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APPLICATION OF GEOPHYSICS TO EXPLORATION FOR HEAVY-MINERAL SAND DEPOSITS - BASED ON AN ADDRESS DELIVERED TO A WAITAID/ADAB SPECIAL GROUP COURSE ON EXPLORATION AND MINING OF MINERAL SANDS 3 MAY 1980, BRISBANE

by

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ABSTRACT

The use of geophysical methods in the exploration for heavy-mineral sand deposits is in an experimental stage. Magnetic and radiometric methods are often the most useful and convenient for direct exploration, and induced polarisation methods may be used. To assist in defining the extent and the geometry of sand deposits where heavy minerals may occur, shallow seismic, gravity, and resistivity methods can be used.

The effectiveness of a particular geophysical method for the detection of heavy-mineral sand deposits depends on the deposit having a physical property contrast with the surrounding material and this contrast producing a response significantly larger than background. The following heavy minerals found in sand deposits have characteristic physical properties to which geophysical techniques respond: magnetite - magnetic susceptibility, monazite - radioactivity, ilmenite and magnetite - induced polarisation.

The amplitude and width of geophysical anomalies over heavy-mineral deposits depend on the amount and type of constituents of the deposit, the geometry and size of the deposit, thickness and nature of overburden, and nature of surrounding barren material. Test surveys show that, in eastern Australia, heavy-mineral beach sand deposits can be found and delineated by radiometrics, if barren overburden is thin, and by induced polarisation, in particular magnetic induced polarisation, if the deposits are sufficiently concentrated.

However, for most routine exploration, drilling is probably cheaper and more effective than geophysics. Examples are given of how seismic, gravity, and resistivity surveys can assist in determining the distribution of sand and bedrock, and the thickness of sand that may contain heavy minerals. These methods are unlikely to detect deposits directly, unless an exceptionally favourable combination of physical properties, size, and geometry occurs. In searching for heavy minerals offshore, seismic surveys can define areas with a sufficient thickness of sand for economic deposits to exist, and, when target geometry and location are favourable, magnetic and radiometric surveys can be carried out relatively easily.

INTRODUCTION

Australia is the leading world supplier of heavy-mineral sand concentrates, but Australia's identified economic resources of mineral sands (Table 1) are likely to be substantially depleted by the turn of the century (Ward, 1982). The main areas of deposits and specific locations mentioned in the text are shown in Figure 1.

Most shallow, high-grade onshore heavy-mineral sand deposits have been mined or are unavailable for mining because of environmental legislation. The heavy-mineral sand targets now are often low-grade, deeply buried or offshore, or some combination of these. Consequently, the usual exploration methods of airphoto-interpretation, surface geological mapping, and scout drilling are proving to be inconclusive. This paper reviews ways in which geophysics may be used in exploration for heavy-mineral sand deposits, and is based mainly on work done by the Bureau of Mineral Resources (BMR) in a program of limited field and laboratory studies, and modelling. The results of geophysical surveys over heavy-mineral sand deposits, reported by other workers, have been used to complement results obtained by BMR.

