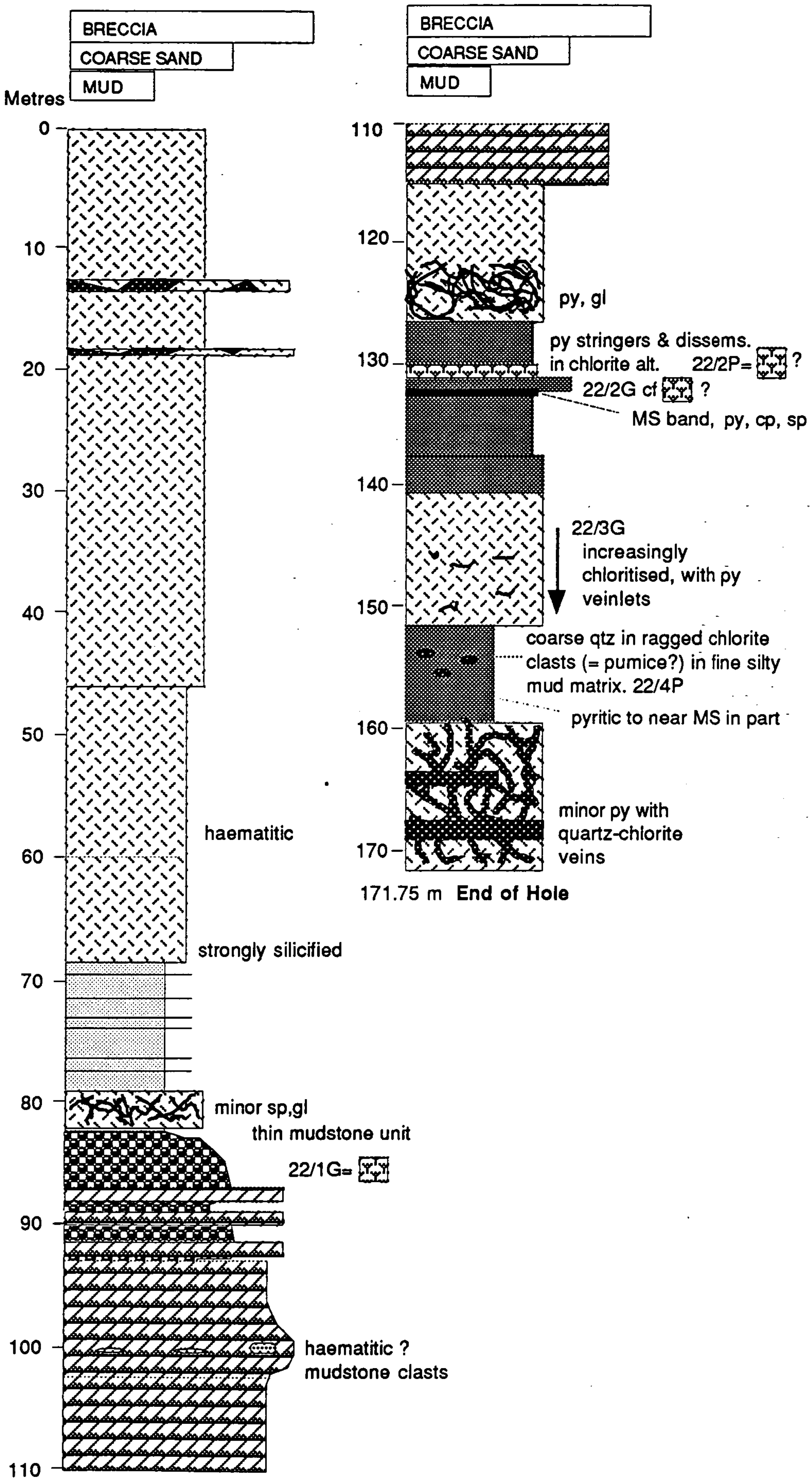
17500E

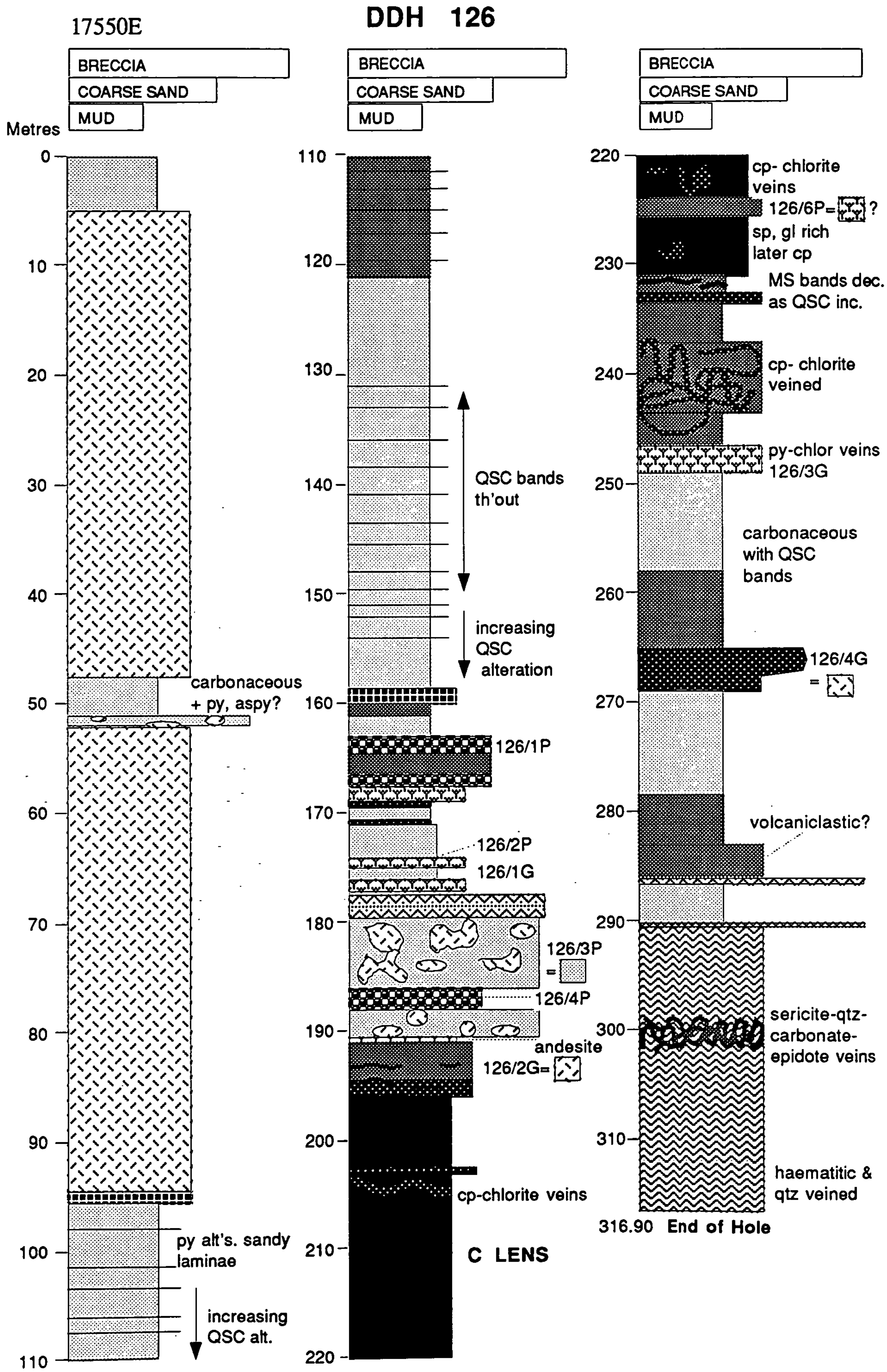
DDH 145



17500E

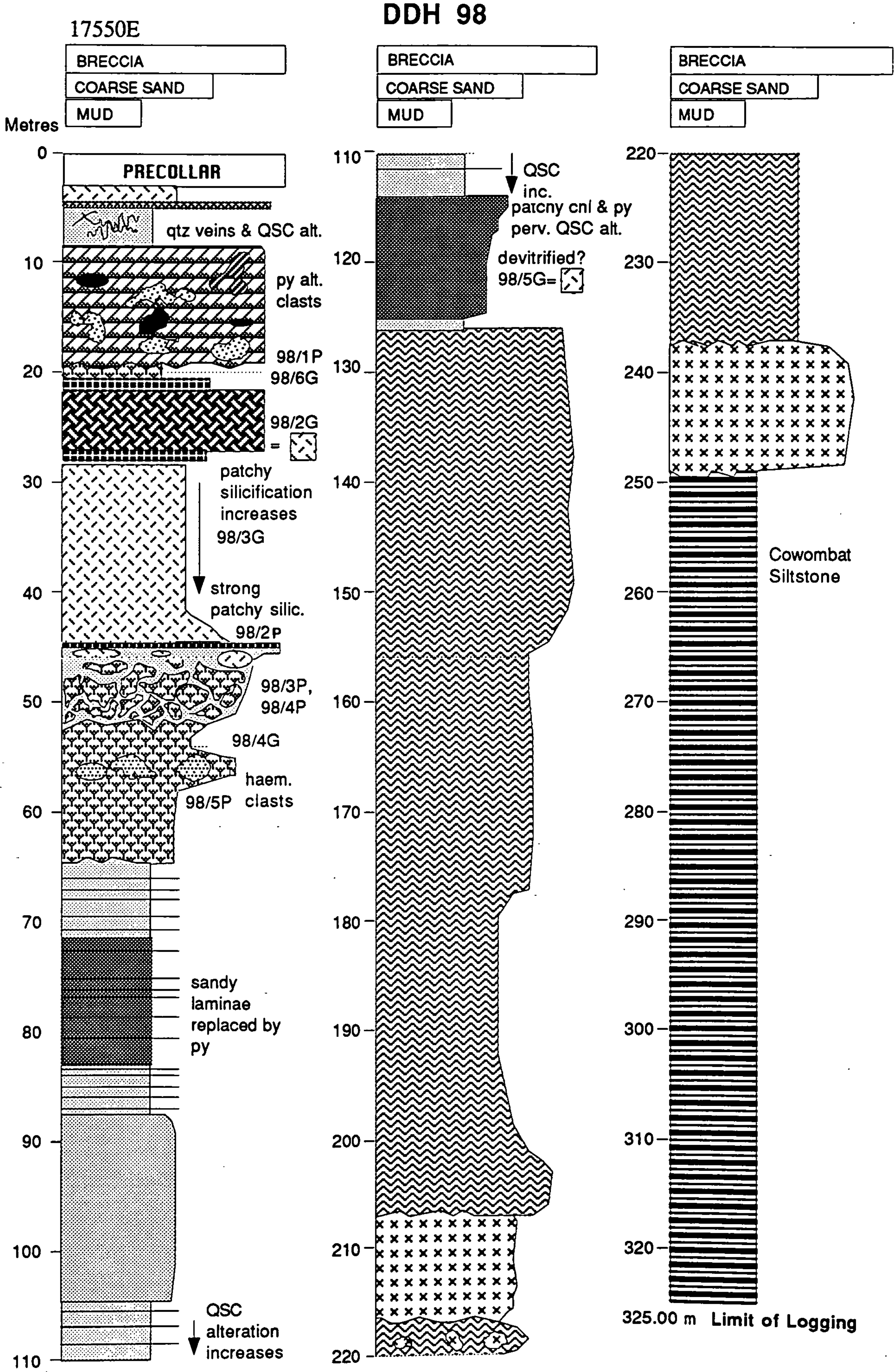
DDH 22



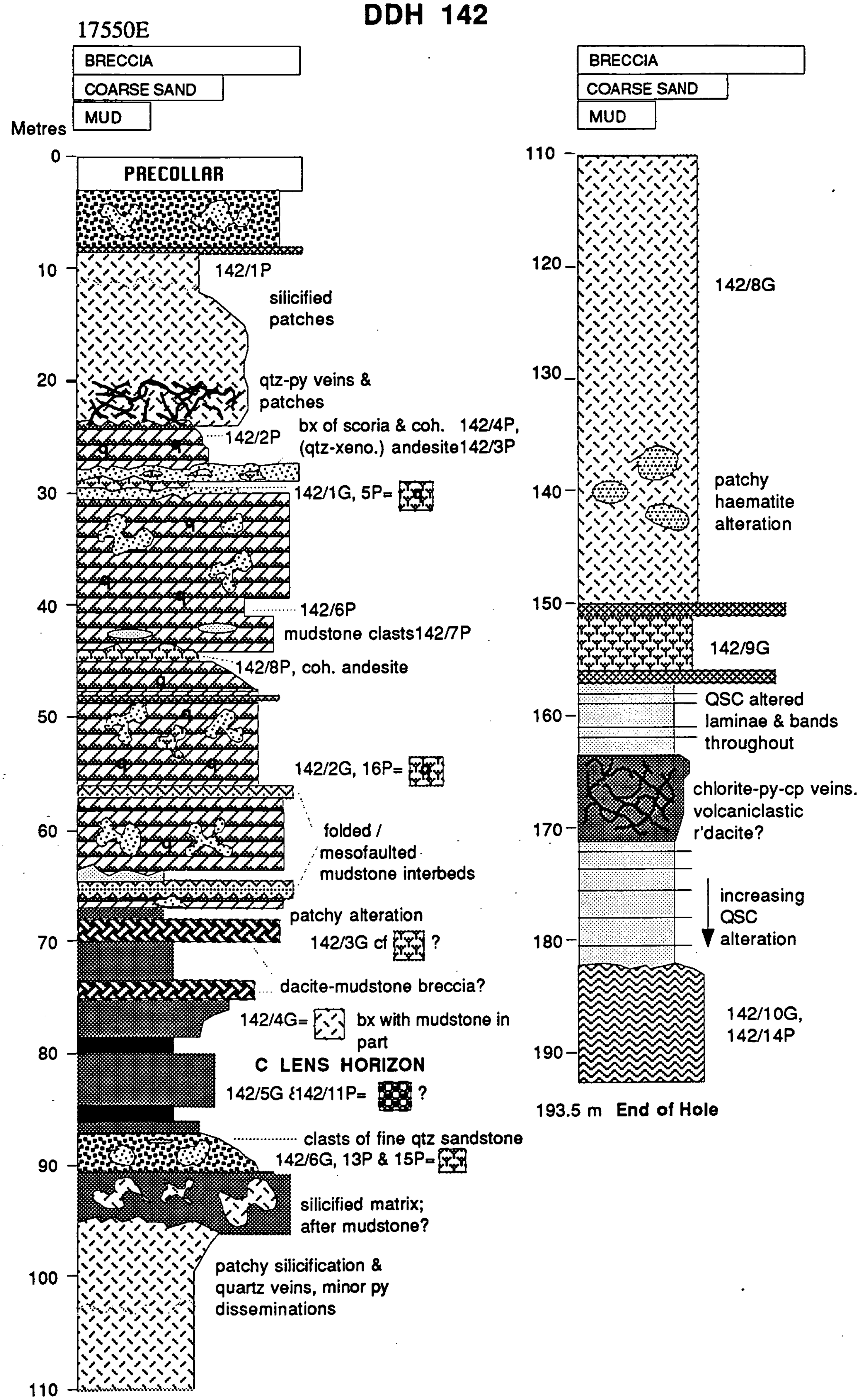


17550E
DDH 126
BRECCIA
COARSE SAND
MUD
Metres
0
10
20
30
40
50
60
70
80
90
100
110
carbonaceous
+ py, aspy?
py alt's. sandy
laminae
increasing
QSC alt.
110
120
130
140
150
160
170
180
190
200
210
220
QSC bands
th'out
increasing
QSC
alteration
126/1P
126/2P
126/1G
126/3P
=
126/4P
andesite
126/2G=
cp-chlorite veins
C LENS
220
230
240
250
260
270
280
290
300
310
cp- chlorite
veins
126/6P= ?
sp, gl rich
later cp
MS bands dec.
as QSC inc.
cp- chlorite
veined
py-chlor veins
126/3G
carbonaceous
with QSC
bands
126/4G
=
volcaniclastic?
sericite-qtz-
carbonate-
epidote veins
haematitic &
qtz veined
316.90 End of Hole

DDH 98

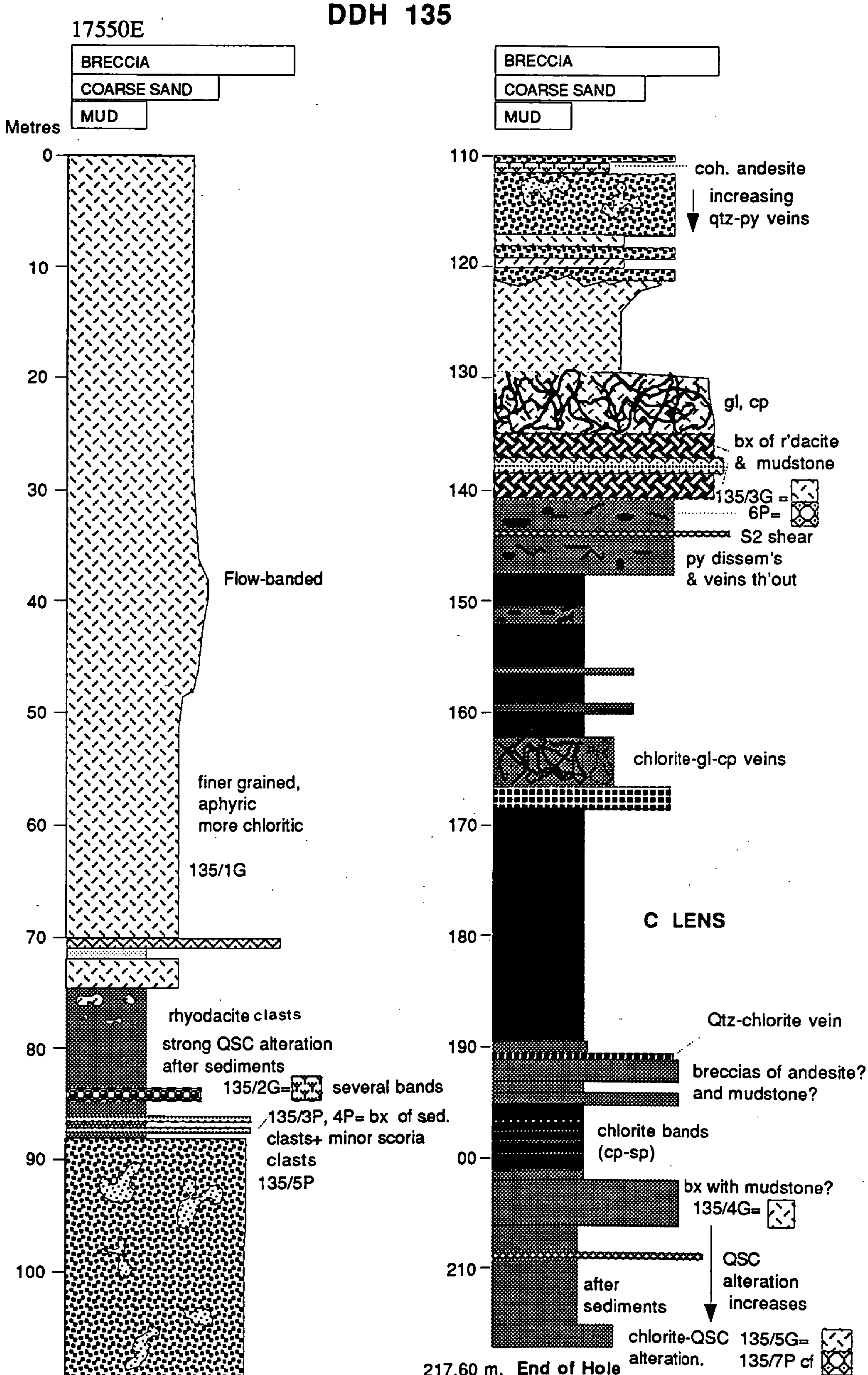

17550E
BRECCIA
COARSE SAND
MUD
Metres
PRECOLLAR
qtz veins & QSC alt.
py alt.
clasts
98/1P
98/6G
98/2G
=
patchy
silicification
increases
98/3G
strong
patchy silic.
98/2P
