NICKEL

GEOPHYSICAL SIGNATURE OF THE SALLY MALAY NICKEL DEPOSIT, WESTERN AUSTRALIA

Kim Frankcombe[1], Gordon Barnes[1] & Devin Trussell[2]

1. Normandy Exploration Ltd, 8 Kings Park Road, West Perth, W.A. 6005
2. Computer Transition Systems, P.O. Box 4553, Melbourne, Vic. 3001
(formerly Australian Anglo American Ltd)

ABSTRACT

The Sally Malay nickel deposit has clear physical property contrasts with its host rocks and therefore lends itself to detection and mapping by geophysical methods. Conductivities as high as 30,000 S/m compared to the resistive country rock mean that electromagnetics is the best method for locating and mapping such a deposit. The magnetic susceptibility and chargeability are two orders of magnitude higher than the country rock, making magnetics and induced polarisation useful methods. Although there is a density contrast of 1 g/cm^3, the gravity method was not used, largely because of the success of electromagnetics, but also because of the steep topography around the deposit.

Its short strike length means that the mineralisation does not make a good airborne target using conventional line spacings.

KEY WORDS: Dixon Range SE52-6, downhole logging, electromagnetics, gabbro-hosted copper-nickel, Halls Creek Mobile Zone, induced polarisation, magnetic induced polarisation, magnetics, mise-a-la-masse

INTRODUCTION

The Sally Malay deposit was discovered in 1974 by Australian Anglo American Ltd as a result of a regional stream-sediment geochemical programme. The next four years were spent evaluating the deposit by mapping, drilling 95 diamond holes (26,430 m) and trialing numerous geophysical methods, many in their early stages of development. Australian Anglo American Ltd was acquired by Normandy Poseidon Ltd in 1989 and an extensive review of their work was conducted. As a result of this review, further exploration work was undertaken, again including a component of geophysics, to test for strike extensions of the mineralisation at depth.

GEOLOGIC SETTING

The Sally Malay deposit is situated in the Halls Creek Mobile Zone, a Proterozoic orogen on the eastern flank of the early to mid-Proterozoic Kimberley Basin (Fig. 1). The Halls Creek Mobile Zone includes structurally complex areas of metamorphosed sedimentary rocks and intrusive and extrusive igneous rocks called the Lamboo Complex. The Lamboo Complex has been subdivided by Thornett (1986) into the Early Lamboo Complex and the Late Lamboo Complex. The Early Lamboo Complex consists of the Tickalara Metamorphics and Mabel Downs Granodiorite while the Late Lamboo Complex is made up from differentiated mafic to ultramafic intrusions with associated granitoids and later mafic and felsic dykes. The Tickalara Metamorphics contain pelitic to psammitic gneisses, marble and mafic to ultramafic granulite intrusive and extrusive rocks. The Sally Malay intrusion and its satellite plutons are part of the Late Lamboo Complex which intruded the granulite-facies portion of the Tickalara Metamorphics. A detailed discussion of the geology of the deposit and the region is given by Thornett (1981, 1986), and a more general overview of the metallurgy of the Halls Creek Mobile Zone is provided by Plumb (1990). The orogenic activity has produced steep dips (75-105°) and the resulting landform consists of saw-tooth ridges. Although the amplitude of the topography around the deposit is less than 100 m, the slope is steep.

The ore is contained within the basal chilled margin of a layered mafic to ultramafic intrusion which has been rotated through 90°. Current estimates of reserves to 900 m subsurface are 5 Mt of 1.7 wt % Ni, 0.6 wt % Cu and 0.1 wt % Co. The deposit is considered marginal to sub-economic. A gossan marks the surface projection of the 200 m long orebody (Fig. 2) which is believed to extend below the present limit of drilling at 900 m. The mineralisation dips steeply to the north but is thought to be cut by several low-angle faults giving it an overall southerly apparent dip. About 500 m below surface, a major low-angle fault displaces the body to the north by about 200 m (see cross section and bench plans in Fig. 3).

METHODS

Geophysics played an important role in Australian Anglo American's exploration of the deposit in the years following its discovery. This commenced with AEM (INPUT Mk V) followed by mise-a-la-masse, ground EM, IP and ground magnetics in quick succession, all within the discovery year. Later helicopter

In "Geophysical Signatures of Western Australian Mineral Deposits", Geology and Geophysics Department (Key Centre) & UWA Extension, The University of Western Australia, Publication No. 26, 1994, pages 157-168

