DEPARTMENT OF PRIMARY INDUSTRIES AND RESOURCES

SOUTH AUSTRALIA

MINERALS DIVISION

REPORT BOOK 97/51

POONA COPPER MINE, MOONTA SOUTH AUSTRALIA: INVESTIGATION OF ALTERATION MINERALOGY USING SHORT WAVE INFRARED ANALYSIS

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Poona Copper Mine, Moonta, South Australia: Investigation of alteration mineralogy using short wave infrared analysis

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SUMMARY

The Poona Copper Mine on northern Yorke Peninsula, South Australia was worked from 1988-92 on an extension of the original Poona lode, a narrow, shear-hosted copper sulphide vein deposit in Moonta Porphyry of Mesoproterozoic age. The orebody is typical of extensive mineralised veins in the Moonta district which were discovered in 1861 and produced for over 60 years to make South Australia a significant world source of copper from 1860s to 1920s. The mine was selected for a pilot study in spectral mapping because it represented both a well documented, recently mined deposit from a major historic centre for copper production, and an example of a Proterozoic Fe oxide Cu-Au-REE style mineralisation of which the world class Olympic Dam deposit is also an example.

The study involved analyses of mainly drill hole samples using a portable short wave infrared (SWIR) analyser, PIMA II. PIMA II is representative of a new generation of portable field instruments. It provides a rapid, cost-effective means of collecting mineralogical data at a drill or mine site. In this study, spectra were interpreted to determine which alteration minerals could be identified and whether these could be used to assist exploration for similar ore deposits. Over 550 samples from 13 drill holes were analysed and 732 spectra were recorded and examined. Minerals which showed SWIR response included chlorite, muscovite, kaolin, alunite, smectite and tourmaline. Subtle variations in spectra, particularly for chlorite, kaolin and muscovite, were noted and investigated in more detail. For these minerals, spectral interpretations were supported by other analytical techniques including X-ray diffraction (XRD), microprobe analyses and scanning electron microscopy (SEM).

The spectral data were useful in mapping both regolith units and alteration mineralogy with the following minerals identified as having a close association with Cu-Au veins and potentially offering broader targets which could be used to focus exploration drilling:

- **Halloysite and kaolinite coexist as separate kaolin species at Poona. The distribution of halloysite is largely constrained to the weathered zone and as a coating on fractures in fresh porphyry to depths of around 80 m. It is argued that at Poona, halloysite is preferentially precipitated from circulating meteoric water high in**

dissolved aluminium and silica that formed during acidic conditions resulting from weathering of sulphide ore. A method of distinguishing halloysite from kaolinite is proposed based on a ratio of the depth of the water feature at 1900 nm and the sum of the depths of the main kaolin absorption features. Halloysite is distributed as a broad envelope about the orebody and could be targeted in exploration drilling as an indicator to mineralised veins which extend into the weathered zone

- **For muscovite, a wavelength shift of the major absorption feature from 2208 nm to 2227 nm is due to a compositional change resulting from substitution of Al by Fe and Mg to approach a phengite composition. The longer wavelength phengitic micas are particularly well developed in the wallrock immediately adjacent to the ore zone. Phengitic mica at Poona is interpreted as the result of hydrothermal alteration by fluids associated with sulphide deposition. Although the phengite zone is typically less than 10 m wide on either side of the orebody, the presence of subparallel shearing with associated minor copper mineralisation extended this zone to 50 m in one drill hole. Broader alteration zones might be expected for larger mineralised veins or for vein stockworks.**

- **Variation in the positions of the chlorite absorption features were due largely to alteration of Fe-rich chlorite with varying proportions of Fe replaced by Mg. This later stage alteration in chlorite may correspond with the period of ore formation at Poona. However the patchy nature of the alteration in individual chlorite grains made it difficult to interpret and map from spectral data alone. Overall, the interpreted distribution of chlorite with higher Mg content is more restricted than that of Fe-chlorite and appears to be related spatially to the zone of mineralisation. The presence and composition of chlorite may have more significance in a regional context in identifying areas of metamorphic/metasomatic alteration that favour mobilisation and concentration of Fe-Cu-Au mineralisation.**

1. INTRODUCTION

The Moonta-Wallaroo District on northern Yorke Peninsula, South Australia (Figure 1 & Figure 2) is historically one of the state's most important copper-gold producing regions. Between 1860 and 1920, the twin mining fields of Wallaroo and Moonta produced some 355,000 tonnes of copper and 2 tonnes of gold (Conor, 1996). The orebodies are largely confined within shear zones and fractures with the mineralisation introduced via hydrothermal activity during deformation and metamorphism associated with either the later stages of the Kimban Orogeny (c.1740 Ma) (Parker, 1993) or intrusion of Hiltaba Suite granites (c.1600 Ma) (Conor, 1996).

Since closure of the mines in 1923 there has been extensive exploration for additional mineralised shears. The challenge has been to locate narrow mineralised veins less than a few tens of metres wide by up to several 100 metres long. The veins can plunge steeply, and in some old mines were worked to depths exceeding 650 m (Parker, 1993). Neither mineralised shears nor the host rocks are exposed at the surface but are covered by a veneer of younger sediments ranging in age from Neoproterozoic to Holocene. In places, the cover and host rocks are deeply weathered and contain saline, conductive groundwater. Despite the difficulties, additional mineralised shears have been located principally using ground electrical methods (SIROTEM) followed up by close-spaced drilling. To date these have resulted in development of small mining operations at Poona (1988-1992) and Wheal Hughes (1991-1994) which together produced around 18,000 t Cu from 450,000 t of ore grading between 4.6-5.3% Cu and 0.7-1.5 g/t Au (Conor, 1996; Both *et al.*, 1993).

Alteration minerals, including mica, chlorite, kaolin and tourmaline, have been widely reported as being associated with shear zones and mineralisation in the Moonta-Wallaroo District. However, few systematic studies have been reported on the nature and distribution of the alteration minerals or their relation to ore-forming processes.

The Poona pilot study was recommended for inclusion in AMIRA project P435, *Mineral Mapping with Field Spectroscopy for Exploration,* as the use of the portable spectrometer PIMA II offered a means of identifying and mapping alteration minerals. Specific objectives of the project were:

- to identify the nature of alteration minerals associated with copper mineralisation at Poona;
- to characterise and understand the spectral signature of these alteration minerals;
- to examine the distribution of alteration minerals with respect to mineralisation and determine if any useful pattern of mineral distribution could be mapped using the PIMA II to provide a broader target zone related to the presence of mineralised veins.

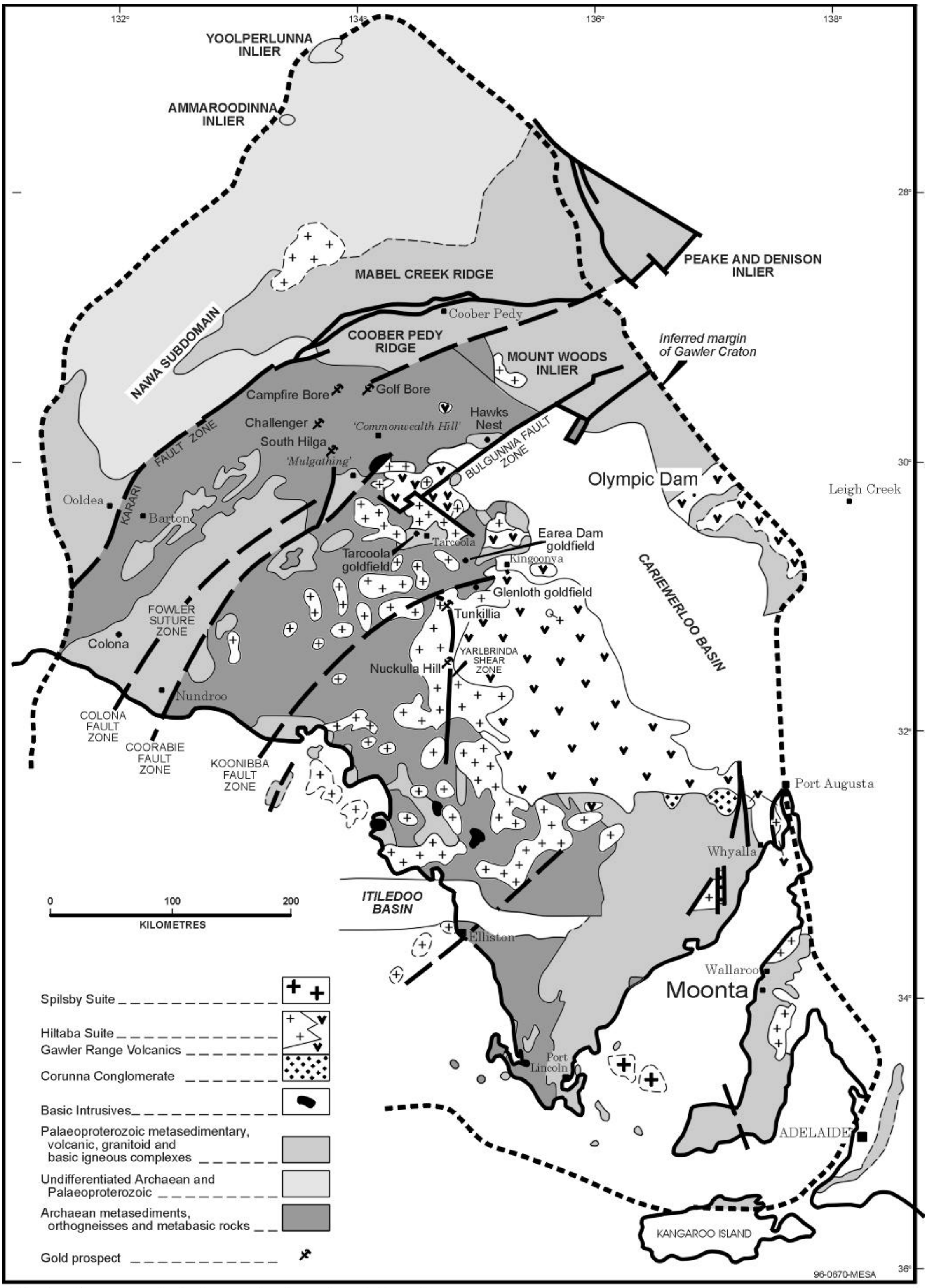


Figure 1: Location diagram showing Moonta in relation to Gawler Craton

2. GEOLOGY

2.1 Regional Geology

The Moonta-Wallaroo mining district lies on the eastern margin of the Archaean to Mesoproterozoic Gawler Craton (Figure 1). Copper mineralisation at Moonta is hosted by Moonta Porphyry and at Wallaroo by Doora Schist. Moonta Porphyry is a strongly foliated grey to reddish pink, porphyritic rhyolite characterised by relict plagioclase grains in a deformed matrix of quartz, feldspar and biotite. The age of Moonta Porphyry is reported as 1741±9 Ma (Fanning *et al*., 1988). Relic primary textures in the porphyry, are interpreted by Lemar (1975) as representing a sequence of comagmatic ash flow tuffs and tuff breccias and intrusive micrograníites. Doora Schist is interlayered with Moonta Porphyry and comprises pelitic mica schist, feldspar porphyry, hornfels, amphibolite and siliceous iron formation (Parker, 1993). Parker (1986) concluded that the region represents either a volcanic arc along the eastern margin of the developing craton, or a second cycle of extension and rifting on an underplated Archaean to early Proterozoic crust. Granite bodies in the area are equated with Hiltaba Suite granite and were emplaced at around 1600 Ma.

The older Proterozoic basement is overlain by thin veneers of flat-lying units that include Neoproterozoic platform sediments of the Burra and Umberatana Groups, Cambrian Kulpara Limestone, Tertiary Melton Limestone, and younger terrestrial clay and carbonate-rich soils.

The interpreted basement geology is shown in Figure 2, and the rock relationships are shown in Figure 3(a & b). Two different interpretations of the rock relationship (Figure 3 (a & b)) from Conor (1996) summarise the current controversy regarding timing of the mineralisation and the geological relationship between Doora Schist and Wandearah Metasiltstone. Conor (1996) argues that mineralisation and metamorphism of Moonta Porphyry and Doora Schist were largely the response to heating and widespread metasomatism associated with emplacement of Hiltaba Suite granite (Tickera and Arthurton Granite). This interpretation equates Doora Schist with Wandearah Metasiltstone suggesting that the textural differences are due to strain partitioning and a steep metamorphic gradient induced by granite intrusion and associated metasomatism. Parker (1993) and Plimer (1980) argue that the mineralisation was largely stratabound, the product of submarine volcanicity, and was subsequently metamorphosed, deformed, and possibly remobilised during a phase of deformation prior to granite emplacement.

Conor’s interpretation draws strong parallels with the giant Olympic Dam Cu-U-Au-Ag deposit which is in a similar tectonic setting on the eastern margin of the Gawler Craton and is related to intrusion of Hiltaba Suite granite (see Figure 1). The interpretation is supported by the observation that much of the mineralisation at Moonta-Wallaroo was introduced (and/or remobilised) hydrothermally along foliation or shear dilatancies, and deposited in structural traps (Conor, 1996; Both *et al.,* 1993). Conor’s interpretation poses a challenge for this study in that by focusing on a single orebody the variation in sample data collected may be too limited to effectively differentiate between localised alteration and contemporaneous broad scale metasomatic alteration.

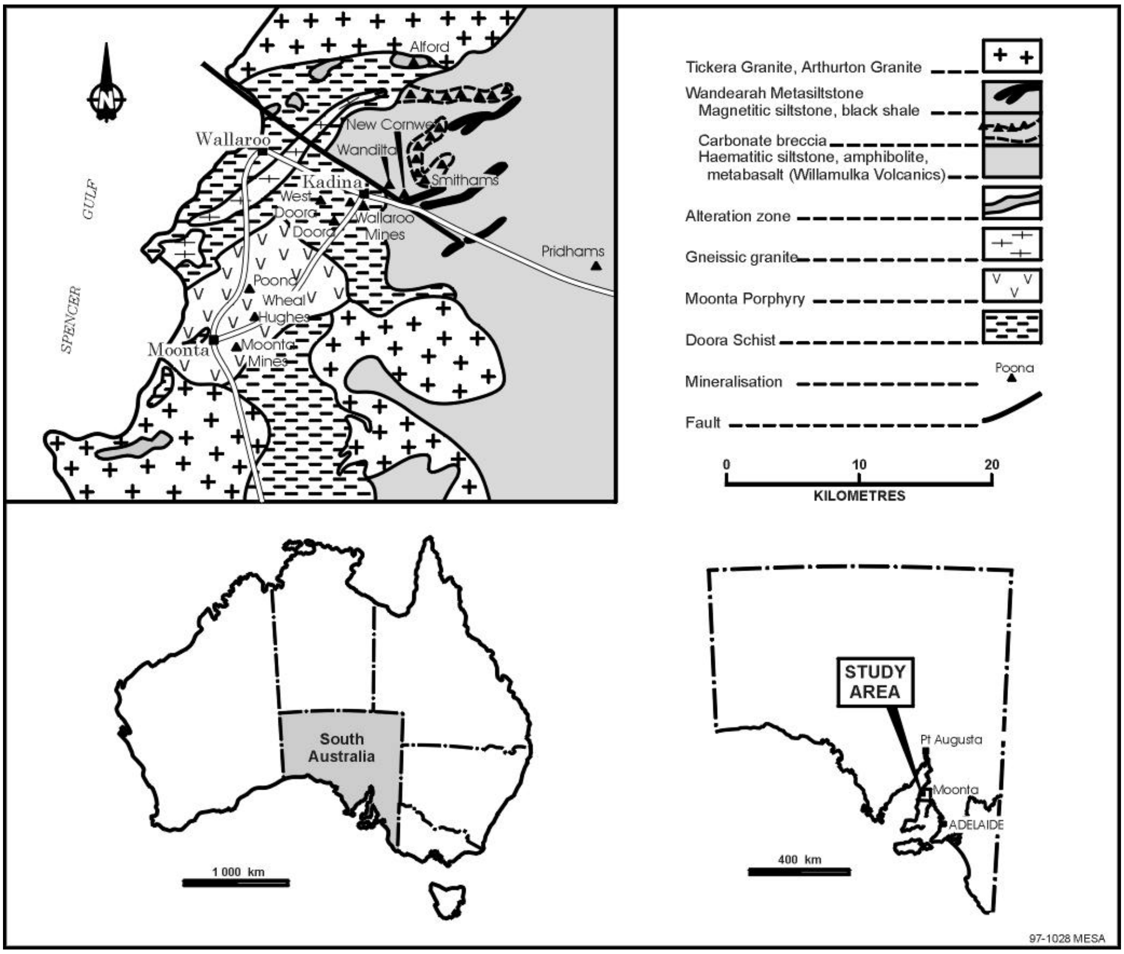
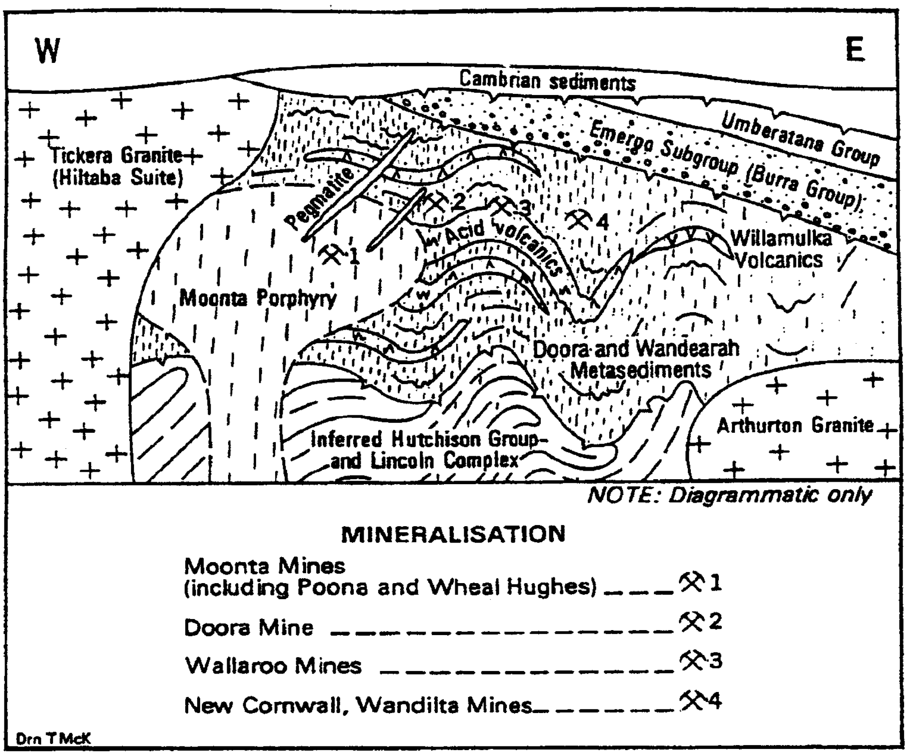
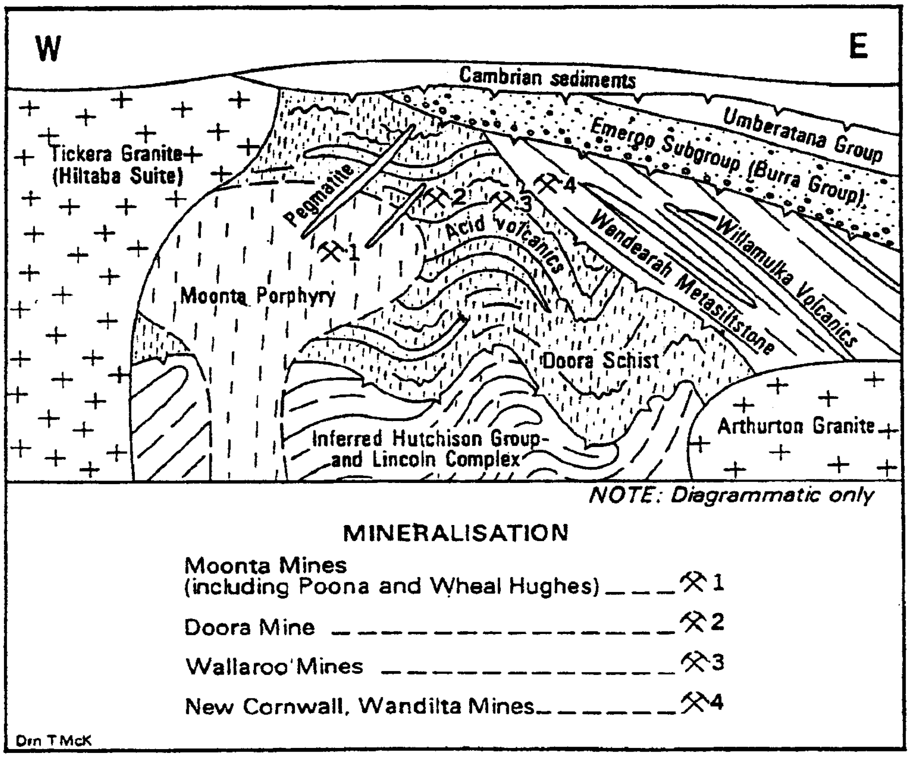


Figure 2: Location and Regional Geology



a) Recomended stratigraphy (this work)



b) Previous stratigraphic scheme (Parker in Drexel *et al.*,1993)

Figure 3 (a & b): - Schematic sections showing two interpretations of structural and stratigraphic relationships of Proterozoic rocks in the Moonta-Wallaroo Mining District (from Conor, 1996).

2.2 Geology- Poona Mine

The Poona orebody is typical of mineralisation in the Moonta lodes. The lodes are all hosted by Moonta Porphyry and comprise mainly tabular veins within fractures and shear zones that make a series of concentric arcs trending from NNE to ENE (Both *et al.*, 1993) (Figure 4). Mineralised veins, up to 12 m in width and several hundred metres in length, were mined to depths of 650 m. Moonta, “vein-type” mineralisation includes chalcopyrite, bornite, chalcocite, pyrite, molybdenite, hematite and magnetite, with traces of gold, silver, bismuth, fluorite, fluorapatite and uraninite (Parker, 1993).

The recently worked Poona Mine is an offset of the main Poona Lode. The orebody is a thin fissure vein, striking 070§, dipping 50§ NW and plunging 22§ west (Figure 5). The vein incorporates brecciated and replaced host porphyry and has a strike length of some 160 m, being terminated at either end by steeply dipping faults that cut the lode almost at right angles. The lode has an average width of 3-4 m and a maximum width of some 6 m (Janz, 1990). The orebody extends beyond 130 m depth but mining cut-off was 85-90 m below surface. Offshoots from the main lode, up to 1 m wide, extend into the hanging wall. Small ‘pods’ of ore in the footwall result from corrugation and kinking on the footwall (Conor, 1996).

Primary ore minerals at Poona include chalcopyrite and pyrite, with minor bornite and gold. Atacamite ($CuCl_2$) and alunite are present in Pleistocene clay directly above the orebody. A 3 m thick supergene zone at the top of the orebody contains native copper, covellite, chalcocite and minor digenite and djurleite. Gangue minerals include quartz, feldspar, hematite, chlorite, tourmaline, and minor sericite, fluorite, epidote, alunite and kaolin.

The paragenetic sequence of mineralisation (Table 1) indicates 3 stages separated by episodes of fracturing and shearing (Both *et al.*, 1993). Iron minerals dominated the first two stages with the third stage responsible for deposition of chalcopyrite, with bornite and gold as small inclusions within chalcopyrite.

Table 1: Paragenetic sequence of mineralisation at Poona Copper Mine (after Both et al., 1993).

	STAGE 1		STAGE 2		STAGE 3
Magnetite	——	F		F	
Hematite	———	r		r	——
Pyrite		a	————	a	
Marcasite		c	———	c	
Chalcopyrite		t		t	————
Bornite		u		u	————
Gold		r		r	——
Carrollite		i		i	————
Quartz	————	n	————	n	————
Chlorite		g	— — ——	g	————
Sericite			— — ——		————
Tourmaline			— — ——		————

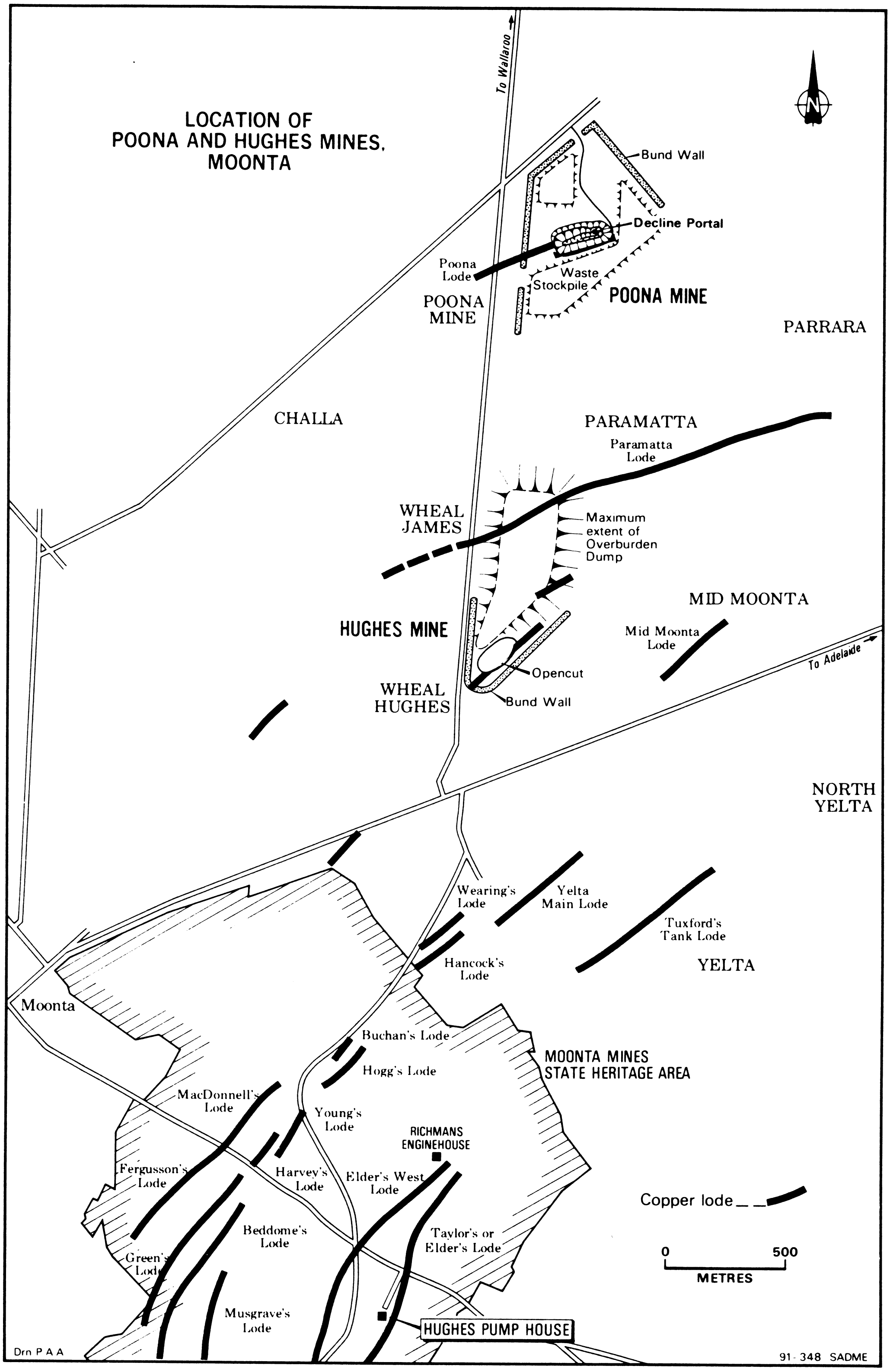
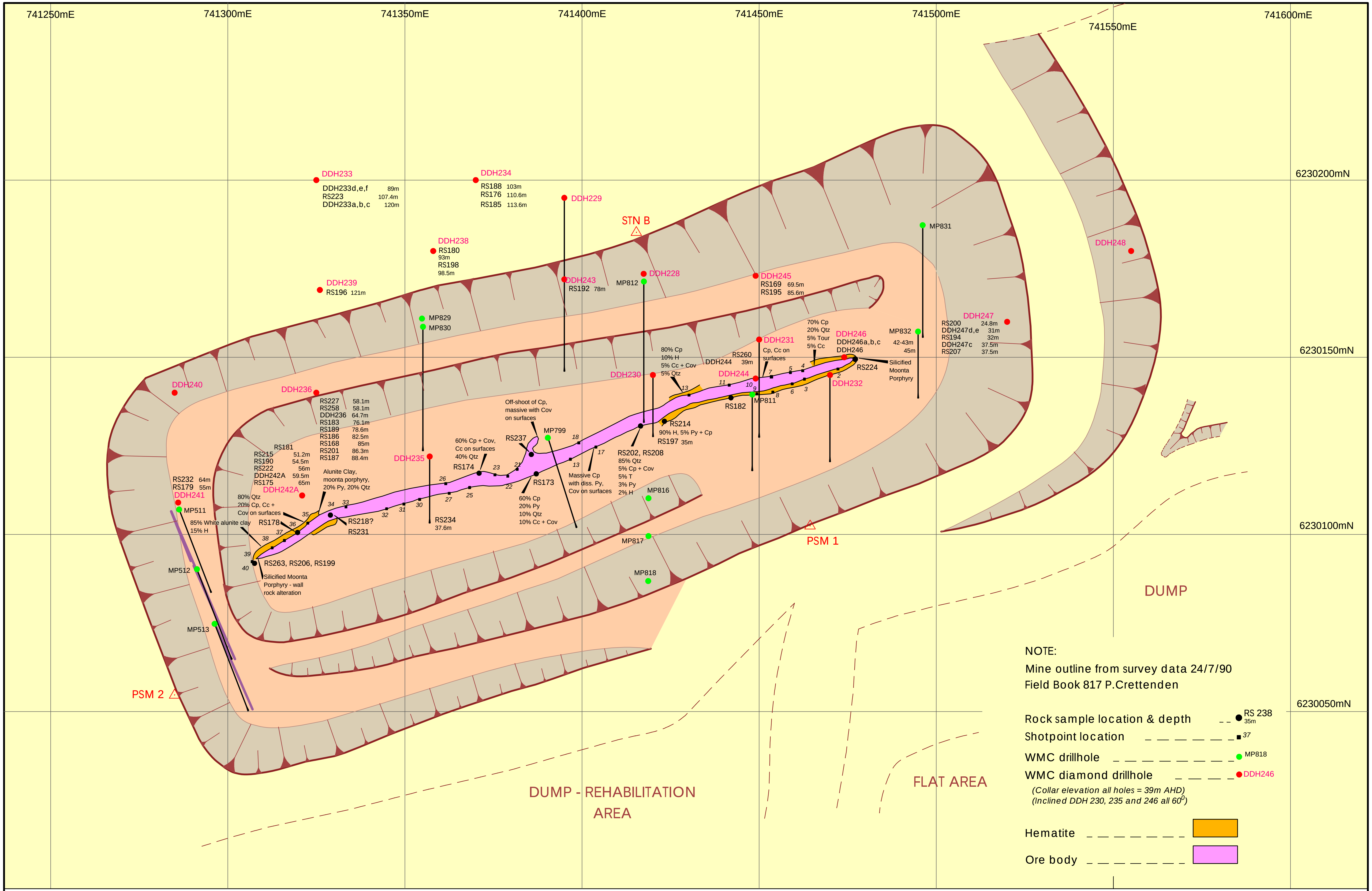


Figure 4: Moonta Mining District, distribution of main copper lodes.



NOTE:
Mine outline from survey data 24/7/90
Field Book 817 P.Crettenden

Rock sample location & depth _ _ ● RS 238 35m
Shotpoint location _ __ __ __ __ _ ■ 37
WMC drillhole _ __ __ __ __ __ __ _ ● MP818
WMC diamond drillhole _ __ __ _ ● DDH246
(Collar elevation all holes = 39m AHD)
(Inclined DDH 230, 235 and 246 all 60^0)

Hematite _ __ __ __ __ __ _ 🟧
Ore body _ __ __ __ __ __ _ 🟪

POONA MINE COPPER DEPOSIT - MOONTA

ROCK SAMPLE LOCATIONS RL-6 LEVEL

Figure 5
95-0461

QD7 6297AM 95-0461.DTA

3. SAMPLES AND METHODS

As an initial study, short wave infrared spectra were taken of selected samples from the ore zone and adjacent wall rock at Poona. These were from a suite of samples, held in storage at the MESA Glenside Core Library, Adelaide, that had been collected by J Hough (Senior Geologist, MESA) during previous geological investigations (Janz, 1990). Preliminary results confirmed that the ore minerals, gangue, and host Moonta Porphyry typically gave little or no spectral response in the infrared spectral range (1300-2500 nm) measured with the portable infrared analyser PIMA II. Minerals which did give a spectral response were largely confined to alteration phases, in particular those coating natural fracture surfaces and infilling joints. These included chlorite, smectite, mica, kaolin, alunite and tourmaline. This suite of minerals became the focus of subsequent investigations.

In order to examine mineralogical changes across the Poona orebody, samples were analysed from selected drill holes that could be used to reconstruct a composite section through the orebody and adjacent host rock (Figure 6). The study was only possible because much of the drill core from previous company exploration in the Moonta-Wallaroo District had been retained and housed by MESA in a purpose-built core library facility at Moonta. The majority of samples included in this investigation were sourced from that facility and the bulk of infrared analyses were done on site at the core library. As interpretation of spectral data proceeded, subsequent trips were made to Moonta to subsample core for additional analyses which included X-ray diffraction (XRD), microprobe analysis and scanning electron microscopy (SEM).

For this study, 12 drill holes and 161 rock specimens were scanned with the PIMA II providing 732 spectra from over 550 samples. Details of drill hole samples included in the study are summarised in Table 2. An indication of the relative position of samples with respect to the ore body is provided on Figure 6 where all drill holes have been projected onto an artificial cross section set perpendicular to the strike of the ore zone.

Analyses were made mostly on core samples where the minor alteration mineral phases could be more readily isolated and measured directly. A natural fracture or joint surface was placed directly against the window of PIMA II and a spectra recorded in around 30 to 60 seconds. All diamond drill holes had been pre-collared as rotary percussion holes. This meant that core samples were mostly restricted to fresh rock and coring was often limited to predicted zones of mineralisation, based on projection of the orebody. Infrared analyses were made at ~1 m intervals, depending on distribution of fracture and joint surfaces. Pre-collar rotary/percussion cutting samples were available only for diamond drill hole DDH 234 and these were analysed at 2 m intervals. Other non-cored, rotary/percussion holes (MP series, Table 2) were included in the study to provide additional spectral data on the mineralogy above the orebody, particularly in the weathered zone.

In general, percussion samples produced low amplitude spectra whereas diamond drill core samples produced higher amplitude spectra which were more readily interpreted. Many of the samples analysed were very dark and as a consequence their spectra were noisy. Three measurements were taken on some samples, especially within the ore zone. These included the host rock, vein material and quartz veins. For percussion samples, spectral analysis of individual chips helped to identify or confirm the presence of particular mineral phases.