98/3P,
98/4P
98/4G
haem.
clasts
98/5P
sandy
laminae
replaced by
py
QSC
alteration
increases
QSC
inc.
patchy chl & py
perv. QSC alt.
devitrified?
98/5G=
Cowombat
Siltstone
325.00 m Limit of Logging

DDH 142



17550E
BRECCIA
COARSE SAND
MUD
Metres
0
10
20
30
40
50
60
70
80
90
100
110
PRECOLLAR
142/1P
silicified patches
qtz-py veins & patches
bx of scoria & coh. 142/4P, (qtz-xeno.) andesite142/3P
142/2P
142/1G, 5P=
142/6P
mudstone clasts142/7P
142/8P, coh. andesite
142/2G, 16P=
folded / mesofaulted mudstone interbeds
patchy alteration
142/3G cf ?
dacite-mudstone breccia?
142/4G= bx with mudstone in part
C LENS HORIZON
142/5G ξ142/11P= ?
clasts of fine qtz sandstone
142/6G, 13P & 15P=
silicified matrix; after mudstone?
patchy silicification & quartz veins, minor py disseminations
BRECCIA
COARSE SAND
MUD
110
120
130
140
150
160
170
180
190
142/8G
patchy haematite alteration
142/9G
QSC altered laminae & bands throughout
chlorite-py-cp veins. volcaniclastic r'dacite?
increasing QSC alteration
142/10G, 142/14P
193.5 m End of Hole