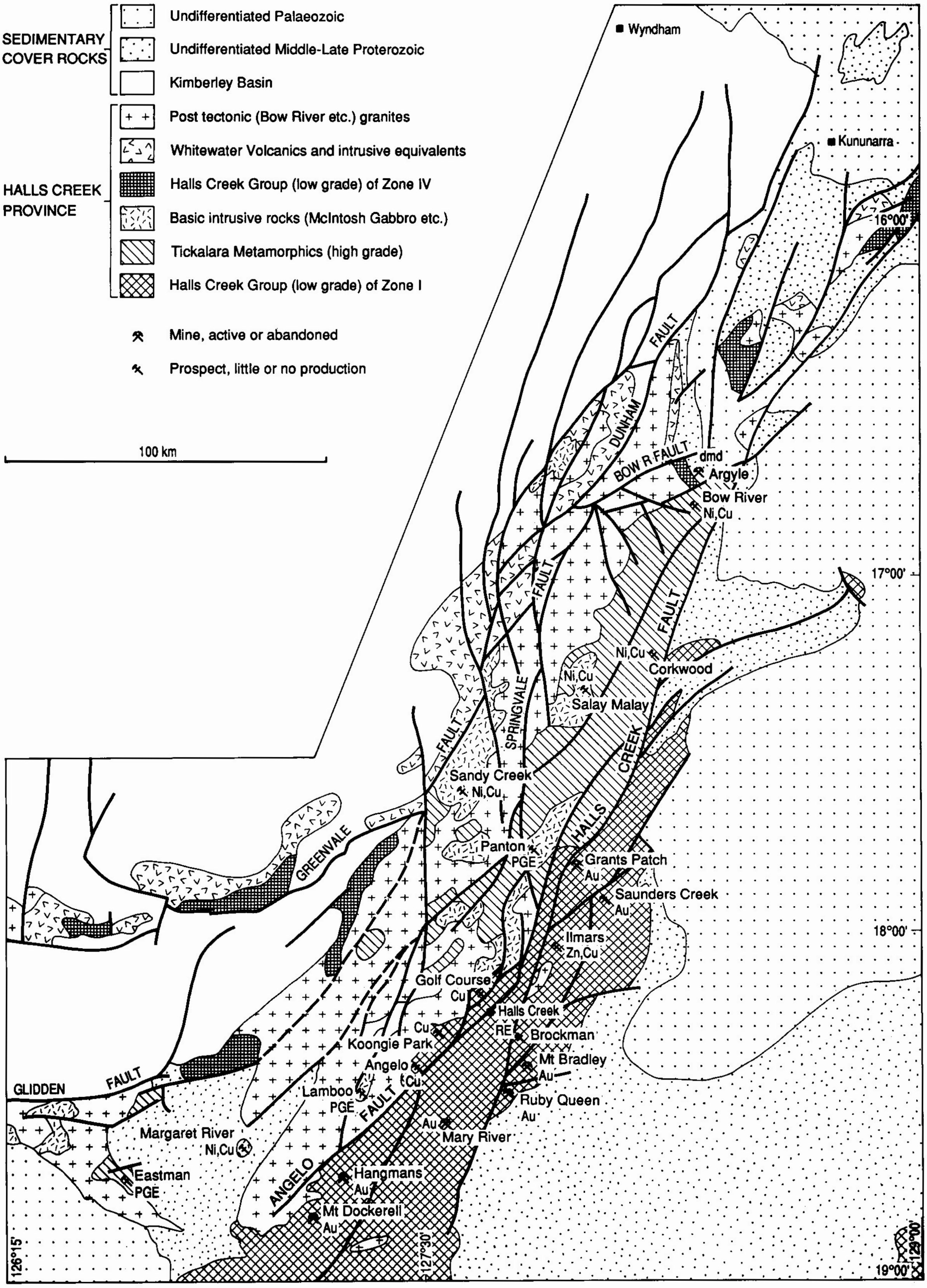
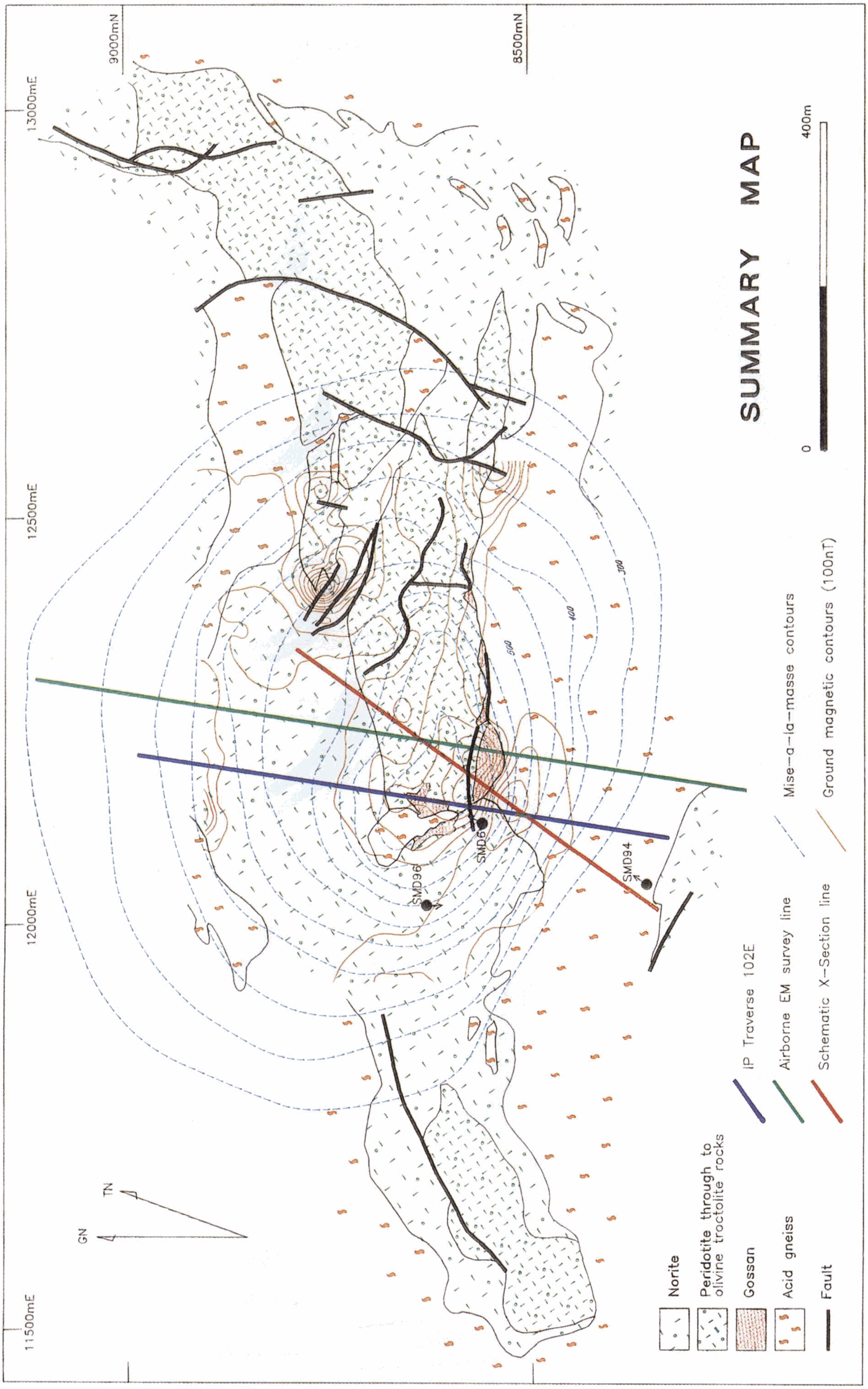
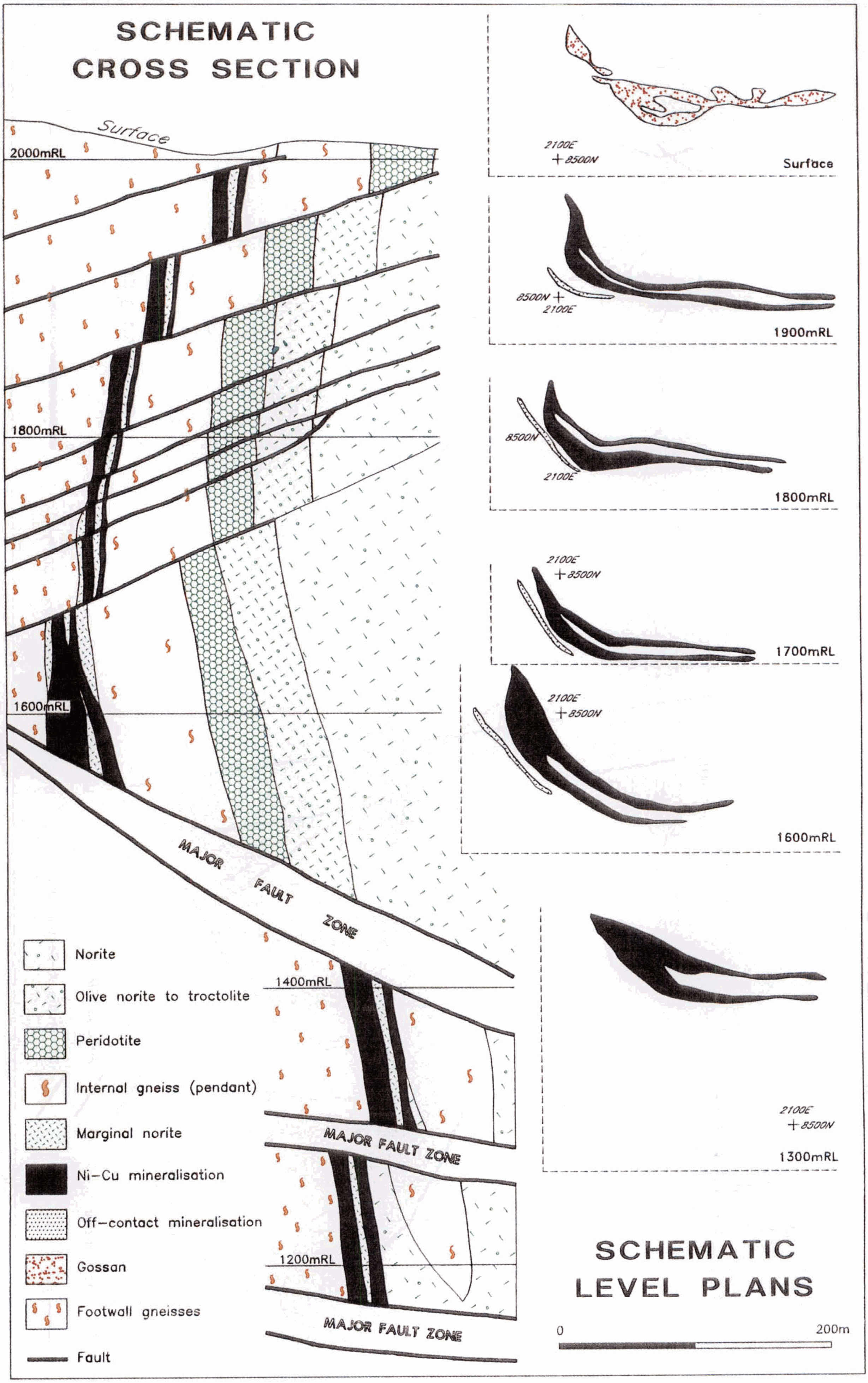