Table 2: Poona Copper Mine, Summary of Drill Hole Samples Analysed

Drill Hole	**AMG ANS66 Grid Reference**	**PIMA Sample #**	**Interval Scanned/ Spacing of Samples**
DDH 230	741420E 6230145N	Poona145-208 (2/3/95)	15-60.4m / approx 1m
DDH 231	741450E 6230155N	Poon045 - 072 (24/8/95)	31-54.1m / approx 1m
DDH 233	741325E 6230200N	RS223,DDH233a,b,c,d,f	89-120m / irregular
DDH 234	741370E 6230200N	Poona001- 041 (cuttings) 042 - 144 (core) (1/3/95)	0 - 82m / 2m samples 82-151m / approx 1m
DDH 235	741357E 6230122N	Poona209-217 (2/3/95)	26.5-47.5m / irregular
DDH 236	741324E 6230140N	RS168,183,186,187,189,201,227 (25/1/95)	58.1-88.4m / irregular
DDH 242a	741321E 6230110N	RS175,181,190,215,222, 59.5m, 65m (25/1/95)	51.2-65m / irregular
DDH 244	741449E 6230144N	Poon073 - 105 (24/8/95)	37 - 59m / approx 1m
DDH 245	741449E 6230173N	Poon001 - 044 (24/8/95)	57 - 92m / approx 1m
MP 511	741286E 6320107N	5570 - 5595 (4/7/97)	0 - 52m / 2m samples
MP 512	741290E 6320090N	5596 - 5622 (4/7/97)	0 - 54m / 2m samples
MP 513	741296E 6320025N	5623 - 5647 (4/7/97)	0 - 50m / 2m samples
MP 811	741448E 6230140N	Poona106-127 (24/8/95)	0 - 42m / 2m samples

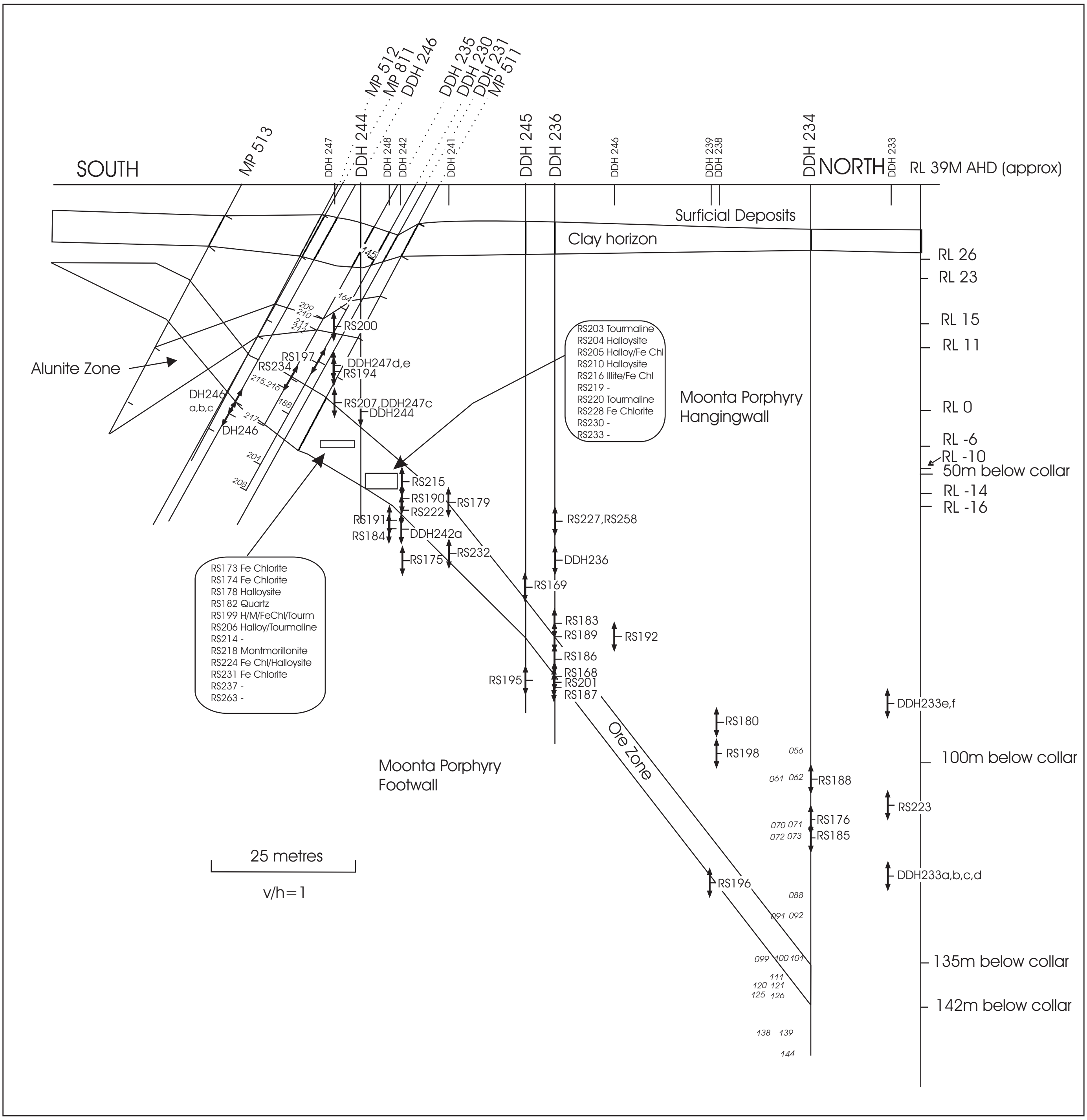


Figure 6: *Drill hole and sample locations on a projected cross section of Poona ore body*

4. SPECTRAL ANALYSIS AND INTERPRETATION

4.1 Sample Strategy

Where percussion drill hole cuttings were available from the pre-collared sections of diamond drill holes, the sampling strategy was to directly scan the chip tray at 2 m intervals with the PIMA facing down in contact with the sample. When it came to the cored sections, three types of sample were scanned: host rock, quartz and vein material. Often the same sample was scanned for three different minerals. Given that the deposit is a shear-hosted vein deposit it was logical that PIMA-visible mineralogical vectors to ore might also be fracture fillings and coatings. In percussion samples, where the rock preferentially parted along natural fractures, these minerals would be expected to present to the instrument when the sample was scanned. In core samples they had to be specifically targeted.

Fresh Moonta Porphyry host rock was scanned in an effort to establish a background signature against which alteration features might be compared. The rock was dominantly feldspar, and based on its pink colour, was initially noted in spectra comments as K-feldspar. Earlier work however had established that feldspar in Moonta Porphyry is predominantly albite with hematite “dusting” causing the pink colour (Conor, 1992).

Quartz was scanned to establish the presence of fluid inclusion water which, if present, would help to confirm a hydrothermal origin for the ore.

Vein material was typically of three types: white, green and black. White minerals were scanned in the search initially for highly crystalline kaolinite or dickite indicative of a hydrothermal system. Green minerals were selected as probable chlorite with the possibility of establishing chemical variation from Mg-rich to Fe-rich species that may be related to reaction with ore fluids. Black minerals were either hematite or tourmaline, both of which are intimately associated with the ore deposit. Hematite is essentially invisible to PIMA spectral wavelengths although iron oxides do influence the shape of the hull at lower wavelengths. Tourmaline was found to have an identifiable spectral signature and provided that the signature could be separated from mixtures, could be identified in percussion samples. This would provide confirmation that a hydrothermal vein had been intersected and could be useful particularly when logging percussion chips.

4.2 DDH 230 (Diamond Drill Hole)

DDH 230 is a cored angle hole from 16 m to 60.4 m dipping 60° towards 180° from a collar position of 6230200N, 741325E, elevation 39 m ADH. PIMA readings were taken at approximately every metre. At the top, several percussion samples were scanned (145, 145a, 146, 147). Nodular calcrete was noted in the percussion samples. The ore zone is between 35.8 m and 43 m depth (see plot of copper values, Figure 7) but core samples from 36 m to 42 m were missing from the collection.

4.2.1 Mineralogy

The mineral species identified from PIMA spectra in hole DDH 230 are summarised below (Figure 7) and stacked spectral plots for all samples and for specific mineral phases are given in Figure 8-Figure 11.

Although both Fe- and Mg-rich chlorite are present in the Poona samples, as confirmed by microprobe analyses (Appendix 2, Table 7 and Table 8, as discussed in Section 5.3, Chlorite, page 68), it proved difficult to positively identify compositional variation in chlorite from the PIMA spectra, although some general trends in spectral variation could be inferred.

Samples noted as fresh Moonta Porphyry during scanning have been grouped in a single stack (Figure 9). The minerals identified in the host rock from PIMA spectra were kaolin (halloysite), Fe-chlorite and montmorillonite. Albite shows spectral response at PIMA wavelengths but many of the alteration minerals present in shear fractures do respond.

The criteria for grouping the spectra in the two plots (Figure 10 and Figure 11) was primarily on colour and then on spectral response. The "green" minerals being essentially chlorite/muscovite mixtures (Figure 10) were separated from "white" minerals (Figure 11). Often two distinct spectra were obtained from different portions of the same. By plotting the minerals separately, trends in spectral variations of a particular mineral with proximity to ore were easier to identify.

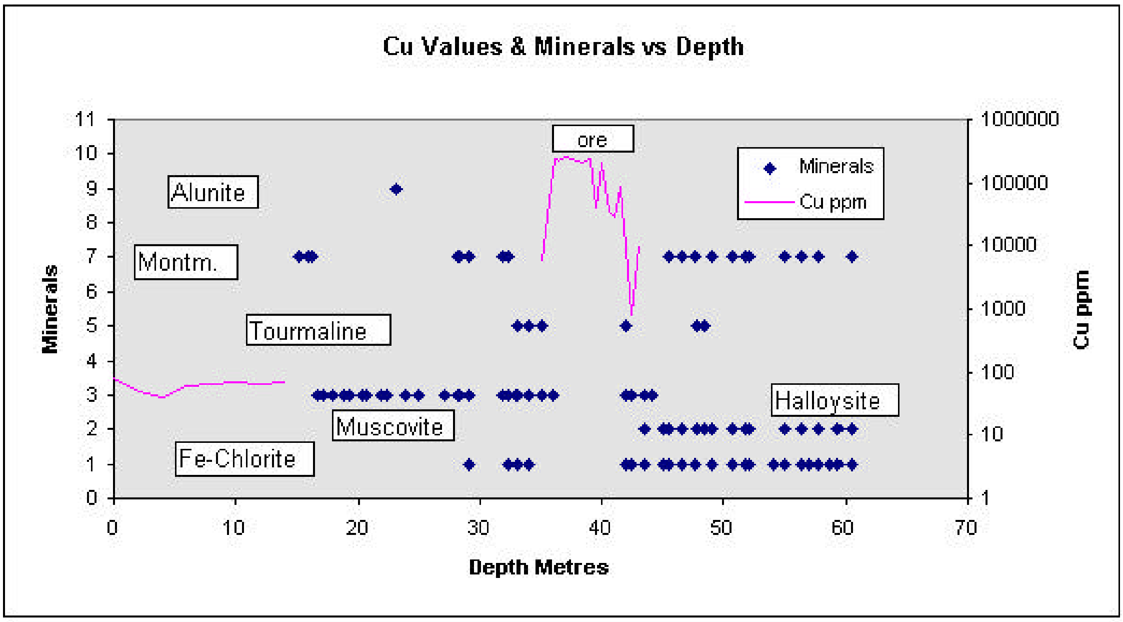


Figure 7: DDH 230 Minerals and Cu Values vs Depth

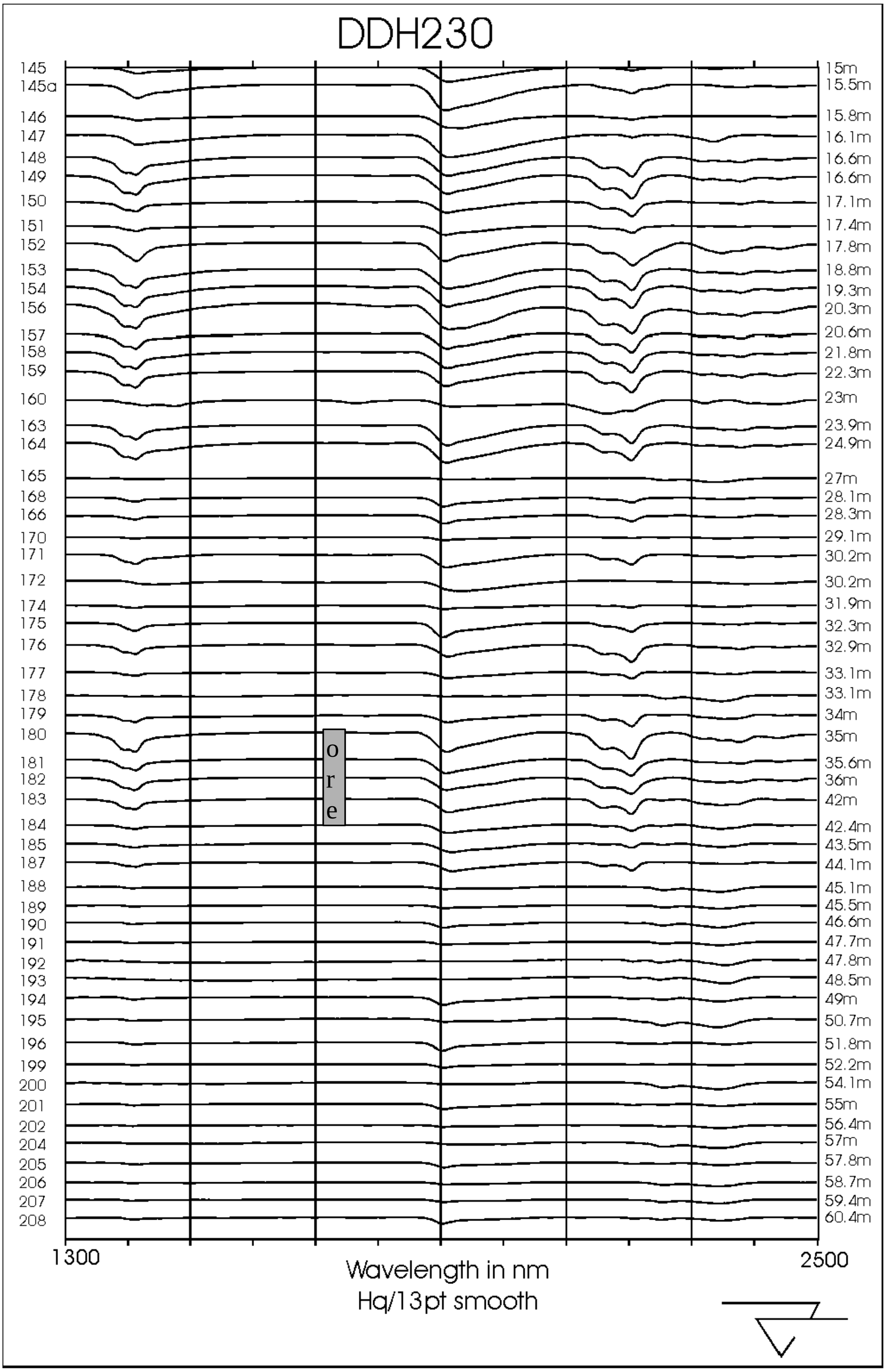


Figure 8: DDH 230 Diamond Drill Hole - stacked spectra hull quotients, all samples.

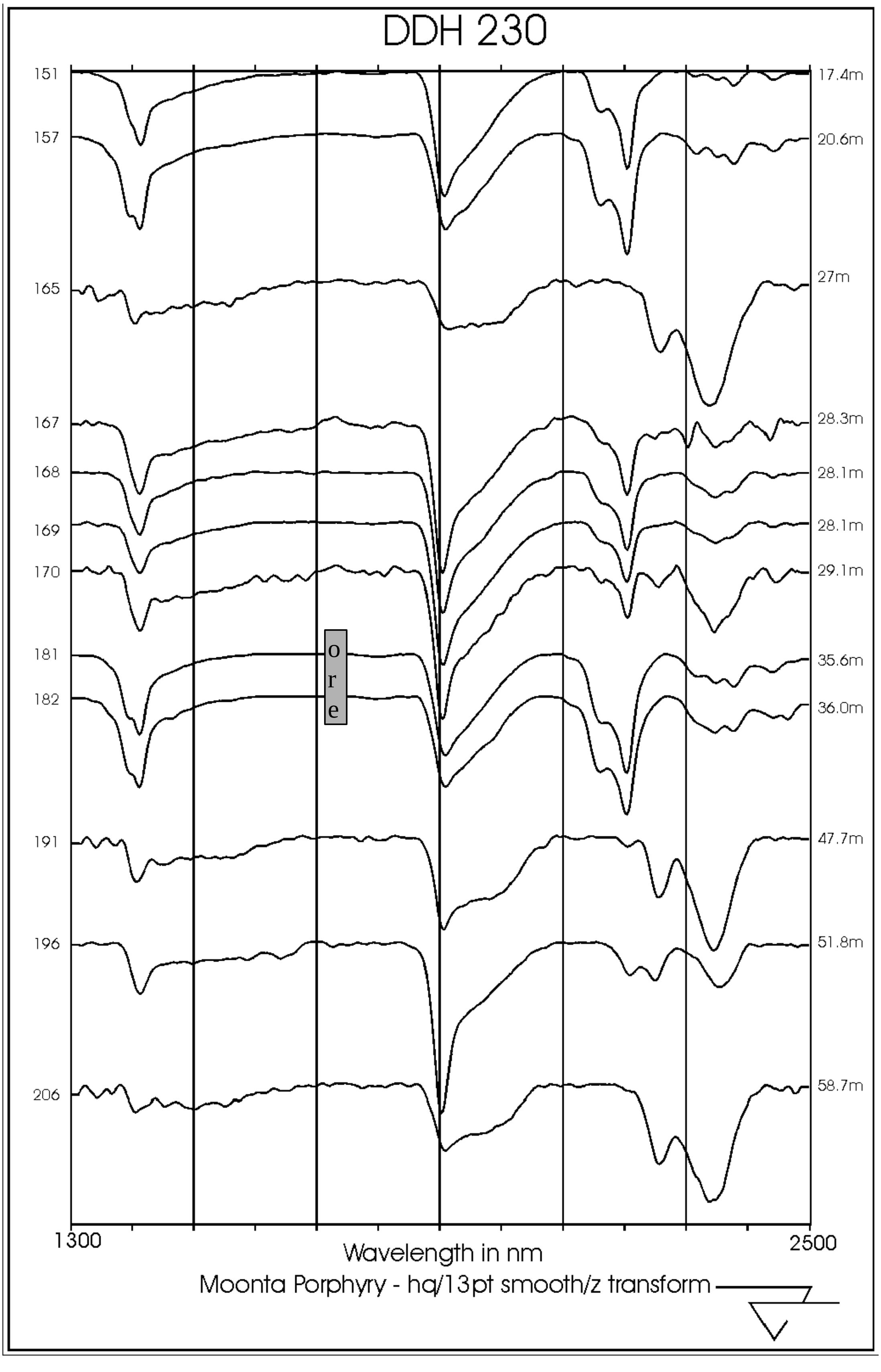


Figure 9: DDH 230 Fresh Moonta Porphyry

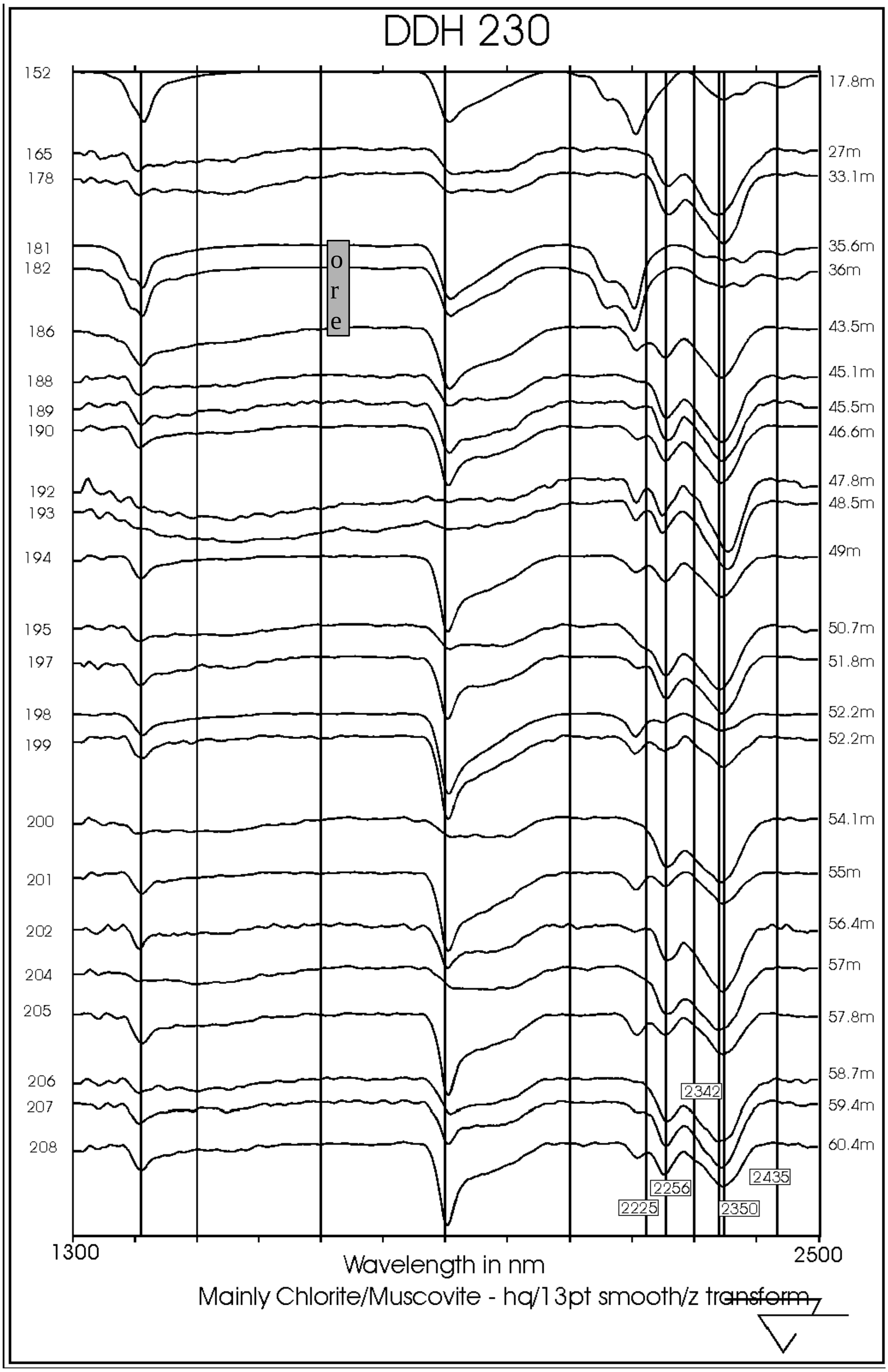


Figure 10: DDH 230 Chlorite/Muscovite Mixtures

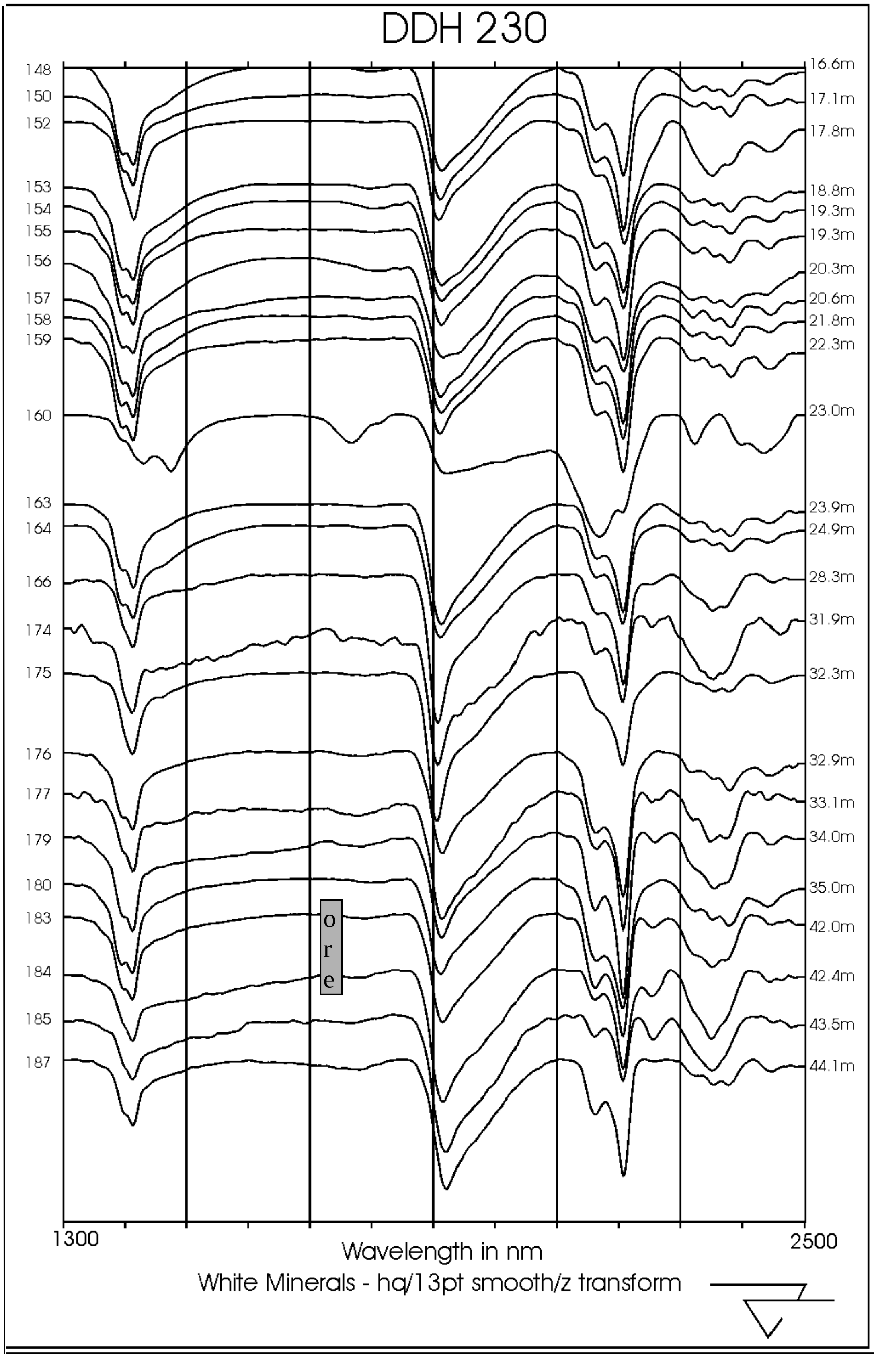


Figure 11: DDH 230 White Minerals

4.3 DDH 231 (Diamond Drill Hole)

The upper section of the hole was a percussion hole for which no samples were available. Core for diamond drill hole 231 begins at 31 m and extends down to a depth of 54 m, inclined 60° towards the south. Spectra were measured at ~ 1 m intervals. The ore zone occupies the section from 40 - 43 m.

4.3.1 Mineralogy

The minerals identified from spectral analysis include Fe- and Mg-chlorite, muscovite, halloysite, montmorillonite and phengite (Figure 12).

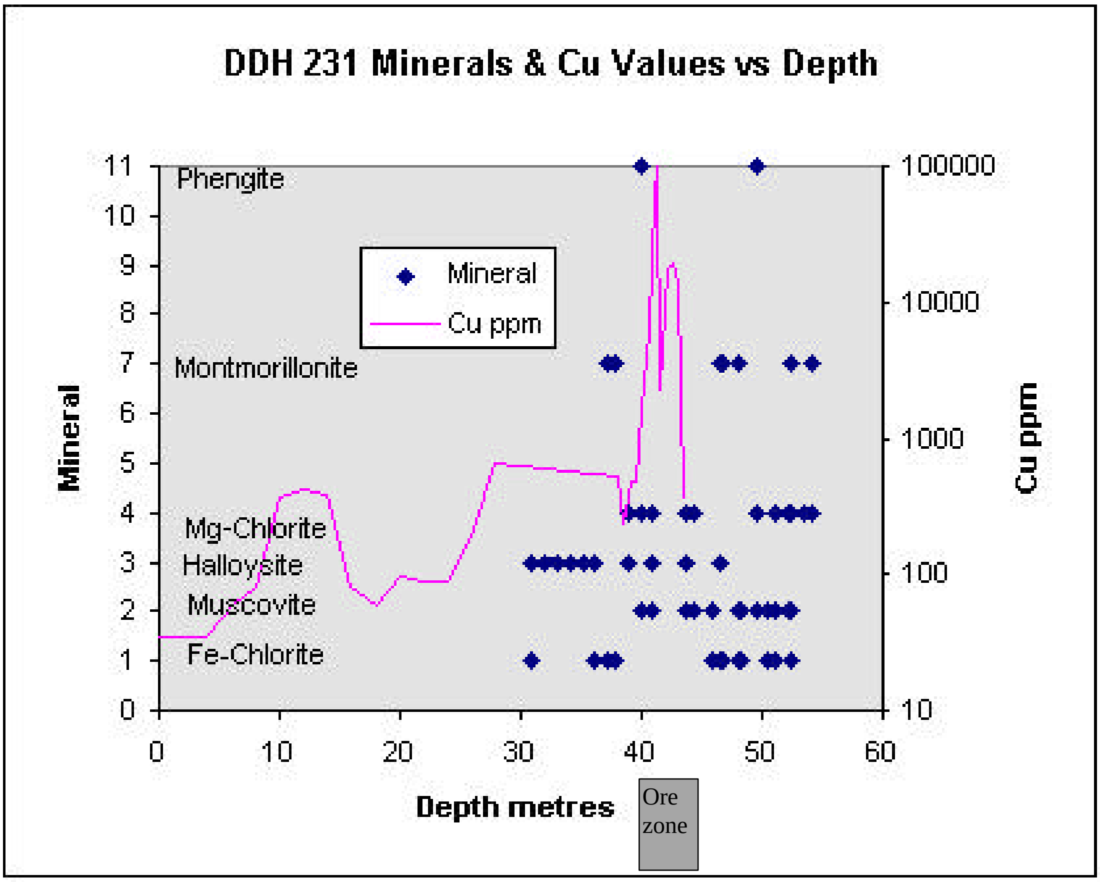


Figure 12: DDH 231 Minerals & Cu Values vs Depth

4.3.1.1 Kaolin

The kaolin spectra have a poorly defined doublet at 1400 nm. In some cases only a shoulder exists for the shorter wavelength feature and so it is necessary to observe the spectra in 2nd differential to determine the wavelength position of this feature.

All the kaolin samples have a deep water feature at 1900 nm, not consistent with kaolinite which has only minor bound water. The water feature may be due either to the presence of smectite or to the kaolin polymorph, halloysite. Halloysite has been characterised from previous studies using the 1400 nm absorption doublet. For halloysite, often the lower wavelength absorption lies between 1388 nm and 1394 nm and the separation of the doublet is

>20 nm. The measurements for kaolin spectra from DDH 231 were ambiguous with the separation of the 1400 nm doublet approaching, but generally <20 nm.

Smectite was not detected by XRD of selected samples but may still be a minor component in some samples. In particular, sample Poon049, shown to contain smectite from SEM studies, has only a single absorption feature at 1400 nm and the asymmetry resembles that of montmorillonite. The other diagnostic absorption feature for montmorillonite at 2207 nm is overlapped completely by kaolin's 2210 nm absorption feature. Therefore the 1900 nm absorption feature may be the only indication that montmorillonite is present with kaolin.

The kaolin mineralogy was resolved by scanning electron microscope (SEM) investigation of four samples, Poon045a (231045a, 31.5 m), Poon049 (231049, 34.1 m, Appendix 1, Plate 1 & Plate 2), Poon054 (231054, 38.9 m) and Poon057 (231057, 43.6 m). All four samples showed halloysite as the dominant kaolin mineral. In Poon045a (231045a, 31.5m) halloysite forms a coating on calcite grains. Calcite was not identified from the spectra either because it is present as a minor component or the coating of halloysite prevented detection. By contrast, sample Poon049 showed layers of halloysite coating chlorite flakes that were partly altered to smectite. The presence of smectite was clearly able to be detected from the spectra of sample Poon045a.

4.3.1.2 Muscovite and Chlorite

Some muscovite in hole 231 has a very long wavelength absorption feature at 2228 nm. In particular, muscovite absorption features are 20 nm higher immediately before and after the ore zone (Figure 13). Away from the ore zone, muscovite is less common but is characterised by an absorption feature around 2206 - 2211 nm.

The footwall spectra show dominantly chlorite mixed with some montmorillonite. Montmorillonite is present as a shoulder on the 2250 nm absorption feature of chlorite. Both water features are asymmetric and the 1900 nm water absorption feature is broad and shallow, indicative of chlorite, and in some spectra extends out to the 2000 nm chlorite feature (Figure 13). The chlorites vary in wavelength but still fall within the spectrally determined iron rich range (Figure 14).

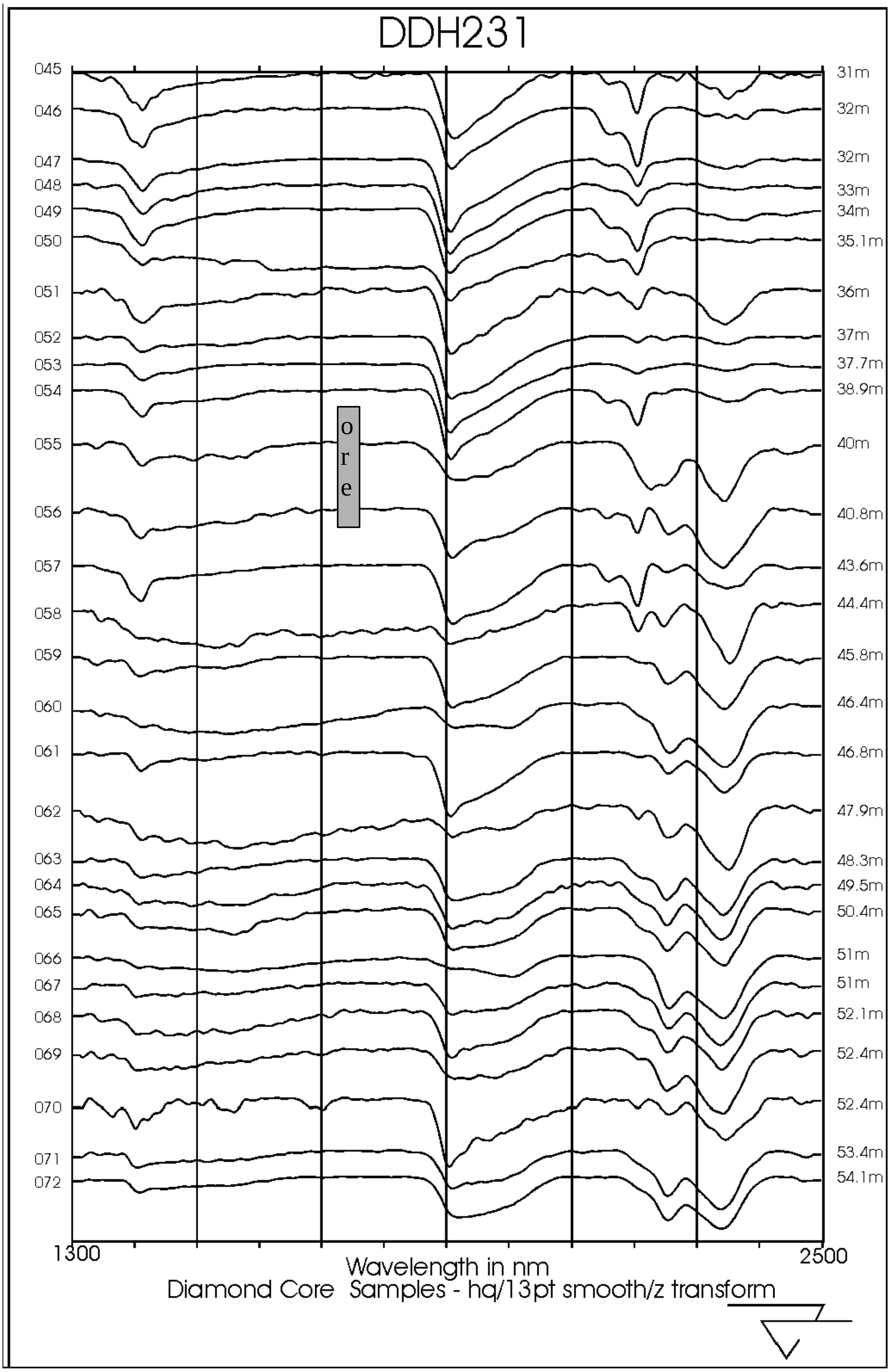


Figure 13: DDH 231 Diamond Drill Hole - stacked spectra.