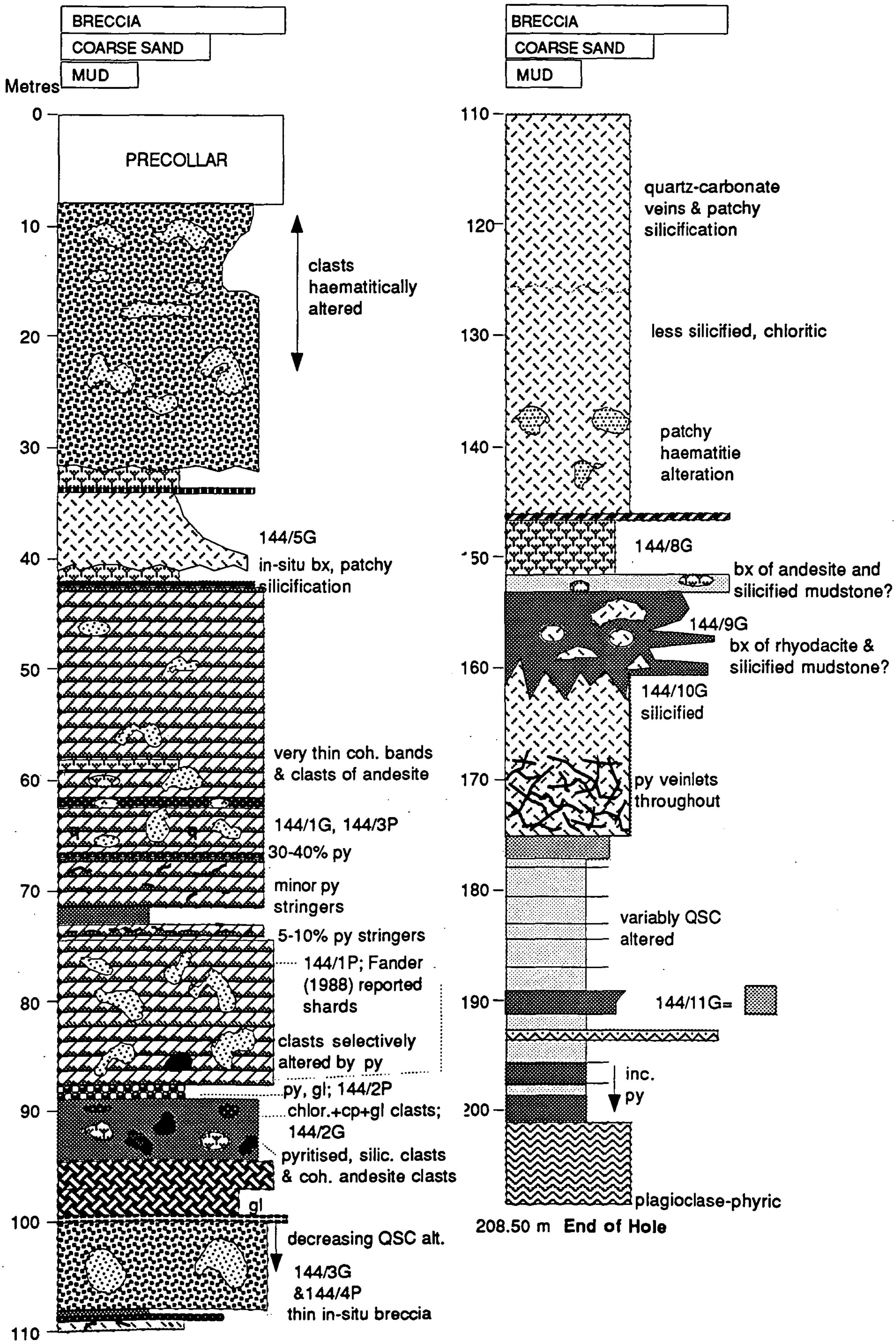
DDH 135



17550E
BRECCIA
COARSE SAND
MUD
Metres
0
10
20
30
40
50
60
70
80
90
100
110
Flow-banded
finer grained,
aphyric
more chloritic
135/1G
rhyodacite clasts
strong QSC alteration
after sediments
135/2G=
several bands
135/3P, 4P= bx of sed.
clasts+ minor scoria
clasts
135/5P
BRECCIA
COARSE SAND
MUD
110
120
130
140
150
160
170
180
190
00
210
coh. andesite
increasing
qtz-py veins
gl, cp
bx of r'dacite
& mudstone
135/3G =
6P=
S2 shear
py dissem's
& veins th'out
chlorite-gl-cp veins
C LENS
Qtz-chlorite vein
breccias of andesite?
and mudstone?
chlorite bands
(cp-sp)
bx with mudstone?
135/4G=
QSC
alteration
increases
after
sediments
chlorite-QSC
alteration.
135/5G=
135/7P cf
217.60 m. End of Hole