FIGURE 1 Geology and mineral deposits of the Halls Creek Mobile Zone. After Plumb (1990).

FIGURE 2 (facing page) Geology of the Sally Malay deposit showing location of traverses, drillholes mentioned in text, and mise-a-la-masse and ground magnetic contours.


SUMMARY MAP
0
400m
13000mE
12500mE
12000mE
11500mE
9000mN
8500mN
GN
TN
SMD6
SMD94
SMD96
300
400
500
Norite
Peridotite through to olivine troctolite rocks
Gossan
Acid gneiss
Fault
IP Traverse 102E
Airborne EM survey line
Schematic X-Section line
Mise-a-la-masse contours
Ground magnetic contours (100nT)



SCHEMATIC CROSS SECTION
Surface
2000mRL
1800mRL
1600mRL
1400mRL
1200mRL
MAJOR FAULT ZONE
MAJOR FAULT ZONE
MAJOR FAULT ZONE
Norite
Olive norite to troctolite
Peridotite
Internal gneiss (pendant)
Marginal norite
Ni–Cu mineralisation
Off–contact mineralisation
Gossan
Footwall gneisses
Fault
2100E
8500N
Surface
1900mRL
1800mRL
1700mRL
1600mRL
1300mRL
SCHEMATIC LEVEL PLANS
0
200m

TABLE 1 Physical properties of ore from the Sally Malay deposit and country rocks.

PROPERTY	ORE	COUNTRY ROCK
CONDUCTIVITY (S/m)	7,000 – 30,000	not measurable
SUSCEPTIBILITY (SI)	0.03 – 0.9	0.00002 – 0.0075
KOENIGSBERGER RATIO	0.2 – 5	0.01 – 20
DENSITY (g/cm^3)	3.6 – 4.8	2.6 – 3.2
CHARGEABILITY (ms)	200 – 400	0 – 5

EM (DIGHEM), further ground magnetics and EM as well as RRMIP and a re-flight of AEM (INPUT Mk V-12) were carried out. Following the Normandy Poseidon takeover of the project, ground and airborne magnetics, fixed-loop TEM and downhole TEM and gamma and density logs were acquired. Both Anglo American and Normandy Poseidon undertook physical property measurements of the core. The results of this work are covered by method rather than chronologically in this paper.

PHYSICAL PROPERTIES

The ore consists of massive pyrrhotite-pentlandite-chalcopyrite up to 30 m thick and a halo of stringer sulphide, also massive from a geophysical perspective. The dominant sulphide is pyrrhotite (50 to 80 vol. % of massive ore) with subordinate pentlandite and chalcopyrite. Physical properties of the ore and country rock obtained from measurements on core are compared in Table 1. Clearly, the Sally Malay mineralisation is an excellent target for a number of geophysical methods.

AIRBORNE ELECTROMAGNETICS

The original INPUT Mk V AEM survey was flown in May 1973 before the discovery, and was re-flown in 1976 with the same system. The flight line is about 20 m to the east of the path indicated in Figure 2 and passes over a thinner part of the orebody than the later surveys. The response was marginally above the noise level of the system and certainly not sufficient to warrant follow up on a reconnaissance survey. The results from the 1976 re-flight are shown in Figure 4. Unfortunately, the original analogue records could not be located so there is no vertical scale on the EM traces. The INPUT system was, however, analogue so, in order for a response to warrant follow up, it had to show on the field records. Given the very high conductivity contrast between the deposit and the country rock, the poor response of this system may seem a little difficult to reconcile. Opinion around the time of the re-flight ascribed the low response to topographic problems. The altimeter trace on the analogue records shows 50 m variation in aircraft elevation for a 400 m line length over the mineralisation. While this certainly would have contributed to the masking of the response, the high time constant (2 to 5 s), high noise level and short pulse width (1 ms) of the Mk V system combined with ore conductivities well beyond the inductive limit of the system would not have helped.

A DIGHEM survey flown in August 1979 clearly detected the mineralisation on lines up to 40 m from the known strike extent of the mineralisation. This survey was flown at 50 m using a transmitter-receiver separation of 9 m and an operating frequency of 900 Hz. The results of a line very close to the path shown on Figure 2 are shown in Figure 4. A trial survey was flown in 1983 with INPUT Mark V-12. Considerable care was taken this time to maintain even terrain clearance and the flight line passed over a thicker section of the orebody. The mineralisation was clearly detected and, as with the DIGHEM, the profiles indicate a northerly dip (Fig. 4).