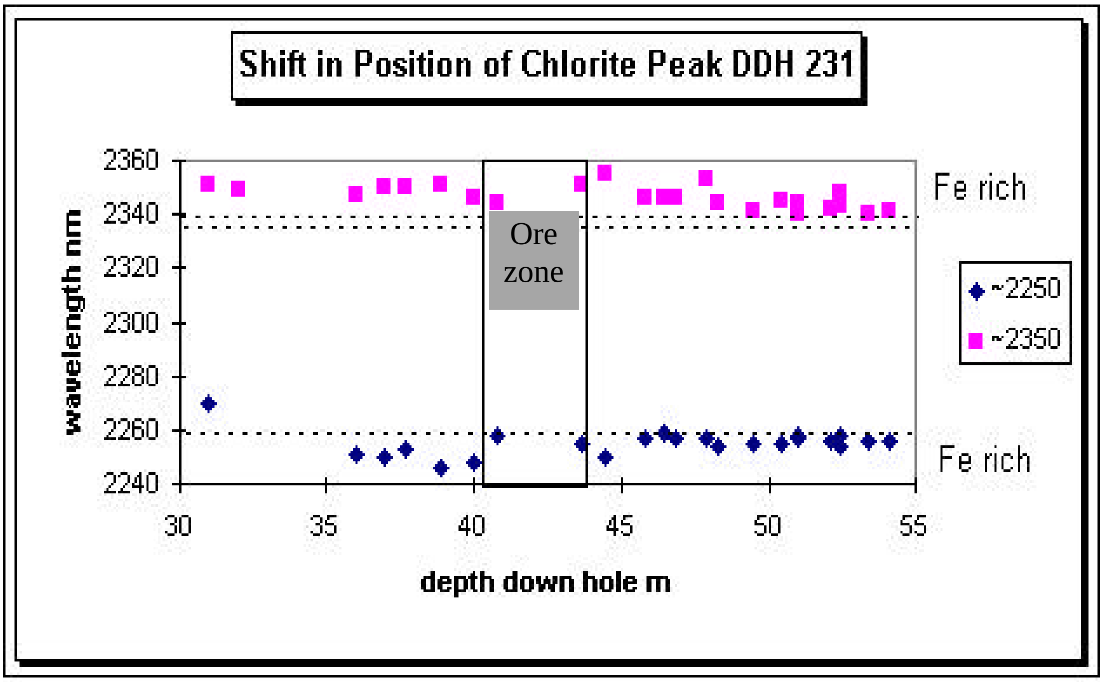


Figure 14: DDH 231 Chlorite variations with depth

4.3.2 Zoning

Mineralogy in the hanging wall is predominantly halloysite with minor occurrences of montmorillonite (Poon049, 34 m) and increasing amount of Fe-chlorite towards the ore zone and in the footwall (Figure 12 & Figure 14).

The ore zone is intersected at 40-43 m. Here the samples become more chloritic with halloysite/chlorite samples present in close proximity to the ore zone. The footwall is predominantly chlorite mixed with montmorillonite. Muscovite with a long wavelength absorption at >2220 nm is present adjacent to the ore zone and is interpreted as being quite phengitic (Figure 12 & Figure 13).

4.4 DDH 233 (Diamond Drill Hole)

The seven spectra (Figure 15) come from scanning three samples from Joanne Hough’s collection held at the Glenside Core Library. The mineralogy is essentially muscovite and Fe-chlorite but the samples also include a tourmaline spectra (DDH233b) (Figure 15). Samples are all in Moonta Porphyry and from the hanging wall with samples DDH233a-d closest to the projected ore zone (Figure 6). Trends are difficult to establish due to the small number of samples but the mineralogy is consistent with the Poona suite.

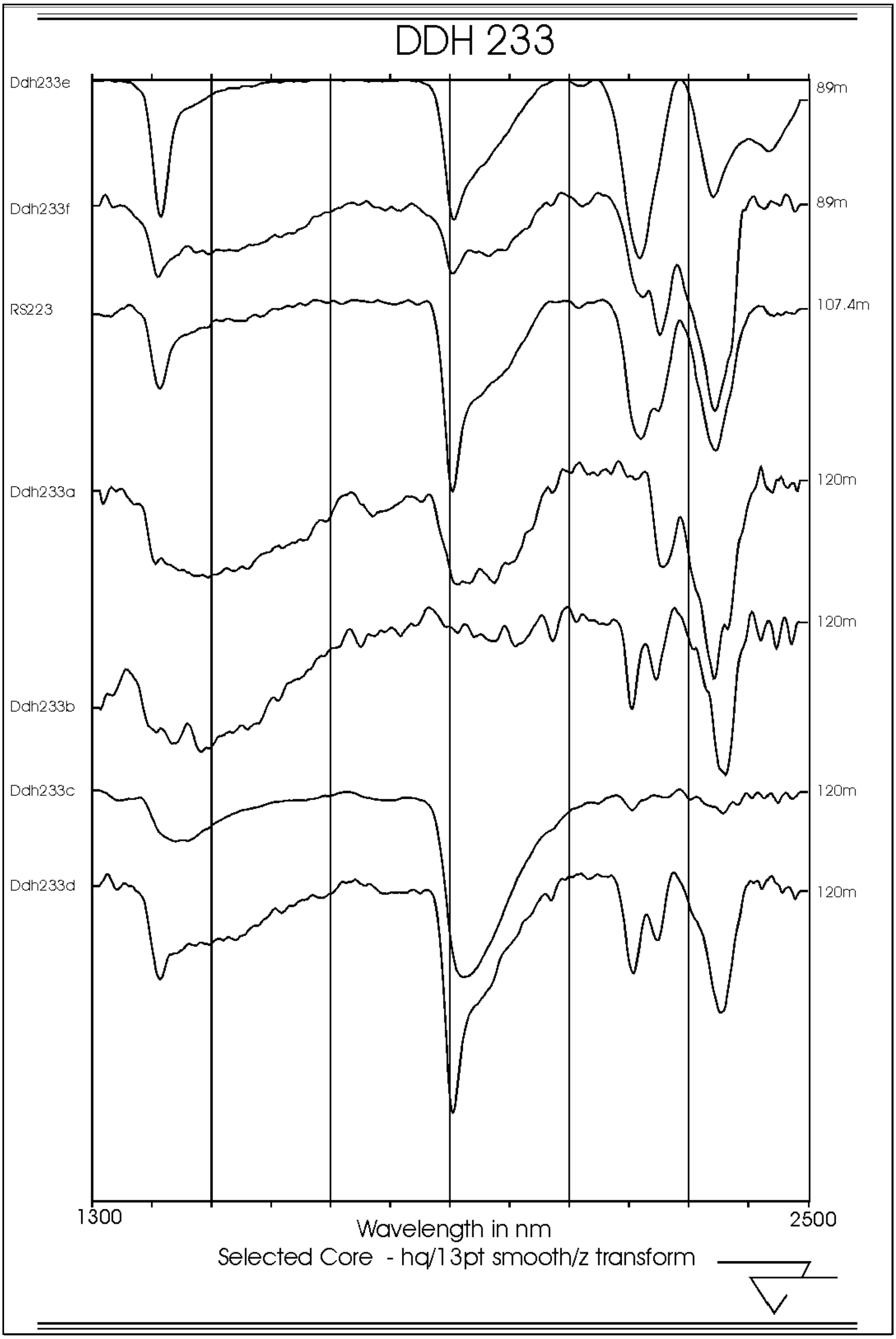


Figure 15: DDH 233 Diamond Drill Hole - Selected Samples

4.5 DDH 234 (Diamond Drill Hole)

DDH234 is the most complete of the holes scanned. Percussion chip samples are available from 0 to 82 m with diamond core for the remainder of the hole to 151 m. The hole is vertical and located at 6230200N, 741370E. The ore zone extends from 134 to 142 m. Spectra are presented in Figure 16 and Figure 17, Figure 19 to Figure 21.

4.5.1 Mineralogy

The principal minerals identified were:

- chlorite with varying Mg/Fe content
- montmorillonite
- kaolin, specifically halloysite
- muscovite with unusually long wavelength 2220 nm absorption feature
- tourmaline
- quartz
- albite with hematitic dusting
- calcite was evident is some samples in the upper part of the hole.

Hematite and sulphides were observed in some samples but gave no spectral response.

Muscovite and illite proved difficult to distinguish in PIMA spectra. The only distinguishing feature being the depth of the 1900 nm water absorption.

The presence of muscovite/illite and montmorillonite in mixtures with chlorite proved difficult to interpret. Both muscovite and montmorillonite share the 2200 nm feature and although montmorillonite has distinctive asymmetric water features these can be masked by the chlorite water features. Muscovite was interpreted where a 1440 nm or 2116 nm peak existed but sometimes the strongly asymmetric water features indicated coexisting montmorillonite ie. a three phase mixture. Muscovite was also interpreted where the 2200 nm feature occurred at long wavelengths such as 2211 nm to 2227 nm. The longest wavelength absorptions were interpreted as approaching phengite composition (increased Fe and Mg content).

A plot of the percussion sample spectra (Figure 16) has been classified into two distinct zones. The upper zone to 20 m comprises mainly surficial deposits and weathered zone. The top of this zone is characterised by iron oxide, carbonate, montmorillonite, and low crystallinity kaolinite. The lower section has distinctive halloysite, characterised by 22 nm separation of the 1400 nm doublet. In the upper zone the first 12 m are considered to be in the calcareous soil horizon with weathered rock from 12-20 m. Montmorillonite dominates the soil horizon with halloysite dominating the lower section of the weathered zone. Below 20 m, the percussion samples are a mixture of muscovite and Fe-rich chlorite. When the relative proportions of muscovite and chlorite are plotted against Cu content (Figure 18) there is a correlation between elevated Cu values and an adjacent zone of increased muscovite content.

An unusual mineral appeared in the percussion section (Figure 16). Samples Poona011 to Poona041 (22-82 m) all show some indication of this mineral. It is best displayed in samples Poona024 to Poona028 (46-56 m) and is characterised by a strong MgOH doublet of 2307 nm and 2345 nm along with a minor inflection at 2276 nm and an absorption at 1715 nm. Water features appear at 1408 nm and 1925 nm. Poona027 (DDH234 52-54 m percussion sample) was investigated using XRD and the minerals identified were quartz, albite, microcline, hematite, muscovite and chlorite. Quartz, albite, microcline and hematite are all essentially invisible to the PIMA and chlorite has absorption features at 2250-60 nm and 2345 nm.

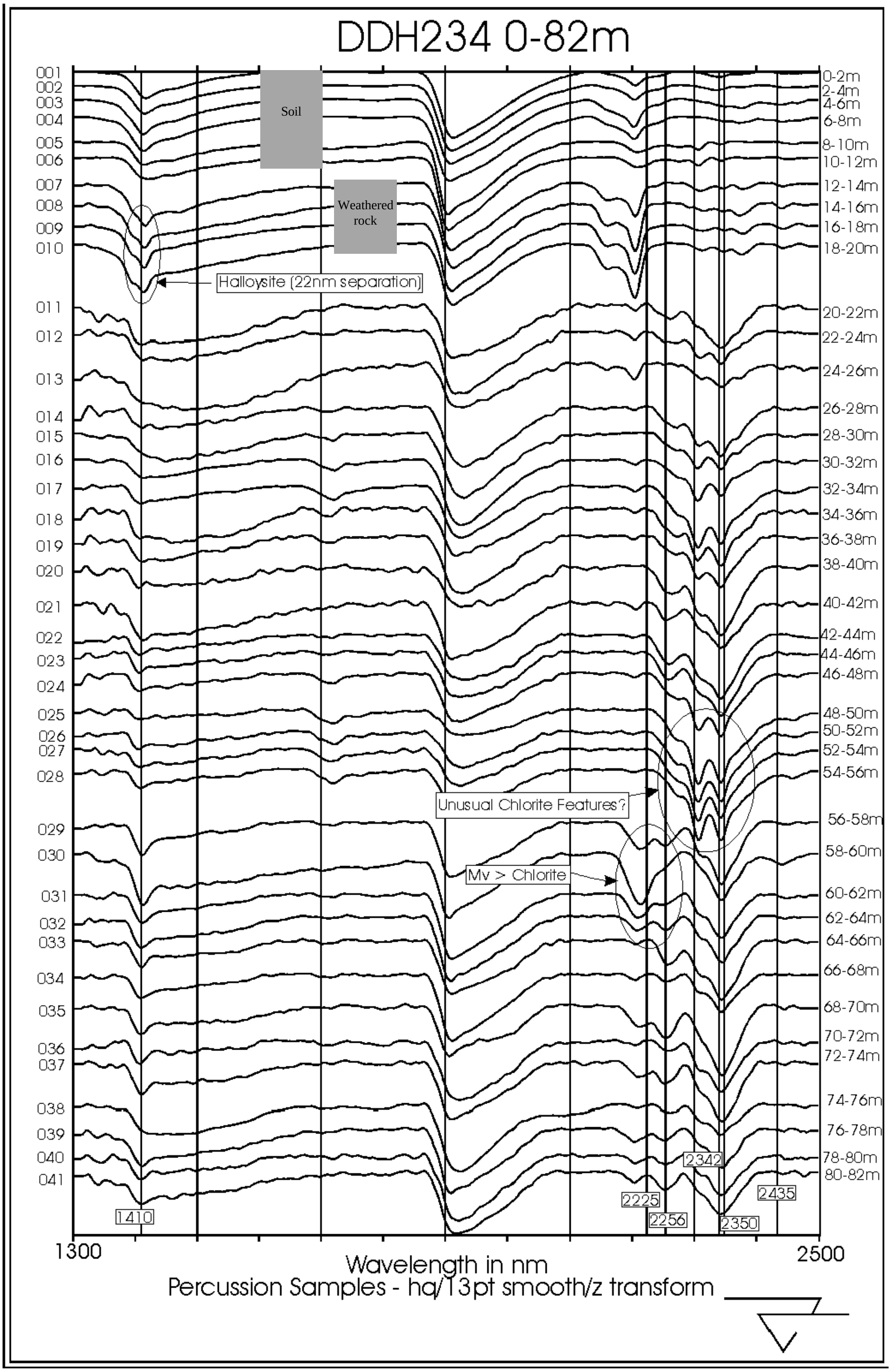


Figure 16: DDH 234 Percussion Section

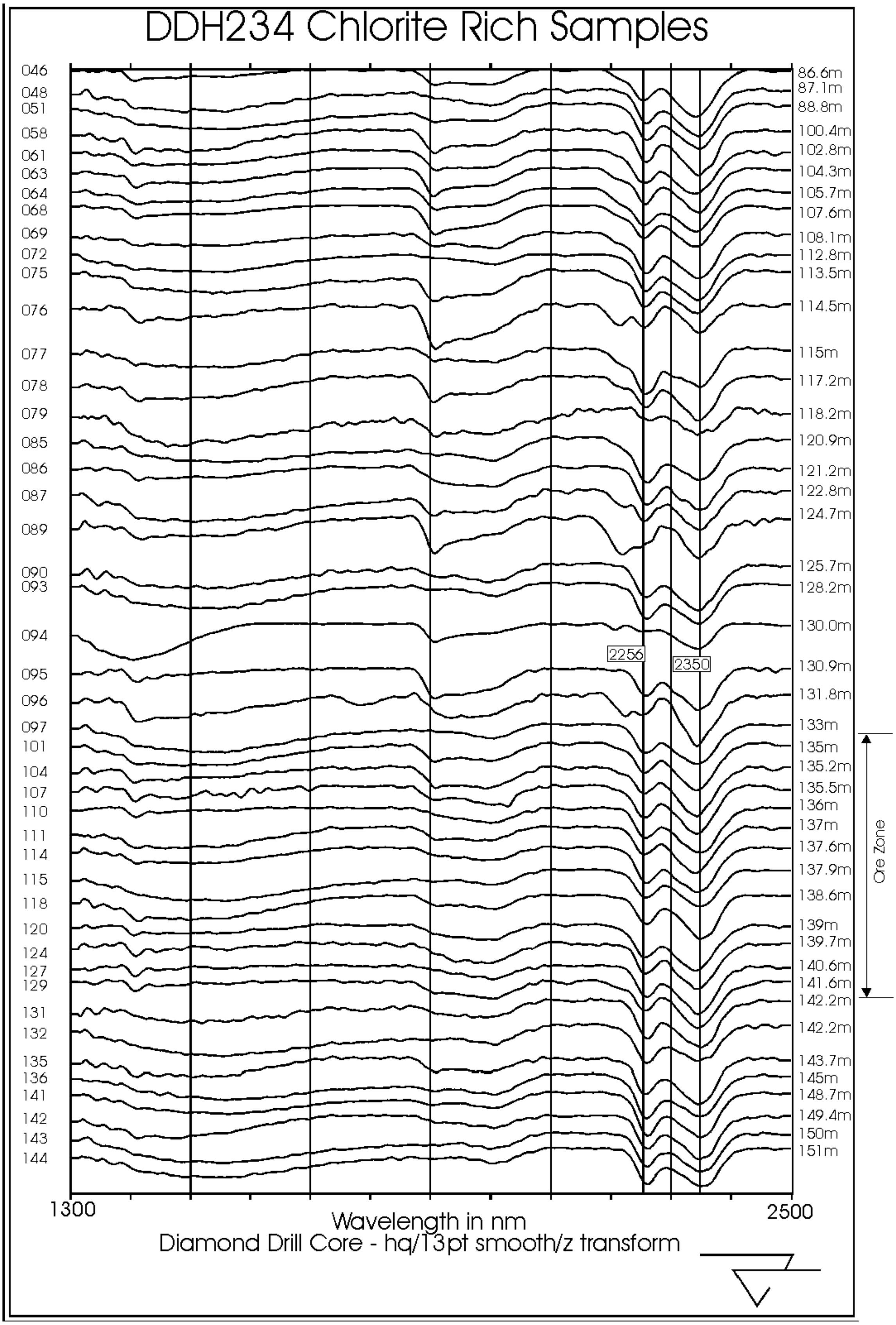


Figure 17: DDH 234 Chlorite rich samples 86.6 - 151m

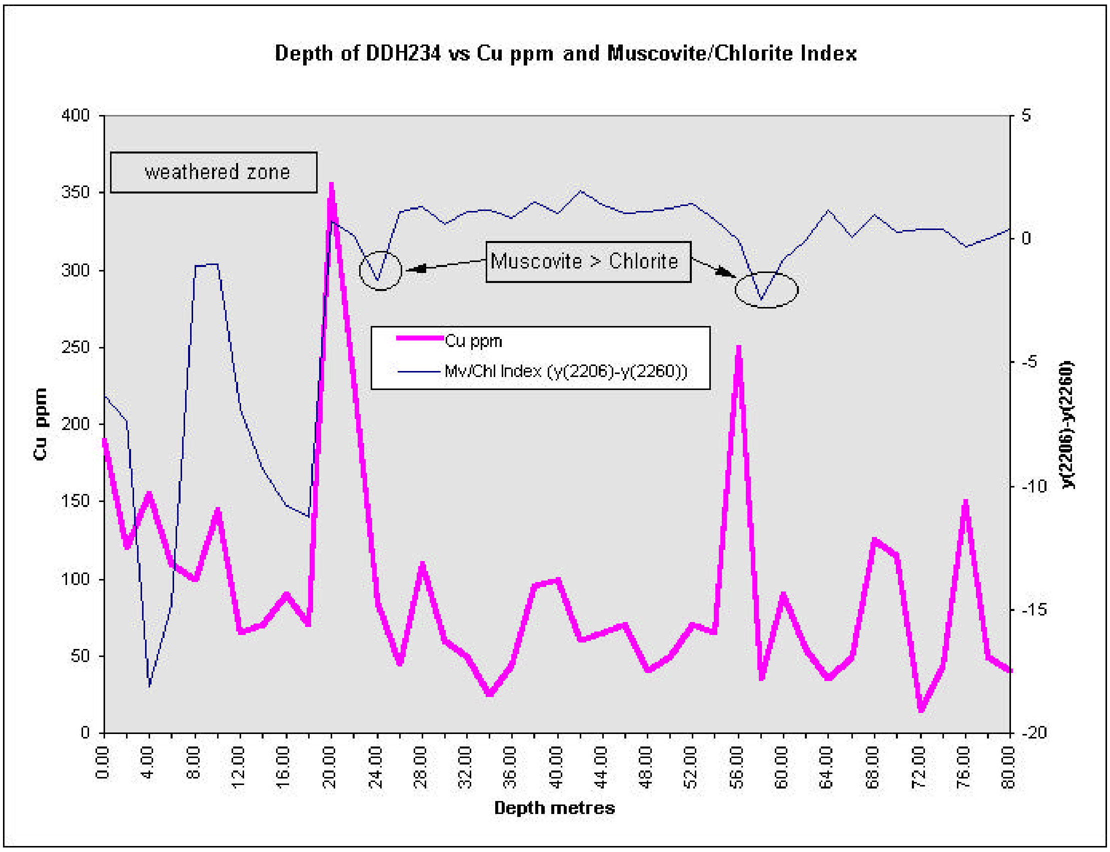


Figure 18: DDH 234 Muscovite and Chlorite vs Cu Values

The 2307 nm, 2345 nm doublet indicates the presence of MgOH and is similar to phlogopite (2328 nm, 2378 nm). The very slight inflection at 2276 nm might indicate the presence of a chlorite 2260 nm feature. There was sufficient chlorite in the sample for microprobe analysis which gave a calculated Fe* = 56 (where Fe* = 100 x (Fe/Fe + Mg) (Appendix 2, Table 7)). From the microprobe results for sample Poona027, it would appear the chlorite is not particularly Mg rich but may be sufficiently different from other chlorites to give the distinctive absorption pattern. A suggestion that high fluorine content might be influencing the pattern is not supported by comparison with spectra of other samples known to contain elevated fluorine levels.

For core samples, stacked plots of scans are presented for like-mineralogy with only one scan for each depth interval Figure 17, Figure 19 - Figure 21. Note that the ore zone extends from 134 m to 142 m.

Of the samples noted as Moonta Porphyry during the scanning (Figure 19) Poona113 (137.6 m) seems most representative of the albite “signature” with only water features in evidence. The remainder appear to be Fe-chlorite/muscovite mixes with chlorite dominant. The asymmetry of the water features in Poona081 and 092 indicate possible montmorillonite in addition to muscovite. Sample Poona088 at 123.6 m displays the tourmaline signature (2247/2364 nm). Muscovite in the footwall (samples 138 and 140) seems to have short wavelength absorption at 2196 nm.

Microprobe analysis of samples 042 and 043 (see Appendix 2, Table 6) from the bottom of the chips and top of the core respectively showed that the muscovite for 043 tended towards phengite in composition (Fe and Mg replacing some Al in octahedral sites).

The remainder of the scanned samples (Figure 20) appear to be mixes of muscovite and chlorite, montmorillonite and chlorite, montmorillonite and muscovite, or muscovite, montmorillonite and chlorite. The majority of the chlorite have an Fe-chlorite signature but slight shifts in the 2256 nm and 2350 nm feature to shorter wavelengths especially when mixed with muscovite suggest the presence of Mg-chlorite as well. However the spectra are difficult to interpret in terms of relative proportions of Mg and Fe chlorite and there does not appear to be any trend with respect to depth or proximity to ore. Within the ore zone however, the Mg-chlorite signature is absent. Microprobe analysis showed compositional zoning of Fe- and Mg-rich areas in individual chlorite grains (Appendix 3, Plate 12). This micron-scale variation in composition appears random and accounts for the difficulty in interpreting sample spectra.

The ore zone appears to be characterised by an absence of Mg-chlorite and phengite. In the footwall the 2200 nm feature of muscovite tends towards shorter wavelengths as well.

Nine quartz samples were scanned, all from within the ore zone and all with strong 1900 nm water features (Figure 21). Samples Poona116, 122, 126 and 128 also had strong broad 1450 nm features which would support the presence of fluid inclusions and a probable hydrothermal origin.

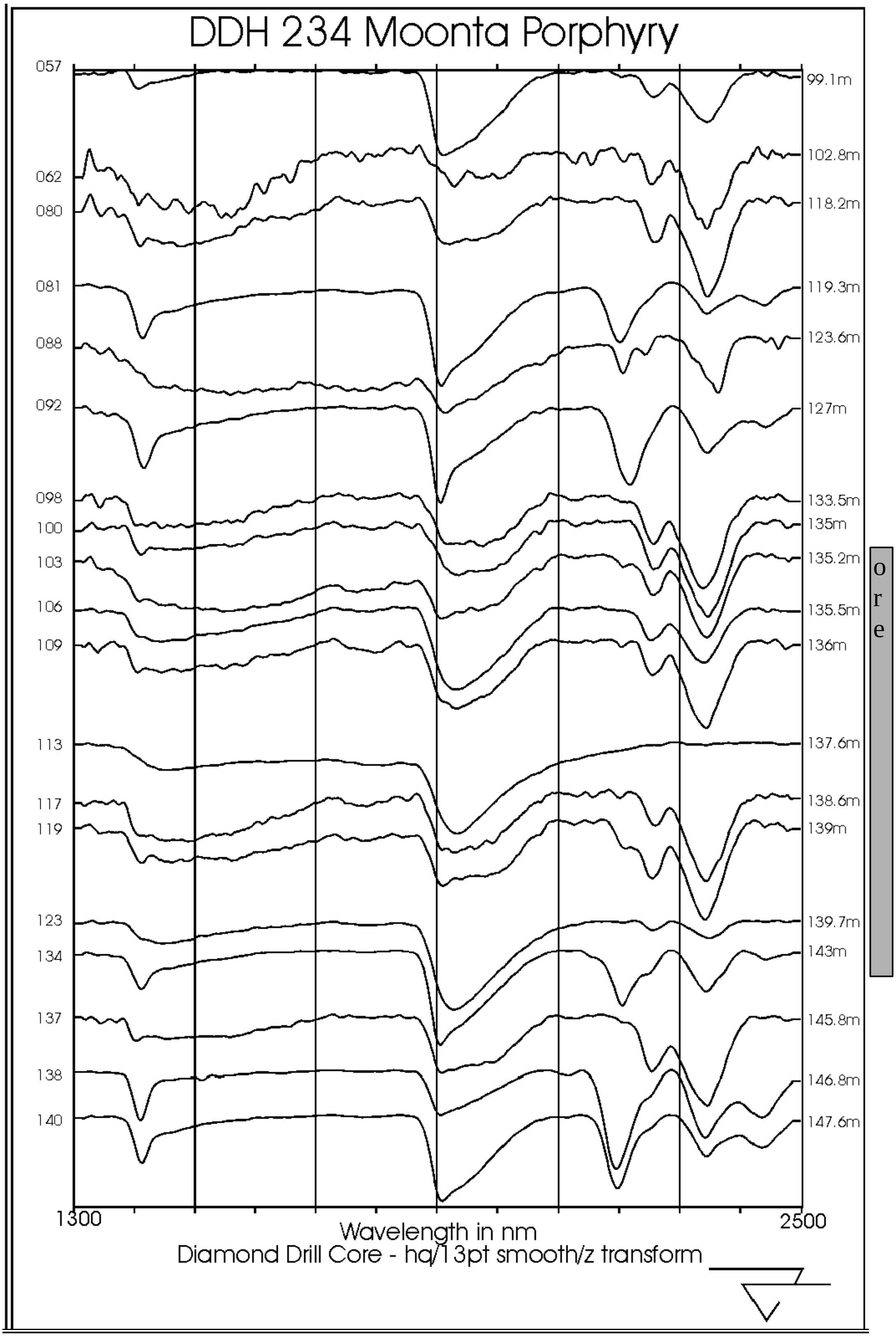


Figure 19: DDH 234 Fresh Moonta Porphyry

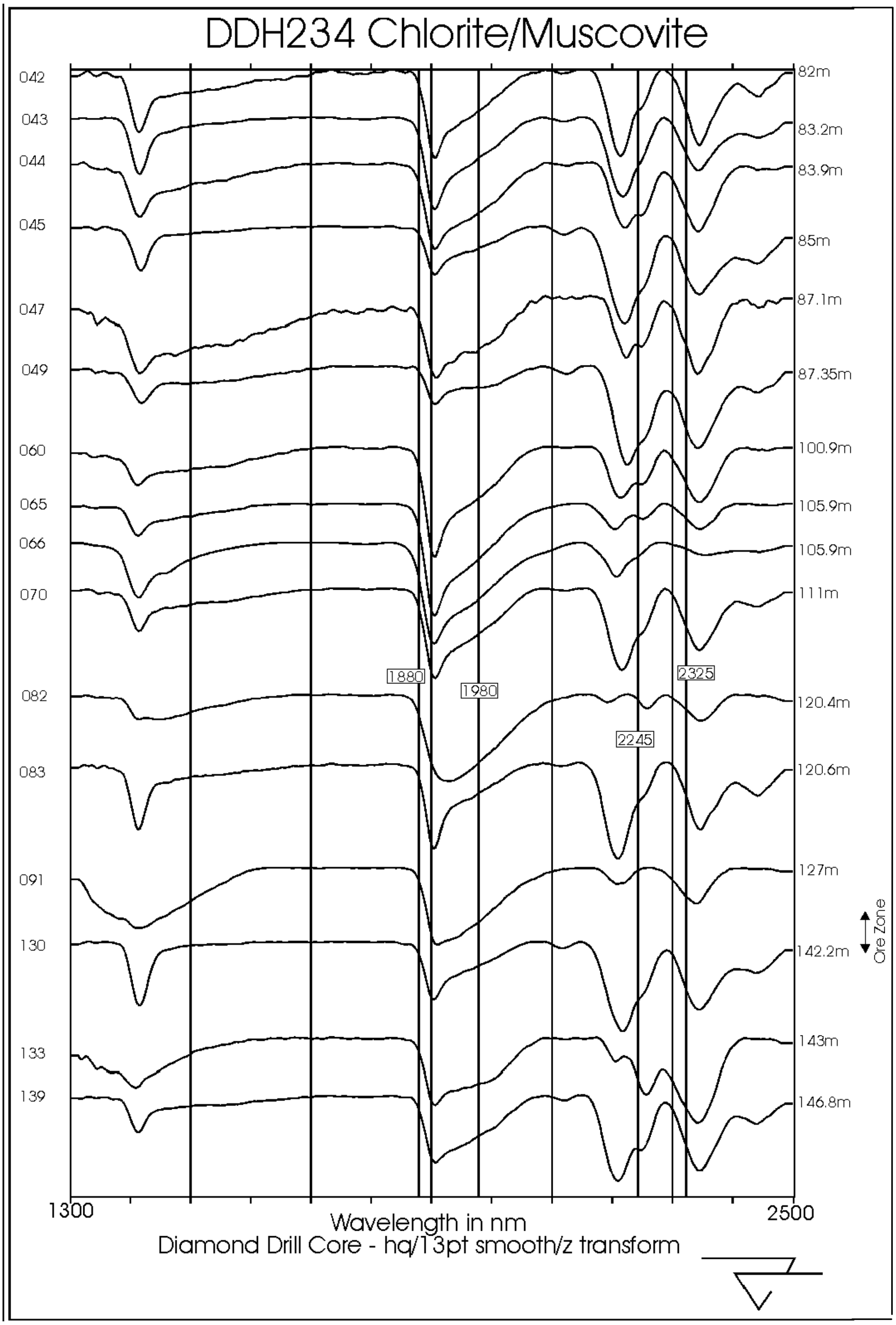


Figure 20: DDH 234 Chlorite and Muscovite

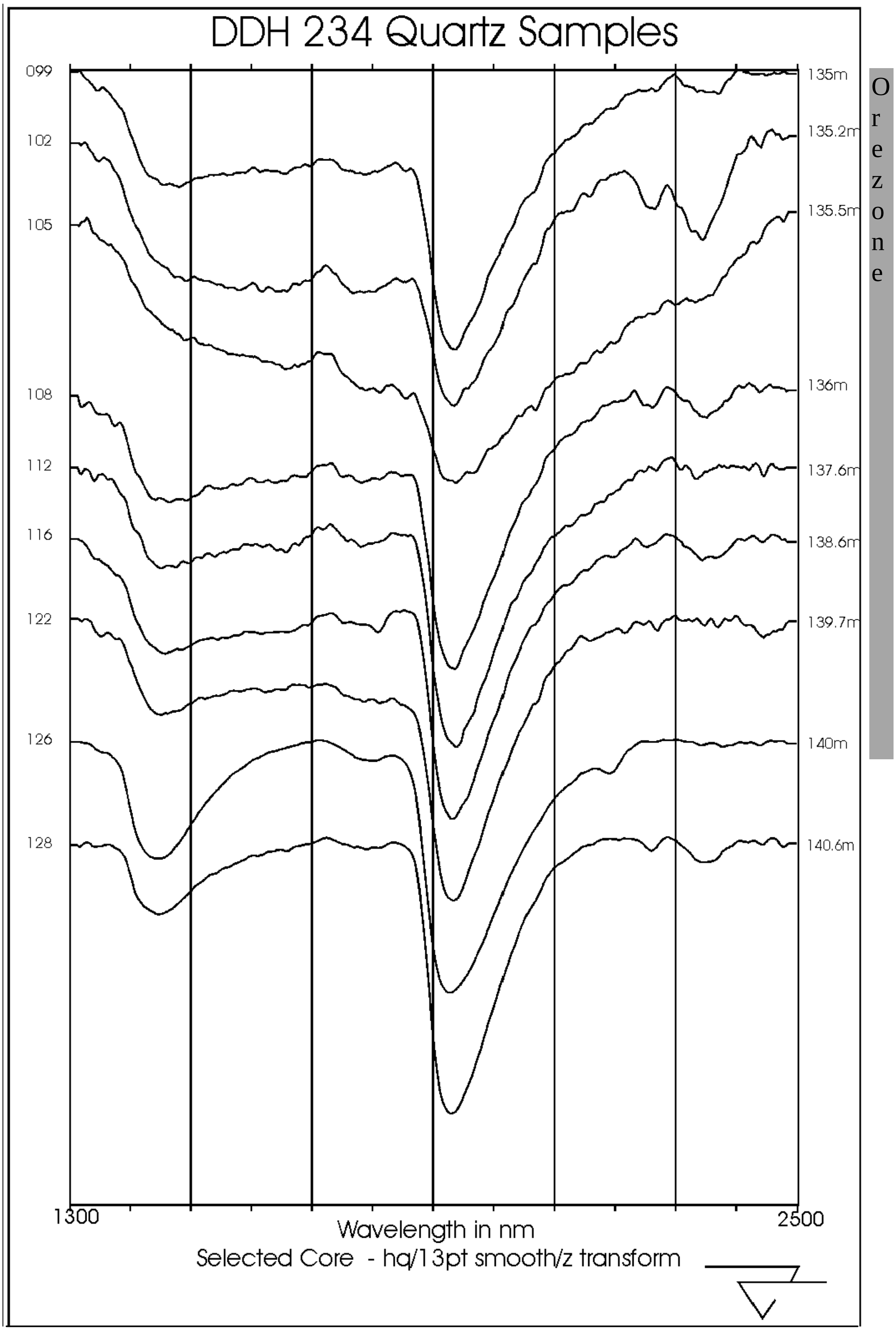


Figure 21: DDH 234 Quartz samples in ore zone

4.5.2 Zoning

A plot of the percussion sample spectra (Figure 16) has been classified into two distinct zones. The upper zone to 20 m comprises mainly surficial deposits and weathered zone. The top of this zone is characterised by iron oxide, carbonate, montmorillonite, and low crystallinity kaolinite. The lower section has distinctive halloysite characterised by 22 nm separation of the 1400 nm doublet.

The next zone from 20-82 m, the remainder of the percussion section, is characterised by various proportions of chlorite and muscovite with Fe-chlorite dominating. There are two muscovite rich sections which correlate with elevated Cu values and the presence of the unusual chlorite spectrum (Poona027, Figure 16) as discussed previously.

The upper cored section from 82-134 m is characterised by a mixture of Fe-chlorite, muscovite, montmorillonite, Mg-chlorite, phengite and tourmaline. In this interval, no consistent pattern emerged from the mineralogy (Figure 22).

The ore zone, 134-142 m, was noted for its lack of phengitic muscovite and chlorite (Figure 22). Kaolin was also absent. The quartz spectra came from this zone as did some of the tourmaline spectra. Electron microprobe analysis indicates that tourmaline from the ore zone is more ferroan (schorl) than the hanging wall (Appendix 2, Table 6).

In the footwall, 142-151 m, chlorite and muscovite only remain. Phengite was absent and the muscovite was tending towards shorter wavelength absorption at 2190 nm.

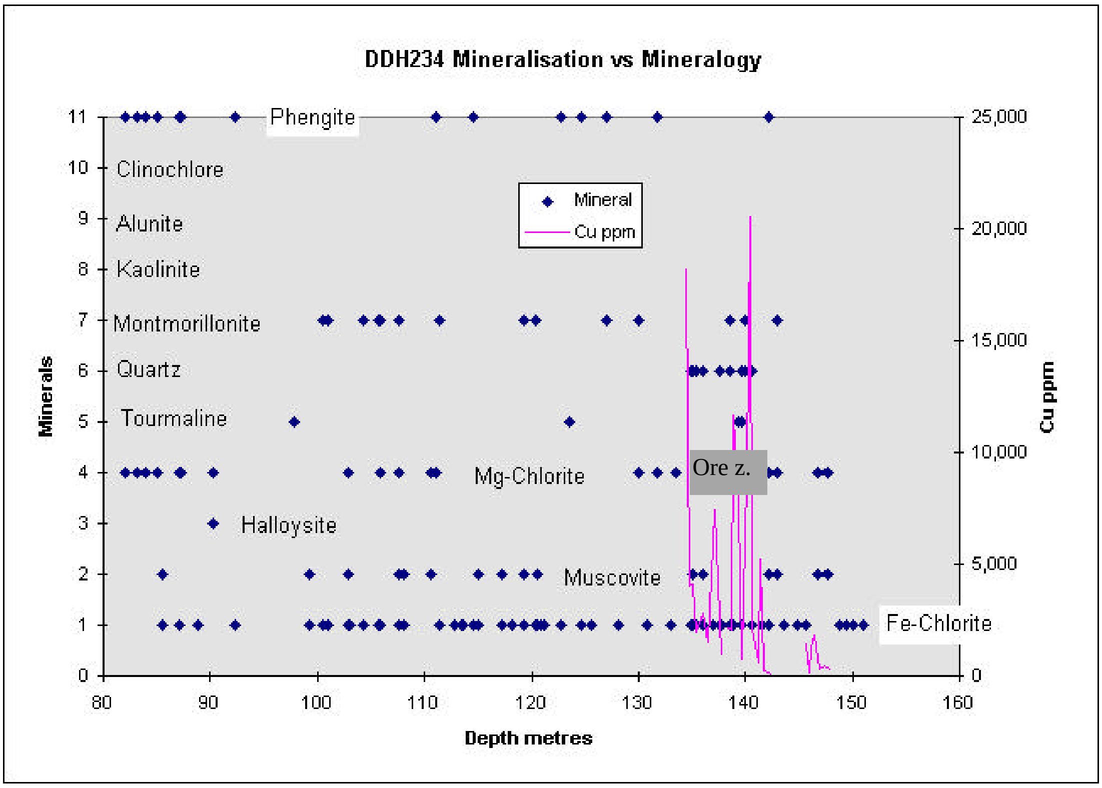


Figure 22: DDH 234 Minerals & Cu Values vs Depth

4.6 DDH 235 (Diamond Drill Hole)

Only five samples were scanned from DDH 235 and three of the samples had two surfaces measured.