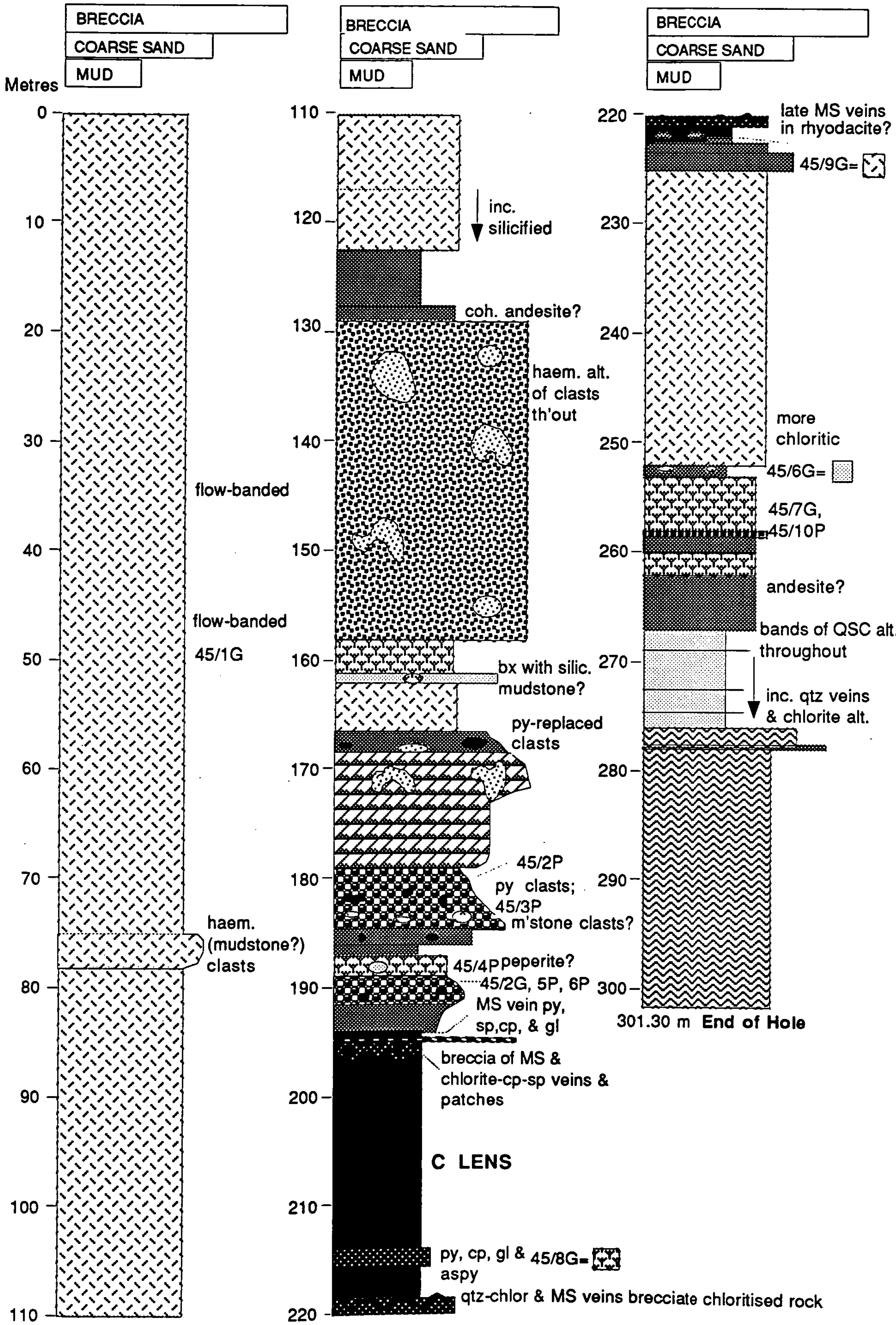
17600E

DDH 144



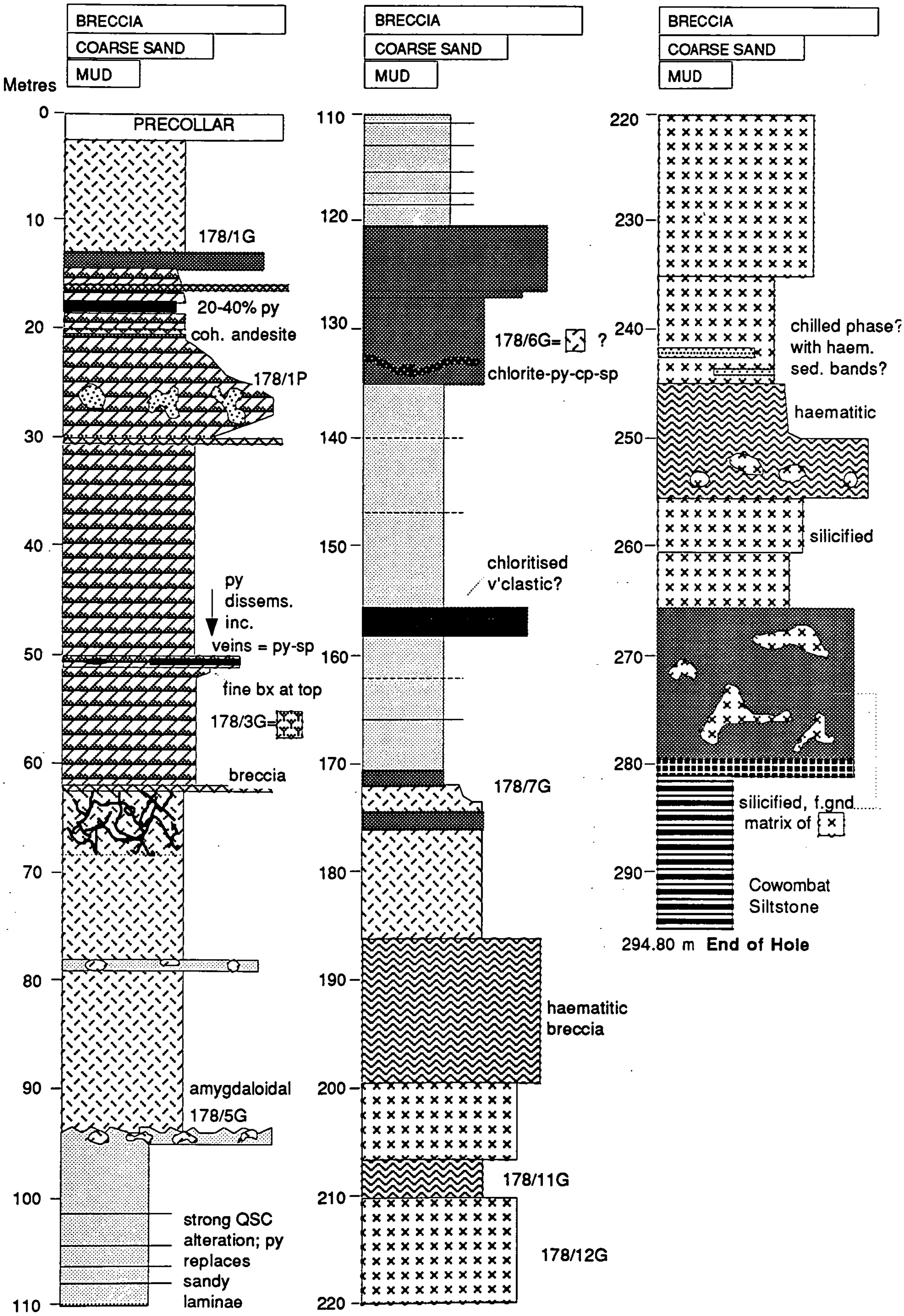
17600E

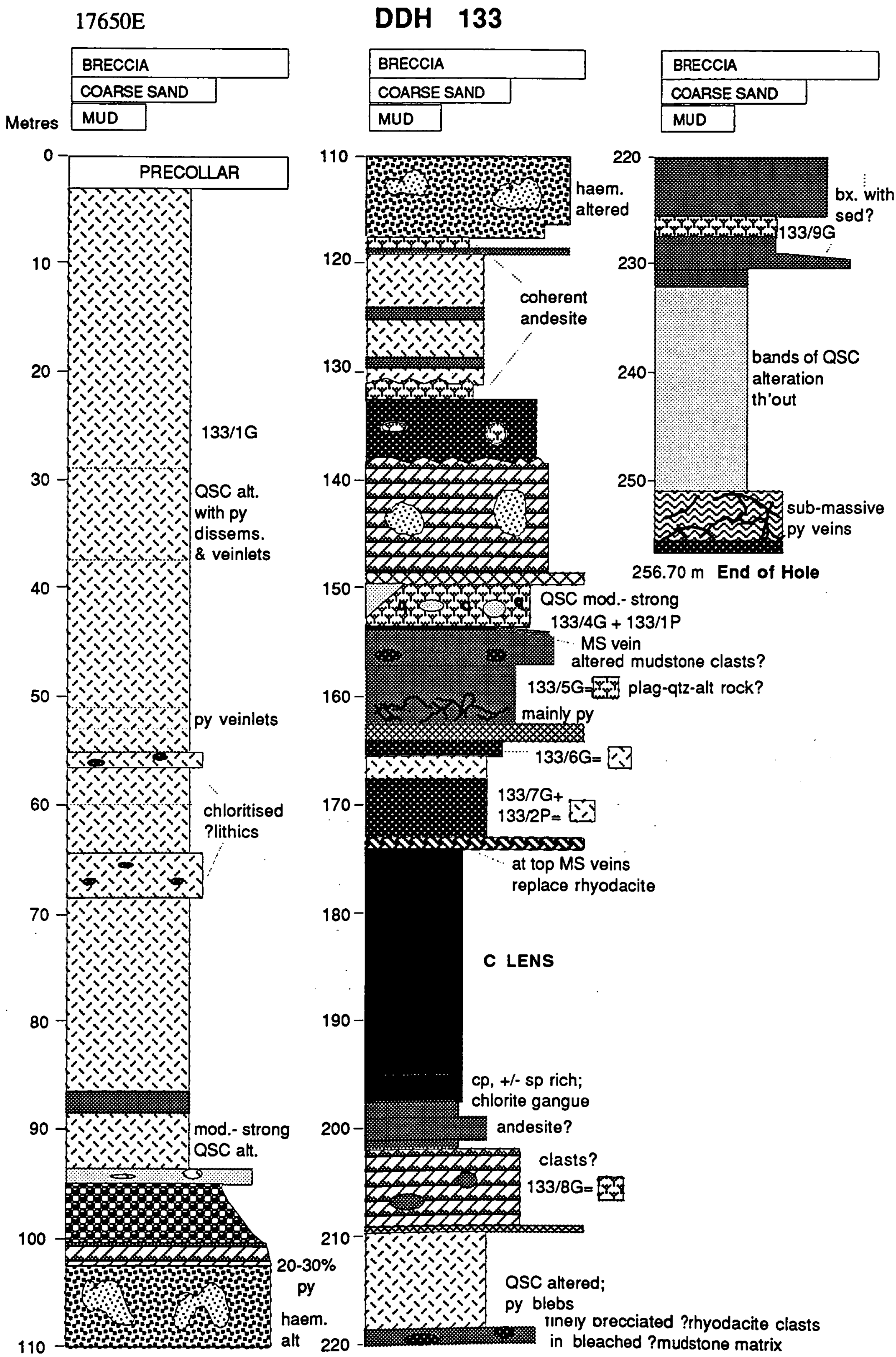
DDH 45



17650E

DDH 178



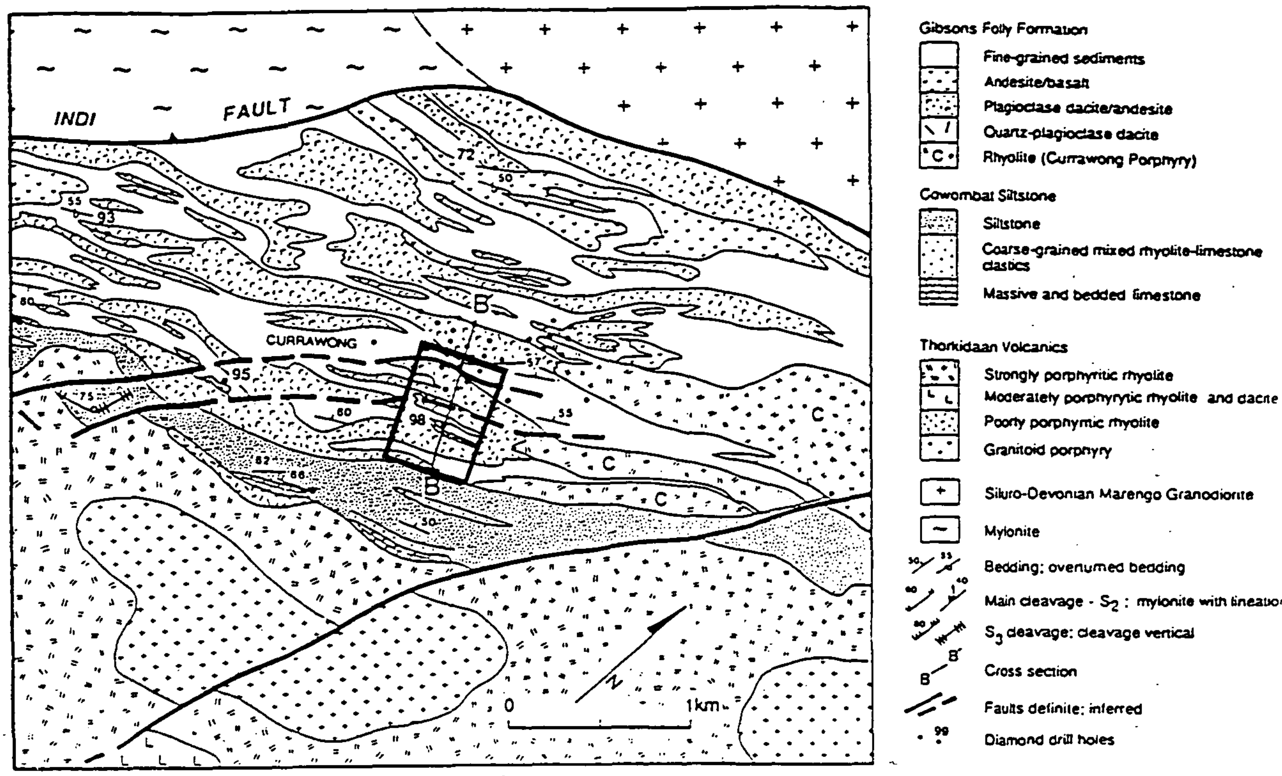

17650E
DDH 133
BRECCIA
COARSE SAND
MUD
Metres
PRECOLLAR
133/1G
QSC alt. with py dissems. & veinlets
py veinlets
chloritised ?lithics
mod.- strong QSC alt.
20-30% py
haem. alt
haem. altered
coherent andesite
QSC mod.- strong
133/4G + 133/1P
MS vein
altered mudstone clasts?
133/5G= plag-qtz-alt rock?
mainly py
133/6G=
133/7G+
133/2P=
at top MS veins replace rhyodacite
C LENS
cp, +/- sp rich; chlorite gangue
andesite?
clasts?
133/8G=
QSC altered; py blebs
finely brecciated ?rhyodacite clasts in bleached ?mudstone matrix
bx. with sed?
133/9G
bands of QSC alteration th'out
sub-massive py veins
256.70 m End of Hole

APPENDIX II

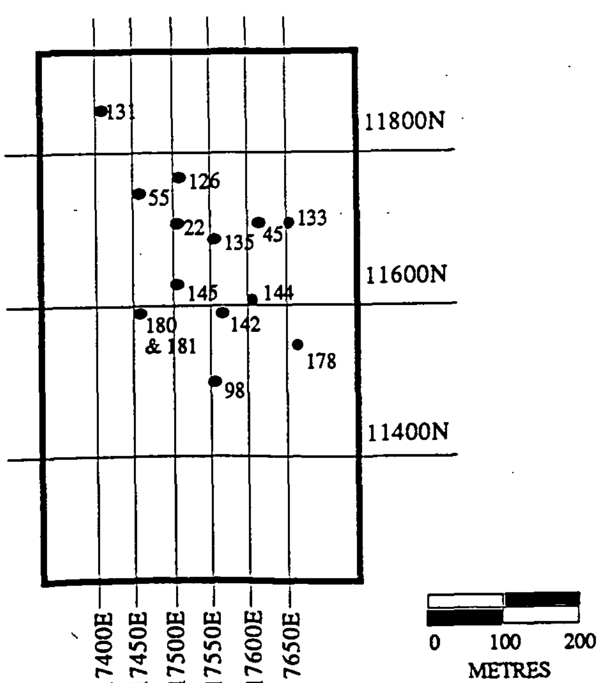
* A: Geological map of Currawong and general location of drill holes (after Allen, 1987).