This comparison of the three systems is both an impressive example of the differences in AEM acquisition systems and an important reminder to present explorers not to rely too heavily on old data or, at least, not to write off ground on the basis of it. It would be interesting to compare the response obtained over the deposit with modern digital airborne EM systems with signal-noise ratios at least two orders of magnitude higher than the INPUT system.

AIRBORNE MAGNETICS

Airborne magnetics was flown with each generation of AEM and resolved clear anomalies in all cases, from about 10 nT in the original INPUT Mk V survey to around 150 nT from the lower altitude DIGHEM survey (Fig. 4). More recently, the deposit fell within the area of a multi-client aeromagnetic survey using 200 m east-west line spacing and 60 m elevation. The deposit unfortunately sits midway between two flight lines and a muted response of only 10 to 20 nT in a background of several hundred nanoTeslas was recorded. In terms of the regional magnetics, it is unlikely one could use airborne magnetics as a direct detection targeting tool. As always, however, it has a mapping role.

MISE-A-LA-MASSE

A mise-a-la-masse survey was carried out in November 1974 using a current electrode placed within mineralisation in drillhole SMD6 (see Fig. 2 for location). The contours outline the surface projection of the upper part of the mineralisation and confirm the true dip. The low-amplitude lobe in the northeast of the roughly circular contour pattern is most probably an artifact of the steep topography.

FIGURE 3 (facing page) Schematic cross-section and bench plans of the Sally Malay deposit.

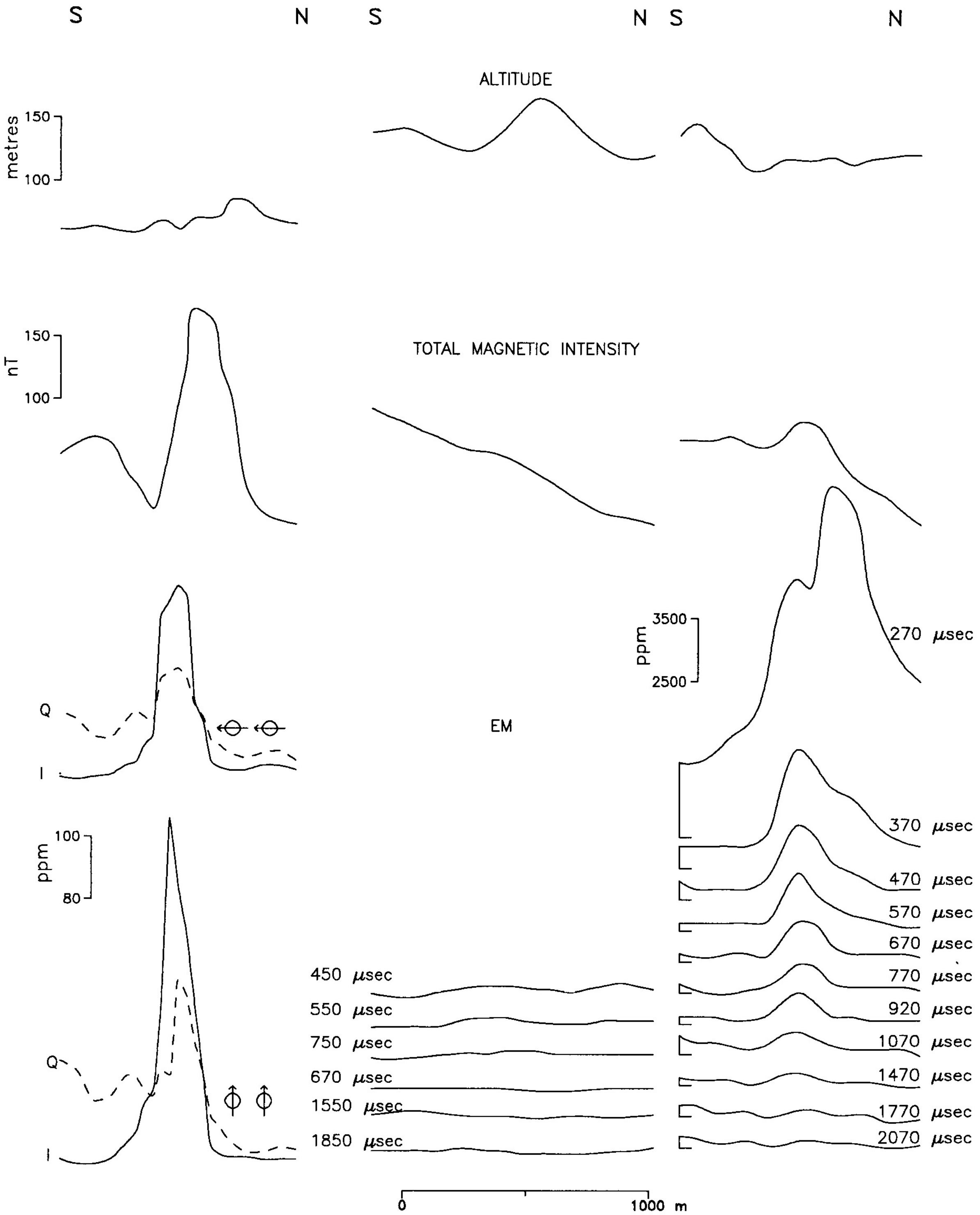


FIGURE 4 AEM profiles for a similar flight line using DIGHEM, INPUT V and INPUT V-12 systems. All profiles were flown in a southerly direction. The magnetic and altitude traces for each system have common scales but the EM has been scaled independently. The DIGHEM EM traces are for in-phase (I) and quadrature (Q), and the coil configuration (co-planar vertical and co-planar horizontal) are shown beside each trace pair. INPUT V data were digitised from field plots without a vertical scale but are likely to be scaled differently for each window. All EM channels on the INPUT V-12 data have the same vertical scale. Window times for both INPUT systems are shown above the respective traces.