Due to the small number of samples and limited depth, it is difficult to observe any trends in the spectra.

The samples were initially interpreted as dominantly kaolinite despite the deep water feature at 1900 nm which would suggest the presence of halloysite. The doublet at 1400 nm is well defined and in all the spectra the shorter wavelength peak is greater than 1394 nm and the distance between the peaks is less than 20 nm. Both features are reported characteristics of kaolinite. The spectra also have deep absorption features at 2380 nm and 2440 nm, indicating the presence of muscovite. The main absortion feature for muscovite is 2202 nm but this is masked by the 2208 nm peak from kaolin.

SEM studies showed that the kaolin in these samples was predominantly halloysite which brings into question the validity of the previously used indicative parameters (Table 3). While the position and separation of the 1400 nm doublet as previously defined would usually indicate the presence of halloysite, our work shows that narrower separations at longer wavelengths can also be due to halloysite. The relative depth of the 1900 nm feature to the depth of the 1400 nm and 2200 nm features may prove to be a better first pass indicator for halloysite (see discussion under Kaolin, page 59). The 1400 nm and 1900 nm absorption features being symmetrical suggests a mixture with sericite. The presence of smectite would result in asymmetrical water features.

The presence of alunite at 26.5 m is indicative of acidic conditions resulting from sulphide weathering.

Table 3: Halloysite Characterisation

Sample	1395[1]	1410	Separation	SEM
211	1394.7	1412.8	18.1	
212	1394.9	1412.7	17.8	Halloysite
213	1396.1	1412.3	16.2	Halloysite
214	1397.2	1412.5	15.3	
215	1395.8	1412.4	16.6	Halloysite
216	1395.4	1415.9	20.5	
217	1396.8	1413.9	17.1	

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[1] Measured using 13pt smoothed z-transformed hull quotient in PIMAVIEW

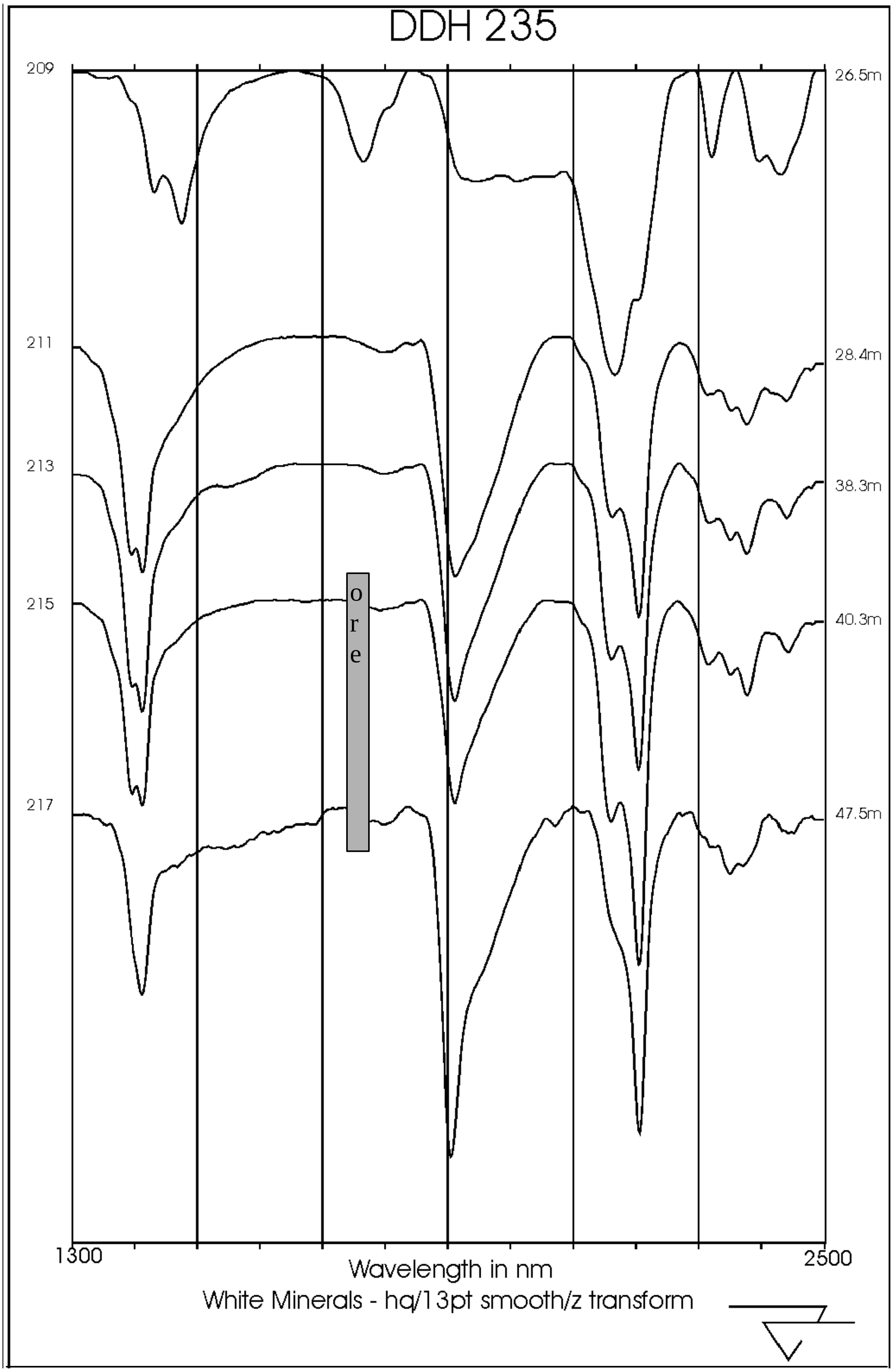

Figure 23: DDH 235 Selected Samples

4.7 DDH 236 (Diamond Drill Hole)

The collection of spectra for this hole were all from samples held at the Glenside Core Library by Joanne Hough as examples of the style of mineralisation at Poona. Nine spectra were taken of eight samples (Figure 24).

The samples display Fe-chlorite signatures. Samples RS183, RS189 also show muscovite (2208 nm and 2202 nm respectively), while RS227a contains montmorillonite.

RS168 and RS201 appear to have tourmaline present characterised by 2249/2370 nm and 2247/2363 nm pairs respectively.

The ore zone for this hole is between 78.8 m and 86.5 m.

4.8 DDH 242a (Diamond Drill Hole)

The collection of spectra for this hole were all from samples held at the Glenside Core Library by Joanne Hough as examples of the style of mineralisation at Poona. Eight spectra were taken from seven samples (Figure 25).

Fe-chlorite dominated but halloysite, tourmaline, and alunite were also interpreted from the spectra. The samples ranged in depth from 51 to 65 m with the ore zone from 49-55 m. Alunite occurred in the footwall in this hole as did a kaolin (1398-1412 nm, 14 nm separation, 2152-2205 nm, 53 nm separation).

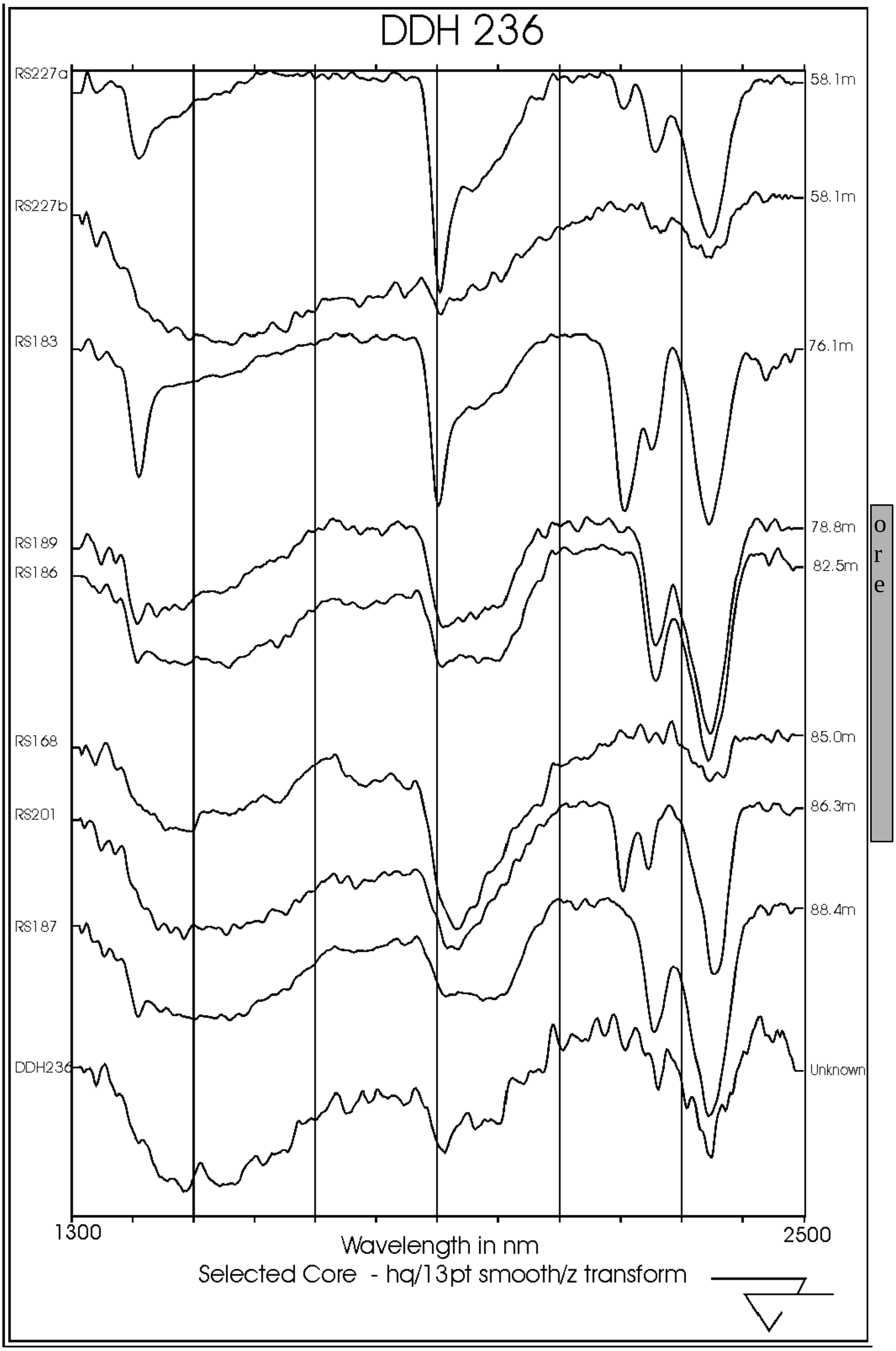

Figure 24: DDH 236 Selected Samples

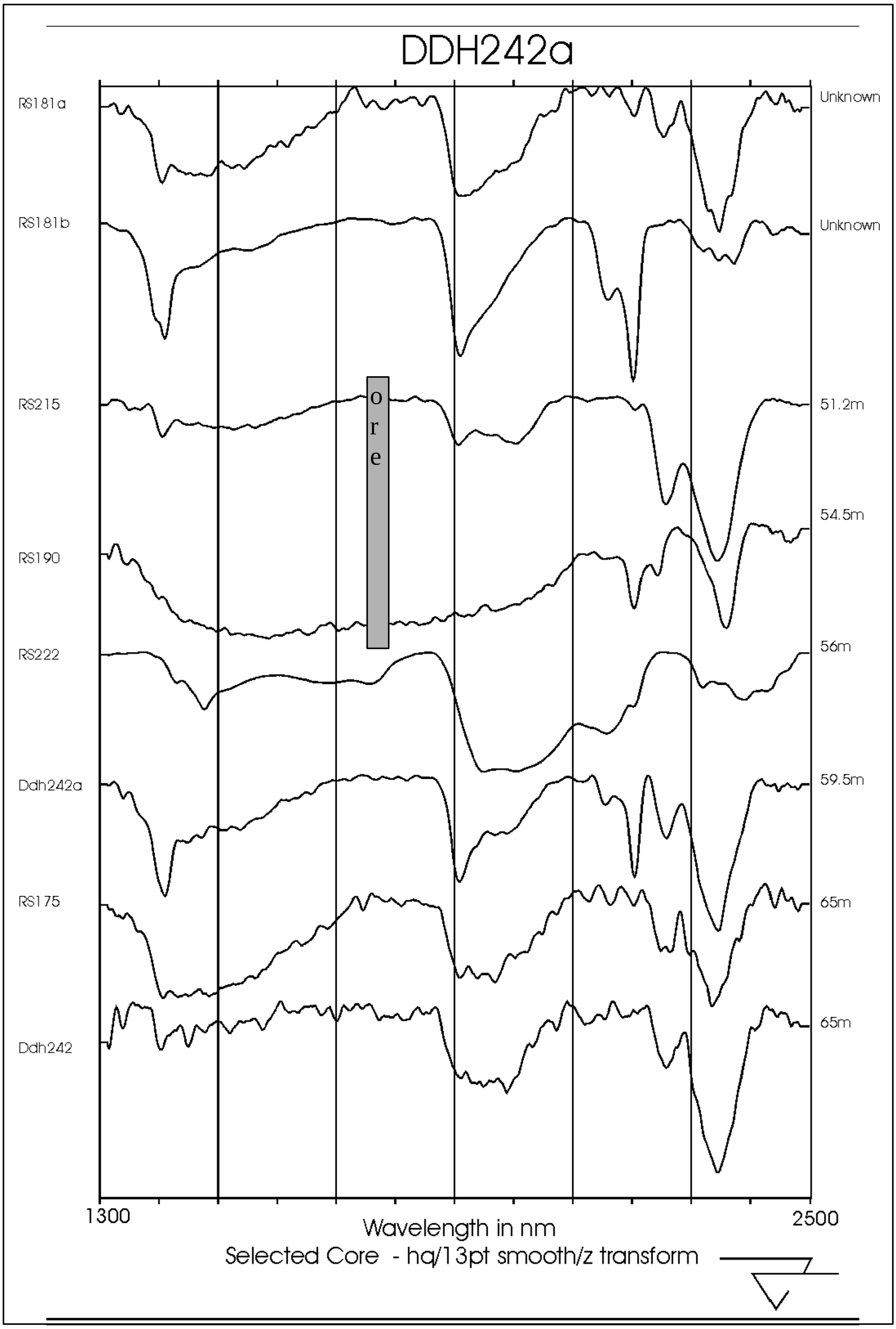

Figure 25: DDH 242a Selected Samples

4.9 DDH 244 (Diamond Drill Hole)

The upper section of percussion chips could not be located. Diamond drill core was scanned from 37-59 m at approximately 1 m intervals. The ore zone is considered to be between 43 m and 47 m. Samples have been plotted in two groups because often the same sample was scanned twice for two different minerals. The principal mineral species present are Fe- and Mg-chlorites (Figure 26), kaolin (interpreted as halloysite), and muscovite (Figure 27).

4.9.1 Mineralogy

The first three spectra scanned (Figure 26) are a mix of chlorite and smectite-montmorillonite. This is interpreted from the asymmetrical water absorption features at 1400 nm and 1900 nm. At a depth of 40 m halloysite is just visible in the spectra but becomes more dominant down hole. Halloysite and chlorite mixtures are prominent within the ore zone (43-47 m). Features attributed to chlorite (2250/2350 nm pair) become quite prominent and the 1900 nm water feature is much broader extending across to the chlorite 2000 nm absorption feature.

In the footwall, halloysite is very dominant with some suggestion of smectite still present in the samples from the asymmetry of the water features. Samples Poon092 - Poon095 have dominant chlorite with Poon092 still showing the presence of halloysite. The next three samples are also halloysite, chlorite and smectitic mixtures. Samples Poon099 to Poon105 are montmorillonite/chlorite mixtures. Spectra for samples Poon103 and Poon104 are very noisy (Figure 27).

The composition of chlorite in sample Poon101, 53.9 m, was determined by microprobe, giving an Fe* = 47. Fluorine content was relatively high at 0.22% (Appendix 2, Table 7).

Four samples were investigated by SEM:

- Sample Poon079, 244079, 41.5 m, SEM # 95-368, (Appendix 1, Plate 8),
- Sample Poon089, 244089, 47 m,
- Sample Poon090, 244090, 48 m, SEM # 97-375, (Appendix 1, Plate 9),
- Sample Poon091, 244091, 49.4 m.

Halloysite was the dominant kaolin mineral in 3 samples while kaolinite is the major component of Poon090 although intimately mixed with about 10% halloysite (Appendix 1, Plate 9).

Chlorite in all samples shows alteration to smectite (Appendix 1, Plate 8) of montmorillonite composition.

There is considerable shift in both the 2340-70 nm and 2250 nm chlorite absorption features but there appears to be no systematic changes with respect to the proximity of the ore zone (Figure 28). At 42.3 m (sample 081) there is an apparent ‘separating’ of the FeOH/MgOH ‘chlorite’ features to 2370/2250 nm, rather than a ‘shift’ normally associated with a compositional change. This may indicate the presence of tourmaline close to the ore zone.

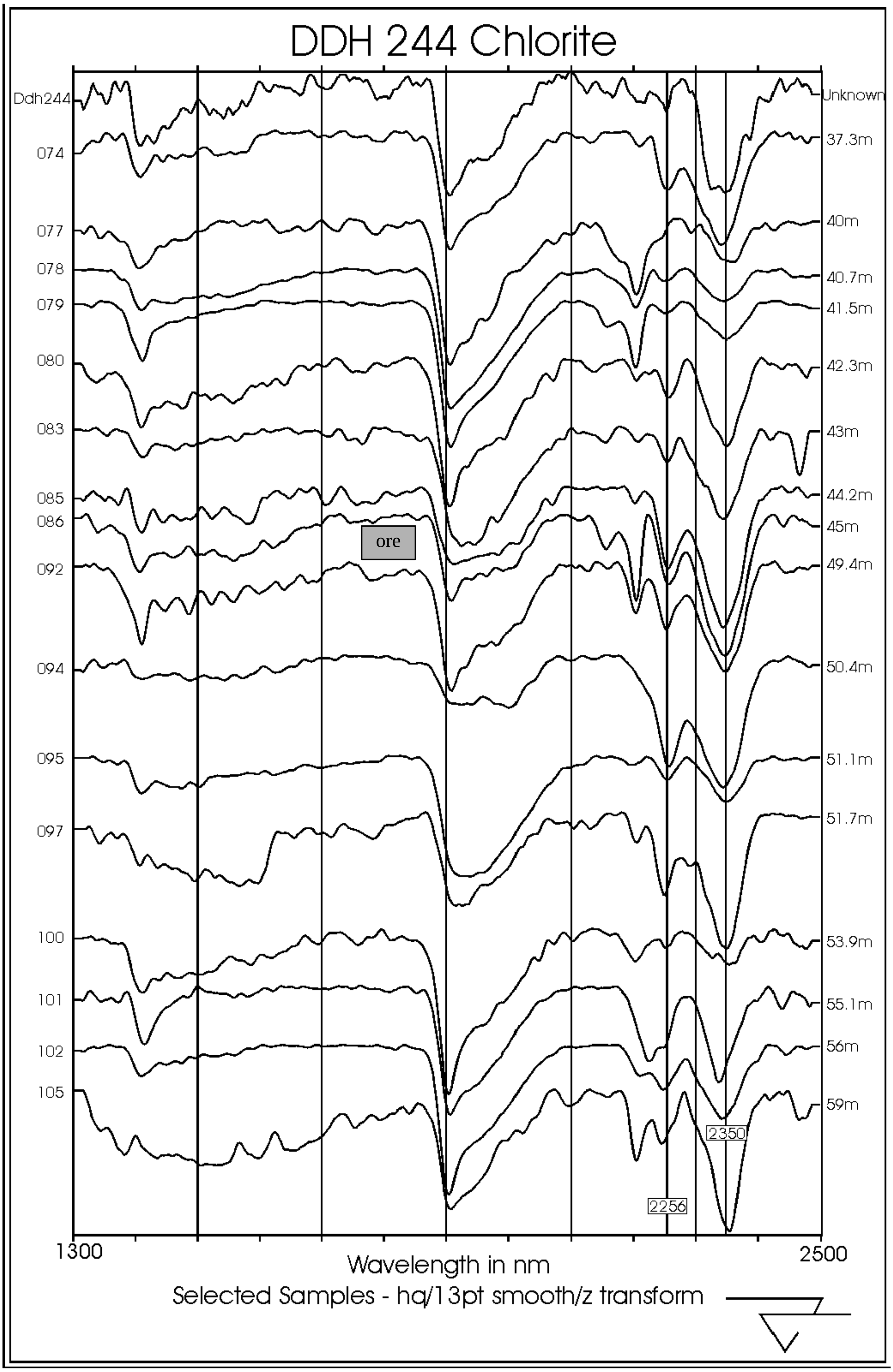

Figure 26: DDH 244 Chlorites

Figure 27: DDH 244 AlOH Minerals

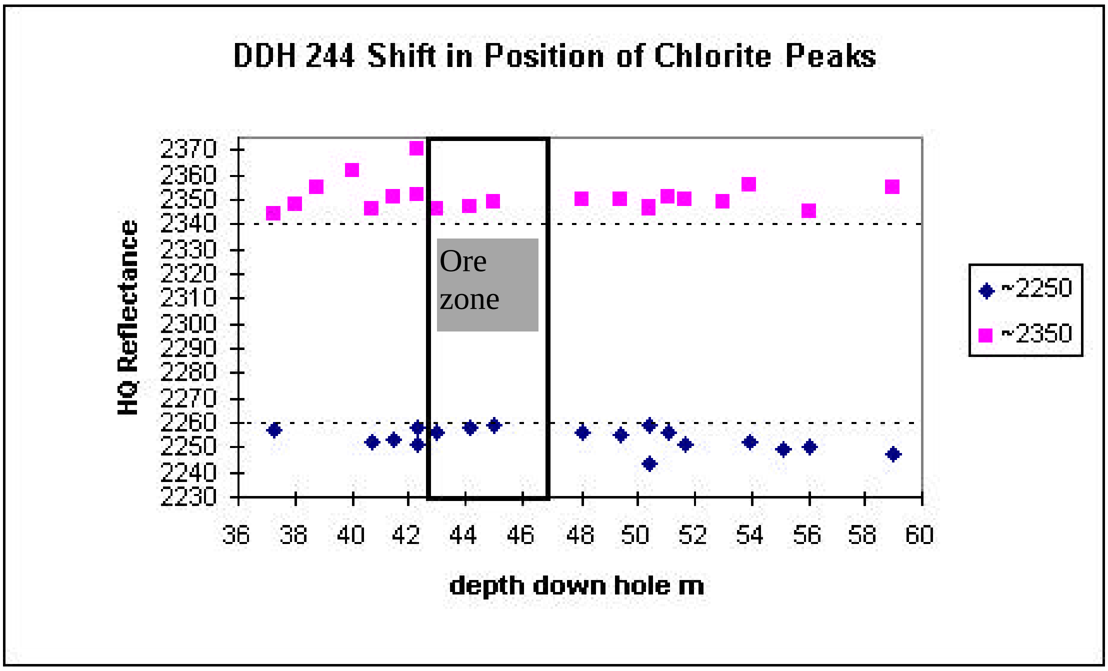

Figure 28: DDH 244 Chlorite Variation Down Hole

4.9.2 Zoning

Figure 29 compares the variation of mineralogy down the hole with changing Cu values. Note the presence of Fe chlorite and halloysite within the ore zone.

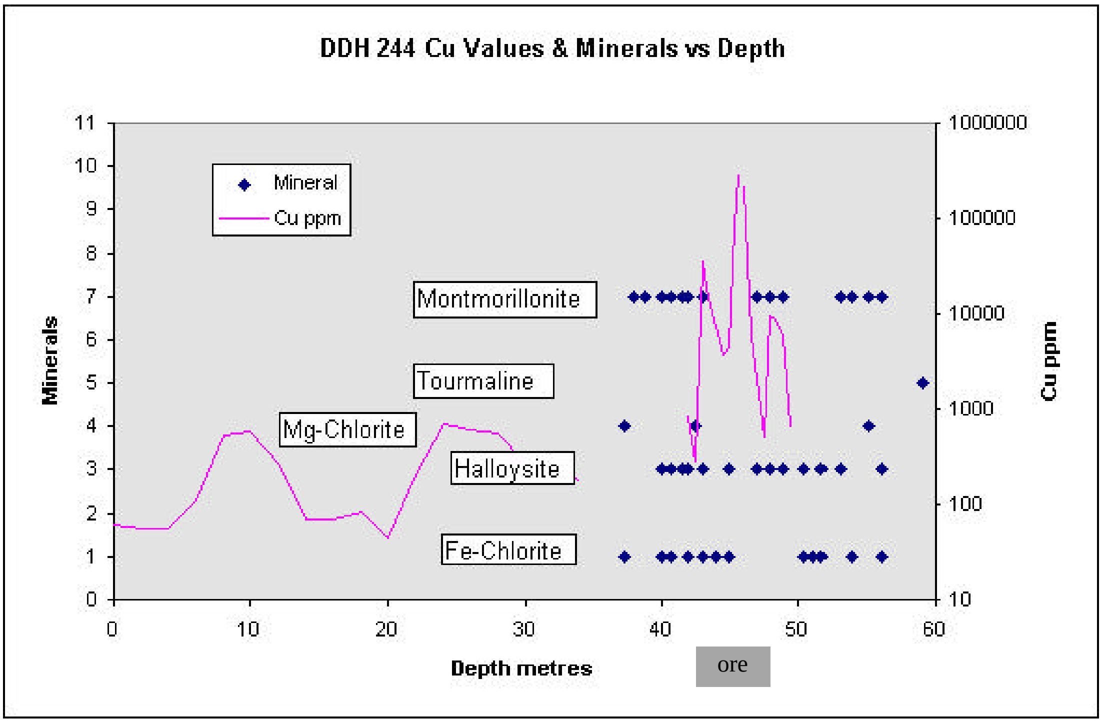

Figure 29: DDH 244 Cu Values and Mineralogy vs Depth

4.10 DDH 245 (Diamond Drill Hole)

The upper section of percussion chips could not be located. DDH 245 is a vertical hole with core starting at 57 m and extending to 91.9 m. PIMA spectra were taken at approximately 1m intervals (Figure 30). Two additional samples RS169/69.5 m and RS195/85.6 m were scanned separately. Ore zone is between 71.7 m and 77.7 m.

4.10.1 Mineralogy

The mineral species identified in the PIMA spectra include: Fe- and Mg-chlorite, halloysite, montmorillonite, muscovite and phengite. The relationship between mineralogy, copper mineralisation and depth are shown in Figure 31.

Samples 18f, 019 and 020 have long wavelength muscovites whose composition determined by microprobe, tended towards Mg rich phengite. Muscovite and phengite are best developed in proximity to the ore zone (Table 6).

There is considerable variation in the position of the chlorite peaks (Figure 32) but the majority of the spectra are still interpreted as Fe-rich chlorite. Spectrally those chlorites with higher Mg content have been identified according to the shift of the 2250/2350 nm absorption pair. Samples 003a, and 019 have 2247/2346 nm features whereas samples 010 (2251/2333 nm), 027 (2251/2342 nm) and 028 (2251/2342 nm) have marginally shorter wavelengths in the 2350 nm region. The composition of samples 019, 020, 030 and 031 have been determined by microprobe. The Fe* range from 44 to 57 (Appendix 2, Table 7). Sample 018f however had very much higher Fe* (= 70) which is similar to the values reported previously (Hafer, 1991, Appendix 2, Table 8).

The kaolin spectra are interpreted as halloysite. This has been confirmed for sample Poon013 (245013, 68.8 m) by SEM investigation. Layers of halloysite were clearly visible in direct contact with Moonta Porphyry.

4.10.2 Zoning

The hanging wall samples are mixtures of montmorillonite and chlorite with some spectra showing evidence of halloysite (Figure 33). The sequence represented by samples Poona007 through to 012 (Figure 33) show progression from montmorillonite dominance at the top of the sequence through to chlorite dominance at the bottom. This shows increased alteration of chlorite to smectite up away from the ore zone. Samples 003a and 019 are included here to show the Mg-richer chlorite as found in this hole.

Samples Poon020 to Poon029 are from the ore zone. The spectra are predominantly chlorite, with long wavelength muscovite (phengitic) present in samples bracketing the ore zone (Figure 34).

Spectra of samples from the footwall show mixtures of chlorite and montmorillonite.