  B: Location of drill holes logged in this project.

* Cross-sections and level plans.

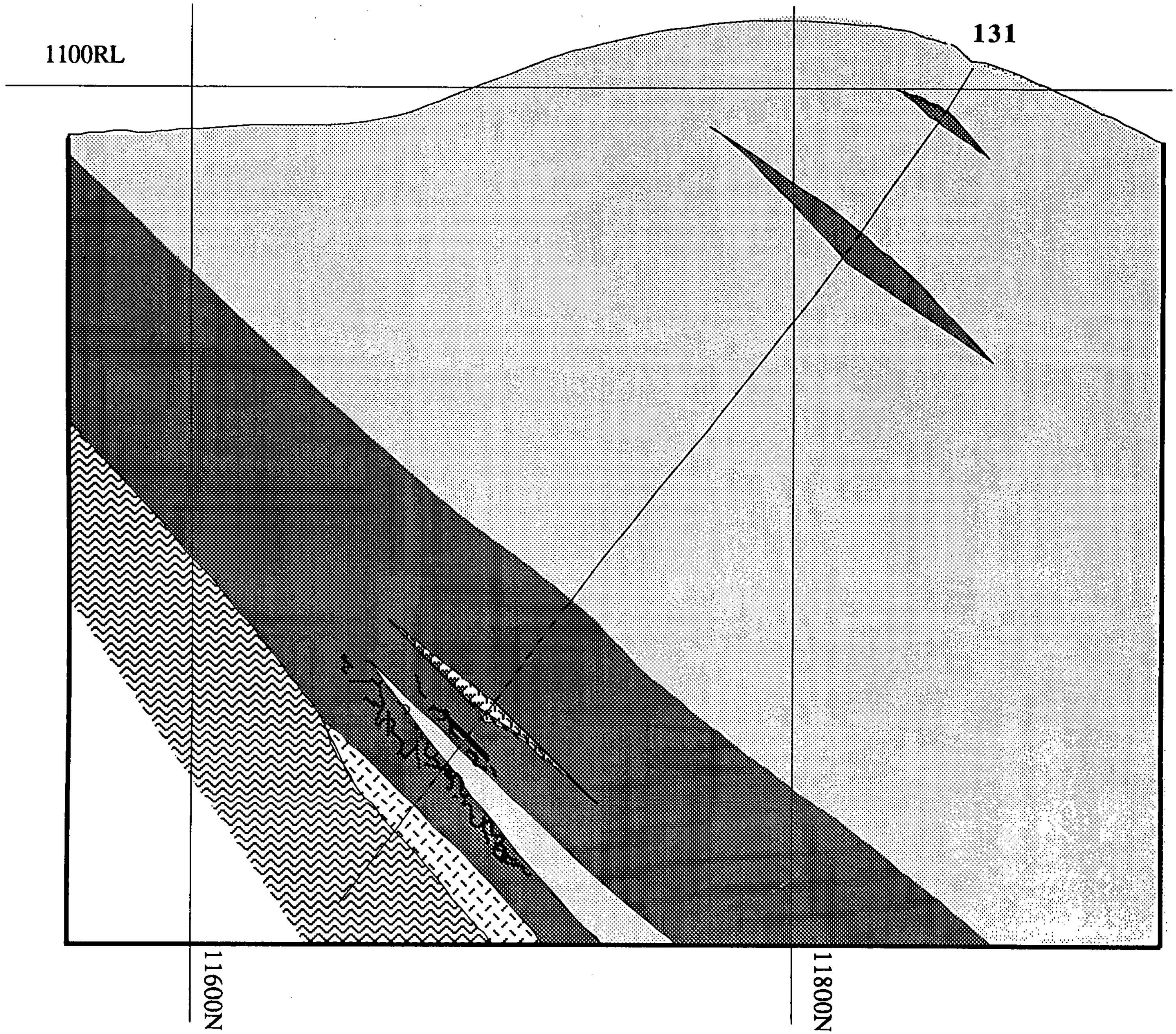


A: Geological map of Currawong and general location of drill holes (after Allen, 1987; note B-B' is shown in Figure 3).



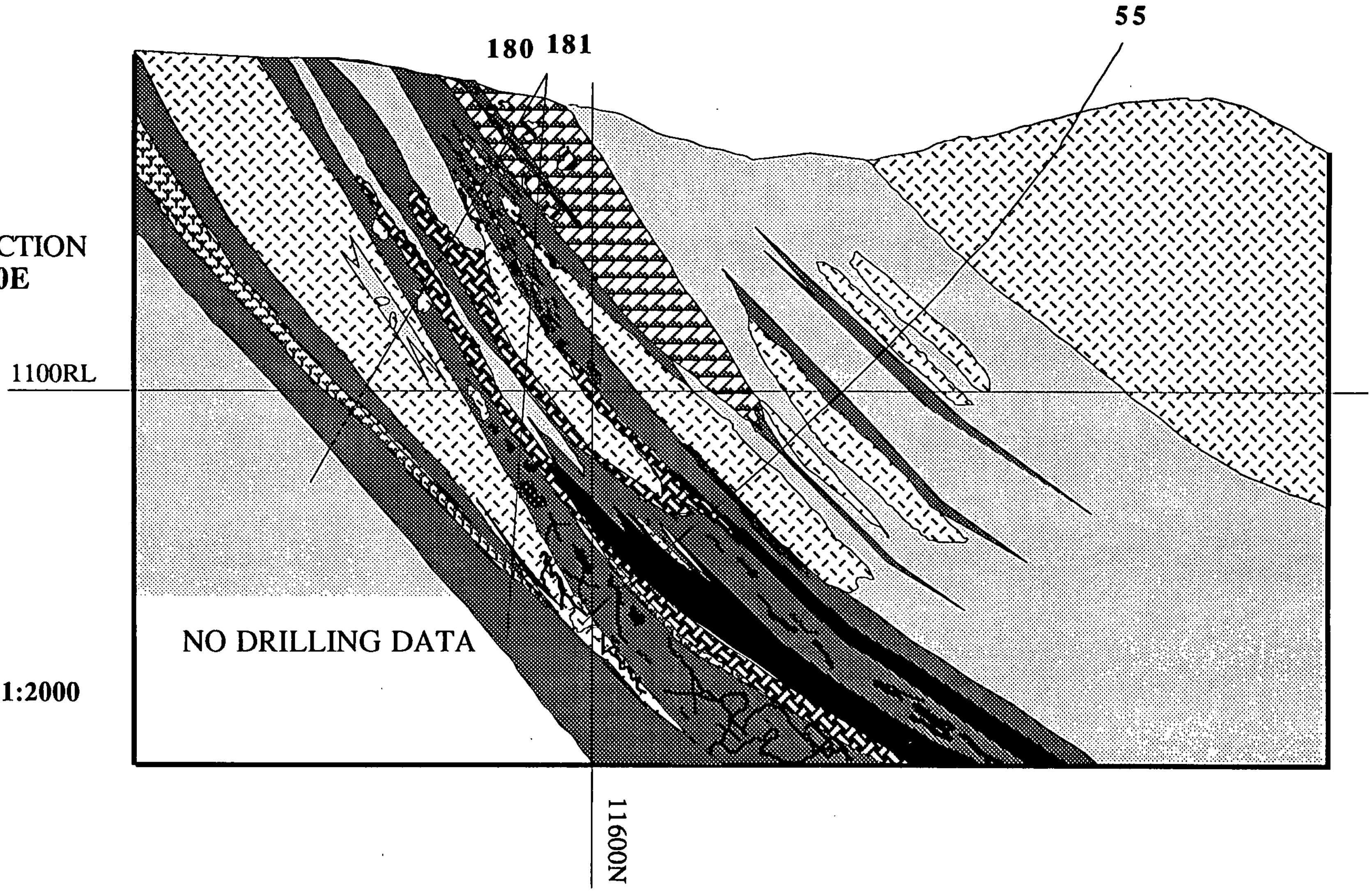
B: Inset from A; location of drill holes logged in this project

CROSS-SECTION
17400E



SCALE : **1:2000**

CROSS-SECTION
17450E



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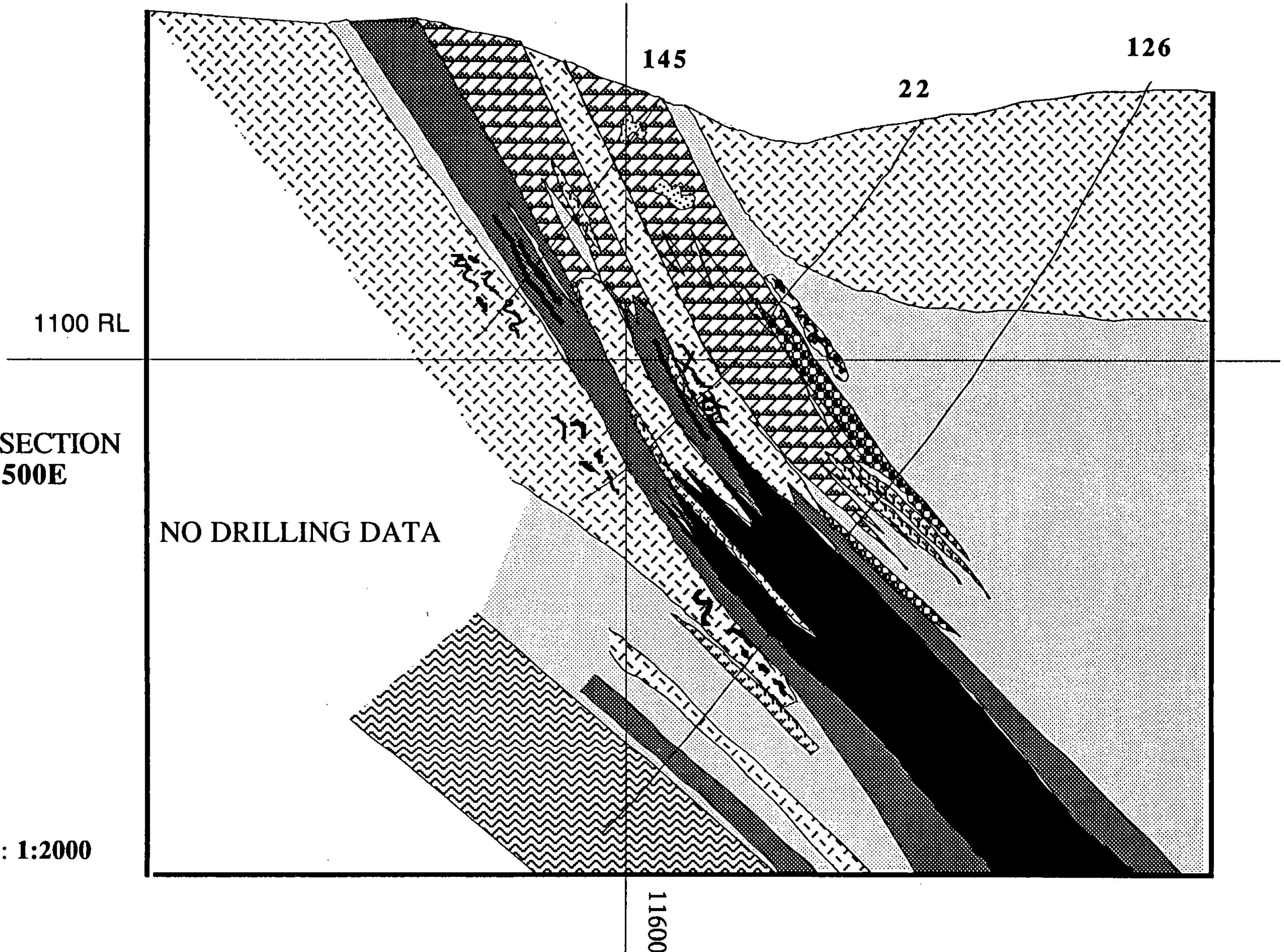