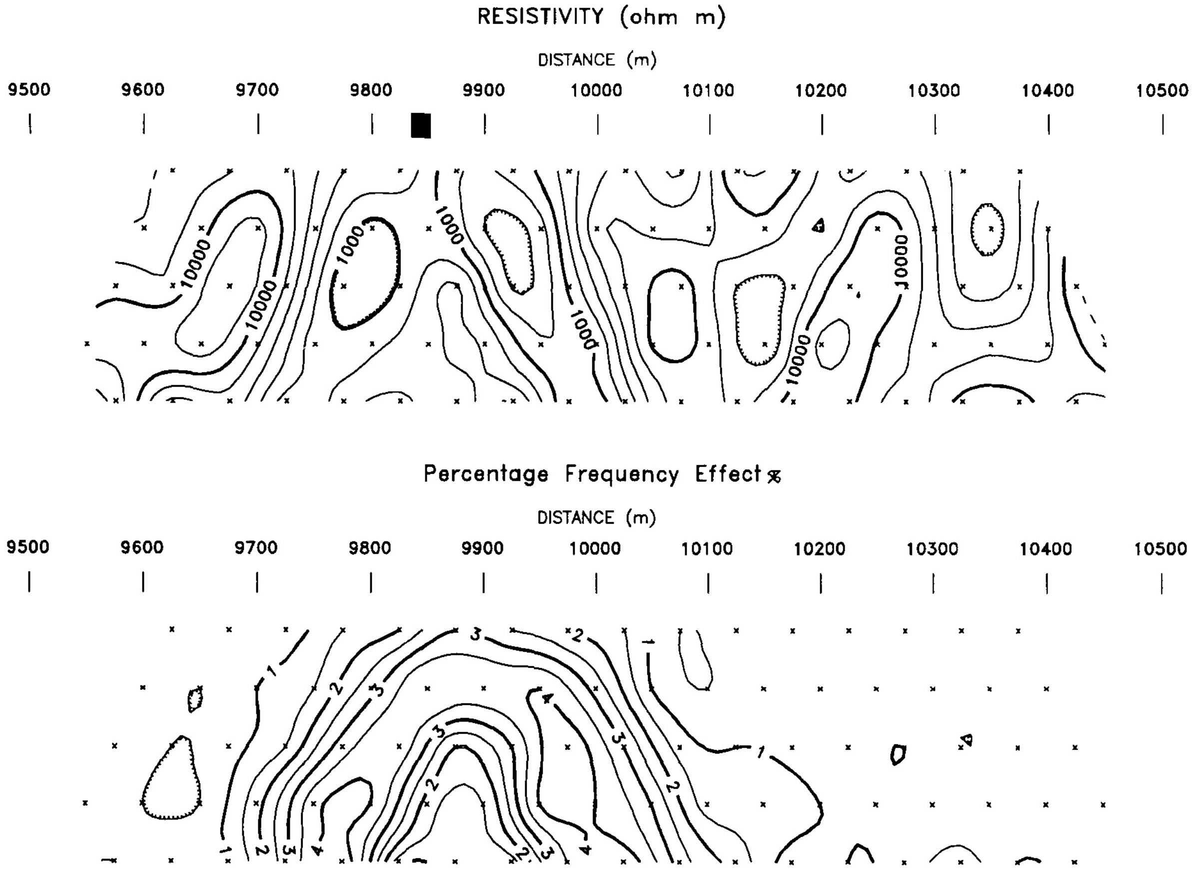


FIGURE 5 Dipole-dipole IP pseudosection line 102E on old grid. The location is shown on Figure 2. The electrode separation was 50 m. The black marker indicates the location of the gossan.

INDUCED POLARISATION

Dipole-dipole frequency-domain IP was collected by the same crew as the mise-a-la-masse, also in November 1974. Frequencies of 0.3 and 2.5 Hz were used with a dipole spacing of 50 and 100 m. Clear polarisation and resistivity anomalies are evident over the mineralisation (Fig. 5). The IP line was made on an old grid, the distance coordinates are therefore different to the figures that follow. The IP results indicate a northerly dip suggesting relatively shallow penetration.

GROUND MAGNETICS

Several generations of ground magnetic data were acquired, each with improved specifications. The latest was undertaken by Poseidon Exploration in November 1990 and used a station spacing of 5 m on 50 m lines. The results are shown in simplified form in Figure 2 and profile in Figure 6. As expected from the high pyrrhotite content, the mineralisation produces a clear response. The 900 nT anomaly is dominated, however, by the effect of the near-surface mineralisation, as confirmed by the rapid upward attenuation to only 150 nT at 50 m elevation recorded by DIGHEM (Fig. 4).

ELECTROMAGNETICS

The very high conductivity of the ore relative to

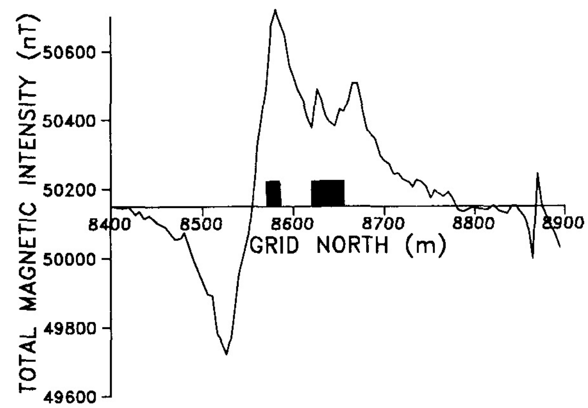


FIGURE 6 Ground magnetic profile for line 12150E. The station spacing was 5 m. The black markers indicate the location of the gossan.

the host rock meant that EM was recognised very early in the deposit's exploration history as a useful tool. Initial surveys were carried out using a Crone shootback system (frequency-domain, tilt-angle measurement); these were followed by Crone PEM (8-channel time-domain system) and vertical loop frequency domain (again tilt-angle measurement) surveys. More recently, the prospect has been covered with fixed-loop TEM using both SIROTEM Mk III and Zonge GDP-16 systems. Responses from the earlier surveys were dominated by the shallow mineralisa-