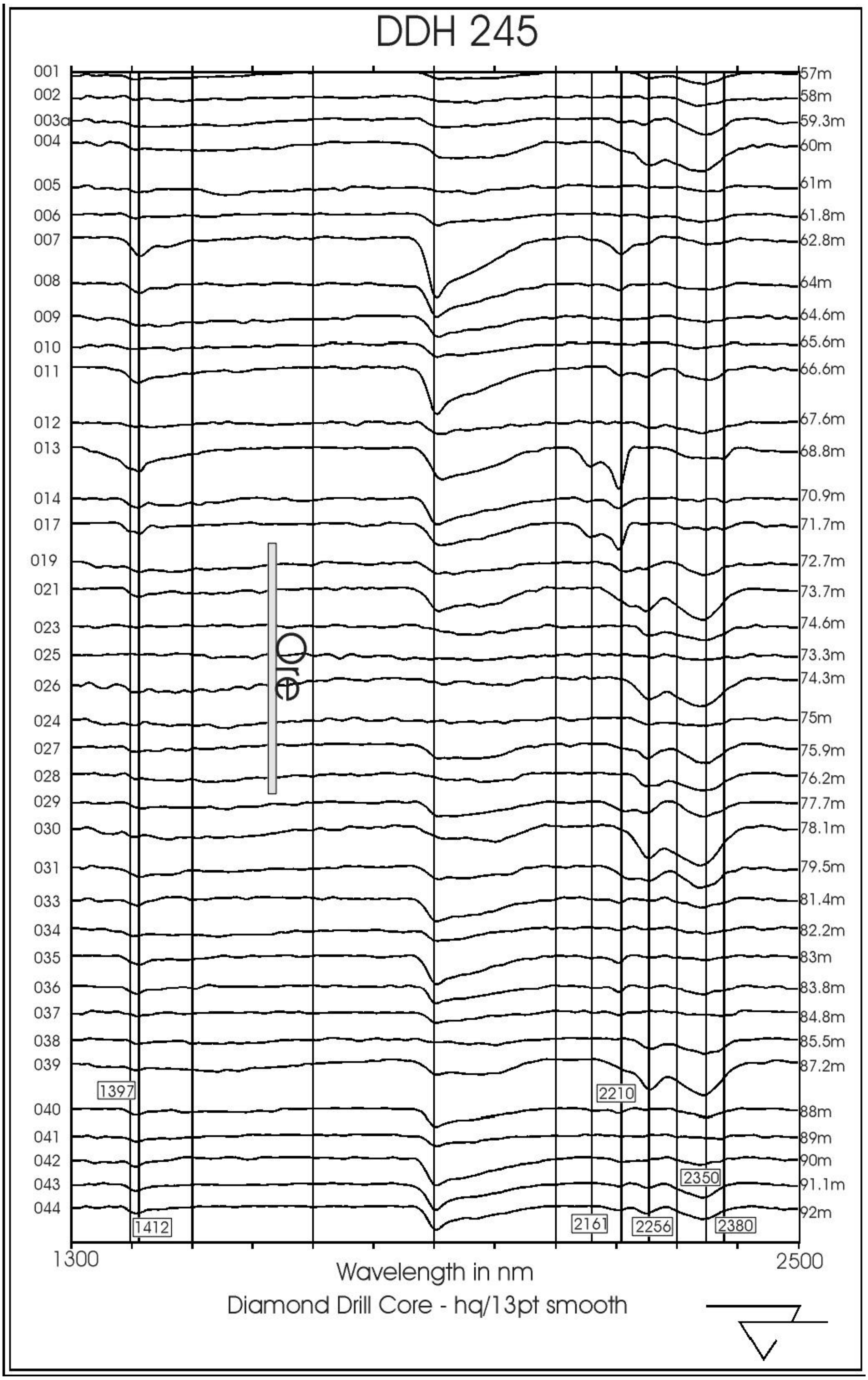

Figure 30: DDH 245 Diamond Drill Hole

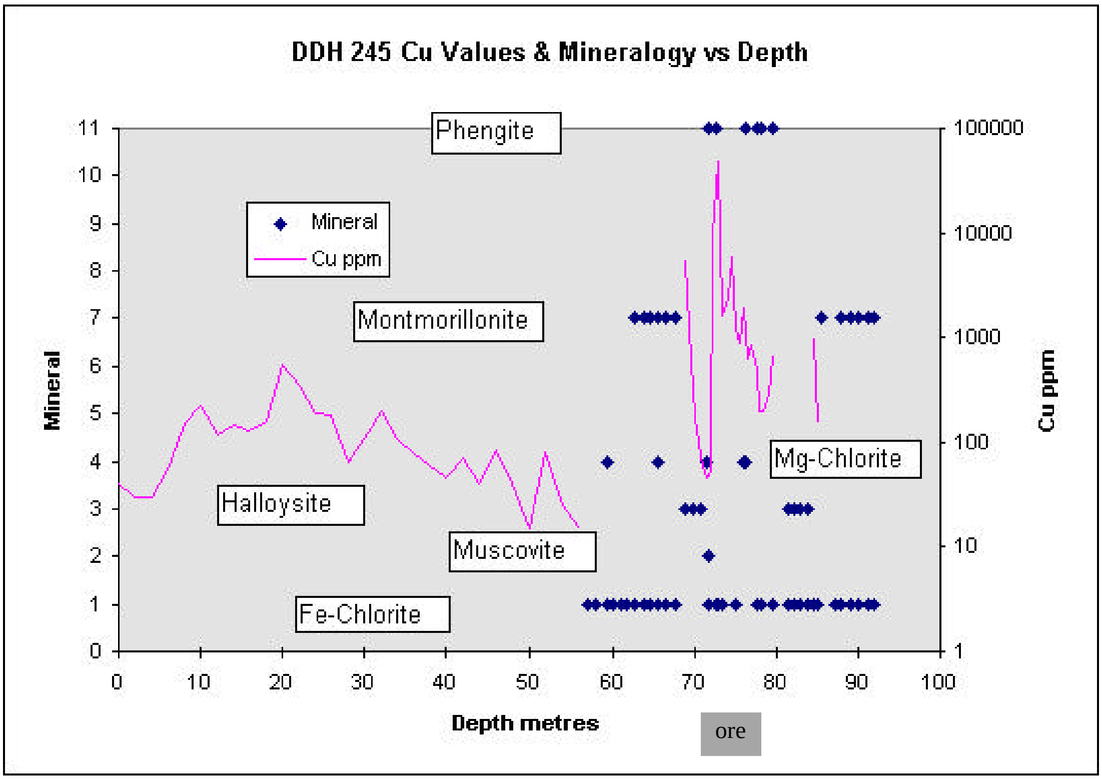

Figure 31: DDH 245 Cu Values and Mineralogy vs Depth

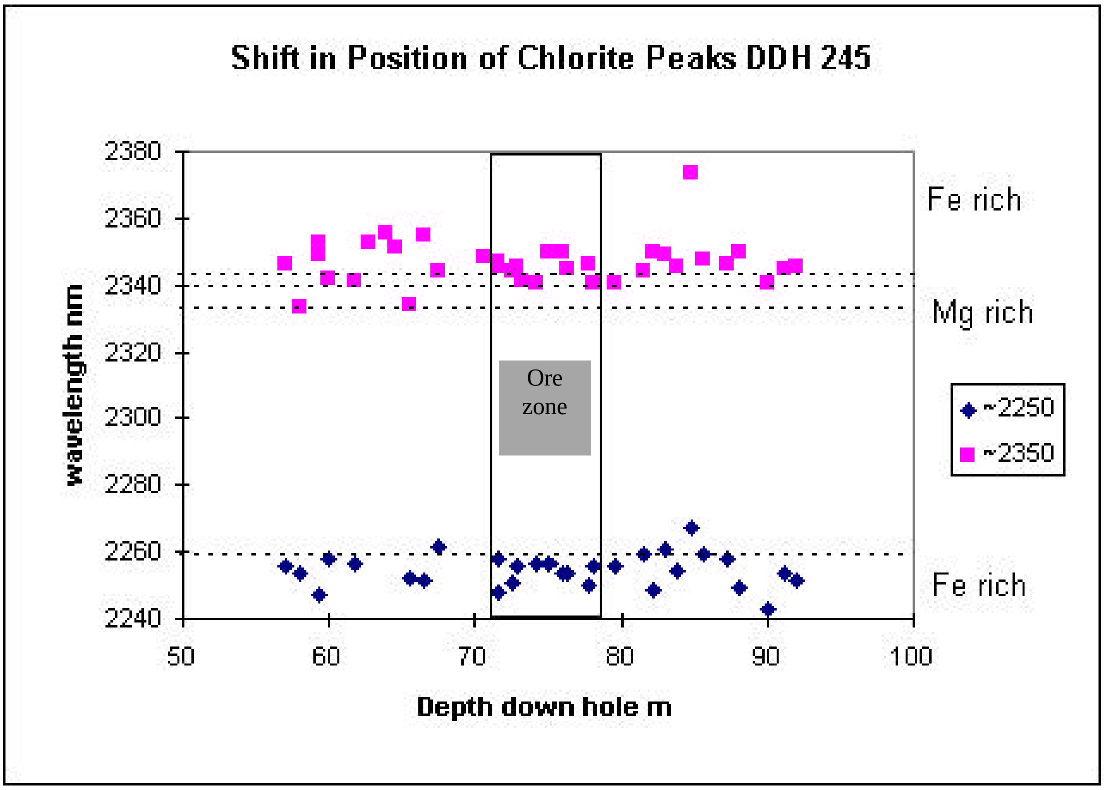

Figure 32: DDH 245 Variation in Chorite with Depth

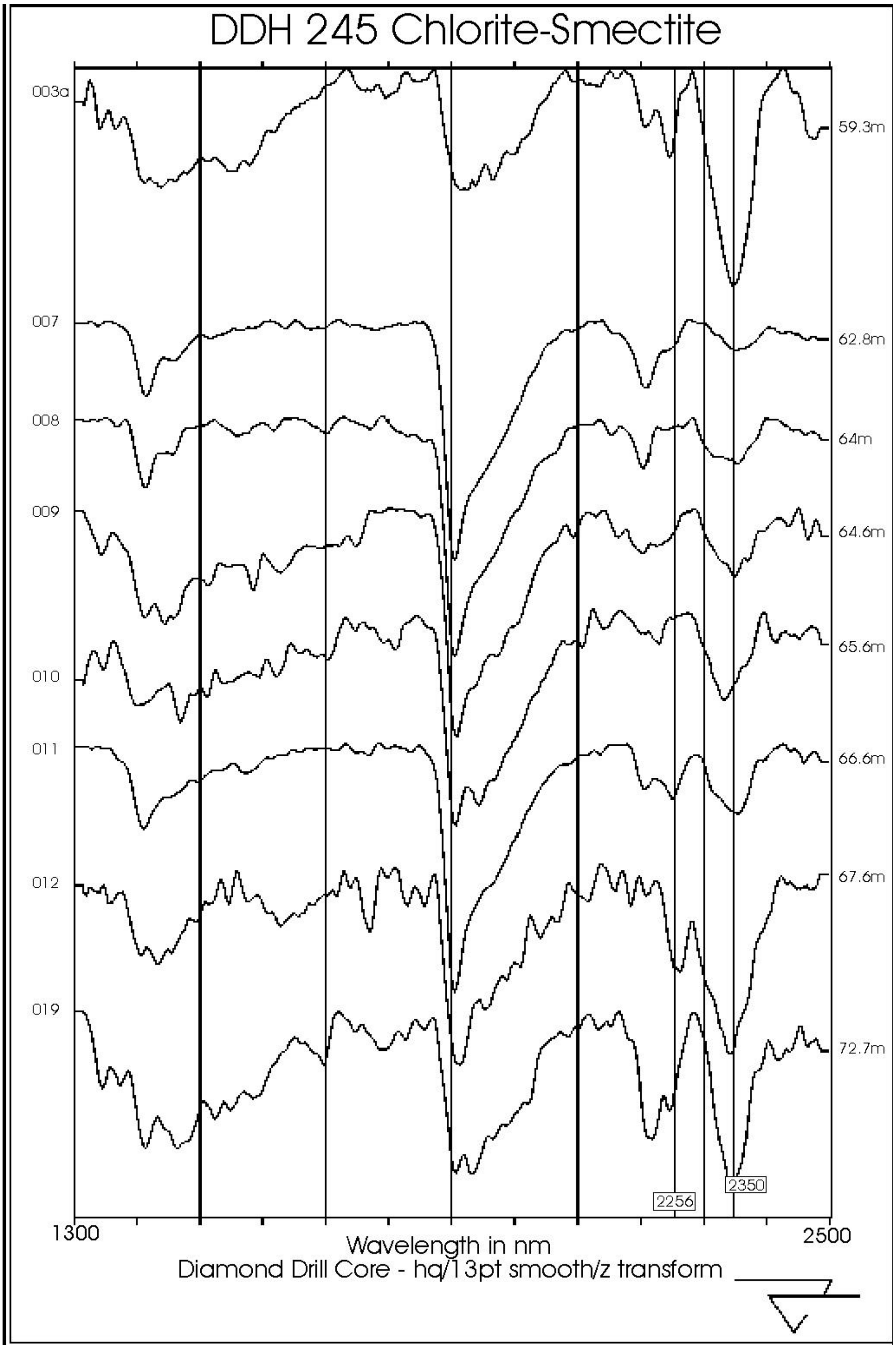

Figure 33 : DDH 245 Hanging wall

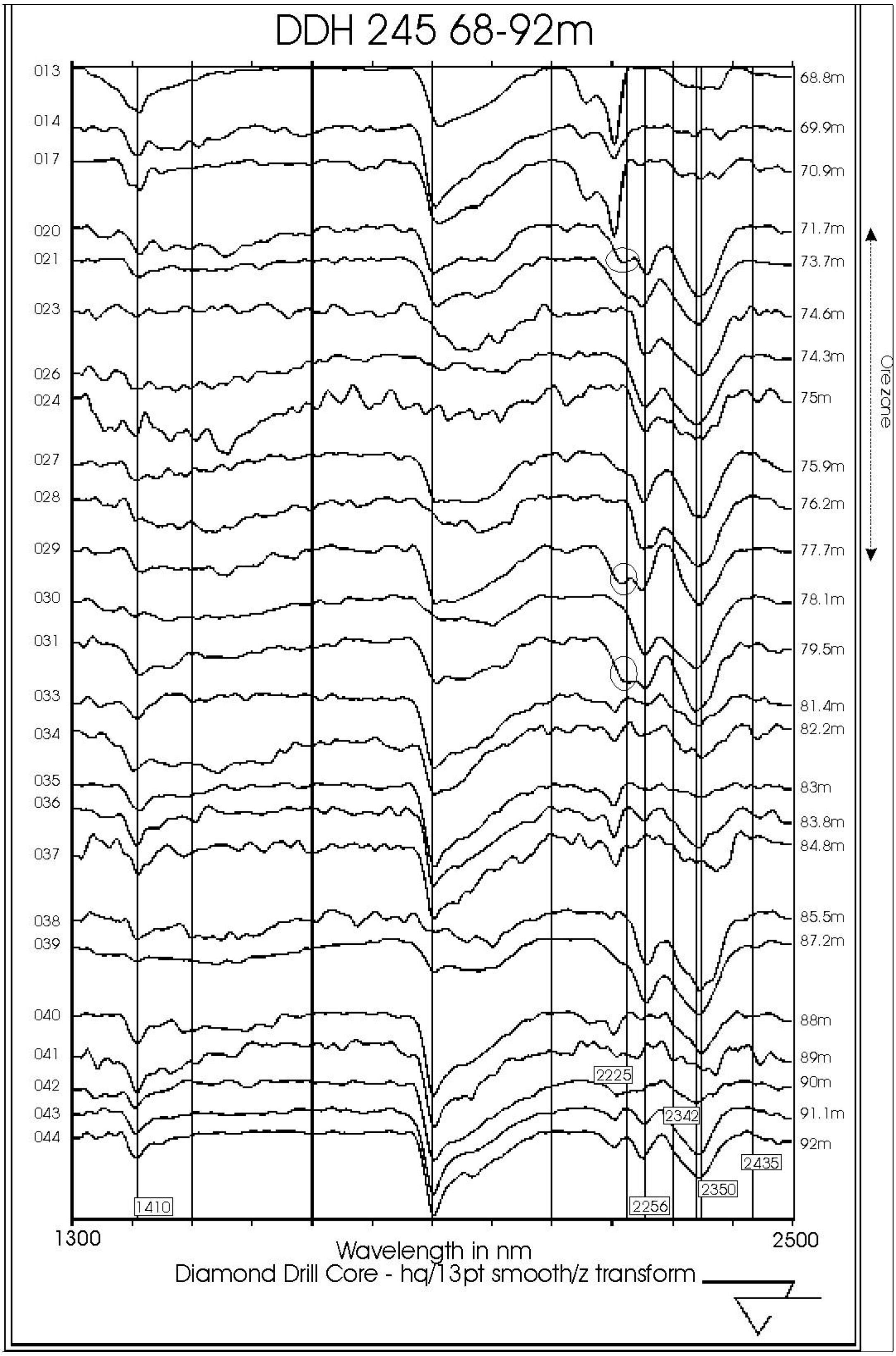

Figure 34: DDH 245 Ore and footwall zones

4.11 Percussion Holes MP 511, 512, 513 & 811

4.11.1 Sampling Strategy

Samples stored in the MESA core library at Moonta were labelled DA185570 through to DA185647. Each sample represents a 2 metre interval. Copper analyses are available for all samples. The samples were relatively dry having been stored for several years in a galvanised iron shed. Subsamples were scanned in a petri dish placed directly on the PIMA window. Acquisition program AAPET38, specifically calibrated for glass, was used throughout. Overhead fluorescent lighting was switched off. Two measurements were taken of each sample, one raw and one after 20 seconds in the microwave on high. Although this decreased the water absorption feature at 1900 nm the spectra were not improved significantly. Individual minerals grains were selectively removed, crushed and analysed separately to improve identification.

4.11.2 MP 511 (Percussion)

MP 511 is an inclined percussion hole 52 m deep dipping 60° to the south. Samples DA185570 to DA185595 were recorded as spectra 5570 to 5595 (Figure 35). The ore zone is between 42 m and 52 m depth.

Mineral variation with depth is apparent from the stacked spectra (Figure 35).

From 0 - 6 m (surficial sediments) spectra are characterised by poorly ordered kaolin and montmorillonite with broad asymmetric water absorption features at 1904 nm and 1411 nm. The presence of kaolin is indicated by the asymmetry of the 2200 nm feature and presence of a shoulder at 2160 nm.

From 6 to 12 m (Pleistocene Hindmarsh Clay) montmorillonite is dominant. An unusual absorption at 1426 nm in sample 5574 (8-10 m) might indicate the presence of Mg chlorite.

From 12 m to 40 m (weathered zone) is marked by a transition from montmorillonite dominance to kaolin dominance at about 34 m. Fe-chlorite appears about 36 m and eventually dominates the basal zone from 40 m. Muscovite is also present in these samples. At the bottom of the hole a very noisy spectra may show the presence of Mg chlorite.

Individual grain analyses are presented in Figure 36. Near the top of the hole (0-14 m) individual grains appeared to be a montmorillonite/muscovite mixture. Alunite is present between 22 m and 30 m and highly ordered kaolin between 18 m and 20 m and at 30 m. At 32 m the sample was interpreted as a kaolin/muscovite mix with a very deep 2202 nm feature.

The majority of kaolin is interpreted as halloysite based on the deep water feature at 1900 nm.

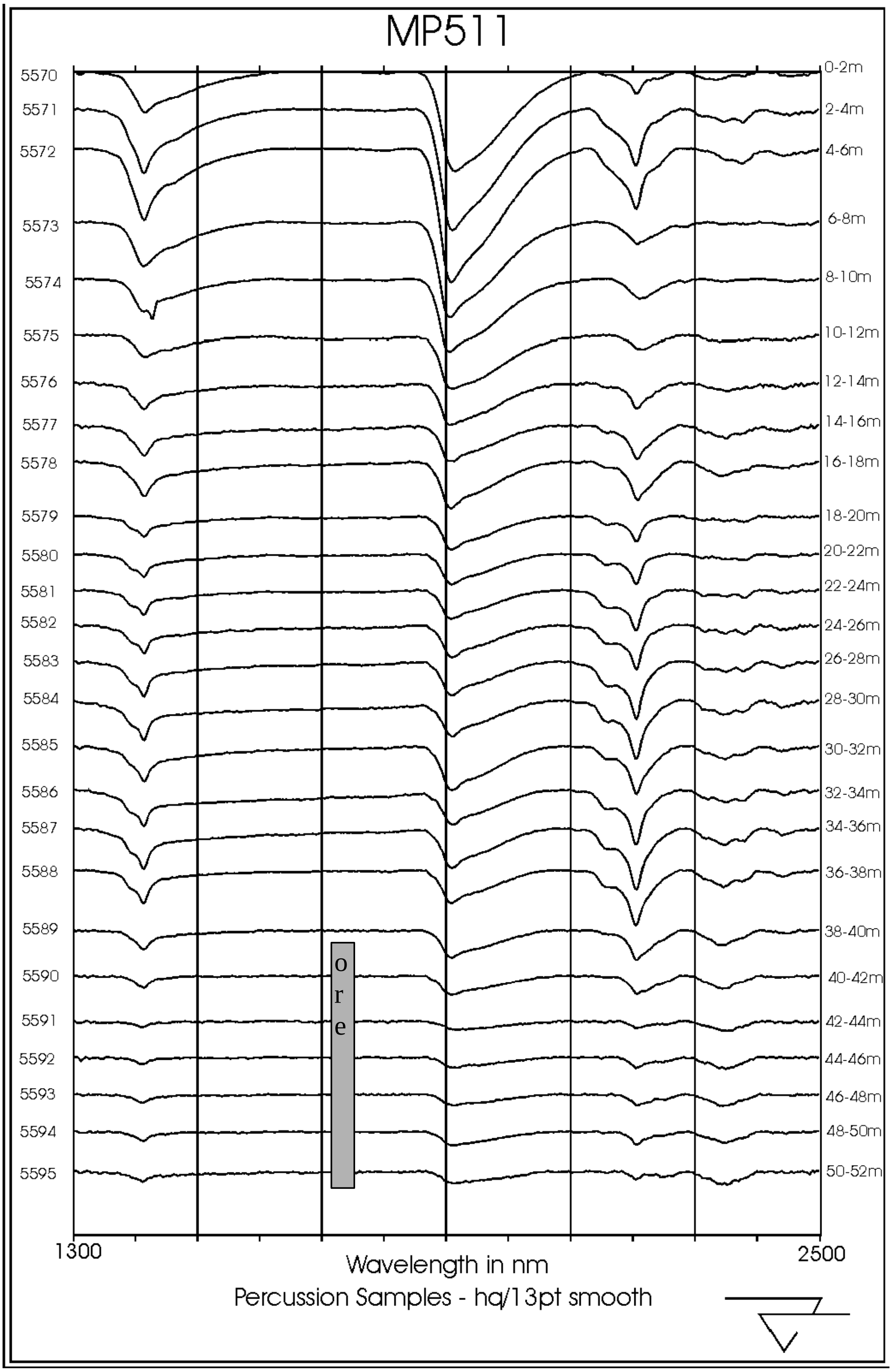

Figure 35: MP 511 Percussion Hole

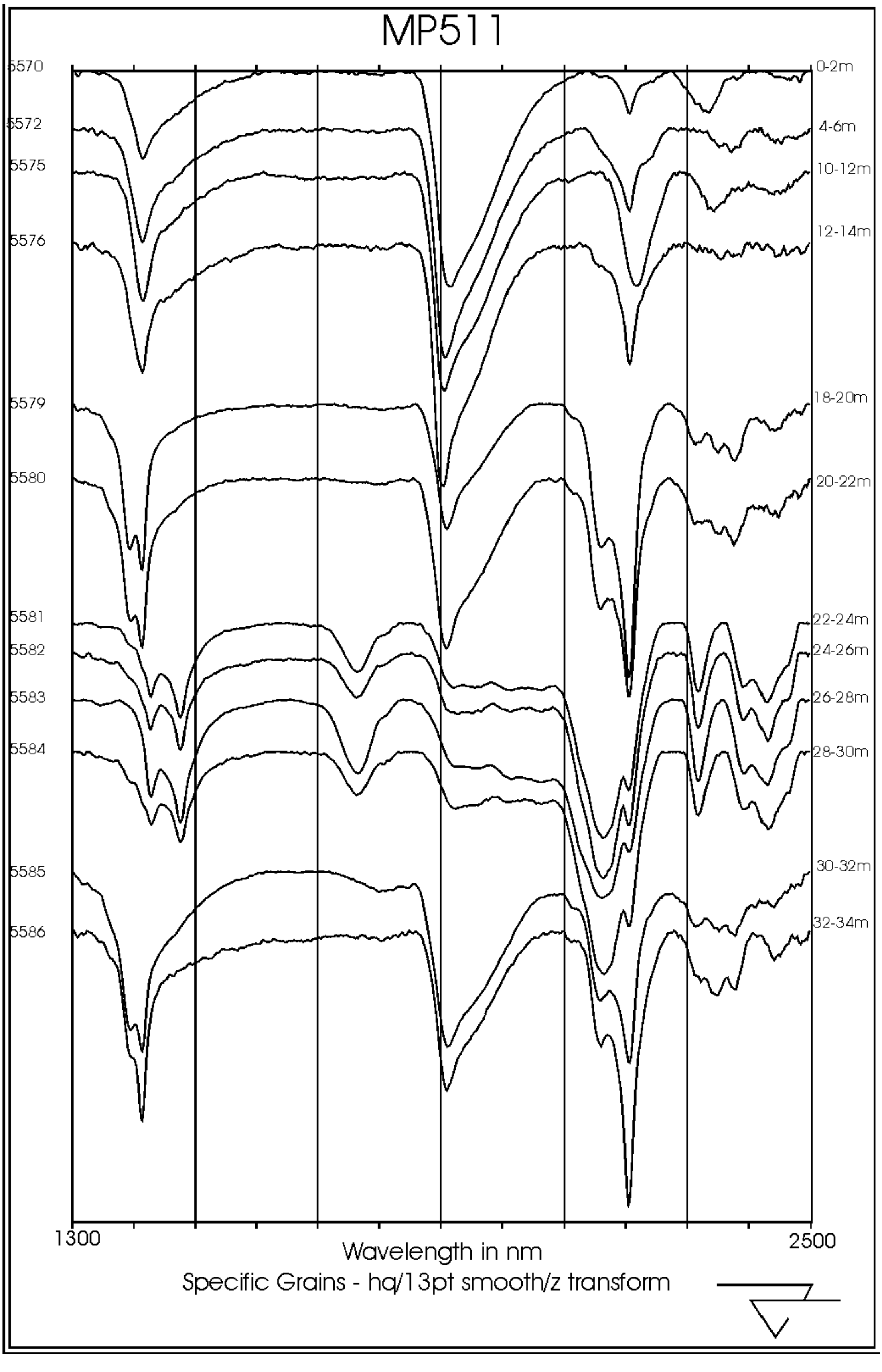

Figure 36: MP 511 Specific grains from the hanging wall

4.11.3 MP 512 (Percussion)

MP 512 is an inclined percussion hole 54 m deep inclined 60° to the southeast. Samples DA185596 to DA185622 were recorded as spectra 5596 to 5622 (Figure 37). Elevated Cu values were recorded between 46 m and 50 m depth.

Four zones are evident.

Zone one, 0 to 6 m, (surficial sediments) are characterised by the presence of montmorillonite and kaolin.

Zone two, 6 to12 m (Hindmarsh Clay), is dominated by montmorillonite.

Zone three, 12 to 46 m (weathered zone) shows increased kaolin content to a maximum at about 40 m reducing to almost nil at 46 m. Kaolin is interpreted at halloysite based on its deep water feature at 1900 nm. Alunite was noted in the spectra at 26-30 m.

Zone 4, 32 to 40 m (unweathered porphyry) shows dominant Fe-chlorite mixed with muscovite.

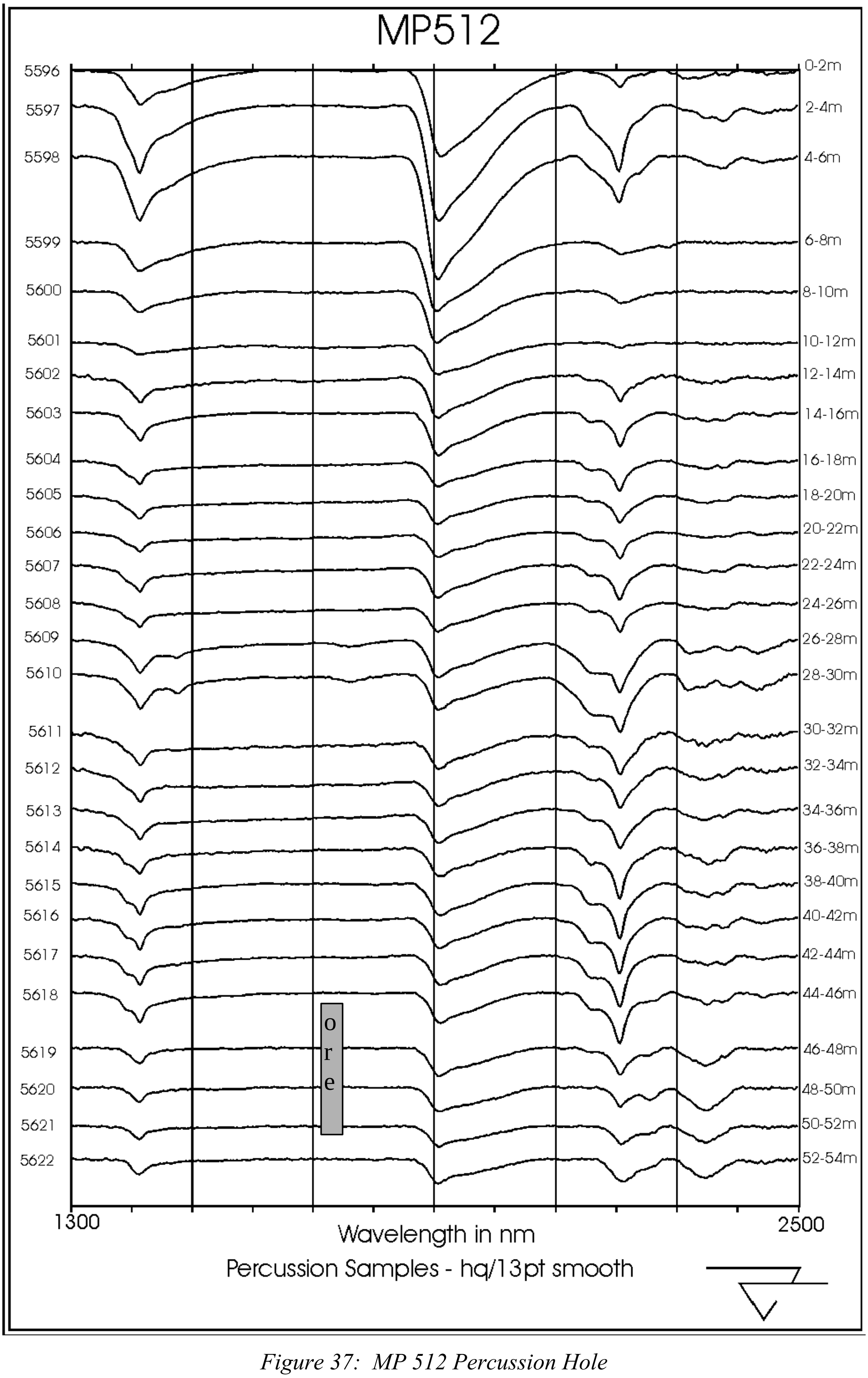

Figure 37: MP 512 Percussion Hole

4.11.4 MP 513 (Percussion)

MP 513 is an inclined percussion hole 50 m deep dipping 60° to the south. Samples DA185623 to DA185647 were recorded as spectra 5623 to 5647 (Figure 38). Elevated Cu values were recorded at 32 m and continue to 40 m.

Five zones are apparent.

From 0 - 8 m (surficial deposits) disordered kaolin and montmorillonite predominate.

From 8 - 12 m ,Hindmarsh Clay is characterised by the presence of montmorillonite.

From 12 - 32 m the weathered zone displays increasing kaolin content with a maximum at around 30 m.

Zone four, 32 - 40 m contains alunite and kaolin with kaolin content decreasing as chlorite content increases. This zone coincides with the elevated Cu values (Figure 38).

A fifth zone is characterised by mixed Fe-chlorite and muscovite and extends from 40 m to the bottom of the hole.

Analysis of individual grains (Figure 39) identified alunite at 32 m, from 36 m to 46 m, and at the bottom of the hole (50 m). Tourmaline grains were identified at 24 m and 34 m, kaolin at 28-32 m and montmorillonite at 46 m.

Kaolin is interpreted as halloysite based on the deep water feature at 1900 nm.

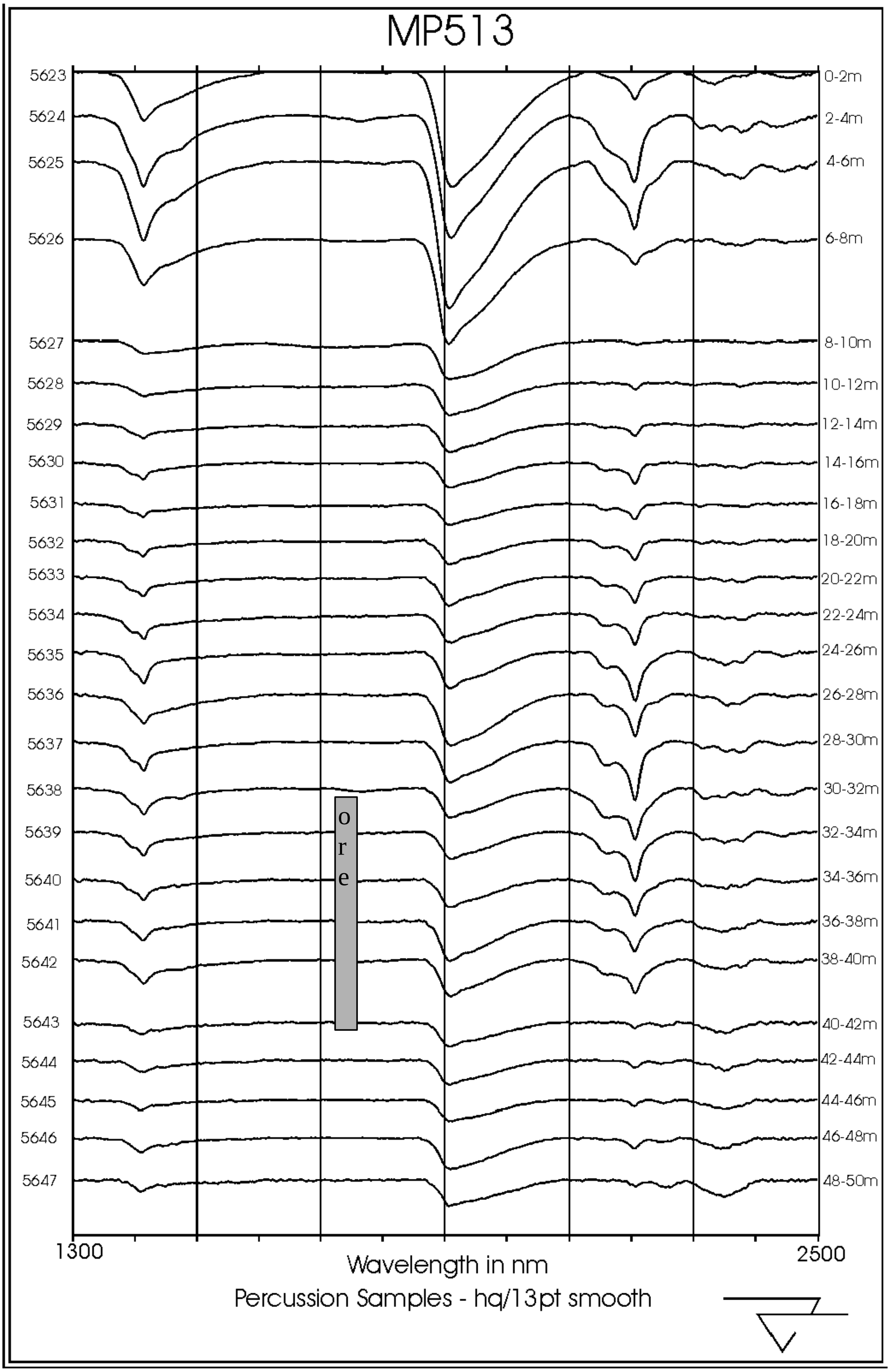

Figure 38 : MP 513 Percussion Hole

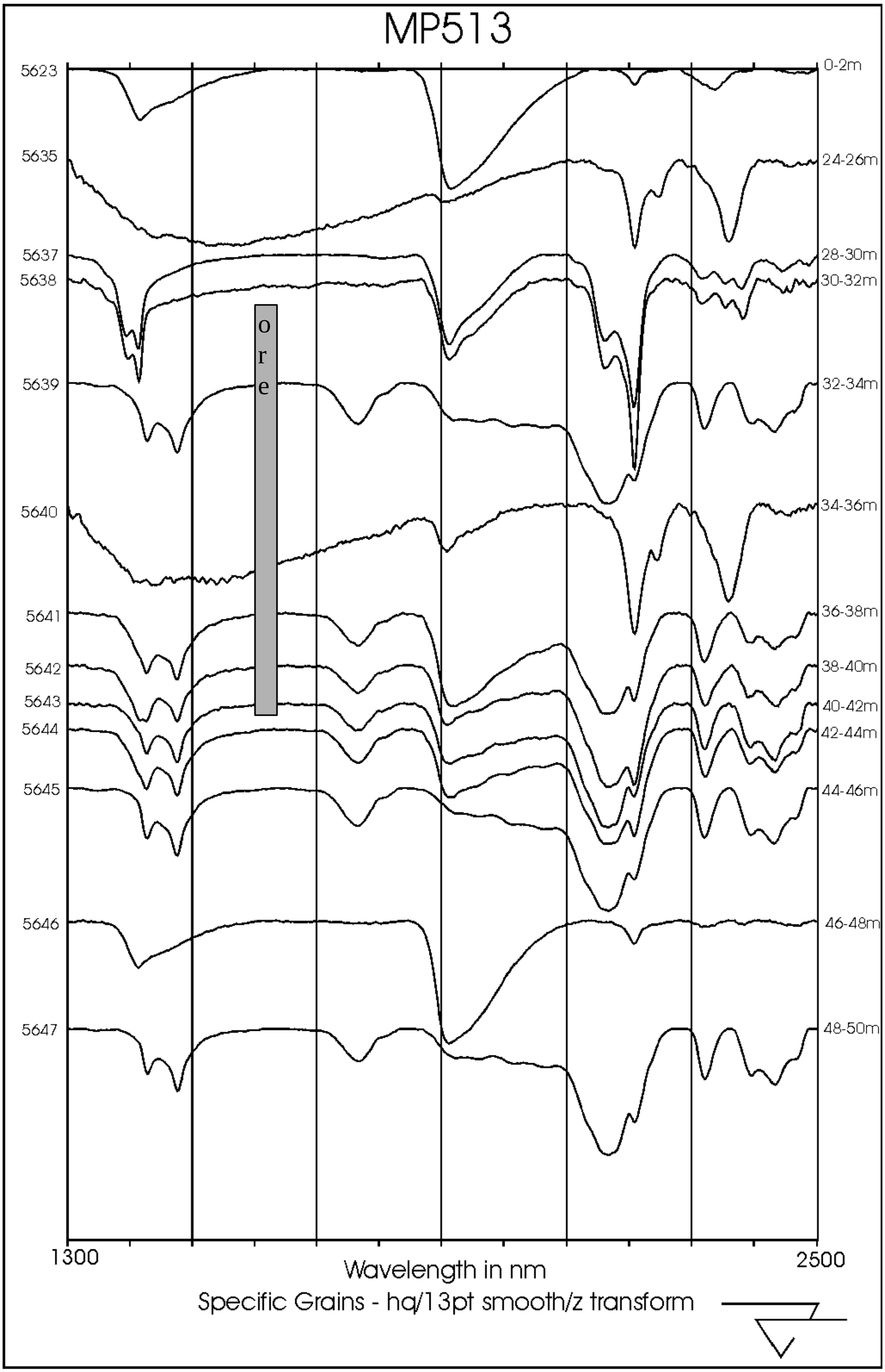

Figure 39: MP 513 Specific Grains

4.11.5 MP 811 (Percussion)

MP 811 is an angled percussion drilled hole 42 m deep inclined 60° to the south. Drill chip samples were taken every 2 m (0 - 42 m). PIMA II spectra (Poona106-120, 24/8/95) were acquire for each sample (Figure 40). Elevated Cu values were recorded between 28 and 40 m.

Four zones are apparent (Figure 41).

- Kaolin and smectite dominate samples from surficial deposits (0-8 m).
- Hindmarsh Clay from 8-12 m is dominantly montmorillonite.
- The weathered zone from 12 to 32 m is predominantly kaolin. These spectra have poorly defined doublets at 1400 nm and a deep asymmetric water absorption feature at 1900 nm and may also contain montmorillonite.
- Zone four, 32-42 m, is a chlorite/muscovite mix. The last three spectra are noisy and difficult to interpret.

Alunite may be present at 36-38 m (sample Poona125).

4.11.6 Discussion of Percussion Holes

The four percussion holes described above were all drilled to intersect the ore zone at relatively shallow depth (<40 m). Stacked plots of PIMA spectra can be subdivided into distinct zones which correlate well with regolith units recognised in mine which can be related to Cu distribution (Figure 41). The top 0-8m of surficial deposits is characterised by montmorillonite and kaolin, the lower boundary marked by a distinct reduction in the 1900 nm water absorption feature. This section had low Cu values. Zone two (Hindmarsh Clay) with dominant montmorillonite corresponded to a minor Cu enrichment zone which was reflected in all holes. This corresponds with small patches of copper chloride and carbonates precipitated from circulating meteoric waters observed in Hindmarsh Clay during excavation of the pit overburden. Zone three (weathered zone) shows increasing halloysite content with depth and is either barren hanging wall or depleted ore with low Cu values. The boundary between zones three and four in all holes corresponded with the commencement of the supergene ore zone with sudden increase in Cu assay values. The mineralogy of this zone varies from hole to hole but Fe-chlorite increases in abundance and kaolin abundance falls. The deepest sections of the holes are characterised by chlorite / muscovite mixes. The results show that PIMA-visible mineralogy in percussion samples can be correlated with regolith stratigraphy which has a significant influence on the distribution of copper mineralisation. For example, the spectral data could be used to confirm regolith boundaries and define the distribution of Hindmarsh clay and base of the weathered zone, both zones showing copper enrichment during weathering and therefore ideal targets for geochemical analyses.

Intersection of the ore vein in the weathered zone of hole MP 513 was indicated by the presence of tourmaline fragments in percussion chips. Tourmaline gives a recognisable spectral signature and the PIMA can be used to confirm the presence of tourmaline by analysing selected grains.