CROSS-SECTION
17500E

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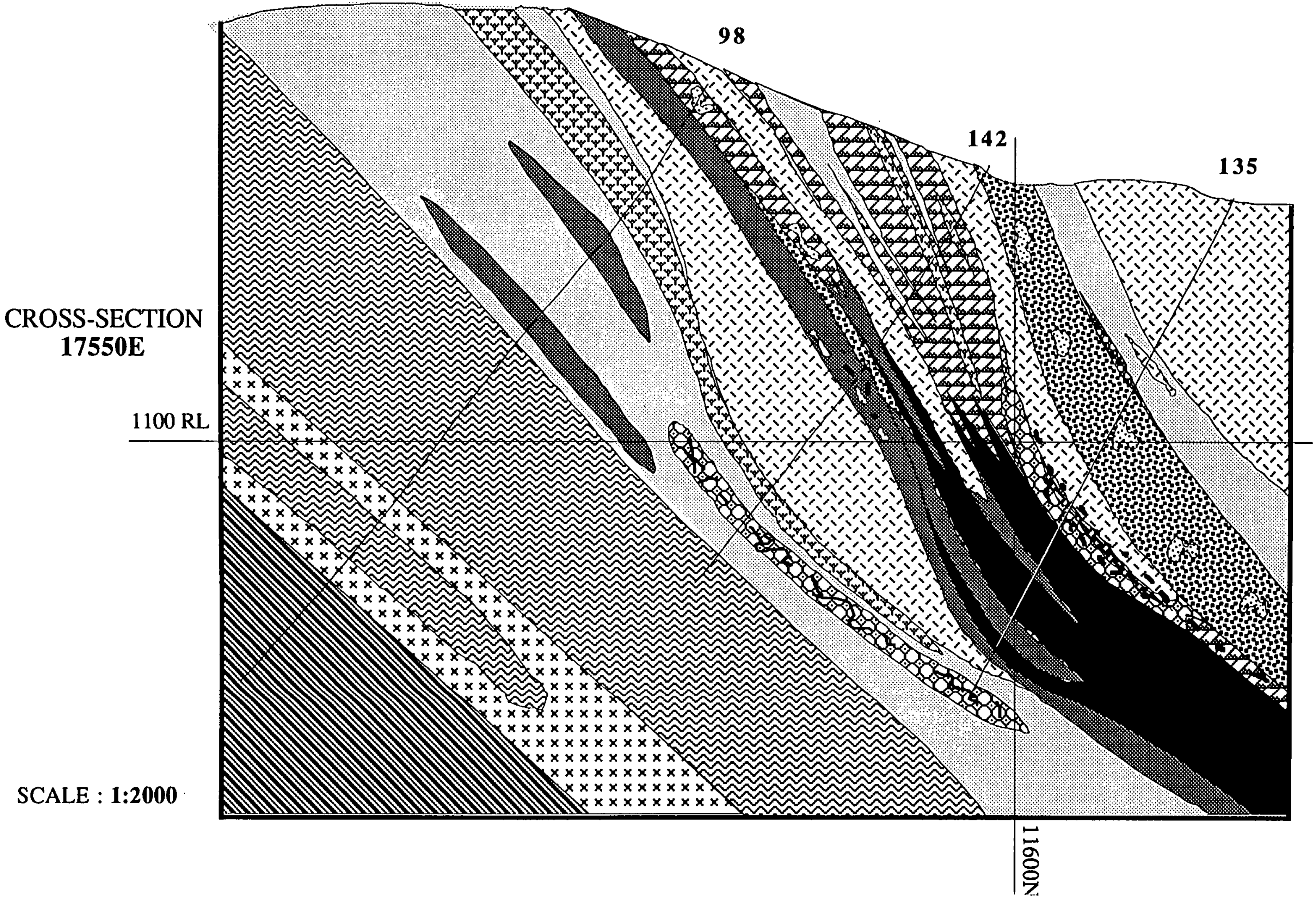
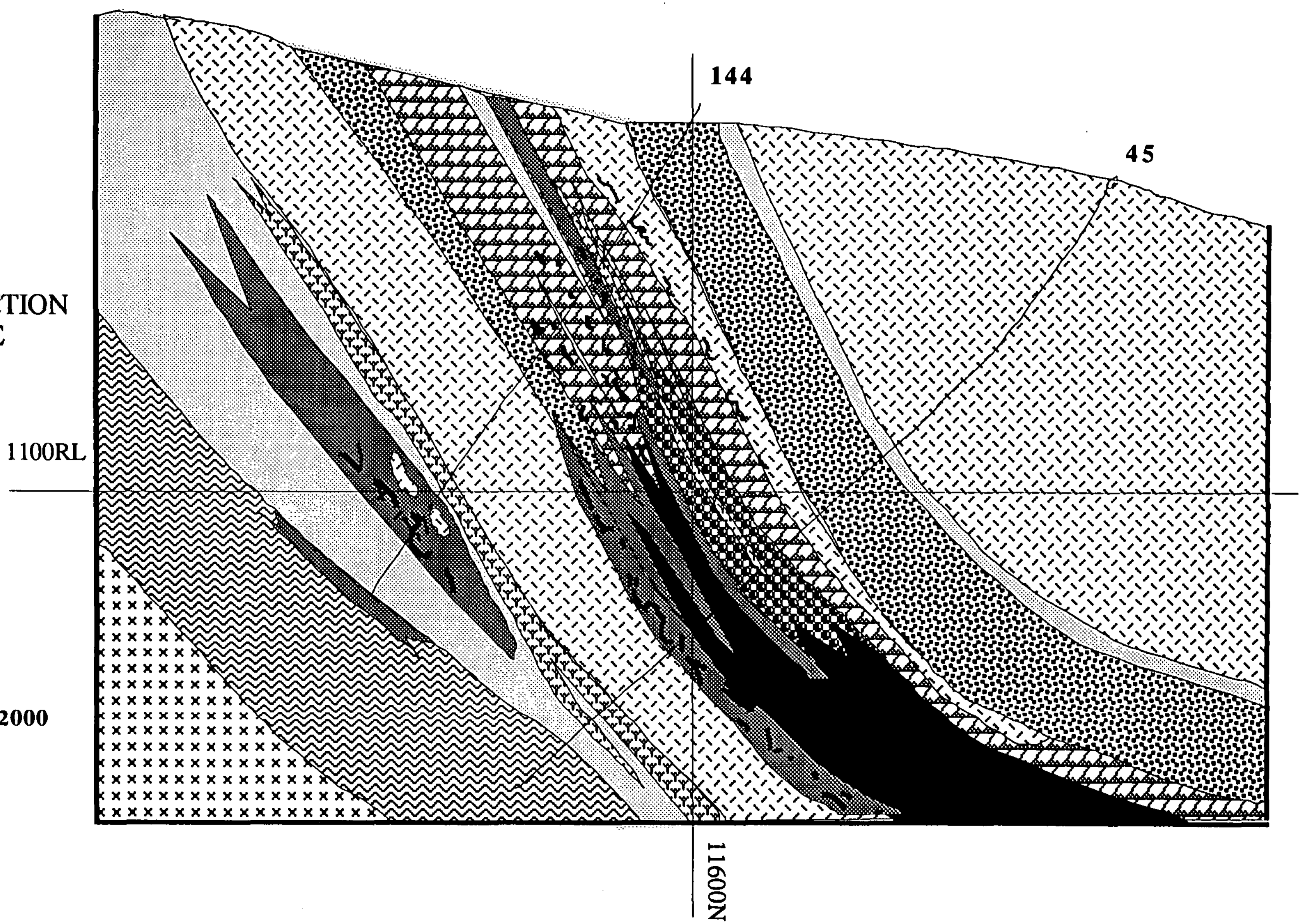