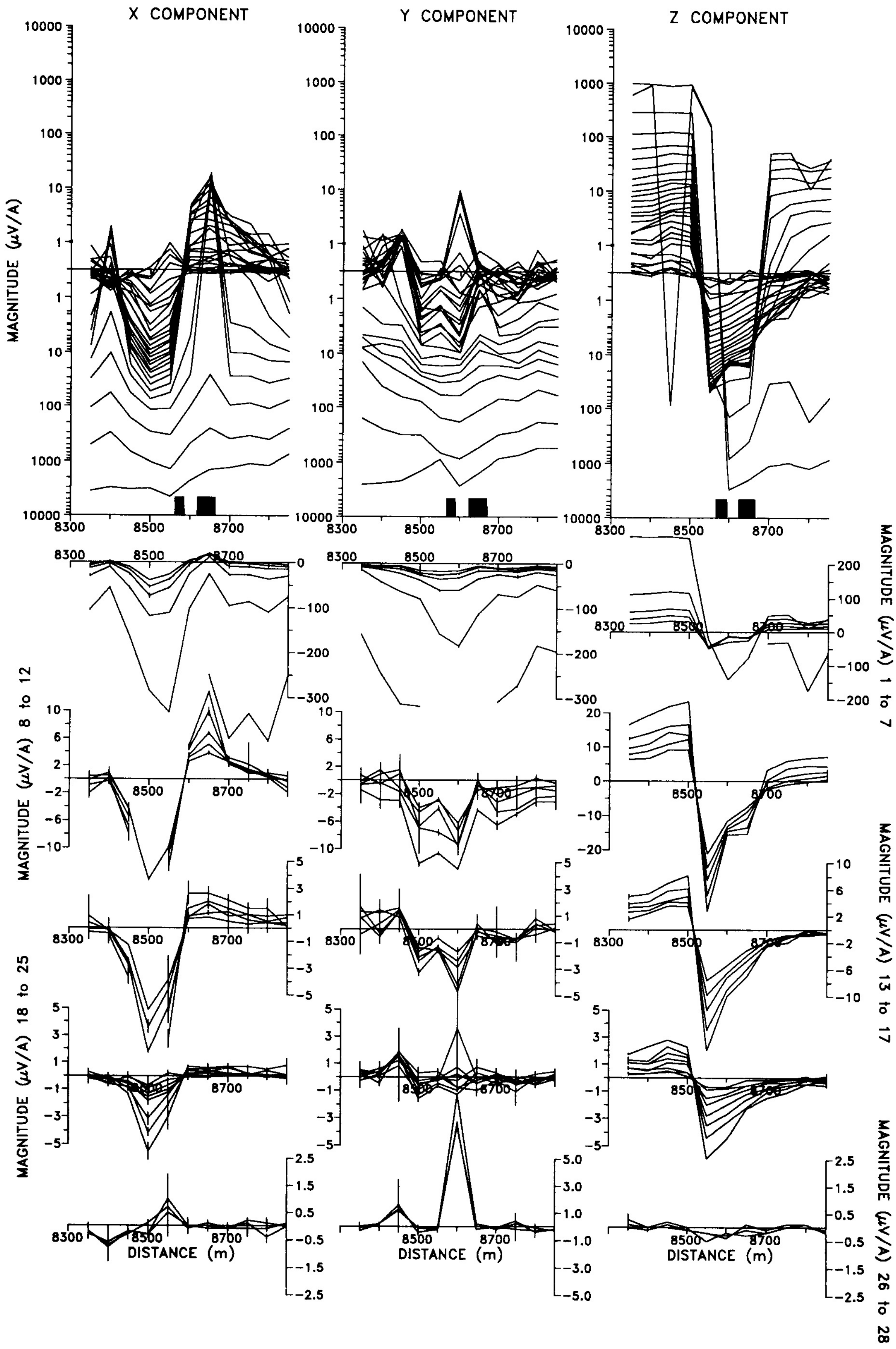


FIGURE 7 Fixed-loop TEM profile for line 12150E collected with Zonge GDP-16. The transmitter loop was to the south of the line, with front edge at 8250N. Window times are the same as the downhole profile in Figure 9. The black markers indicate the location of the gossan.

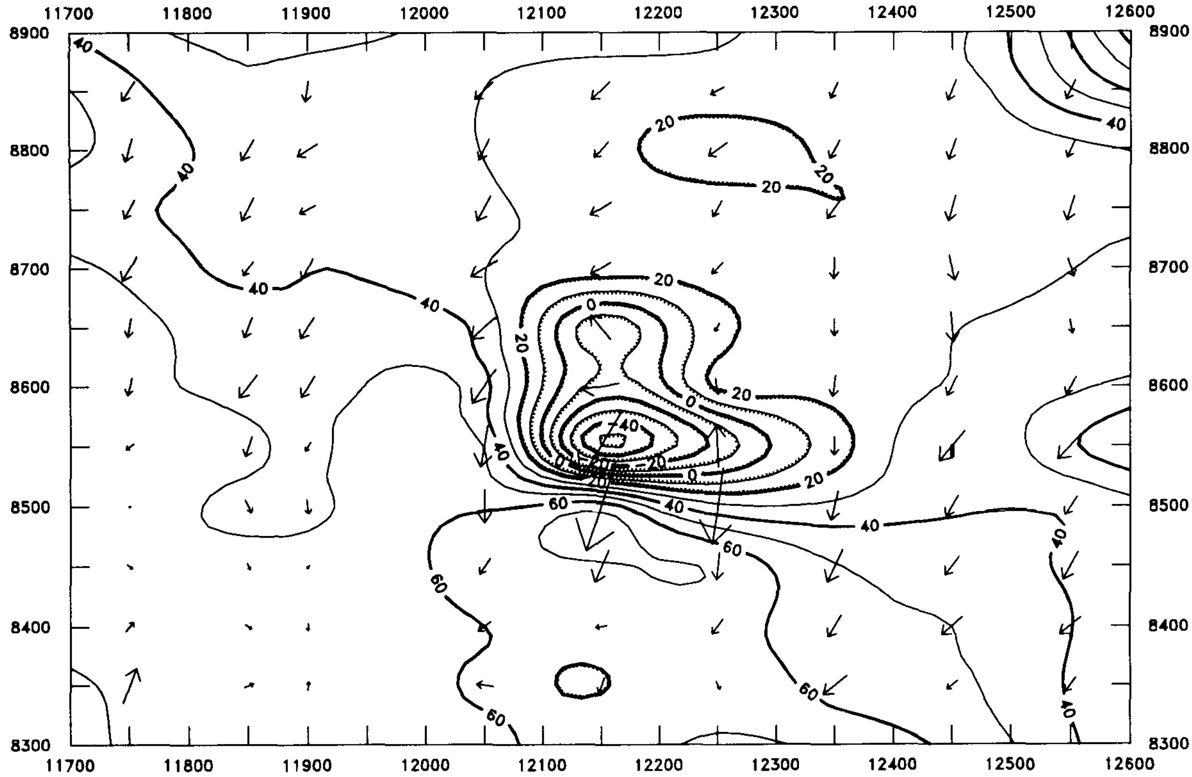


FIGURE 8 Contours of Z component magnitude, fixed-loop TEM, window 5 (121 μs) for the Sally Malay deposit. The arrows indicate the direction and relative magnitude of the horizontal components.

tion.

At first glance, the fixed-loop profile, collected with the GDP-16, in Figure 7 indicates a northern dip even though the anomaly is to the south of the gossan. However, the asymmetry of the response will also be affected by the steep topography which causes the receiver to be below the gossan around 8600N (local grid). The offset of the anomaly to the south of the gossan indicates coupling with one of the deeper fault slices.

As part of the most recent EM programme, six holes drilled by Poseidon Exploration were logged using the same transmitter loop as the surface work and a single component axial downhole SIROTEM probe coupled to a Zonge GDP-16 receiver and Zonge GGT-30 transmitter (Fig. 9). The profile in Figure 9 is from hole SMD96 (see Fig. 2 for location) which was designed to test the eastern extent of the lower mineralisation. The off-hole conductor at around 130 m depth is part of the main near-surface mineralisation to the east of the hole. The picture is complicated further down the drillhole where the hole passes obliquely through the base of a mineralised zone, on through a low-angle fault, and then back into mineralisation offset to the south. Migration and rotation of the eddy currents with time are clear. The resistive nature of the host rocks is evident from the early-time positive response at surface even though the hole collar was nearly 400 m outside the loop. Time constants calculated on late-time decays are as high as 80 ms but routinely around 60 ms. It should be remembered that the conductivity of the ore combines to produce induction numbers well beyond the inductive limit and early- to mid-time responses from impulse systems will be muted, producing flatter than expected decays. There is, however, no doubt about the very high conductivity of the ore when it is still producing a clear anomaly 90 ms after transmitter turn off.