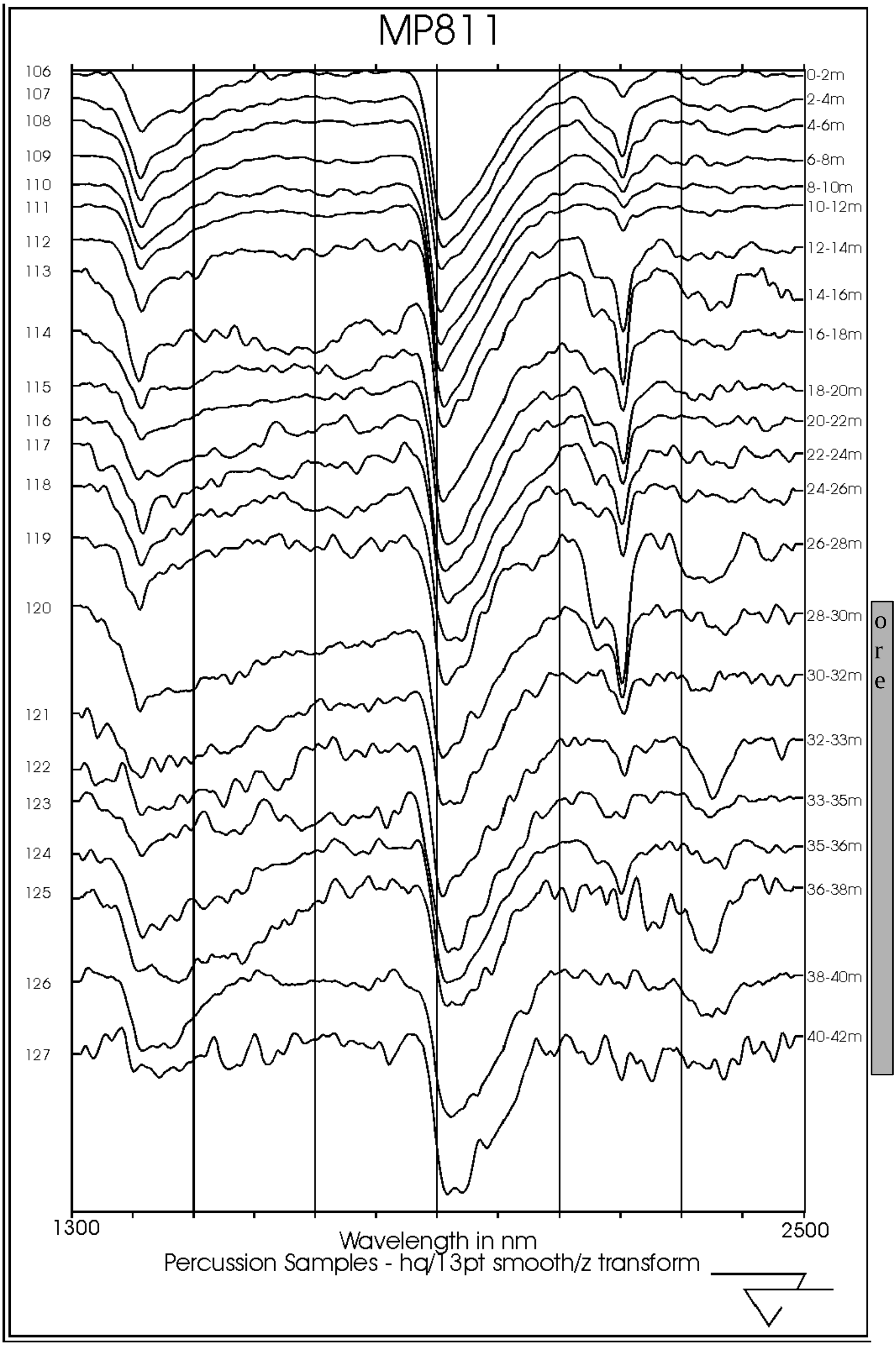

Figure 40: MP 811 Percussion Hole

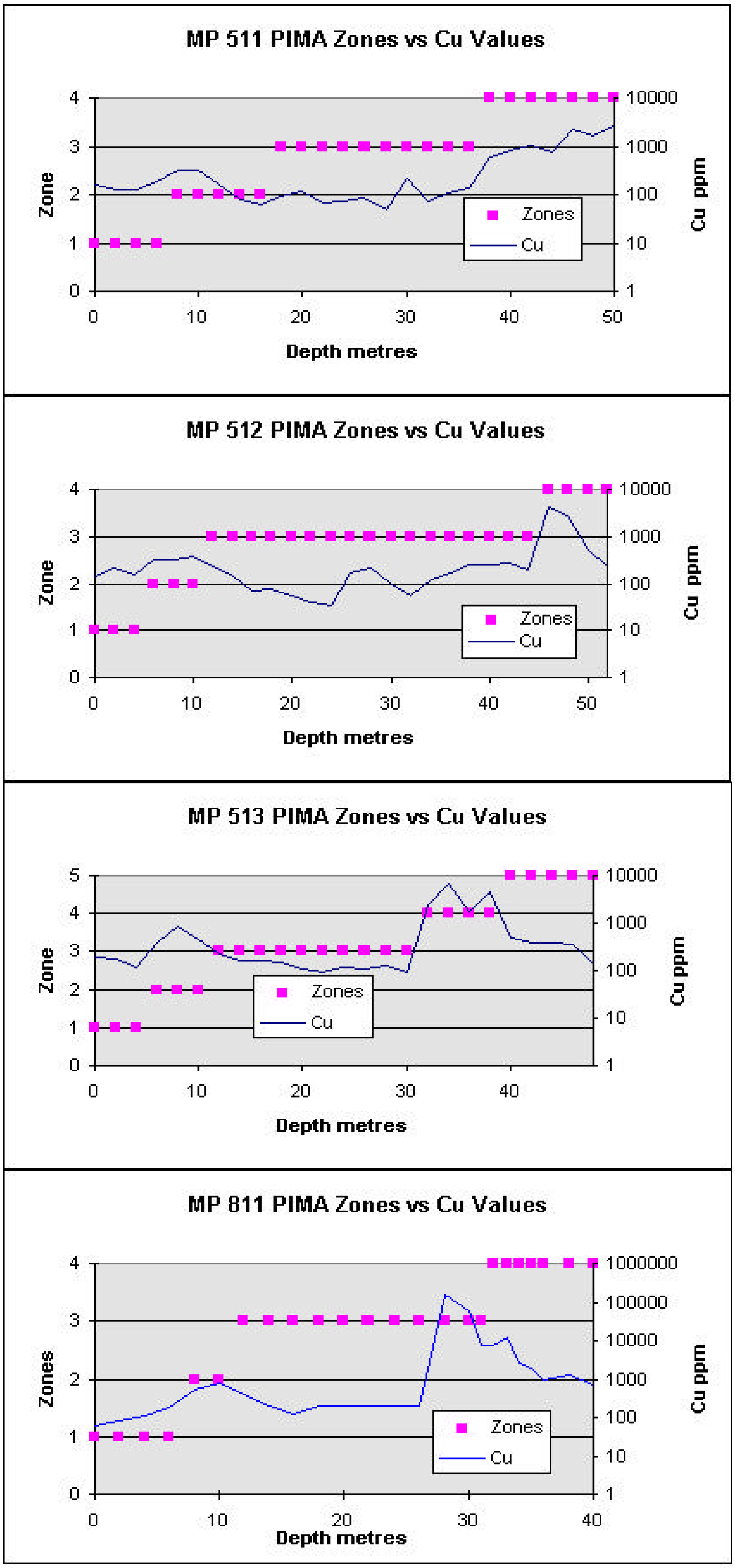

Figure 41: PIMA Zones vs Cu Values (MP511, MP512, MP513, MP811)

5. REVIEW OF MINERALS IDENTIFIED FROM PIMA SPECTRA

5.1 Kaolin

Kaolin[2] is a common mineral phase in samples from the Poona Mine and is readily identified from PIMA spectra. It is present as poorly crystalline kaolin in surficial deposits overlying smectitic Hindmarsh Clay and is abundant throughout the zone of weathering in Moonta Porphyry. Kaolin in surficial deposits is distinguished from that in the weathered zone by lack of an absorption doublet at 1400 nm, a weak doublet in the diagnostic 2200 nm region, and the presence of a weak FeOH absorption near 2240 nm. At both Poona and Wheal Hughes Mines, kaolin is also present below the weathered zone as a coating on fractures in porphyry. The presence of kaolin at depth has given rise to speculation that the clay is an alteration product resulting from reaction of host porphyry with circulating hydrothermal fluids (Both *et al.*, 1993; Conor, 1996).

During this study, kaolin was targeted for investigation as a possible indicator to the presence of mineralisation. Kaolin signatures in the spectra were initially interpreted as kaolinite based on the position and separation of characteristic absorption doublets at 1400 nm and 2200 nm. Often, however, the spectra showed an anomalous deep water absorption feature at 1900 nm, not consistent with kaolinite. The presence of smectite or the kaolin polymorph halloysite were suspected and samples were examined by scanning electron microscopy (SEM) to resolve the issue. XRD analysis was not undertaken because for mixtures of kaolinite and halloysite, kaolinite dominates the XRD pattern (Janik and Keeling, 1996).

For SEM investigation, small fragments of drill core containing kaolin were mounted on an aluminium stub using "Araldite™". Percussion samples were dispersed in distilled water and a drop of the suspension dried on a carbon block stub. All samples were sputter coated with 30 nm of gold and examined using a Cambridge S250 SEM fitted with a Link system energy dispersive X-ray analyser.

Sample details and results are summarised in Table 4 with selected electron micrographs presented in Appendix 1, Plates 1-11.

Significant observations and conclusions for this study included:

- tubular halloysite was the dominant kaolin in samples from below the weathered zone,
- fresh, uncorroded albite is coated with halloysite (Plate 5) indicating that below the weathered zone halloysite was deposited from solution and did not form by alteration of adjacent feldspar,
- some halloysite shows evidence of deformation (Plate 7) and was precipitated prior to, or during brittle fracture events,
- halloysite was the last mineral phase to be precipitated, infilling fractures in unweathered porphyry and sulphide veins (Plate 6) and coating pre-exisiting calcite, chlorite and chlorite alteration product, montmorillonite (Plate 2),
- halloysite was deposited on fracture surfaces, often in layers of matted fibres (Plate 1, Plate 4) that suggest cyclical deposition,
- kaolinite is present as a minor constituent in about half the samples and as the dominant kaolin polymorph in one sample (DDH 244, 48 m, Poon090, Plate 9).

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[2] Kaolin in this report is the generic term covering both kaolinite and halloysite. Halloysite is the hydrated polymorph of kaolin and forms tubular fibres compared to kaolinite's platey morphology.

While the above confirmed that halloysite was a late stage precipitate it was uncertain as to whether halloysite was the product of late stage, low temperature hydrothermal activity or the result of supergene weathering processes.

Comparison was made with suspected hydrothermal kaolin from the broad Alford alteration zone (Figure 2) which is known to carry disseminated sulphides (Conor, 1996). Samples were collected from outcrop on the beach north of Wallaroo and examined using PIMA and by SEM. All samples from the Alford zone are kaolinite and of very different character compared with the Poona kaolin samples (compare Plate 1 and Plate 11).

While halloysite is present at depths of 69 m at Poona, it is noticeably absent in the vicinity of the ore zone intersected at around 130 m in hole DDH 234.

On consideration of the evidence, it is concluded that halloysite is a product of weathering of sulphide ore in the oxidised zone. Acid weathering conditions evidenced by the presence of alunite in the weathered zone would have released alumina and silica into meteoric water circulating through fractured Moonta Porphyry. Empirical evidence from the literature, summarised in Hill (1990 p.1687), suggests that under acidic conditions, halloysite is deposited in preference to kaolinite.

Halloysite forms a broad plume in unweathered Moonta Porphyry that might be a useful indicator to mineralisation where the ore zone extends into the zone of weathering.

5.1.1 PIMA Characterisation of Halloysite

Recognition of halloysite in PIMA spectra was considered significant in the context of the present investigation. Previously established discrimination techniques use the 1400 nm doublet to distinguish kaolinite from halloysite. If the shorter wavelength absorption feature falls between 1388 nm and 1394 nm and the doublet spacing is greater than 20 nm then the mineral was considered to be halloysite. If the wavelength absorption was greater than 1394 nm and the spacing was about <20 nm then kaolinite was interpreted. From the processed spectra (hull quotient, 13 point smoothed and z-transformed) the shorter absorption feature[3] of the 1400 nm doublet had a wavelength between 1390 and 1397 nm and a doublet separation generally <20 nm (Table 5). For Poona samples, the criteria generally failed to indicate the presence of halloysite and did not distinguish Poona kaolin from kaolinite in the Alford alteration zone (Figure 42).

The presence of halloysite in Poona kaolin samples can be determined from a ratio of the depth of the water feature at 1900 nm and sum of depths of the characteristic kaolin absorption features. This also discriminates between kaolin samples from Poona and Alford and gives an indication of the presence of smectite with halloysite (Figure 43).

Comparison of Poona spectra with Alford spectra (Figure 44) shows that other means of discrimination could be applied including the relative depth of absorption of features comprising the characteristic doublets. For the 2160/2206 nm doublet Alford kaolinite has a significantly deeper 2160 nm feature and at the 1395/1410 nm doublet the depths of the individual features are approximately equal.

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[3] When the shorter absorption was present as a shoulder only, position of the minima was determined using 2nd derivative.

Table 4. Summary of SEM investigation of kaolin in drill hole samples

Drill Hole	Depth (m)	Spectra reference	Relationship to mineralisation	SEM No.	Observations
231	31.5	Poon 045a	Below weathered zone above ore zone.	3489	White to pale brown kaolin coating subvertical joint surface in relatively fresh porphyry. Halloysite tubes 2-3 microns long. Some calcite grains to 5 microns across also present and coated by halloysite.
	34.1	Poon 049	Above ore zone	3490	White to pale, orange-brown kaolin as a thin coating on subvertical joint surface. Kaolin is halloysite built up in numerous layers (Plate 1) coating Fe-Mg chlorite which shows various stages of alteration to smectite (Plate 2) of montmorillonite composition (Fe, Mg, Ca).
	38.9	Poon 054	Above ore zone, relatively fresh porphyry with some reddish Fe oxides.	3491	Thin white kaolin coating on fracture/foliation surface at 90° to core axis. Dominant halloysite tubes with minor kaolinite flakes to 5 microns width. Hematite rosettes to 5 microns across also present as surface coating. Fungal hyphae contamination.
	43.6	Poon 057	Ore zone	3492	Minor white kaolin on fracture surface of reddish black porphyry. Kaolin predominantly halloysite as thin and thick (0.9 µm diam.) tubes.
234	12-14	Poona 007	Dried suspension of dispersed sample	3493	Mixture of halloysite tubes and kaolinite flakes, up to 2 µm across, in approximately equal proportions.
	18-20	Poona 010	Dried suspension of dispersed sample.	3494	Dominantly halloysite tubes, to 3 µm length, with minor kaolinite.
235	28.4	Poona 211/212	Above mineralisation, base of weathered zone.	3530	Kaolin coating as thin tubes of halloysite 1-3 µm long (Plate 3).
	38.1	Poona 213/214	Hanging wall, immediately above ore zone.	3531	Relatively thick kaolin coating fracture surface in unaltered feldspar (albite) porphyry. 85-90% halloysite deposited in layers. Minor kaolinite present and generally more common in the kaolin layer in contact with the fresh porphyry.
	40.1	Poona 215/216	Ore zone	3532/ 3533	Halloysite tubes as layers coating fresh fracture surface in feldspar (Plate 4). Feldspar shows no evidence of alteration or dissolution (Plate 5). Halloysite infills fractures in sulphide veinlets (Plate 6). Deformation of halloysite veinlets indicates movement post halloysite deposition (Plate 7).

Table 4 (cont.)

235	47.5	Poona 217	Footwall, immediately below ore zone.	3534	Dominant halloysite with minor kaolinite. Halloysite coating directly on smectite formed by alteration of Fe-chlorite.
244	41.5	Poona 079	Directly above ore zone.	3495	Slightly brecciated porphyry with hematite veinlets. White kaolin present as thin patchy coating on chlorite in fracture surfaces. Kaolin is halloysite coating fresh and altered Fe-rich chlorite flakes. Chlorite altering to Fe-Mg-Ca smectite (Plate 8).
	47	Poon 089	Ore zone, between Cu mineralisation.	3496	White to pale grey kaolin as thin coating on fracture surfaces in pale grey porphyry. Kaolin as halloysite forms thin tubular fibres to 4 microns length. Minor kaolinite present, particularly at margins of the clay coating.
	48	Poon 090	Base of ore zone.	3497	Brecciated grey porphyry with stringers of sulphide and hematite. Kaolin, as thin white coating on fracture surfaces, is mainly ragged flakes of kaolinite with minor halloysite (Plate 9).
	49.4	Poon 091	Immediately below ore zone.	3498	0.4m below zone of brecciation. thin white to pale yellow kaolin on fracture surfaces. Kaolin is halloysite deposited in layers on fresh porphyry.
245	68.8	Poon 013	Below zone of weathering, immediately above the ore zone.	3499	Thin white kaolin coating on steeply inclined fracture in pink foliated porphyry. Kaolin is halloysite deposited in layers directly onto unweathered porphyry. Kaolin coating around 40 microns thickness.
Wallaroo Beach	north	Alford 03	Alford alteration zone	3650	Massive white kaolinised rock showing moderate porosity. Kaolin as kaolinite forming ragged-edged platelets and stacks of platelets.
	middle	Alford 04	As above	3652	Kaolin forms as randomly distributed, ragged-edged platelets to 10 µm across (Plate 10). Minor halite present.
	south	Alford 05	As above	3654	Kaolinised white rock with porous texture and including veinlets of massive kaolin. Kaolin is present as poorly crystalline, ragged-edged kaolinite platelets and small crystal stacks <2 µm across. Veinlets contain similar kaolinite showing swirl texture and less porosity (Plate 11).

Table 5: SEM Samples kaolin characterisation

Sample[4]	1390[5]	1410	Spacing	2160[6]	2206	Spacing	Description
231045a	1392	1411	19	2163	2206	43	Calcite with h
231049	1396	1412	16	2166	2206	40	Chlorite with h.
231054	1393	1412	19	2163	2206	43	Dominant h.
231057	1392	1410	18	2160	2206	46	2 types of h.
234007	1394	1416	22	2163	2206	43	50:50 h/k
234010	1392	1410	18	2162	2206	44	Dominant h.
235212	1394	1412	18	2164	2206	42	Dominant h.
235213	1394	1412	18	2163	2206	43	90:10 h/k
235215	1396	1412	16	2162	2206	44	Layers of h.
235217	1397	1411	14	2160	2208	48	Dominant h.
244079	1390	1412	22	2163	2206	43	Chlorite with h.
244089	1390	1411	21	2165	2208	43	H. with minor k
244090	1396	1412	16	2160	2206	46	Mainly kaolinite
244091	1395	1412	17	2161	2206	45	Abundant h.
245013	1394	1412	18	2161	2206	45	Halloysite
Alford3	1398	1410	12	2162	2206	44	Kaolinite
Alford4	1397	1410	13	2160	2206	46	Kaolinite
Alford5	1398	1410	12	2160	2206	46	Kaolinite

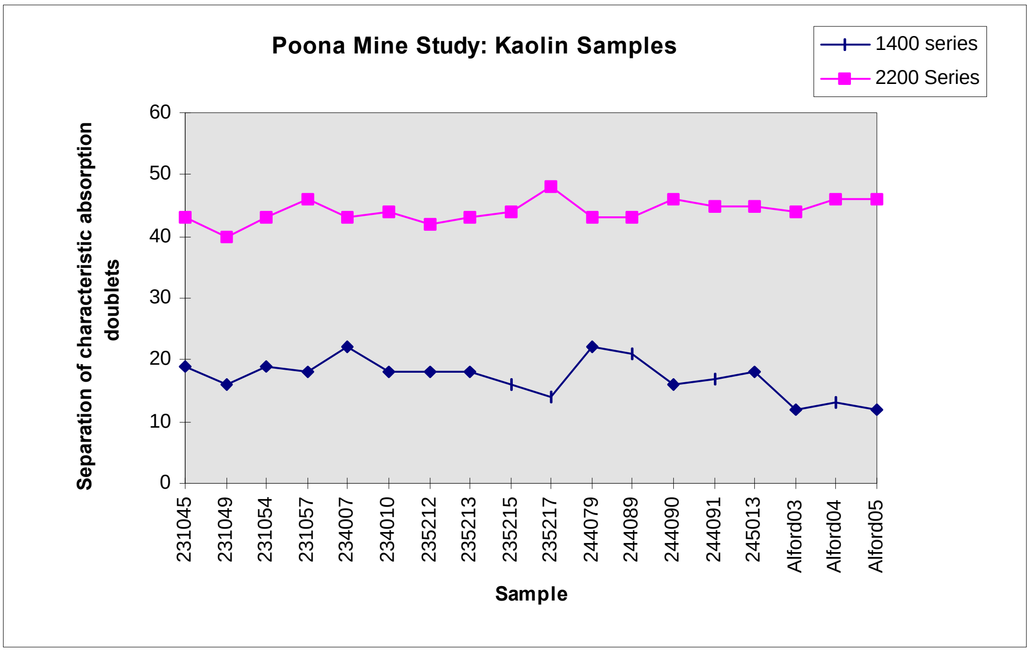

Figure 42: Variation in the separation of characteristic absorption doublets in kaolin samples from Poona and Alford alteration zone (measured from hull quotient spectra).

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[4] Drillhole number linked with sample number

[5] For shoulder inflections only, measured using 2nd derivative in PIMAVIEW

[6] Measured using 13pt smoothed z-transformed hull quotient in PIMAVIEW

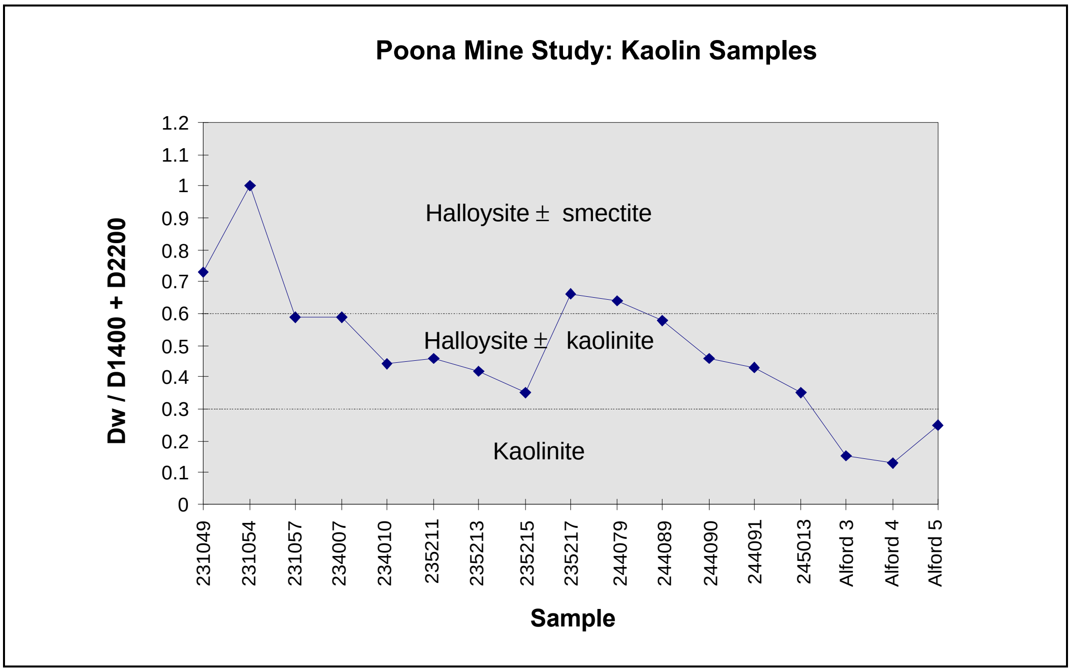


Figure 43: Discrimination of kaolin samples containing halloysite

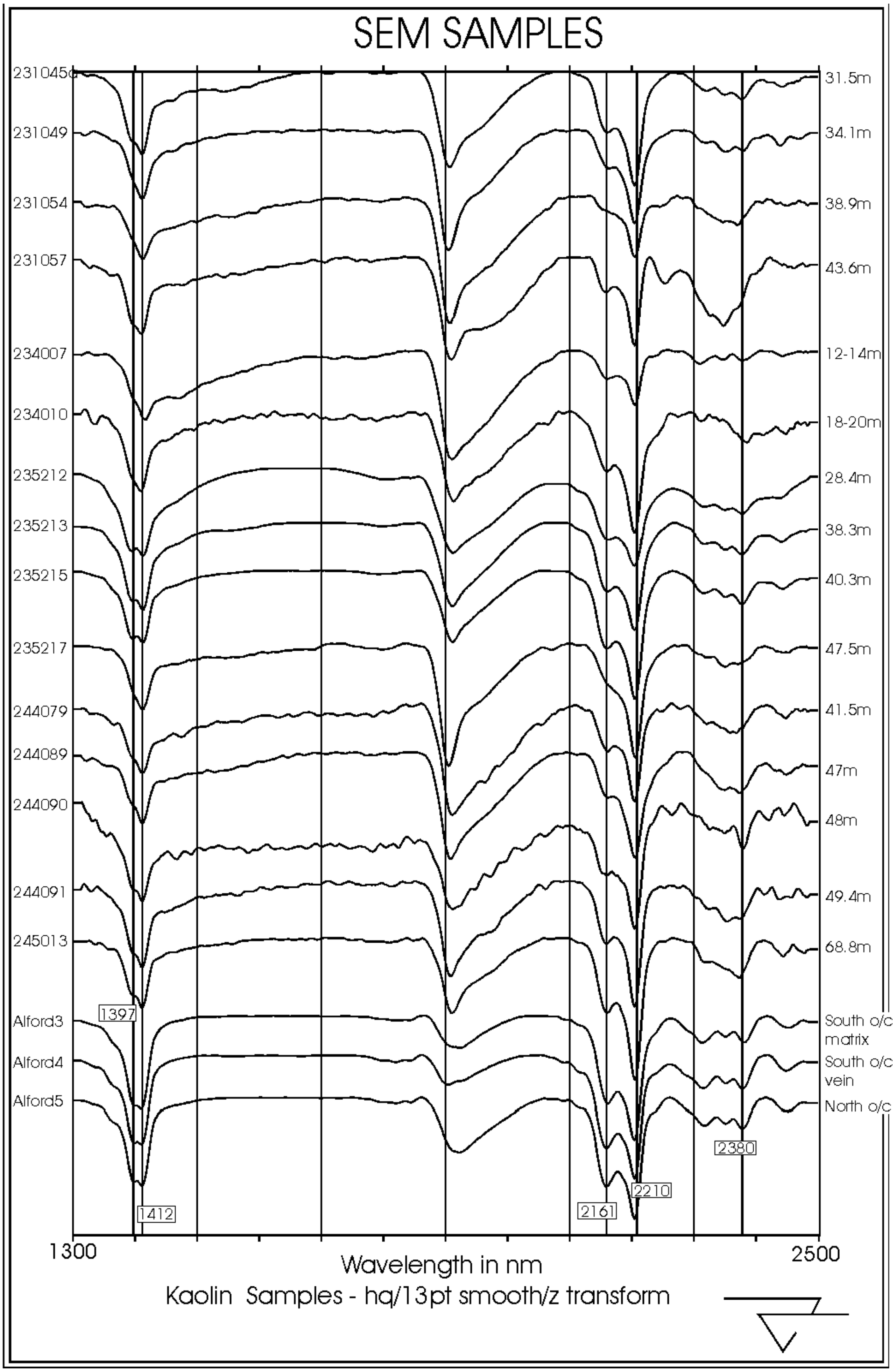


Figure 44: Kaolin samples included in SEM examination

5.2 Muscovite

Initial identification of muscovite proved difficult because illite has a very similar spectra. The only difference is in the 1900 nm water feature and when muscovite is mixed with montmorillonite or chlorite the other minerals could well account for the apparent water in the muscovite signature. Muscovite became an issue when a long wavelength species was identified and subsequently confirmed in microprobe and XRD analyses of selected samples whose PIMA spectra appear in Figure 45. Its composition makes it a previously unidentified end-member of the muscovite-phengite series with its main absorption feature moving towards the longer wavelengths of 2225 nm and 2227 nm. When previous interpretations were reviewed muscovite could be recognised by the presence of 2116 nm and the 2340/2435 nm features.

For the interpretation the presence of a 2225 nm absorption feature was particularly noted and interpreted as phengite.

In mixtures of muscovite and kaolin the muscovite signature can be completely overprinted by kaolin absorption features. Yang *et al.* (1996a), suggest that in mixtures of sericite and kaolin, increasing kaolin will shift the 2200 nm absorption feature to longer wavelengths closer to 2208 nm. Samples higher in ‘normal’ sericite will have wavelengths closer to 2202 nm.

DDH 245 has examples of long wavelength micas. The absorption feature at 2222 nm reaches 2227 nm in proximity to the ore zone and then decreases again in the footwall. Microprobe analysis (Appendix 2, Table 6) shows that the micas are high in F and depleted in Al. Depletion of aluminium in the octahedral site gives a composition tending towards phengite. Long wavelength muscovites occur within the immediate wall rocks of the ore zone. Their identification from PIMA spectra could serve to indicate close proximity to hydrothermal mineralisation. Where subparallel shearing with minor copper mineralisation is present adjacent to the main lode, as in DDH 234, phengite alteration can be detected some 50 m into the hanging wall above the main orebody. In this case, phengite continues through to the main lode and could clearly be used as a vector to mineralisation.

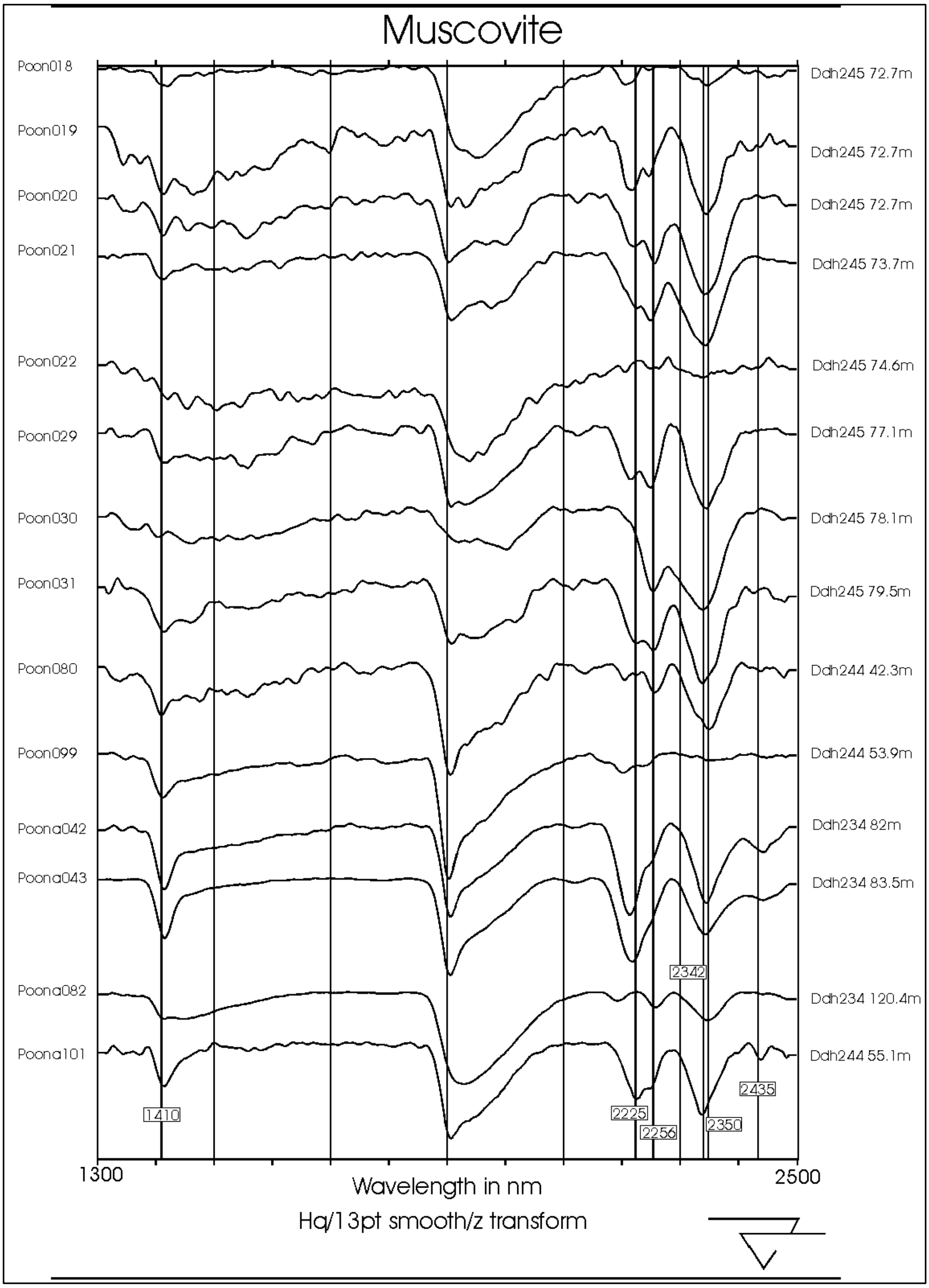


Figure 45: Muscovite Spectra from Selected Samples

5.3 Chlorite

Eighteen samples whose PIMA spectra indicated the presence of chlorite (Figure 46) were examined by microprobe, at CSIRO, North Ryde, in order to establish a relationship between compositional variations and PIMA absorption features. Backscatter electron images of chlorite grains taken with the microprobe indicate compositional variation within individual grains (Appendix 3, Plate 12, Plate 15, Plate 16, Plate 17, Plate 18, Plate 19). The pattern of variation within the grains indicates alteration with Mg replacing Fe. Spectrally it proved difficult to establish a pattern related to the spatial distribution of chlorite with respect to composition. Although combined microprobe results from previous work at the University of Adelaide and the recent work at CSIRO indicated two distinct populations of chlorite present in the Poona system, the shifts in the absorption features of the spectra were not always sufficient to place the composition confidently into the shorter wavelength Mg-rich variety. The variable nature of the later Mg alteration in chlorite is such that that they can not be positively identified based only on spectral data. Integration of spectral and microprobe data for drill holes, however suggest that overall the distribution of higher Mg-chlorites is more intimately associated with ore.

The ore system is characterised as having Fe-rich fluids which precipitated hematite very early in the process. It is considered that the Fe-rich chlorites were formed at this stage. At a later stage, possibly during sulphide deposition, Mg-rich fluids altered the Fe-chlorites by replacing some of the Fe to give chlorite grains with Mg enriched rims.

From Appendix 2, Table 7 it can be seen that samples 19, 20, 30, 31, 101, 42 and 43 are similar in their Fe content but 18 (DDH 245) has a higher Fe* and clusters with most of the University of Adelaide samples (Fe* = 60-80) (Appendix 2, Table 8). There is significant variation in some samples which possibly reflects a varying degree of later hydrothermal alteration.

While fluorine content in chlorite is less than that for muscovite, the fluorine content determined in Poona chlorites is regarded as anomalous in most samples and may be indicative of reaction with hydrothermal fluids having elevated fluorine content. Lowest F content was in sample 18f which also recorded the lowest Mg content (Appendix 2, Table 7).

Sample p18 has a higher Fe* in the chlorites than the other samples which were microprobed. This suggests that the chlorites formed from fluids in the early stages of metamorphism rather than later hydrothermal fluids associated with sulphide mineralisation.

5.3.1 Timing of Chlorite formation

Hafer (1991) used chlorite samples taken from the ore zone at Poona to determine temperatures of formation. Results showed a large variation in temperature for chlorite crystallisation ranging from 163º to 326º. A $\log fS_2$- $\log fO_2$ diagram (Hafer, 1991) plots chlorite within the pyrite and pyrrhotite stability fields. Hafer concluded that as pyrrhotite was not found within the Poona ore lode, the chlorites within this field were not in equilibrium with the sulphides and therefore were not precipitated during mineralisation. Hafer suggested that these chlorites may be a result of post-sulphide fluid mobilisation associated with shearing. The present study however suggests that Fe-rich chlorites formed during early metamorphism / hydrothermal alteration and were in place before mineralisation. These chlorites were unstable with respect to later hydrothermal fluids and hence the partial alteration through replacement of Fe with Mg.