98
142
135
CROSS-SECTION
17550E
1100 RL
SCALE : 1:2000
11600N

CROSS-SECTION
17600E



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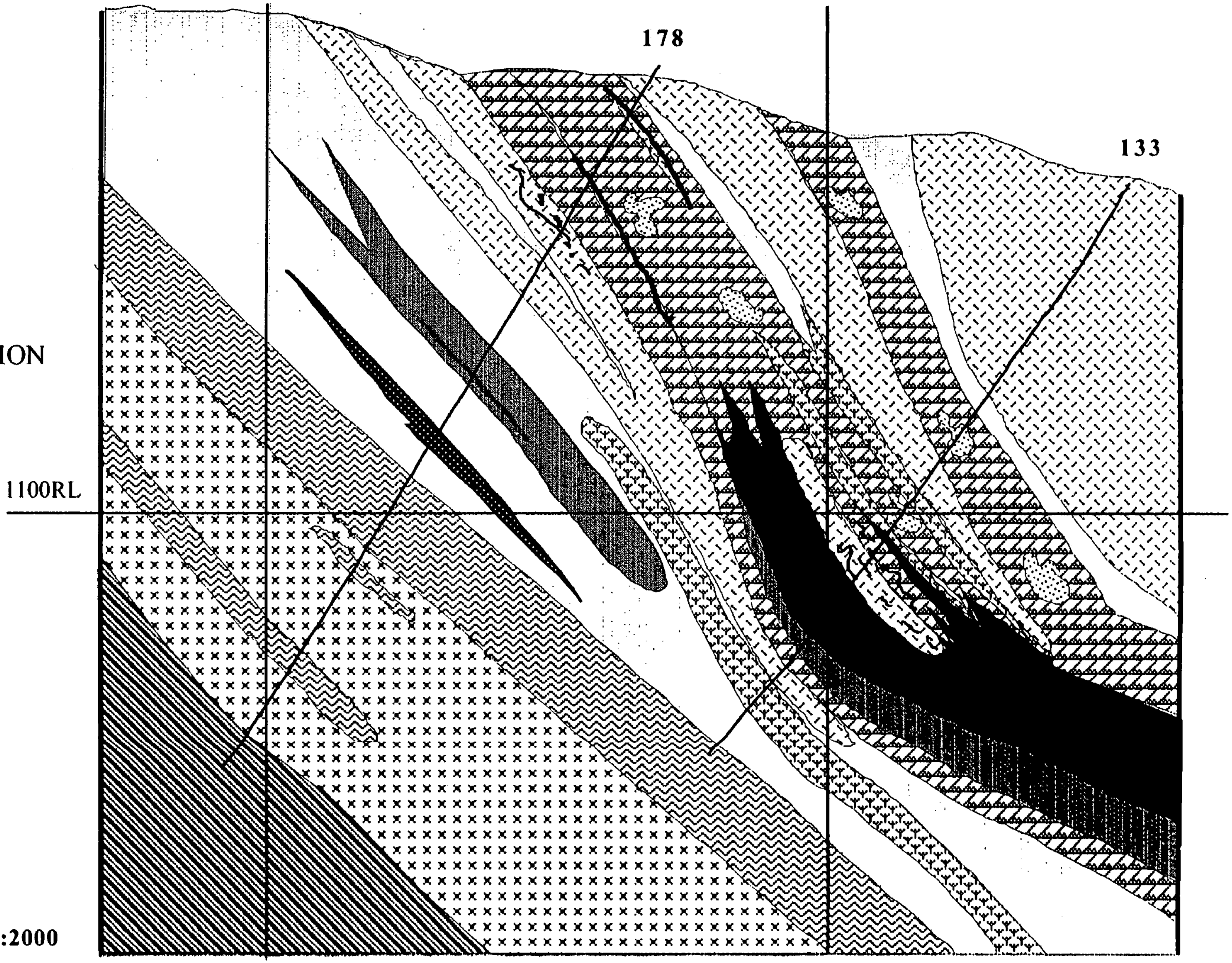
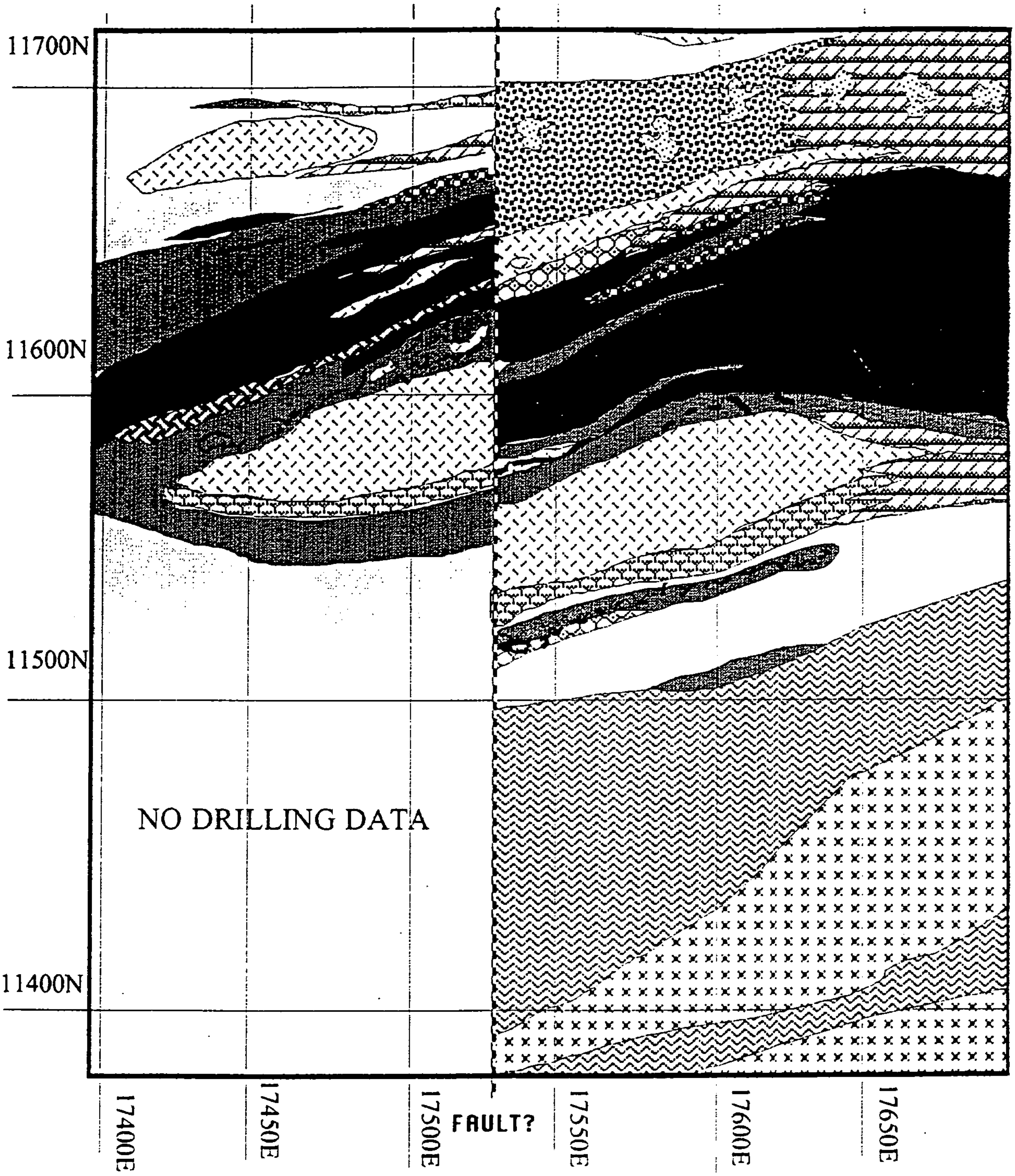