RAPID RECONNAISSANCE MAGNETIC INDUCED POLARISATION

A trial RRMIP survey was carried out in September 1981 (Fig. 10) to the east of the main gossan. Current electrodes were placed at 11970E and 13170E on line 8560N. A station spacing of 50 m was used for the 1 Hz survey and 25 m for the 3 Hz survey. The broad northern flank of the magnetometric resistivity anomaly indicates a dip to the north. The maximum depth to source is estimated at 100 m (Howland-Rose, 1981). The weak IP response of the 1 Hz survey relative to the 3 Hz survey remains unexplained.

DOWNHOLE LOGGING

Several drillholes were logged with gamma, magnetic susceptibility and density tools as a trial. Very good correlation was evident between the mineralisation and magnetic susceptibility, as expected. There is also a clear correlation between the ultramafic rocks and low natural gamma levels (Fig. 11). Once the responses were qualitatively calibrated against the core, they were found to be very useful in the precollars which were not cored.

Several thin pegmatites filling the low-angle faults were initially missed in drill-chip logs. Kicks on the gamma logs, however, indicated less mafic material and re-examination of the chips confirmed the existence of the pegmatite and thus helped construct the

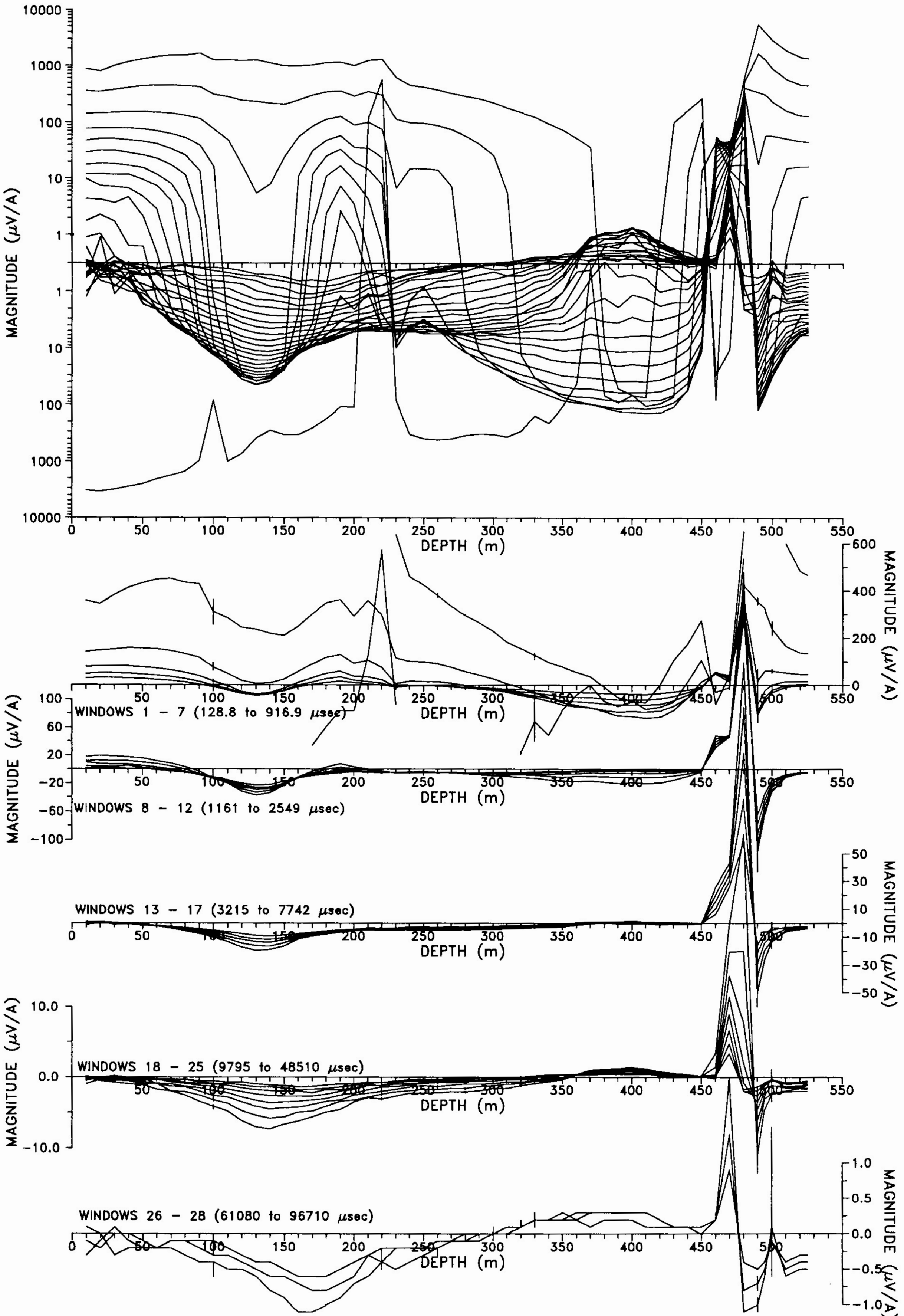


FIGURE 9 Downhole TEM stacked profiles from SMD96 (see Fig. 2 for location). Data were collected with a Zonge GDP-16 receiver on 2 Hz time base.

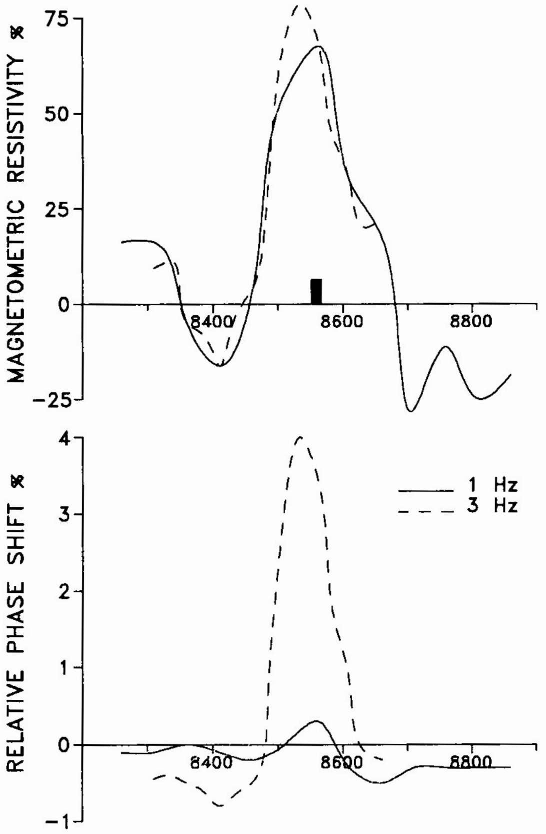


FIGURE 10 RRMIP profile for line 12270E. Current electrodes at 11970E and 13170E on line 8560N. The black marker indicates the location of the gossan.