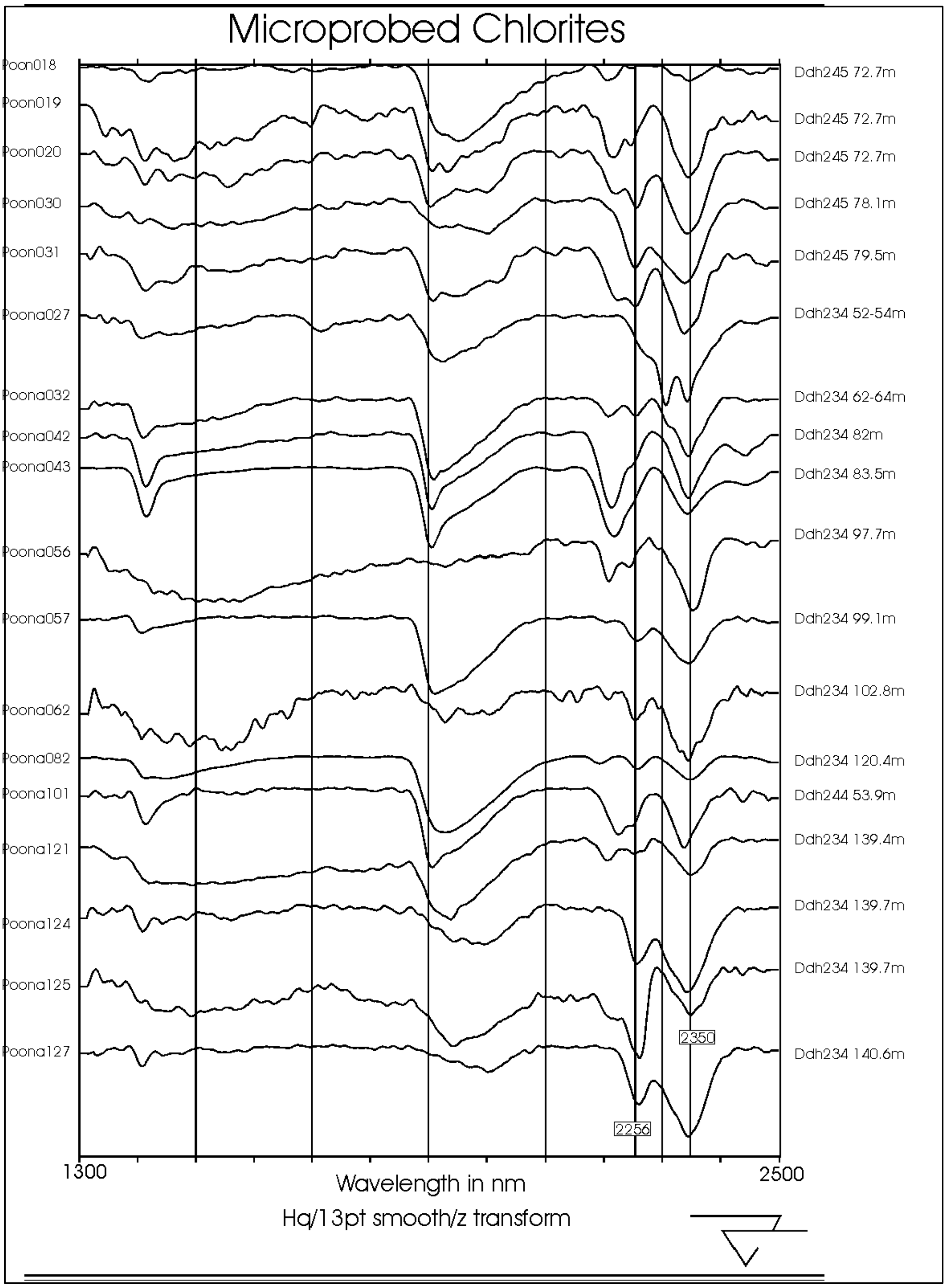


Figure 46: Chlorite Spectra of Microprobed Samples

5.4 Tourmaline

Tourmaline is a common gangue mineral associated with the Poona orebody. Samples were specifically scanned with PIMA in order to identify a diagnostic spectral signature. On first interpretation, the spectra were thought to be a muscovite/sericite - Fe-chlorite mixture. Microprobe analysis showed that chlorite was associated with tourmaline (Plate 14) in some samples. However by collecting spectra from several samples all readily identified in hand specimen it was possible to distinguish a muscovite-chlorite mix from a tourmaline spectra.

Pure tourmaline has:

- a broad noisy spectra between 1300 nm and 2100 nm
- a 2206 nm absorption feature (which may be confused with AlOH of muscovite)
- 2247 nm and 2364 nm absorption features (the 2247 nm absorption could be confused with Mg-chlorite while 2364 nm may be confused with Fe-chlorite but when they occur together they are more likely to indicate tourmaline than chlorite).

Tourmaline from Ardlethan, (Yang *et al.*, 1996b) has a slight inflection the absorption spectra at about 2300 nm (2292 nm), which is not pronounced in tourmaline from Poona.

With chlorite the 2250/2350 nm features move together towards shorter wavelengths for Mg-rich and longer wavelengths for Fe-rich varieties. In tourmaline the features ‘separate’ to 2247/2364 nm rather than ‘shift’. Mixtures containing chlorite and tourmaline can be identified by a broad or double feature in the 2350 nm region. Significant spectral features for tourmaline are highlighted in Figure 47 which includes an Fe-chlorite and a muscovite/Fe-chlorite mix for comparison.

Microprobe analyses detected both dravite (Mg rich) (sample DDH 234, 97.7m) and schorlite (Fe rich) (sample DDH 234, 139.4m) (Table 6). There were insufficient samples analysed by microprobe to establish whether compositional variation in tourmaline could be interpreted from changes in the SWIR spectra.

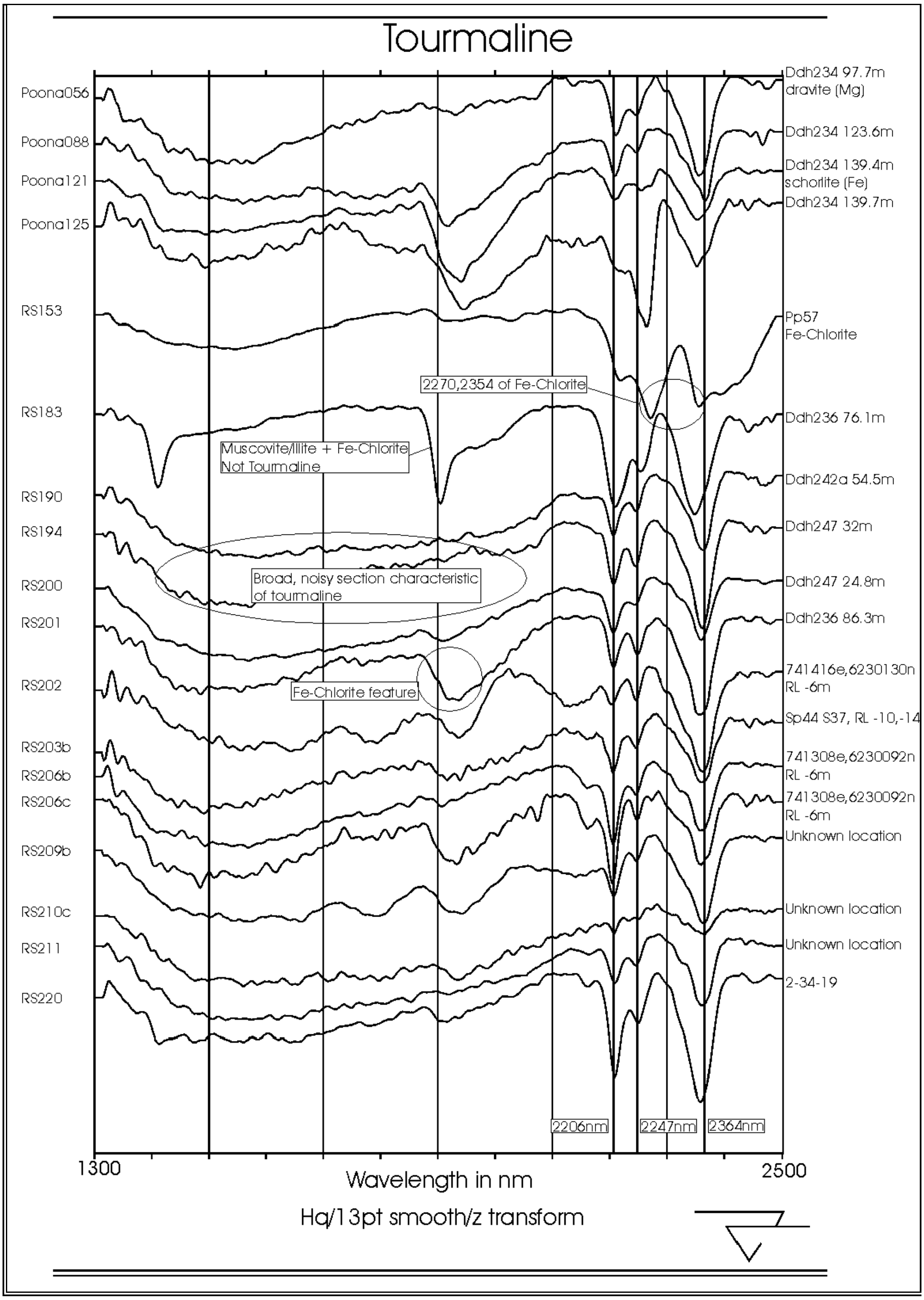


Figure 47: Tourmaline Spectra

6. DISCUSSION

The geological setting based on previous work by Conor (1996) and Parker (1993) can be summarised as follows. The Moonta Porphyry of Mesoproterozoic age was a barren rhyolite plug associated with extrusive bimodal volcanics and mixed chemical and fine clastic marine sediments. With the intrusion of the Hiltaba Suite Tickera Granite, at around 1600 Ma, the whole sequence was deformed and metamorphosed, the grade of metamorphism decreasing away from the pluton. Strain partitioning gave rise to intense local deformation zones.

Sulphide mineralisation was associated with emplacement of the granite. Either the metals and sulphur arrived as the volatile fraction of the granite or the associated heat and deformation caused mobilisation of stratiform ores from the overlying sedimentary sequences. The ore fluids precipitated mainly copper sulphides in structural traps that included shear fractures in Moonta Porphyry.

Widespread hydrothermal and metasomatic alteration have been identified as associated with the processes of deformation and metamorphism (Conor, 1996). Examples include widespread chloritisation of mafic minerals and localised zones of intense kaolinisation such as the Alford alteration zone. At Poona, metamorphism of Moonta porphyry is recognised by a distinct foliation defined by recrystallisation and elongation of original quartz phenocrysts, and the presence of aligned mica and chlorite.

Spectral analyses of unweathered porphyry in drill hole samples from the Poona Mine define widespread distribution of Fe chlorite and muscovite (Figure 48a). These are products of broader scale metamorphism associated with granite intrusion. The Poona study was too localised to investigate any regional trends related to variation in the nature and composition of these two minerals.

Alteration specific to hydrothermal sulphide mineralisation at Poona generally appears restricted to a narrow zone extending less than a few tens of metres from the lode. Spectral and mineralogical studies indicate that the zone is characterised by the presence of elevated Mg content in chlorite, increased phengitic character in muscovite, and the presence of tourmaline (Figure 48c-e). Elevated fluorine content, determined by microprobe analysis of altered chlorite and phengite are consistent with a granitic source for the fluids.

Positive identification of the hydrothermal minerals in SWIR spectra is not always straightforward:

- Mg replacement of Fe in chlorite is generally patchy and the shift in characteristic absorption from around 2350 nm to <2340 nm (higher Mg) is often not pronounced and seldom conclusive.

- As muscovite approaches the composition of phengite there is a distinct shift in the characteristic absorption at around 2200 nm to higher wavelengths up to 2225 nm. While the shift is quite distinct, the change is generally restricted to the ore zone and the immediate wall rocks. Muscovite is often a minor component of the sample and in mixtures with kaolin, the change in muscovite composition could go undetected.

- Tourmaline distribution at Poona is also restricted to close proximity to the ore zone. It is a dark mineral and typically has a noisy spectra. Diagnostic tourmaline absorption features at 2206 nm, 2247 nm and 2364 nm also overlap those of muscovite and chlorite.

Other mineral phases identified using PIMA and related to the mineralisation are kaolin (as the polymorph halloysite) alunite and montmorillonite. Halloysite and alunite are weathering products that appear to be specific to weathering of the sulphide orebody. Montmorillonite in Moonta Porphyry is an alteration product of chlorite and most probably formed by reaction with circulating meteoric fluids.

- **Alunite** is restricted largely to the zone of weathered sulphide ore (Figure 49a) but is also present in overlying Hindmarsh Clay where it is associated with oxidised copper minerals and copper chloride deposited from circulating meteoric water. The presence of alunite at Poona invariably indicates close proximity to weathered sulphide ore.

- **Halloysite** is widely distributed in the weathered zone and as a broad envelope about the orebody to around 80 m depth (Figure 49b). Below the weathered zone, halloysite is present as layers of matted fibres coating fractures in porphyry and ore minerals. In this situation, halloysite was clearly deposited from solution and did not form by local alteration of alumina-silicate minerals.

  Contrary to findings from studies elsewhere (Pontual, 1996 pers comm.), halloysite at Poona is not readily distinguished from kaolinite on the basis of the position and separation of the characteristic absorption doublet at 1400 nm. A more reliable feature, used with Poona samples to distinguish them from Alford hydrothermal kaolinite, was the ratio the depth of the water absorption feature at around 1900 nm divided by the sum of the depths of the main absorption features.

  Recognition of halloysite in drill hole samples in weathered or fresh Moonta Porphyry could prove to be a useful guide to the presence of nearby sulphide orebodies provided they extend into the zone of weathering.

- **Montmorillonite** is interpreted from PIMA spectra to be more widespread below the weathered zone than either alunite or halloysite (Figure 49c). Much of this interpretation is based on the presence of asymmetric water absorption features at around 1410 nm and at 1900 nm. This requires confirmation by other mineralogical techniques before the distribution can be mapped with confidence.

For Poona samples, the main water absorption feature at around 1900 nm is significant in the identification of halloysite and montmorillonite. Further work is required to investigate sample preparation techniques that will provide optimum sample “dryness” necessary to maximise the useful information available from this part of the spectra.

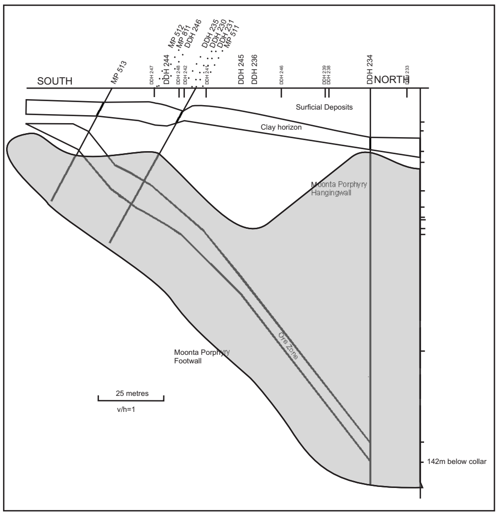
PIMA spectra of drill hole cuttings demonstrate that the technique is well suited to mapping regolith boundaries at Poona:

- Surficial sediments and carbonate soils are recognised by the presence of poorly ordered kaolin together with smectite.

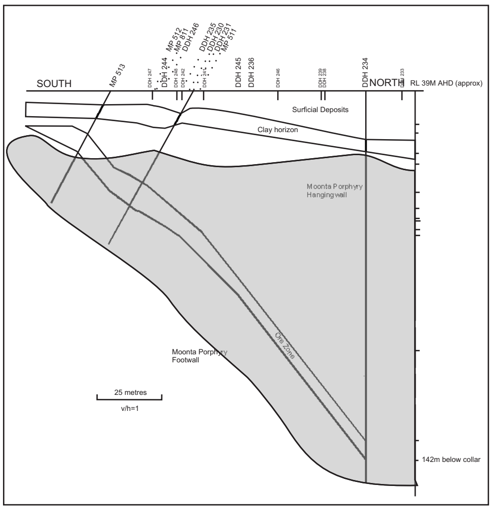
- Hindmarsh Clay has dominant montmorillonite mineralogy.

- Weathered Moonta Porphyry is characterised by dominant kaolin, typically showing a deep water feature.

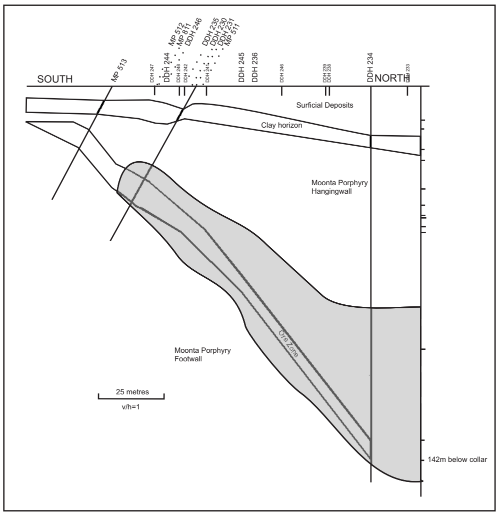
- Unweathered Moonta Porphyry shows dominant chlorite mineralogy and the presence of muscovite.



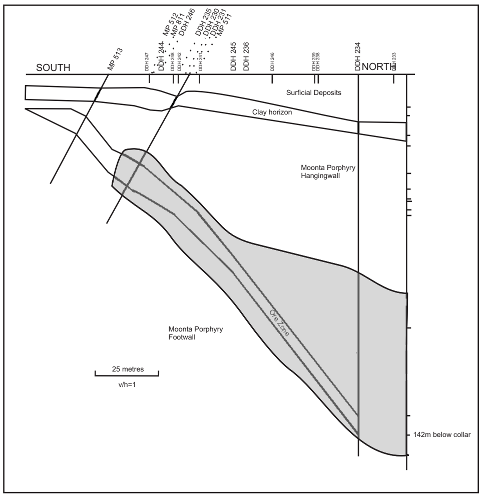
(a) Fe-Chlorite



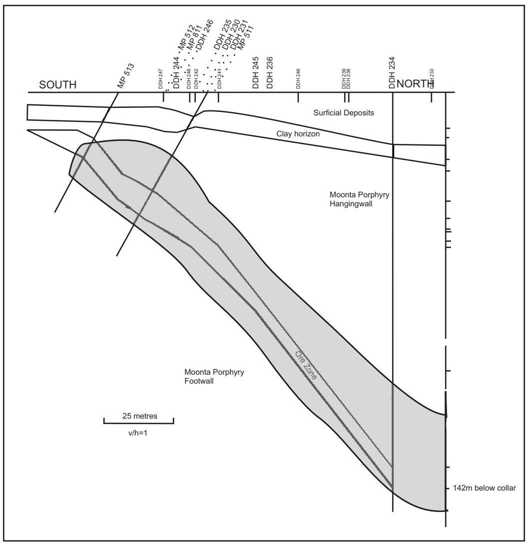
(b) Muscovite



(c) Mg Chlorite

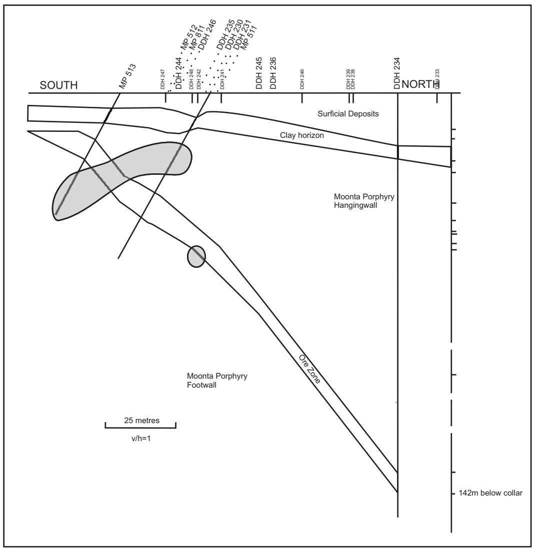


(d) Phengite

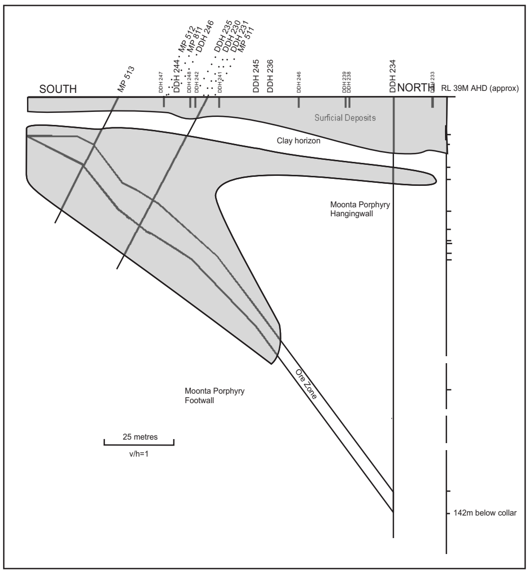


(e) Tourmaline

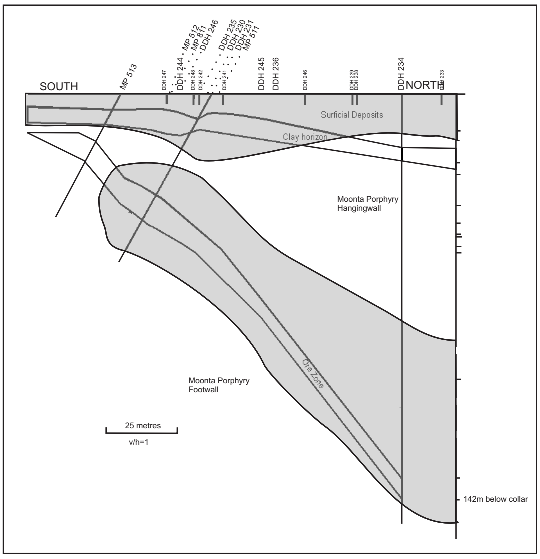
Figure a e : Diagrammatic cross sections showing distribution of metamorphic and hydrothermal alteration minerals at Poona



(a) Alunite



(b) aolin



(c) Montmorillonite

Figure 9 a c : Diagrammatic cross sections sho ing distribution of surficial and eathering alteration minerals at Poona

7. SUMMARY AND CONCLUSIONS

The Poona Copper Deposit is a narrow, steeply dipping copper sulphide lode confined within an ENE/WSW shear in Moonta Porphyry. The orebody is weathered to depths of around 30 m and was covered by some 10 m of clay and soil. The lode is typical of hydrothermal vein deposits in the historic Moonta Mining District that from 1860 to 1920 were an important source of copper and gold production in South Australia.

In order to investigate alteration mineralogy at the deposit, selected samples from 9 cored drill holes and 4 percussion holes were analysed using portable short wave infrared spectrometer, PIMA II. Over 550 samples were analysed giving 723 spectra. Conclusions on sampling and analytical techniques, nature of the alteration mineralogy, and implications for exploration are summarised below.

7.1 Sampling and Analytical Techniques

- Subsamples of dry percussion chip samples, mainly from regolith units, were readily scanned through the base of a glass petri dish. When taken at regular 2 m intervals, these provided the best comparative spectra that were ideal for observing trends in mineralogical changes, particularly when viewed in stacked plots. Individual grains were sometimes selectively chosen and analysed to give positive identification of significant minor alteration minerals such as alunite and tourmaline.

- For core samples, mineral coatings on fracture surfaces were targeted for analysis. Several spectra were often taken at a given depth interval in order to record variation in the nature of the coating or the presence of different mineral phases. This generally improved spectra quality and limited the number of mineral phases in individual spectra, both of which aided interpretation. While this technique proved suitable for identifying mineral phases it was less well suited to observing and displaying mineralogical changes with depth.

- The presence of halloysite was suspected for kaolin samples showing a deep water feature at 1900 nm. This was confirmed by SEM investigation. Using the ratio of the depth of the water feature and the sum of the depths of the main kaolin absorption features provided a means of discriminating between halloysite and kaolinite samples from the Moonta district.

- Identification of halloysite and montmorillonite in Poona samples was based largely on the depth or shape of the water absorption feature at 1900 nm. Further work on maximising the information available in this part of the spectra is warranted.

7.2 Alteration Mineralogy

- Broad metamorphic alteration in Moonta Porphyry is characterised by the presence of Fe chlorite and muscovite. Regional variation in the nature and composition of these minerals was not investigated but may have significance in identifying metamorphic conditions favourable to development of mineralised districts, particularly along the margin of the Gawler Craton.

- Alteration mineralogy, associated with hydrothermal activity along the Poona lode system, that could be identified from PIMA spectra included:
    - increased Mg content in Fe chlorite, indicated by a weak shift in characteristic absorption from 2350 nm to <2340 nm.

    - change in muscovite composition to approach phengite, defined by a distinct shift in characteristic absorption from around 2200 nm to higher wavelengths up to 2225 nm.
    - presence of tourmaline showing diagnostic absorption features at 2206 nm, 2247 nm and 2364 nm.

  This alteration was generally confined to a narrow zone on either side of the lode ranging from a few metres (phengite and tourmaline) to a few 10s of metres (chlorite). Spectra were often difficult to interpret due to patchy replacement of Fe in chlorite by Mg, and overlapping reflections of kaolin with phengite, or chlorite with tourmaline.

- Alteration due to weathering of the sulphide ore is recognisable in PIMA spectra by the presence of alunite and halloysite (kaolin polymorph) and possibly montmorillonite (after chlorite). Spectral mapping shows the distribution of these minerals as follows:
  - alunite is in close proximity to the weathered ore zone, extending upwards into overlying Hindmarsh Clay.
  - halloysite is broadly distributed in weathered porphyry above the ore body and extends to depths of 80 m as a coating on fractured fresh porphyry and sulphides.
  - montmorillonite, formed from chlorite alteration in Moonta Porphyry, appears to parallel halloysite distribution but has been interpreted from spectra to extend to greater depth. This interpretation requires confirmation by other analytical techniques.

- Regolith boundaries separating surficial sediments, Hindmarsh Clay, weathered and fresh porphyry can be interpreted with a high degree of confidence from the spectra of percussion chip samples.

7.3 Implications for Exploration

- Investigations at Poona indicate that many of the hydrothermal alteration minerals associated with Moonta lode systems can be identified using SWIR analyses. These present limited targets in exploration of narrow vein systems in that they have either a relatively restricted distribution (phengitic muscovite, tourmaline) about the ore body, or are difficult to quantify from the spectral data (e.g. patchy Mg replacement of Fe in chlorite). Larger mineralised veins or stockwork vein systems could be expected to have broader zones of alteration.

- At Poona, weathering of sulphide ore and formation of halloysite appear to be related. Halloysite is broadly distributed in the weathered zone above the ore body and forms coatings on fractures in the porphyry. Halloysite in fractures persists to around 80 m depth in a 20-30 m wide envelope about the ore body. Halloysite can be identified in SWIR spectra and is a potential indicator to mineralisation that could be targeted in shallow exploration holes drilled to sample unweathered basement.

- Regional variation in the composition of mica and chlorite in the Proterozoic basement rocks along the margins of the Gawler Craton could be investigated using SWIR. This was outside the scope of the present investigation but our results indicate the potential for these minerals to define areas of metamorphic/metasomatic alteration that may have associated hydrothermal Fe-Cu-Au mineralisation.

8. ACKNOWLEDGMENTS

The authors gratefully acknowledge advice and assistance from colleagues including Stuart McClure, CSIRO Land and Water, for assistance with the SEM investigations, Joanne Hough (previously Janz) of MESA for advice regarding ore genesis and provision of samples from Poona, Colin Conor of MESA for his views on interpretation of the regional geology and Sasha Pontual, consultant, AusSpec International Pty Ltd, Melbourne, for technical assistance with interpretation of some spectra. Jon Huntington and other members of the P435 research team from CSIRO Division of Mining and Exploration provided ongoing support and critical review of our interpretations of the data.

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Appendix 1: Photomicrographs From SEM Investigation

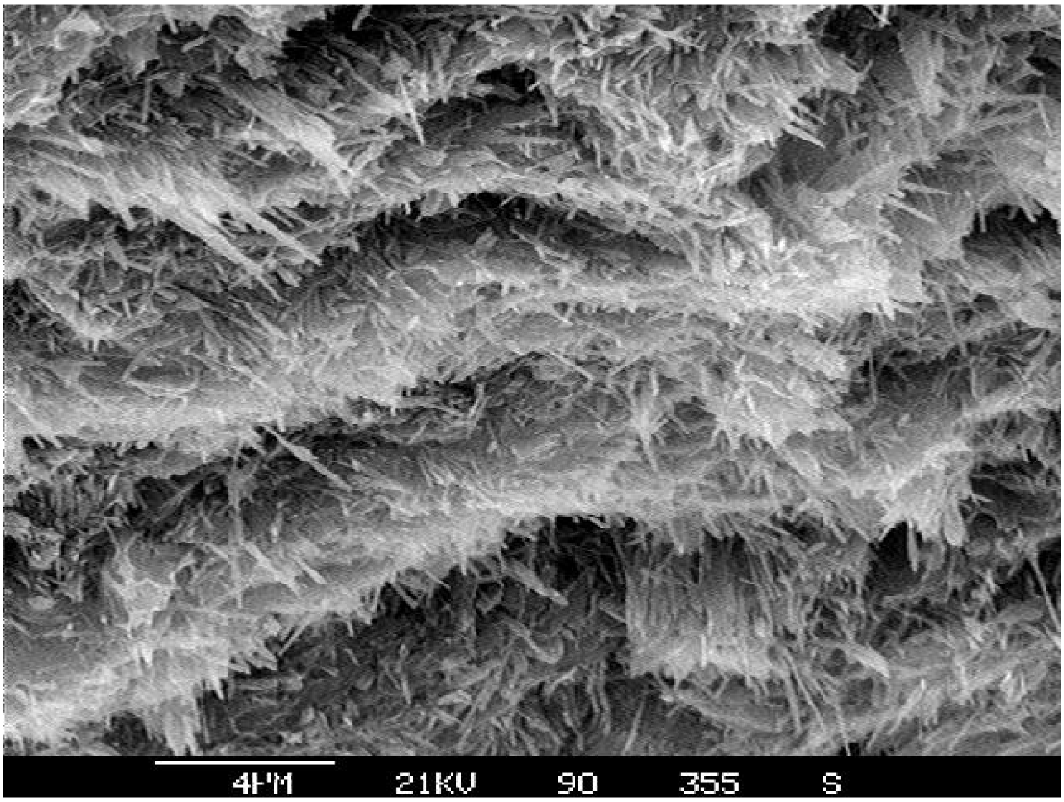

Plate 1: DDH231, 34.1 m (Poon049,). Kaolin on fracture surface deposited as layers comprising tubular halloysite. SEM photo # 90-355. Scale bar 4 µm.

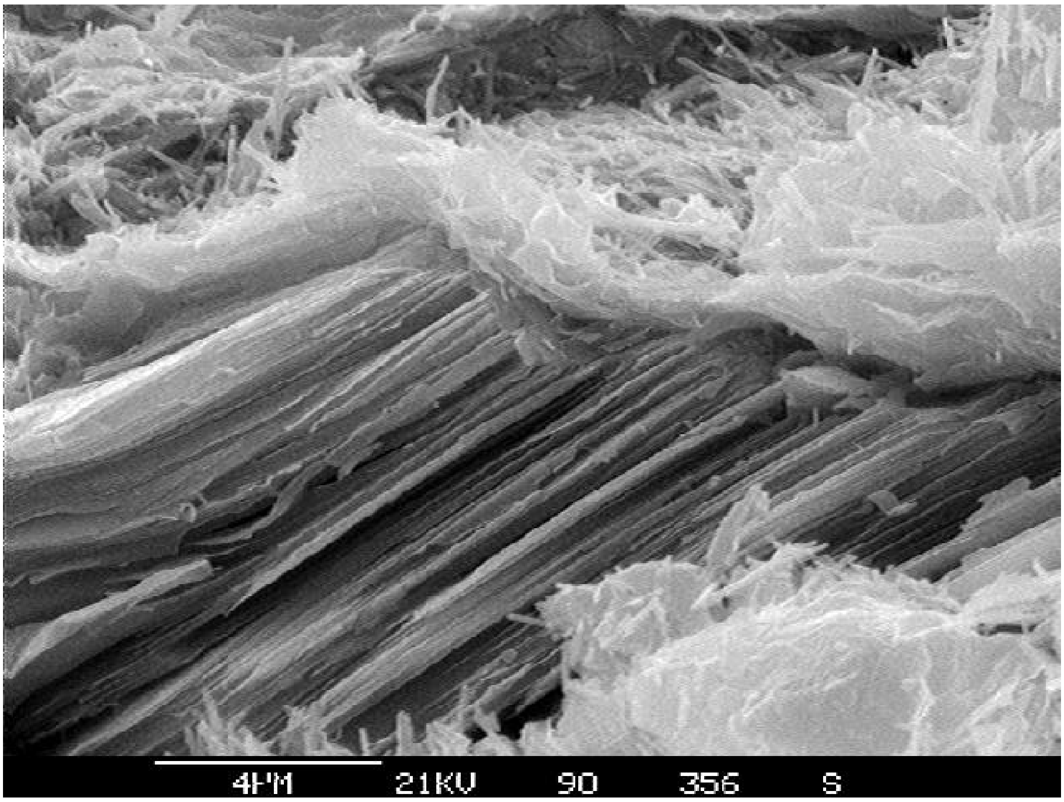

Plate 2: DDH231, 34.1 m (Poon049). Grain of chlorite, partly altered to smectite and coated by kaolinite platelets and tubular halloysite. SEM photo # 90-356. Scale bar 4 µm.

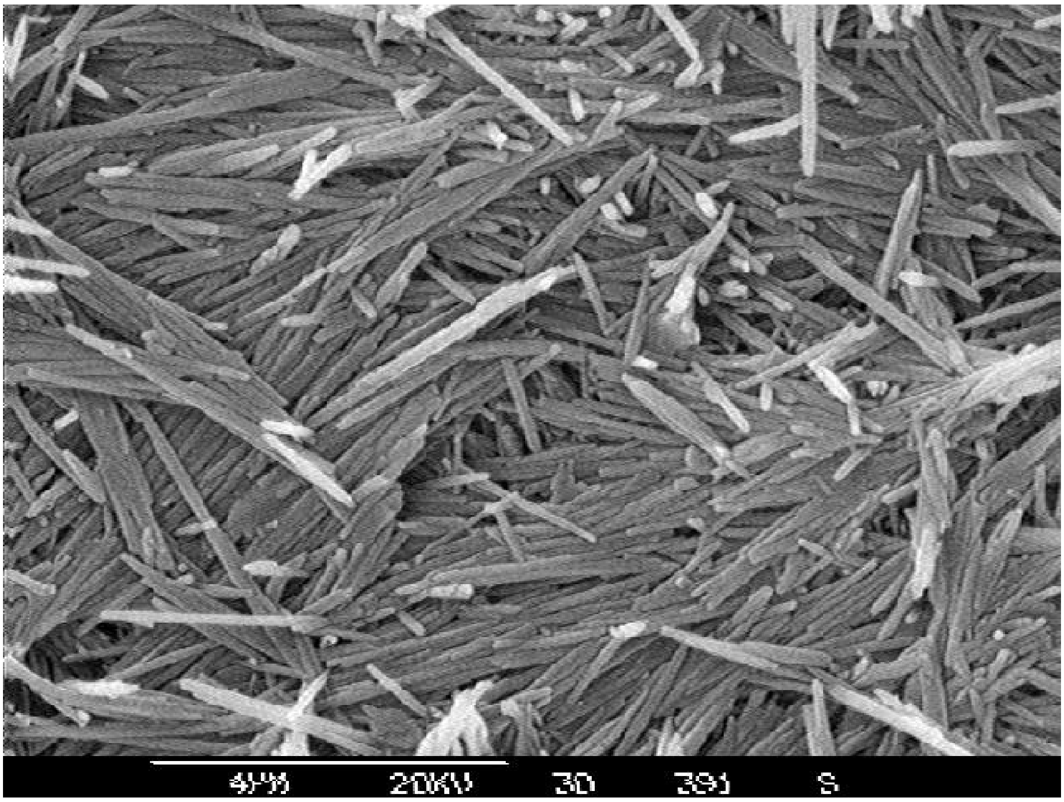

Plate 3: DDH235, 28.4 m (Poona212) Layer of halloysite tubes. SEM photo # 30-381. Scale bar 4 µm.