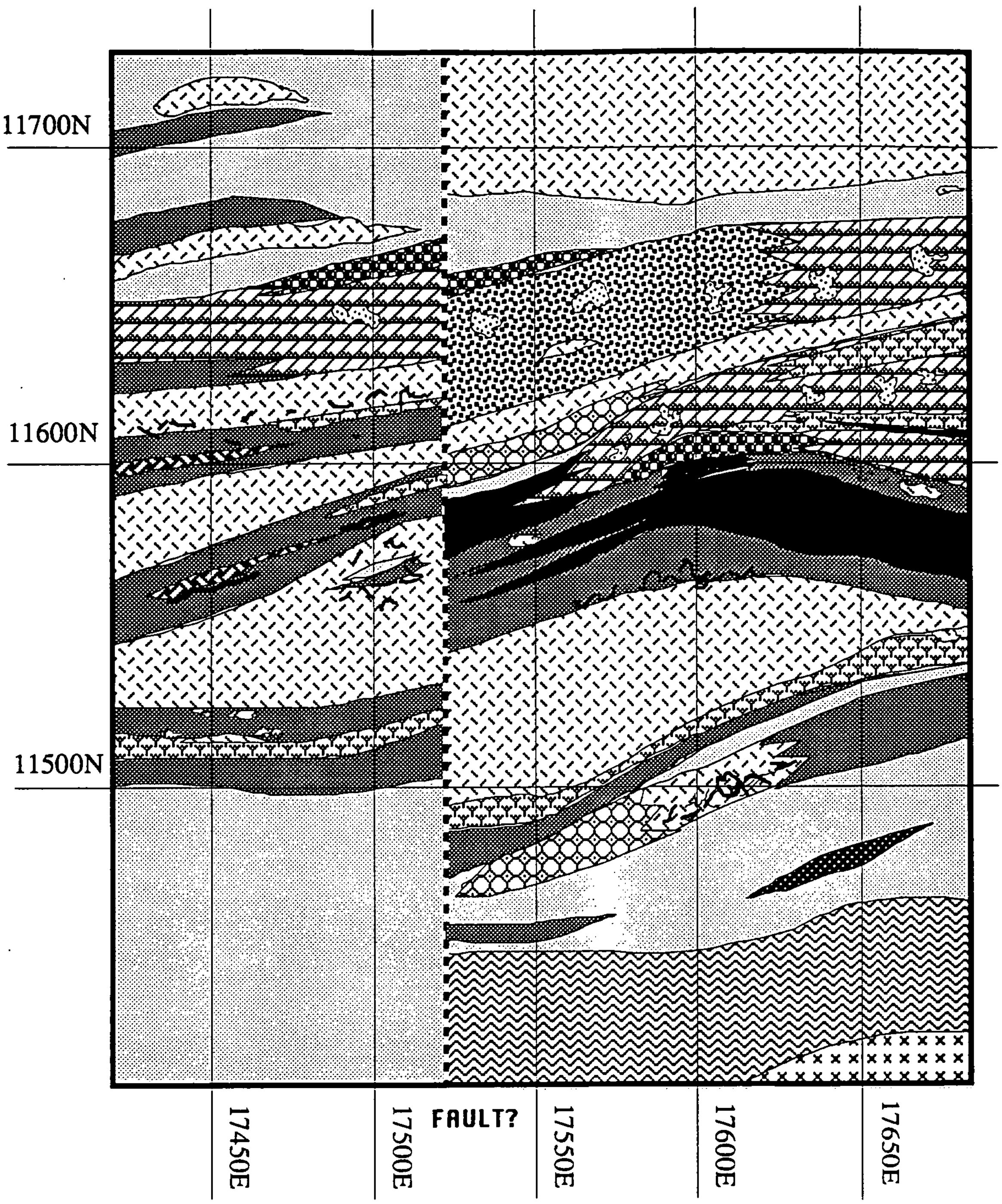
CROSS-SECTION
17650E

SCALE : **1:2000**



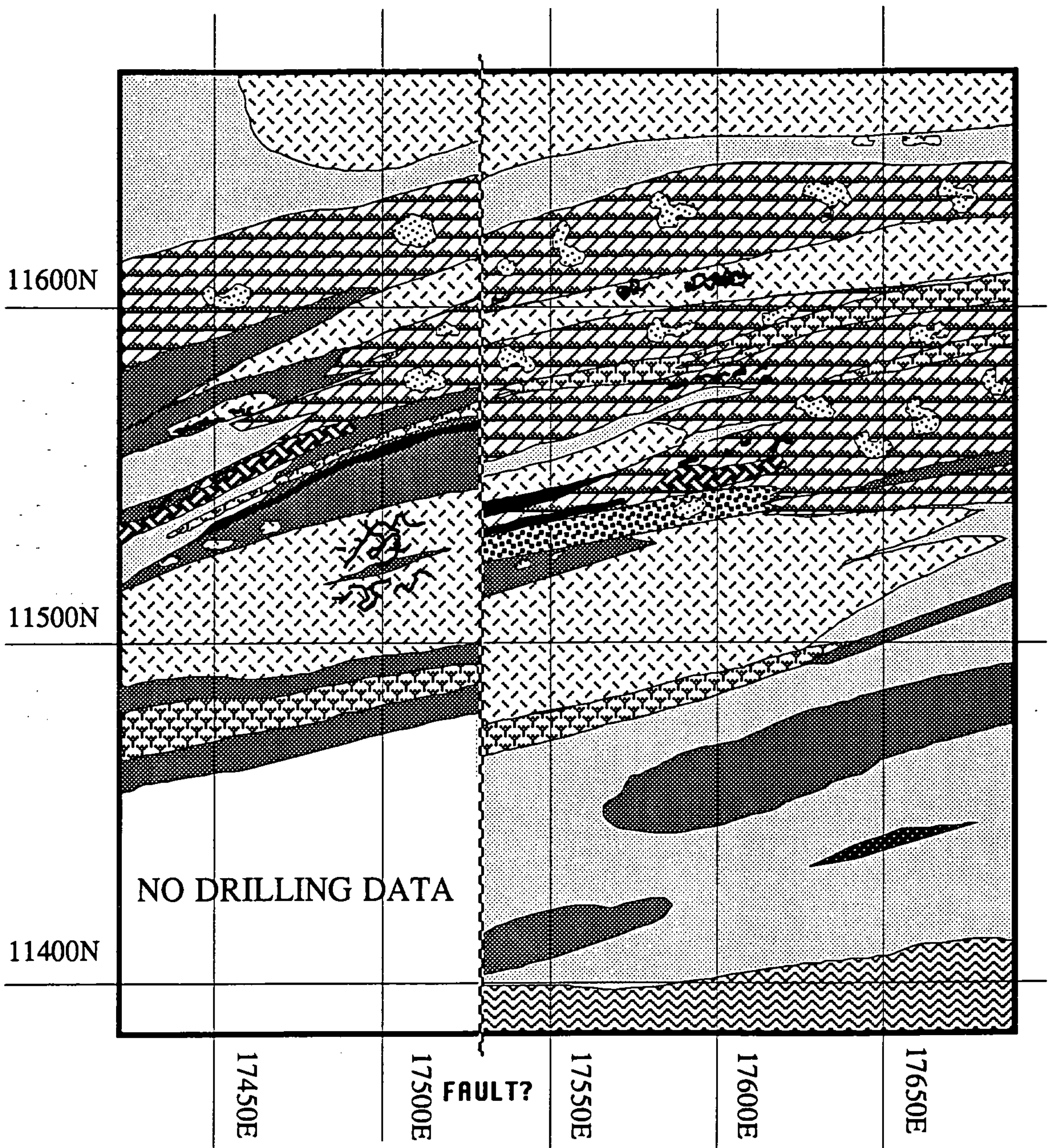
Level plan 1050 RL

SCALE 1:2000



Level plan 1100 RL

SCALE 1:2000



Level plan 1150 RL

SCALE 1:2000

APPENDIX III

XRF analyses used in the Geochemical study

* Coherent units

* Volcaniclastic and altered units

Coherent units

Rock type	Sample number	TiO2 ppm	Nb ppm	Zr ppm	Y ppm	Zr/TiO2	Nb/Y	SiO2 %	Ti ppm	Ti/Zr
Currawong	178/12G	1800	7.8	143	37.7	0.079	0.21	N/A	N/U	N/U
porphyry	#66/394	1500	7	128	34.2	0.085	0.2	76.15	899	7.03
	#67/392	1500	6.4	115	34.5	0.077	0.19	73.91	899	7.82
	#134/489	1700	7.1	118.1	39.3	0.069	0.18	75.95	1019	8.63
	#177/291	1500	8.6	116.3	33.5	0.078	0.26	76.71	899	7.73
Plagioclase-	133/1G	2500	5.4	165	32.7	0.066	0.165	N/A	N/U	N/U
phyric	135/1G	2500	5.4	159	28.9	0.064	0.187	N/A	N/U	N/U
rhyodacite	142/8G	2100	7.1	196	35.4	0.093	0.201	N/A	N/U	N/U
	144/5G	2400	5.7	168	25.7	0.07	0.222	N/A	N/U	N/U
	144/9G	2500	7.7	232	42.1	0.093	0.183	N/A	N/U	N/U
	178/1G	2300	5.4	161	27.2	0.07	0.199	N/A	N/U	N/U
	178/5G	3600	5.4	146	33	0.041	0.164	N/A	N/U	N/U
	178/7G	2000	5.9	156	24.5	0.078	0.241	N/A	N/U	N/U
	181/2G	2100	6.9	191	43.7	0.091	0.158	N/A	N/U	N/U
	22/3G	2400	5.4	159	26.8	0.066	0.201	N/A	N/U	N/U
	45/1G	2500	5.7	167	24.6	0.067	0.232	N/A	N/U	N/U
	55/1G	2300	6.1	167	31.4	0.073	0.194	N/A	N/U	N/U
	98/3G	1700	5.4	141	23.6	0.083	0.229	N/A	N/U	N/U
	#45/63	2500	5.3	166.4	25.6	0.067	0.207	72.97	1499	9.007
	#145/32	2300	6	163	28.9	0.071	0.208	72.74	1379	8.459
	#181/104	2200	5.9	148.3	27.1	0.067	0.218	72.96	1319	8.893
	#135/15	2500	5.5	159	19.7	0.069	0.279	73.33	1499	9.426
	#67/148	3500	5	109.6	18.6	0.031	0.269	75.33	2098	19.145
	#134/223	2300	5.7	163.2	27.5	0.071	0.207	73.86	1379	8.449
FB/BX variant	131/7G	1500	7.3	210	38.5	0.14	0.19	N/A	N/U	N/U
of plag-phyric	131/8G	1400	6.9	195	34.6	0.139	0.199	N/A	N/U	N/U
rhyodacite	142/10G	1800	8.6	245	40.8	0.136	0.211	N/A	N/U	N/U
	178/11G	2400	9.5	283	40.4	0.118	0.235	N/A	N/U	N/U
Andesite	126/3G	8100	3.5	91	22.9	0.011	0.153	N/A	N/U	N/U
	133/9G	7500	3	81	17.9	0.011	0.168	N/A	N/U	N/U
	142/9G	7100	3.5	99	18.6	0.014	0.188	N/A	N/U	N/U
	144/8G	7700	3.4	95	23.2	0.012	0.147	N/A	N/U	N/U
	145/4G	7500	1.5	43	17.7	0.006	0.085	N/A	N/U	N/U
	180/2G	6700	3.3	87	17.3	0.013	0.191	N/A	N/U	N/U
	45/7G	7700	3.6	95	21.7	0.012	0.166	N/A	N/U	N/U
	98/4G	8700	3.4	103	22	0.012	0.155	N/A	N/U	N/U
	98/6G	7200	2	49	14.8	0.007	0.135	N/A	N/U	N/U
	#135/111	4800	4.3	112.6	22.2	0.023	0.194	66.39	2878	25.56
	#144/41	6600	3.3	55.4	18.4	0.008	0.179	52.83	3957	71.42
	#145/45	5700	3.9	92.9	22.1	0.016	0.176	59.74	3417	36.78
	#93/143	5700	2.7	65.2	19.6	0.011	0.138	50.49	3417	52.41
	#98/64	6200	3.3	78.8	17.4	0.013	0.197	55.93	3717	47.17
	#148/191	7700	3.6	76.4	17	0.01	0.212	62.53	4616	60.42
Quartz-	131/4G	3500	3.7	112	22	0.032	0.168	N/A	N/U	N/U
xenocrystic	133/4G	5300	5.3	165	32.9	0.031	0.161	N/A	N/U	N/U
andesite	142/1G	7200	3.9	85	18.7	0.012	0.209	N/A	N/U	N/U

N/A=not analysed. N/U=not used. Sample number prefix #=unpublished data of Dr J Stolz.

Volcaniclastic and altered units

Rock type	Sample number	TiO2 ppm	Nb ppm	Zr ppm	Y ppm	Zr/TiO2	Nb/Y
Andesitic	142/6G	7900	4.8	119	22.2	0.015	0.216
scoriaceous bx	144/3G	9000	4.4	95	19.3	0.011	0.228
Qtz-x'crystic	142/2G	8000	3.7	82	17.6	0.01	0.21
andesitic	144/1G	8500	4	83	20.3	0.01	0.197
scoriaceous bx	145/1G	9000	4.2	91	26.6	0.01	0.158
Qtz-plag-	135/2G	6700	5.4	133	28.8	0.02	0.188
bearing	145/3G	6300	5.4	144	28.5	0.023	0.189
altered rocks	180/1G	8200	5.6	139	29.3	0.017	0.191
	45/2G	5500	4.9	130	21.9	0.024	0.224
Plagioclase-	126/4G	1900	6.3	186	36.6	0.098	0.172
bearing	135/3G	3600	7.4	199	36.8	0.055	0.201
altered rocks	135/5G	2300	6.2	182	35.8	0.079	0.173
	178/6G	1800	6.2	133	19.2	0.074	0.323
Strongly	126/2G	2000	4.5	121	18.5	0.06	0.243
altered rocks	131/6G	1800	5.2	145	23.8	0.081	0.218
-volcanic	133/5G	5100	4.3	114	23.7	0.022	0.181
precursor?	133/6G	2000	6.5	182	33.7	0.091	0.193
	133/7G	2800	9	270	48.2	0.096	0.187
	133/8G	7700	3.5	93	24.3	0.012	0.144
	135/4G	2400	7.3	199	38.3	0.083	0.191
	142/3G	4100	8.2	152	34.8	0.037	0.236
	142/4G	2200	6.7	177	31.6	0.08	0.212
	142/5G	5100	4.5	109	22.3	0.021	0.202
	144/10G	2200	7	182	61.2	0.083	0.114
	144/2G	5800	2.5	53	10.9	0.009	0.229
	178/3G	8900	4	82	19.7	0.009	0.203
	180/3G	2100	6.5	188	32.9	0.09	0.198
	181/1G	2400	7.4	209	37.1	0.087	0.199
	181/3G	2100	6.2	171	33.3	0.081	0.186
	22/1G	7900	5.4	144	29.4	0.018	0.184
	22/2G	5000	9.7	180	30.9	0.036	0.314
	45/8G	8900	5.4	137	24	0.015	0.225
	45/9G	1800	6.1	163	29.5	0.091	0.207
	55/2G	2000	5.8	162	30.1	0.081	0.193
	98/2G	2400	7.6	220	38.2	0.092	0.199
	98/5G	3800	5.1	148	23.6	0.039	0.216
Strongly	126/1G	6000	10.7	152	24.1	0.025	0.444
altered rocks	131/1G	6900	12.5	164	28.5	0.024	0.439
-sedimentary	131/2G	6200	11.3	165	22.4	0.027	0.504
precursor?	131/3G	1700	4	51	4	0.03	1
	131/5G	2100	5	59	10.3	0.028	0.485
	144/11G	4800	9.9	149	23.1	0.031	0.429
	45/6G	6500	11.7	157	30.6	0.024	0.382