structure of the mineralisation. In drillhole SMD94 (see Fig. 2 for location), a pegmatite-filled shear at 80 m was initially overlooked in core; however, the clear spike in the natural gamma log prompted a second look and the pegmatite was confirmed. It appears that a thin stringer of mineralisation at 325 m may also have been overlooked in the core logging. It is obvious from the geophysical logs that the gneiss varies down hole: this was mapped in the core logging but the lithological log had to be simplified for the figure. Although in recent years the use of natural gamma logs has declined, it offers a cheap mapping tool for RC and RAB holes, and even in diamond drillholes it

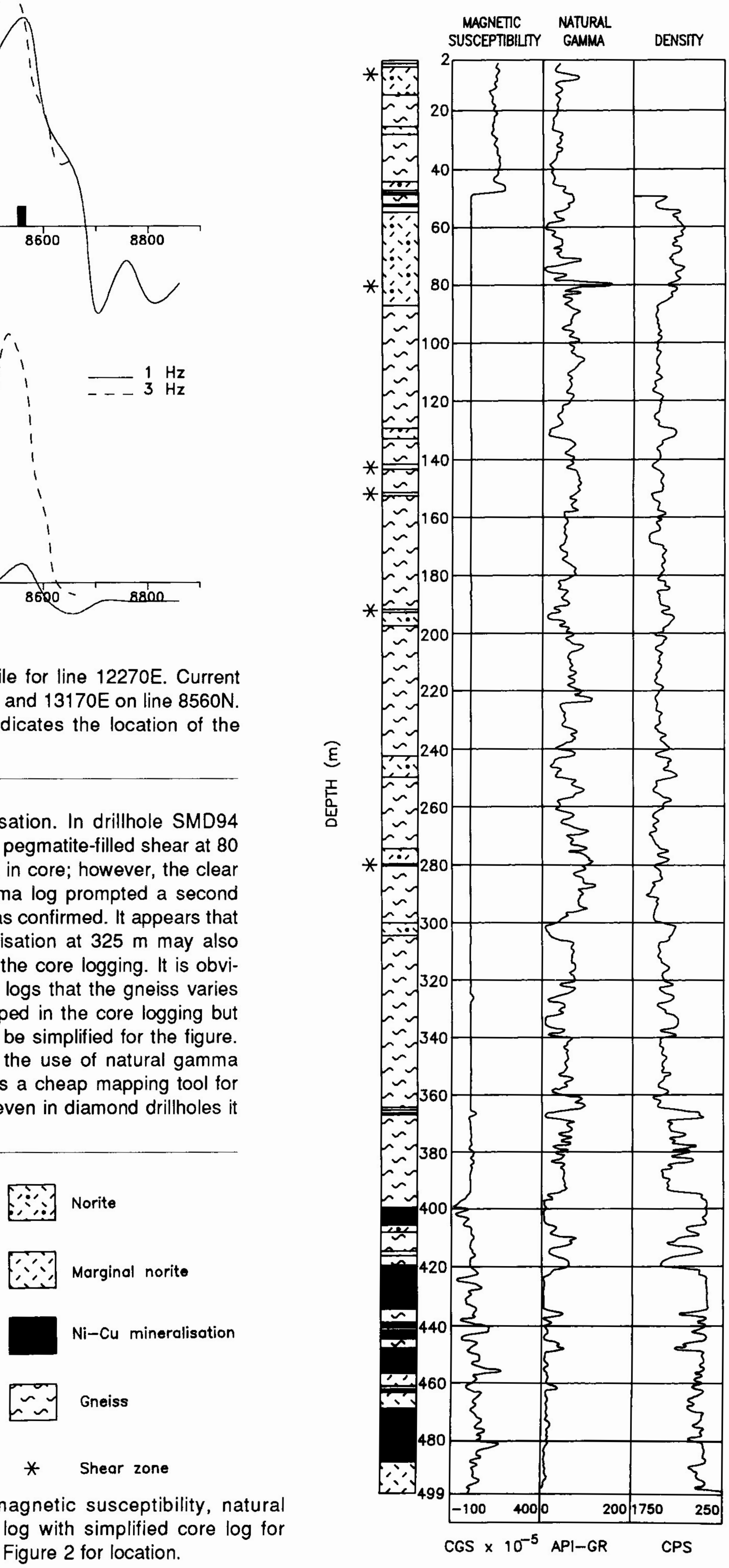


FIGURE 11 Downhole magnetic susceptibility, natural gamma and density log with simplified core log for drillhole SMD94. See Figure 2 for location.

produces a subjective record which may encourage re-examination of the core.

CONCLUSIONS

The physical property contrasts of the Sally Malay deposit make it an excellent target for a number of geophysical methods. Primary among these are EM and ground magnetics. Because of the steep topography and small physical size of the deposit in plan section, airborne methods using conventional 200 to 400 m line spacing could easily fail to detect it. Perhaps in very resistive, topographically rough terrains, such as the East Kimberley, fixed-wing EM surveys should be flown at a constant level rather than draped, at least until primary field corrections are substantially improved.

Although some of the datasets, particularly the downhole and most recent TEM, provide opportunities for more quantitative analysis and modelling, this has not been carried out to any large degree. These TEM surveys had two purposes, firstly to resolve any near-surface ore to the east of the gossan and secondly to detect any large unknown bodies to the west of the deeper mineralisation. On both these counts, it was clear from inspection of the profiles that no large bodies, capable of affecting the economics of the deposit, had been detected and so only qualitative analysis has been undertaken. If, in the future, only a marginal increase in ore volume is required to change the project status, this modelling will clearly be required.

ACKNOWLEDGEMENTS

Thanks go to Stuart Dodd and Graham Butt who searched the archives at Geoterrex to locate useable INPUT V-12 profiles and flight lines, and to Garry Humfries at Scintrex for locating the original RRMIP data. This work is published with the permission of Normandy Poseidon Ltd.

REFERENCES

HOWLAND-ROSE A.W., 1981. Report on RRMIP survey at Sally Malay. Internal Company Report, Australian Anglo American Ltd (unpublished).

PLUMB K.A., 1990. Halls Creek Province and the Granites-Tanami Inlier – regional geology and mineralisation. *In* Hughes F.E. (ed.), *Geology of the Mineral Deposits of Australia and Papua New Guinea,* pp. 681-697. Australasian Institute of Mining and Metallurgy , Melbourne.

THORNETT J.R., 1981. The Sally Malay deposit: gabbroid associated nickel-copper sulphide mineralisation in the Halls Creek Mobile Zone, Western Australia. *Economic Geology* **76**, 1565-1580.

THORNETT J.R., 1986. Evolution of a high grade metamorphic terrain in the Proterozoic Halls Creek Mobile Zone, Western Australia. Ph.D. thesis, The University of Western Australia, Perth, 350 pp. (unpublished).