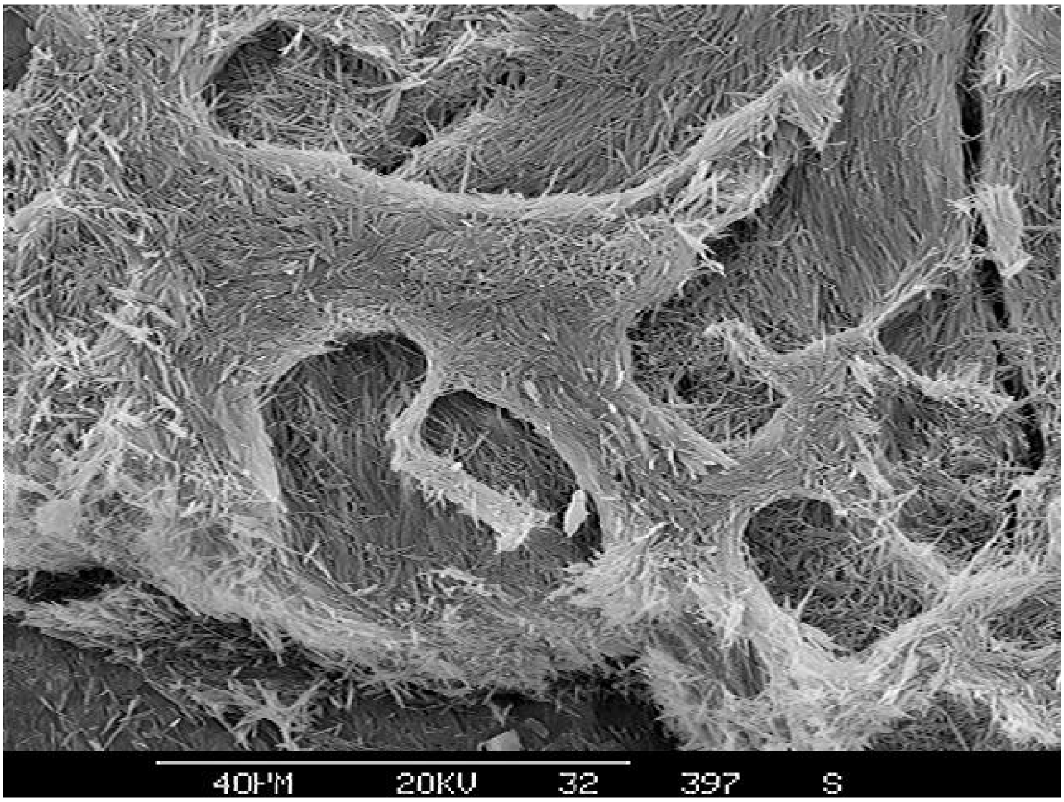

Plate 4: DDH 235, 40.3 m (Poona215). Layering in deposition of halloysite. SEM photo # 32-397. Scale bar 40 µm.

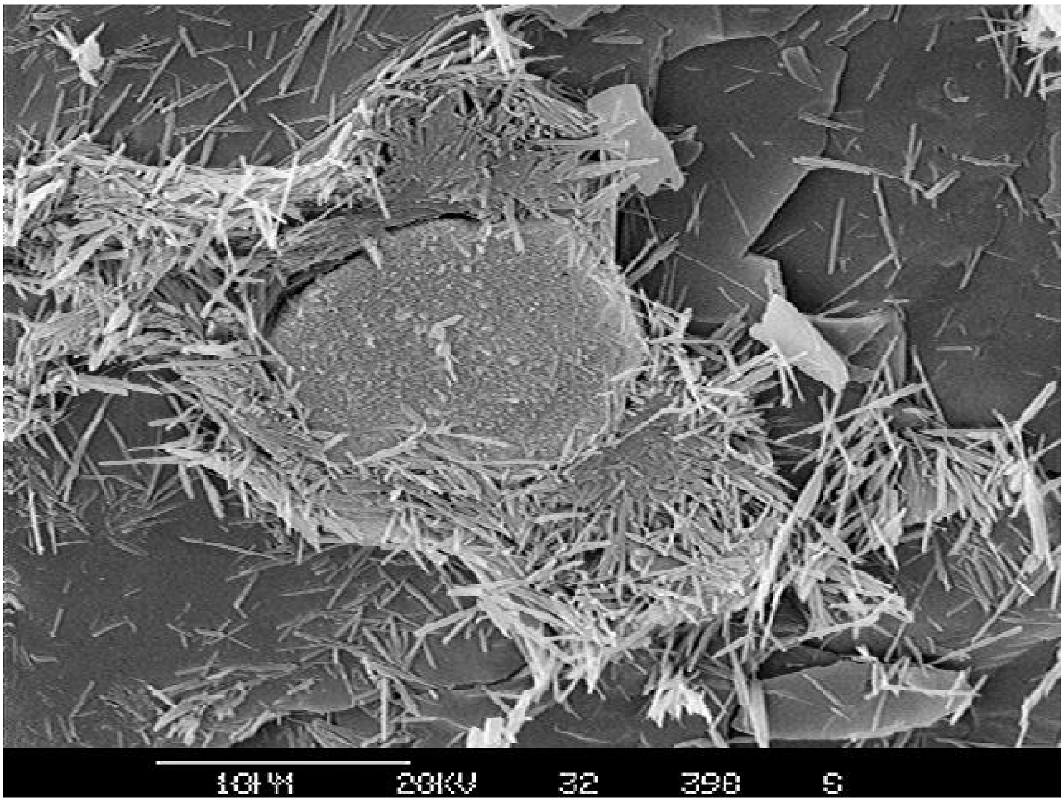

Plate 5: DDH 235, 40.3 m (Poona215). Halloysite tubes coating fracture surface on unweathered feldspar grain. SEM photo # 32-398. Scale bar 10 µm.

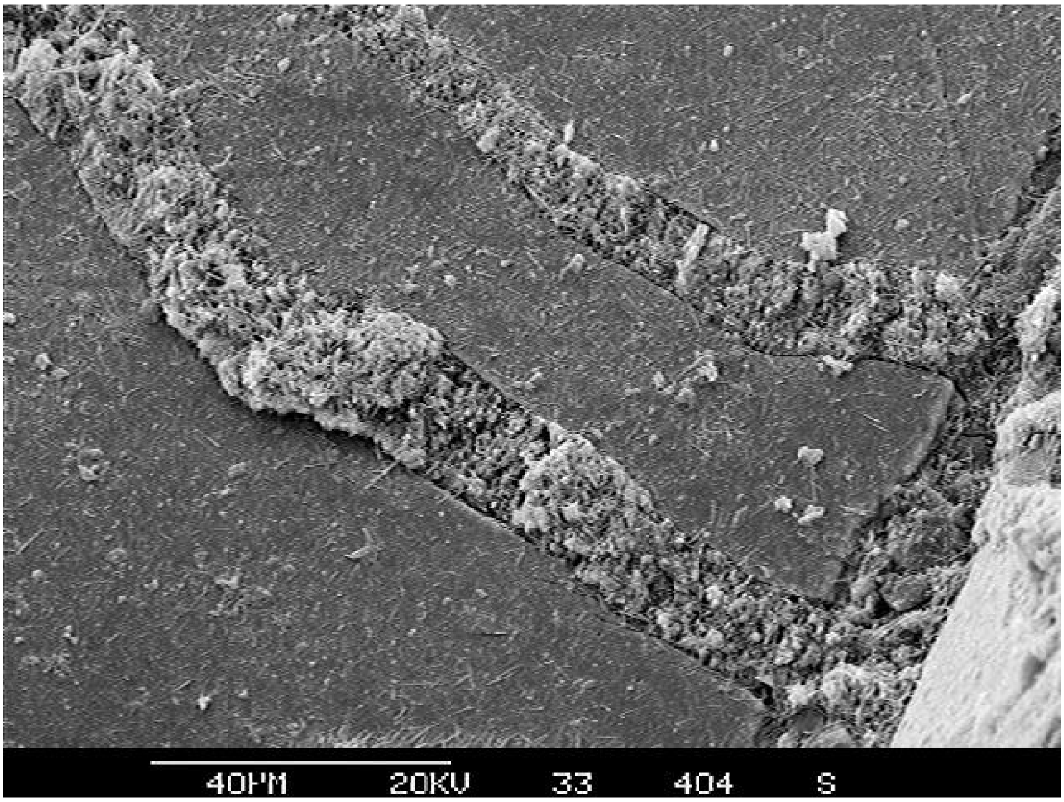

Plate 6: DDH 235, 40.3 m (Poona215). Halloysite veinlets infilling fractures in fresh sulphide grain. SEM photo # 33-404. Scale bar 40 µm.

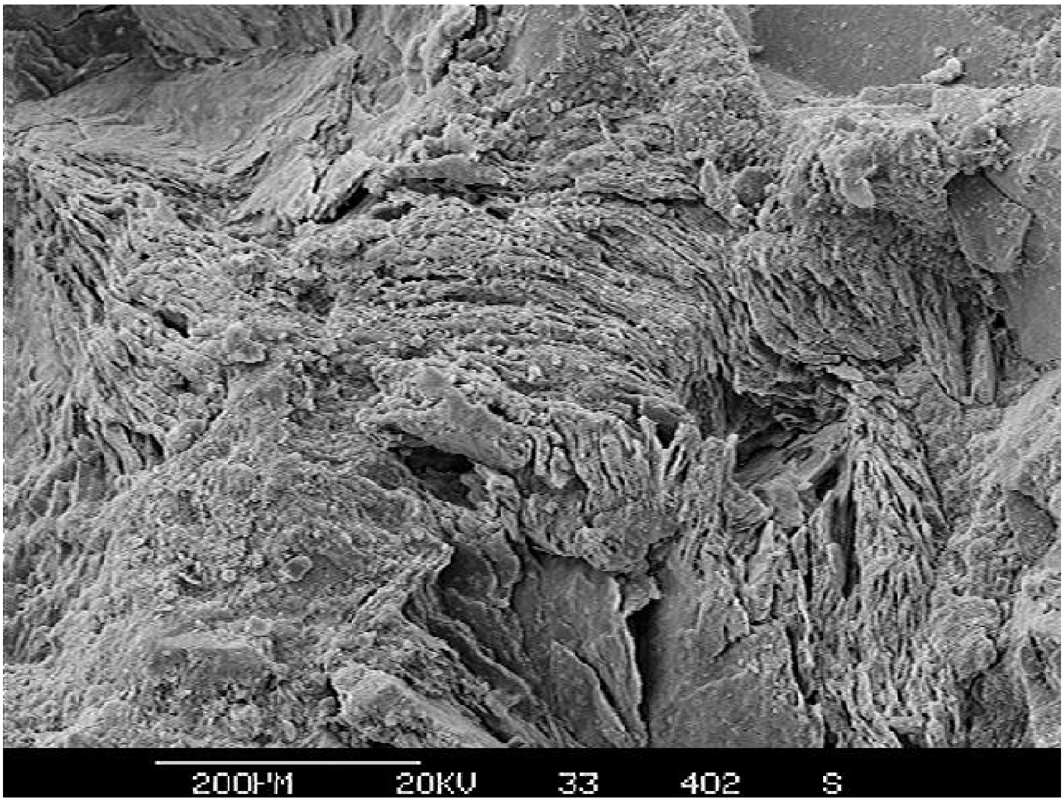

Plate 7: DDH 235, 40.3 m (Poona215). Kaolin veinlet composed of layers of tubular halloysite showing deformation post deposition . SEM photo #33-402. Scale bar 200 µm.

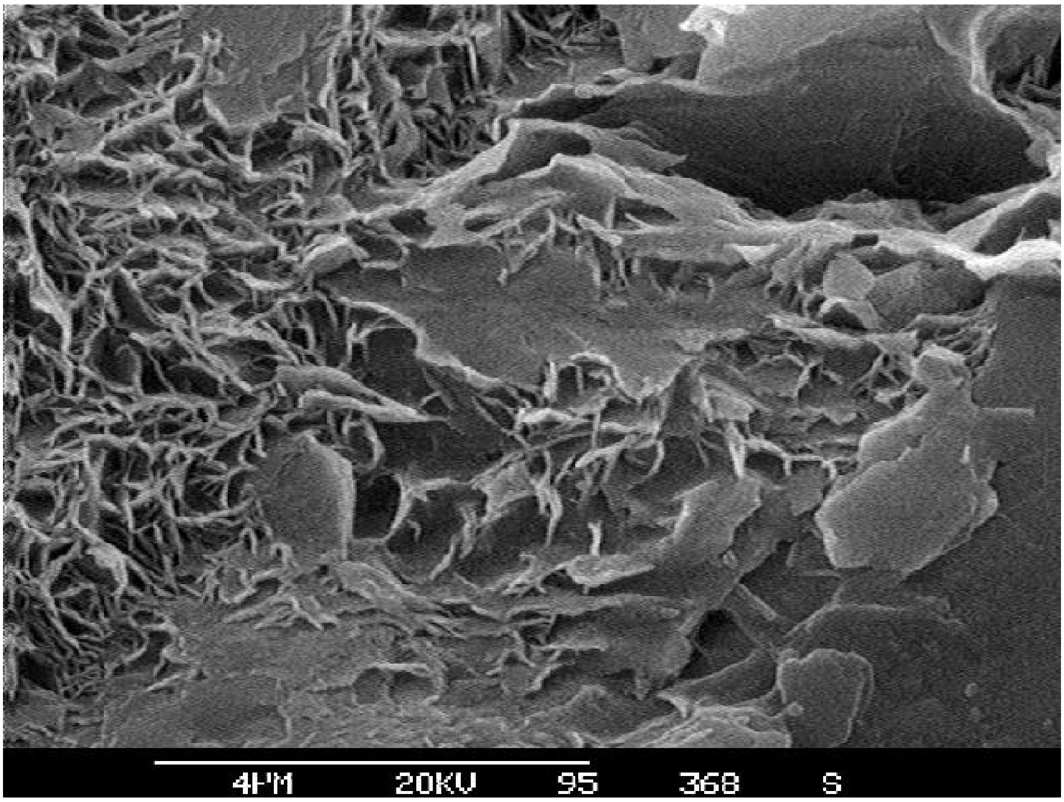

Plate 8: DDH244, 41.5 m, (Poon079). Chlorite almost completely altered to smectite. . SEM photo # 95-368. Scale bar 4 µm.

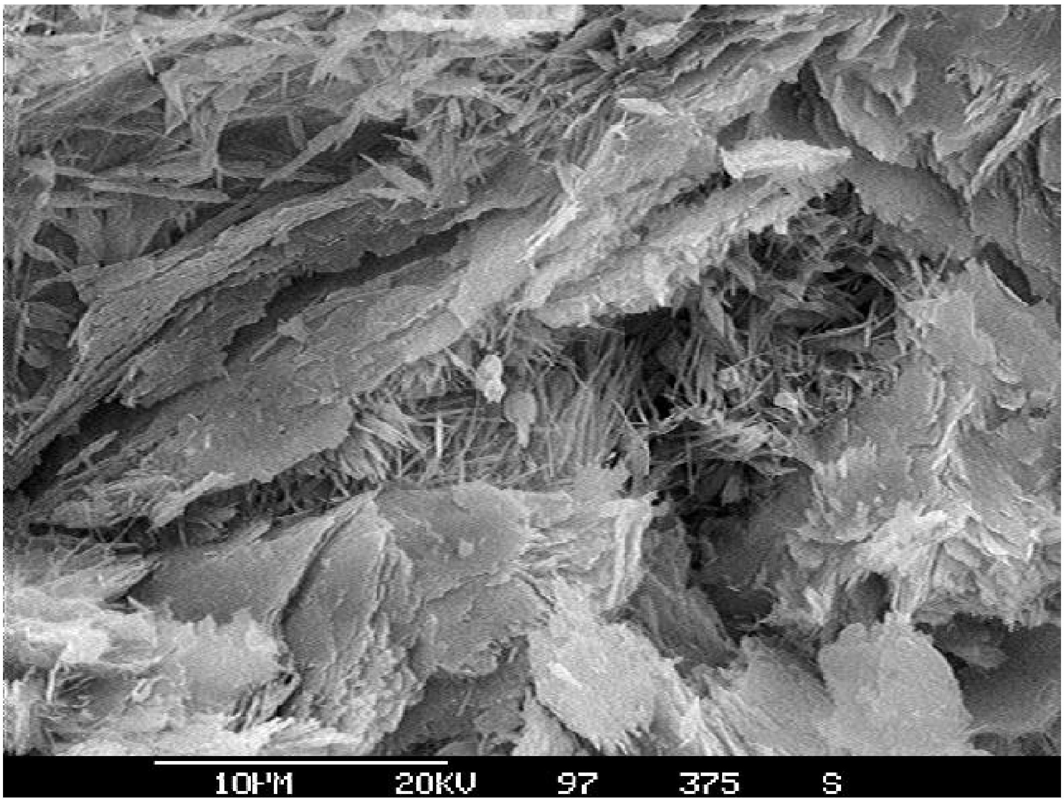

Plate 9: DDH244, 48m (Poon090). SEM Photomicrograph - Ragged-edged kaolinite flakes together with halloysite tubes. SEM photo # 97-375. Scale bar 10 µm.

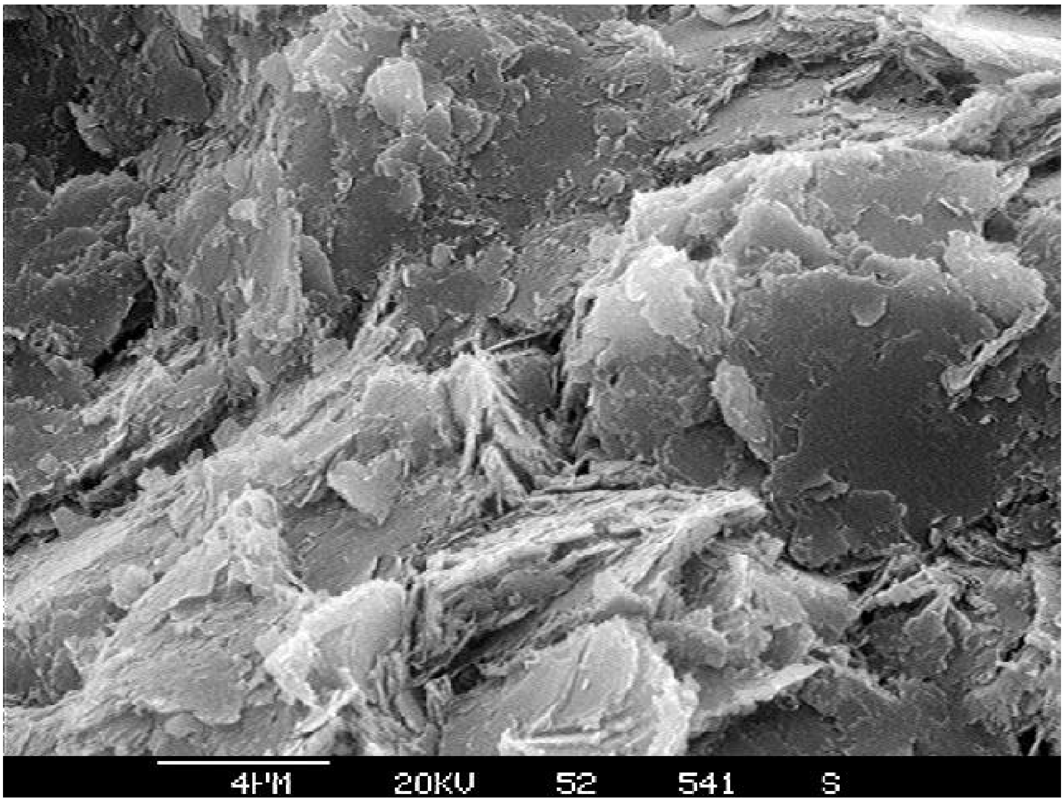

Plate 10: Wallaroo Beach, Alford alteration zone (Alford 04). Ragged-edged kaolinite flakes 1-10 µm across. SEM photo # 52-541. Scale bar 4 µm.

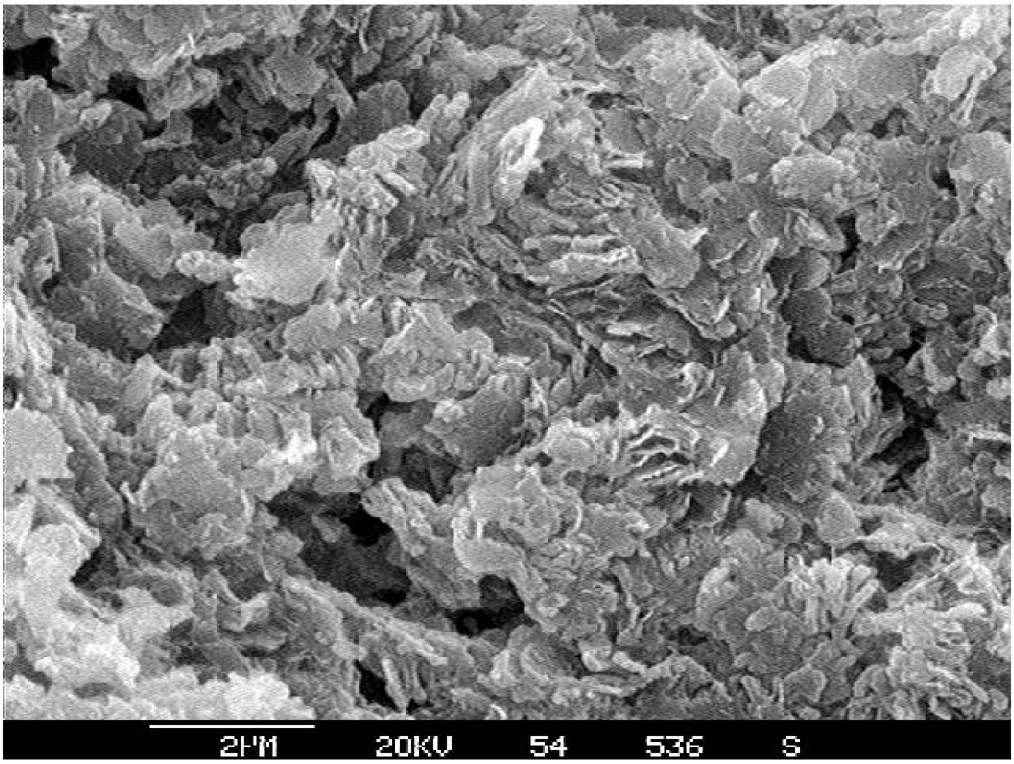

Plate 11: Wallaroo Beach, Alford alteration zone (Alford 05). Porous sample with predominantly fine-grained ragged kaolinite flakes <2 µm across. SEM photo # 54-536. Scale bar 2 µm.

Appendix 2: Microprobe Results

Table 6: Microprobe Results for Mica and Tourmaline

MICAS	18f	19	20	42	43	62	82	Tourmaline	56	121	125
DDH	245			234					234		
DEPTH (m)	72.7	72.7	72.7	82	83.5	102.8	120.4		97.7	139.4	139.7
PIMA 2220	2221	2223	2221	2215	2222						
	ore zone			hw					hw	ore	zone
K	1.44	1.42	1.39	1.57	1.43	1.83	1.64	SiO2	33.54	33.54	34.93
Na	0.03	0.03	0.06	0.04	0.07	0.03	0.05	Al2O3	23.01	24.74	25.89
Ca	0.01	0.01	0.01	0.01	0.01	0.01	0.01	FeO	11.11	12.5	14.01
Ba	0	0	0.01	0	0	0.01	0	MgO	6.74	6.03	5.8
∑	1.48	1.46	1.47	1.62	1.52			CaO	1.81	1.45	0.98
Al	3.21	3.04	2.9	3.36	3.02	0.22	2.96	Na2O	1.82	2.05	2.36
Fe	0.39	0.27	0.38	0.28	0.28	2.74	0.62	K2O	0.04	0.05	0.05
Mg	0.72	0.84	0.97	0.44	0.8	2.49	0.63	TiO2	0.86	1.04	0.71
Ti						0.34	0.01	Cr2O3	0.01	0.01	0.02
∑	4.32	4.15	4.25	4.08	4.1			MnO	0.02	0.03	0.03
Si	6.65	7.17	7.14	6.84	7.23	5.65	6.84				
Al	1.35	0.83	0.86	1.16	0.77	2.35	1.16				
∑	8	8	8	8	8						
OH	3.76	3.64	3.62	3.77	3.66	3.4	3.71				
F	0.22	0.33	0.39	0.21	0.35	0.64	0.24				
Cl	0.01	0.01	0.01	0.01	0.01	0.02	0.02				
Fe*	0.35	24	28	40	26	52.5	49.8	Fe*	48	54	58
F wt%	0.48	0.76	0.86	0.49	0.85			F	0.6	0.61	0.72
Notes	Phengite					Biotite	Phengite		Dravite	Schorl	Schorl

Table 7: Chlorite Microprobe Results

CHLORITES	18f	19	20	30	31	101	27	32	42	43	56	57	62	82	121	124	125	127
DDH	245					244	234											
Depth (m)	72.7	72.7	72.7	78.1	79.5	53.9	52-54	62-64	82	83.5	97.7	99.1	102.8	120.4	139.4	139.7	139.7	140.6
PIMA 2220	2221	2223	2221	2207	2221	2223												
PIMA 2260	2248	2246	2256	2254	2252	2252	2260	2256	2256	2252	2245	2258	2256	2260	2254	2259	2263	2262
	ore			fw			hw/distal											
Fe	6.65	5.38	4.99	4.22	4.9	4.62	5.43	5.44	4.62	5.23	5.36	5.03	5.35	6.18	4.51	5.73	4.98	5.31
Mg	2.84	4.48	4.85	5.45	5.18	5.3	4.23	4.09	4.63	4.18	4.35	4.89	4.26	3.24	5.16	3.75	4.69	4.47
Al	2.52	2.16	2.15	2.18	1.96	2.05	2.22	2.36	2.51	2.52	2.21	2.06	2.31	2.49	2.25	2.42	2.29	2.2
Cr	0	0	0	0	0	0	0	0	0	0								
V	0	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0.01	0	0	0
Ti	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0	0.02	0.01	0	0.01	0	0
Ca	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0.01	0	0.01	0.01	0
Na	0.04	0.03	0.01	0.06	0.01	0.02	0.02	0.03	0.01	0.01	0.05	0.01	0.02	0.03	0	0.02	0	0.01
K	0.01	0	0.01	0.03	0.01	0.01	0.01	0.01	0.03	0.01	0	0	0	0.01	0	0.02	0	0.01
∑	12.08	12.09	12.04	11.97	12.09	12.04	11.93	11.95	11.82	11.96								
Si	5.37	5.7	5.81	5.95	5.88	5.86	5.9	5.78	5.86	5.56	5.86	5.9	5.77	5.57	5.86	5.68	5.75	5.82
Al	2.63	2.3	2.19	2.05	2.12	2.14	2.1	2.22	2.14	2.44	2.14	2.1	2.23	2.43	2.14	2.32	2.25	2.18
∑	8	8	8	8	8	8			8	8								
OH	15.93	15.91	15.84	15.7	15.75	15.78	15.77	15.83	15.8	15.83	15.8	15.68	15.87	15.9	15.76	15.88	15.79	15.85
F	0.06	0.14	0.2	0.3	0.25	0.22	0.18	0.14	0.18	0.13	0.18	0.26	0.13	0.08	0.2	0.1	0.17	0.14
Cl	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01
Fe*	70	55	51	44	49	47	56	57	50	56	55.2	50.7	55.7	65.6	46.7	60.5	51.5	54.3
Fe* range	63-77		46-57					49-60		49-59	50-60				38-62	51-71	37-54	47-63
F(wt%)	0.08	0.19	0.26	0.42	0.33	0.31	0.23	0.2	0.24	0.18								
FeO(wt%)	32.34	27.11	25.12	21.95	24.69	24.44			23.41	26.54								
MgO(wt%)	7.74	12.67	13.71	15.94	14.65	15.74			13.16	11.9								
Significant variation	*		*	*		*				*								
Note:	Fe* = 100 x (Fe/Fe+Mg)										55.2 for biotite							

Table 8: Moonta Chlorite Microprobe Analyses: Adelaide University (calculated from Hafer,1991)

CHLORITES	953-152	953-100	953-104	953-145	953-148	953-114	953-149	953-107
Fe	5.35	6.37	7.00	4.60	5.39	7.11	6.84	6.49
Mg	3.38	2.80	1.90	4.95	3.45	1.99	1.95	2.78
Al	2.82	2.73	2.87	2.34	2.89	2.69	2.94	2.56
Ca	0.05	0.03	0.03	0.02	0.03	0.03	0.03	0.04
Na	0.09	0.03	0.03	0.05	0.02	0.03	0.02	0.04
K	0.02	0	0.0	0.0	0.0	0.01	0.01	0.01
Ti	.01	.01	.01	0	.01	0	.01	.01
∑	11.72	11.97	11.84	11.96	11.79	11.86	11.80	11.93
Si	5.72	5.34	5.44	5.70	5.50	5.56	5.44	5.60
Al	2.28	2.66	2.56	2.30	2.50	2.44	2.56	2.40
∑	8	8	8	8	8	8	8	8
OH (calc)	15.98	16.03	16.01	15.96	15.99	15.96	15.99	16.02
Fe*	61	69	79	48	61	78	78	70

Appendix 3: Backscatter Electron Images From Microprobe Study

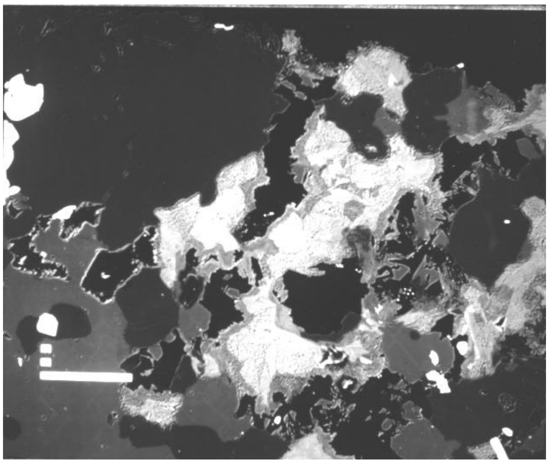

Plate 12: Zoned hanging wall chlorite, brighter areas Fe-rich, darker ring more Mg-rich. Darker areas are quartz and feldspar. White area are Fe oxide.
Scale bar = 100 microns. Sample Poona056 (DDH 234:97.7m). (Neg 5537)

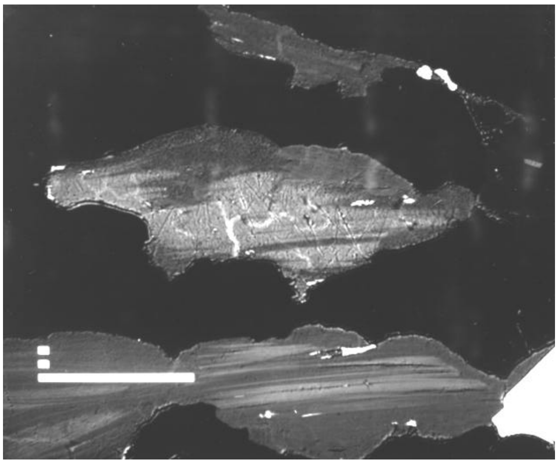

Plate 13: Biotite (light grey) and chlorite (darker grey) in albite (black). (White = rutile). Scale bar = 100 microns. Sample Poona062 (DDH 234:102.8m). (Neg 5538)

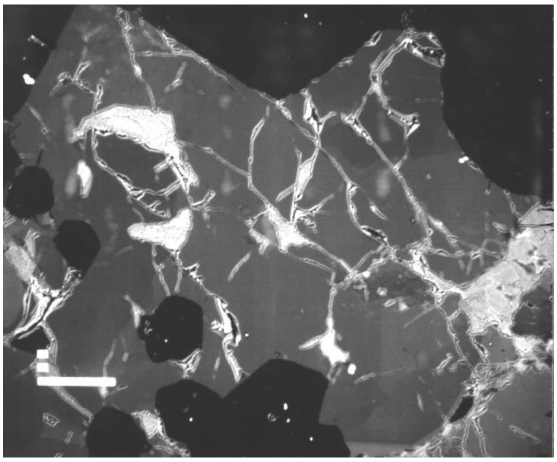

Plate 14: Schorl (dark grey) cut by Fe chlorite (pale grey) in ore zone. Black = quartz.
Scale bar = 100 microns. Sample Poona121 (DDH 234:139.4m) (Neg 5540)

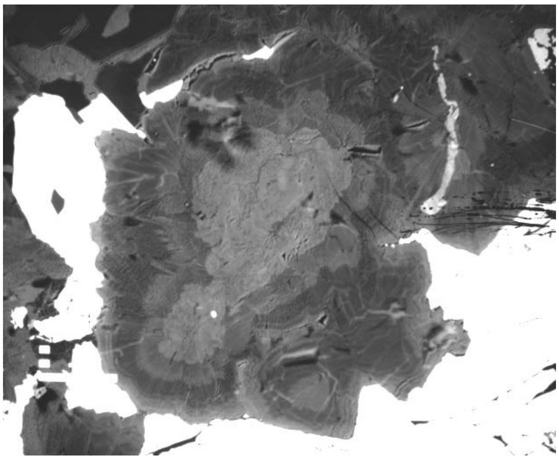

Plate 15: Zoned low Fe chlorite (grey) in chalcopyrite (white). Brightest sections of chlorite have the highest Fe content.
Scale bar = 100 microns. Sample Poona121 (DDH 234:139.4m). (Neg 5541)

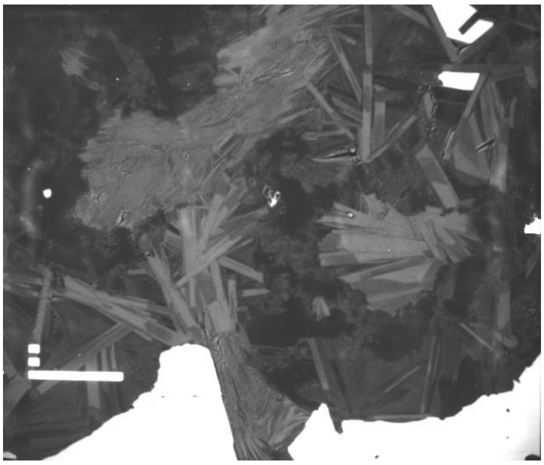

Plate 16: Zoned chlorites (pale grey) in ore zone with brighter areas representing more Fe rich. Grey background is K-feldspar, white is chalcopyrite.
Scale bar = 100 microns. Sample Poona 124 (DDH 234:139.7m) (Neg 5544)

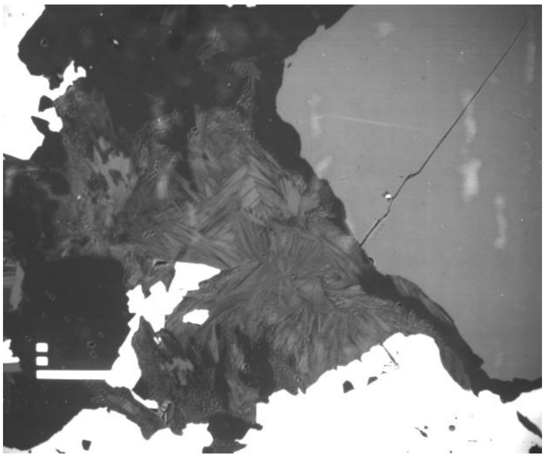

Plate 17: Compositional variations in chlorite in ore zone, brighter areas more Fe rich. Large grey grain is apatite, white is chalcopyrite, dark matrix is K-feldspar. Scale bar = 100 microns. Sample Poona 124 (DDH 234:139.7m) (Neg 5546)

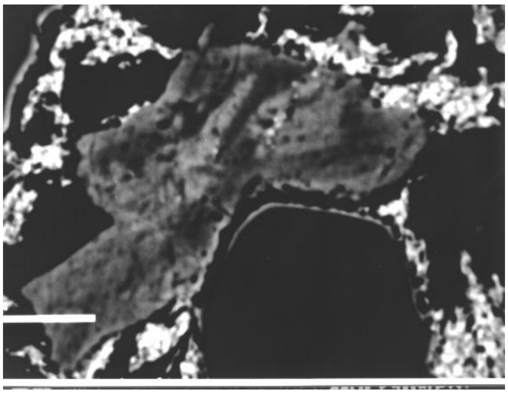

Plate 18: Compositional variations in ore zone chlorite, brighter areas more Fe rich. Scale bar = 10 microns. Sample Poon018f (DDH 245:72.7m). (Neg 5442)

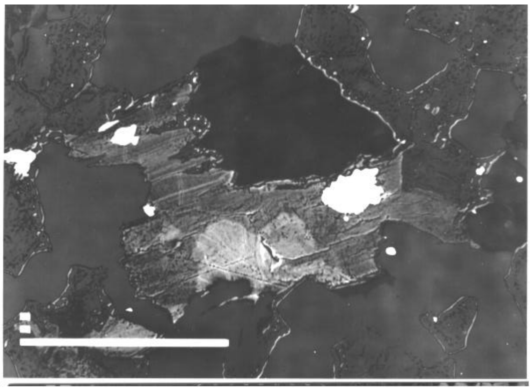

Plate 19: Compositional variations in ore zone chlorite, brighter areas more Fe rich (Black areas = K-feldspar, white = rutile). Scale bar = 100 microns. Sample Poon20 (DDH 245:72.7m). (Neg 5443)