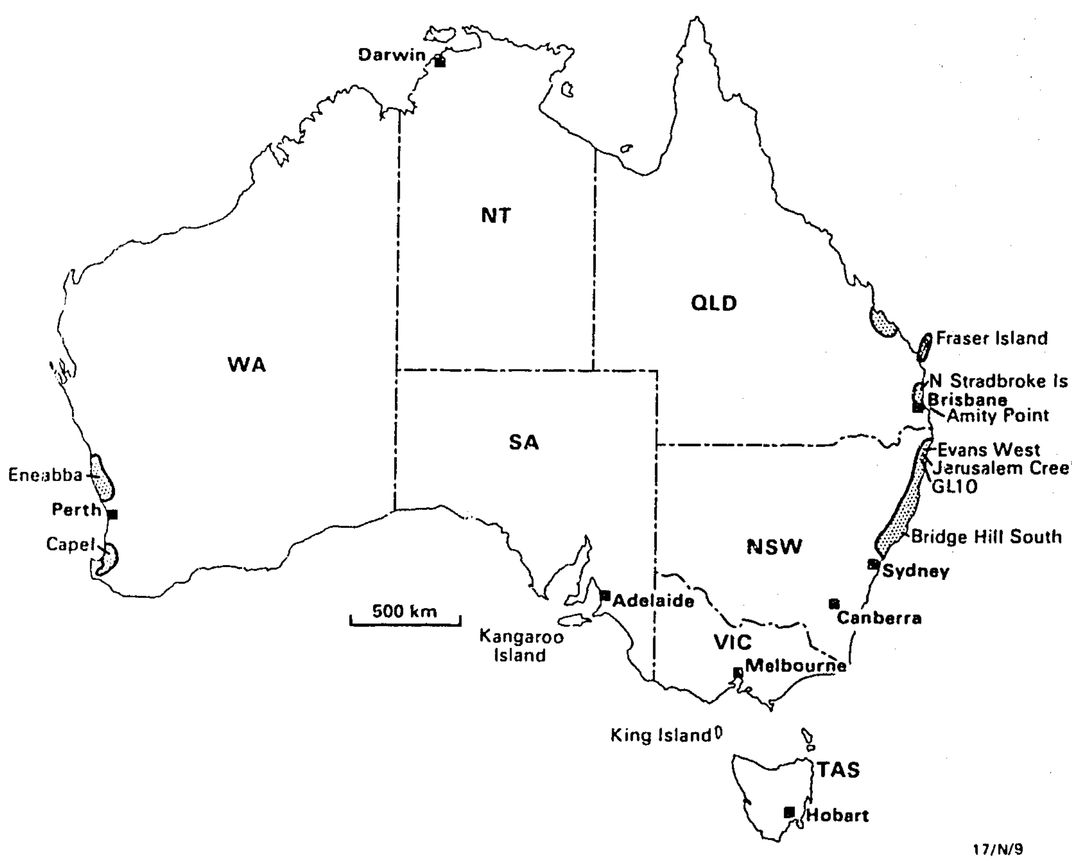


Figure 1. Main Australian areas of heavy-mineral sand deposits.

Table 1. Australian identified resources of heavy-mineral sands, December 1981 (tonnes x 1000)

	Demonstrated Rutile	Zircon	Ilmenite	Monazite	Inferred Rutile	Zircon	Ilmenite	Monazite
RESERVES								
East Coast	6156	5746	13738	56.4	259	248	546	2.7
Western Australia								
Southwest	95	1304	12853	67.4	4	14	126	0.1
Midlands	3008	6403	16295	207.0		not available		
Total	9259	13453	42886	330.8	273	262	672	2.8
SUBECONOMIC RESOURCES								
East Coast		not	available		807	1075	5160	11.7
Western Australia								
Southwest	81	175	1089	5.8	39	504	4547	24.0
Midlands	1054	1829	6266	100.0	4	8	25	1
Total	1135	2004	7355	105.8	850	1587	9732	36.7

Source of data: Resource Assessment Division, Minerals Branch, BMR.

There are two roles in which geophysics can be used in exploration for heavy-mineral sands - firstly, for direct detection of deposits, and secondly, in resource assessment. The resource assessment role includes locating areas favourable for the occurrence of deposits, and determining the depth and extent of material that is host to deposits.

DIRECT DETECTION OF DEPOSITS

Before a geophysical survey is undertaken to search for heavy-mineral sand deposits, an attempt should be made to estimate the dimensions and depth of the anticipated target, and its likely contrasts in physical properties with the surrounding barren material. This information will indicate which geophysical techniques could be used, and provide a guide for traverse and station spacing. Size, grade, and depth combinations required for a target to be economic should be known, and consideration made as to whether the size and composition of deposits considered to be economic are likely to differ significantly in different parts of the area to be explored.

High-grade deposits in Australia are often less than 10 m thick, less than 30 m wide, and usually several kilometres long. As a consequence, distances between observations along traverses must be short - often only 5 m. However, in the early and reconnaissance stages of a geophysical survey, traverses may be a considerable distance apart - usually several hundred metres. Economic low-grade deposits are usually thicker and wider than high-grade deposits, and station spacings can be larger.

For a geophysical method to detect a deposit, the deposit must have a physical property contrast with the host material large enough to produce an anomaly that is firstly measurable, and, secondly, significantly different from anomalies arising from other sources. These latter sources may be geological - such as laterite - or cultural - such as material transported to build roads, and fences, pipes, and buildings.

Heavy-mineral sand deposits in Australia are usually mined for rutile, ilmenite, and zircon, which are the main heavy-mineral constituents. Deposits may also contain magnetite and monazite. These two minerals, as well as ilmenite, have characteristic physical properties that can be utilised during exploration (Table 2). In large enough quantities, they will give the deposit a sufficiently large physical property contrast with the surrounding material to permit detection by geophysical surveys.

Table 2. Characteristic physical properties of some minerals occurring in heavy-mineral sand deposits

Mineral	Characteristic physical property
Magnetite Fe_3O_4	Magnetism
Monazite (Ce, La, Y, Th) PO_4	Radioactivity
Ilmenite $FeTiO_3$	Polarisation
Magnetite Fe_3O_4	

In Table 2, monazite includes all radioactive phosphate minerals. Zircon, being much less radioactive than monazite, is not included. Ilmenite has a much lower magnetic susceptibility than magnetite and is not considered to significantly contribute to magnetic properties of deposits. Magnetite, however, frequently contains titanium impurities.

Likely physical property contrasts between heavy-mineral sands and barren material can be estimated from their mineralogy, but are better measured on samples from in or near the area being explored. Measurements can include laboratory measurements of physical properties on samples, measurements of physical properties in situ, surveys over ore or concentrate dumps, and field geophysical measurements over known deposits.

Magnetic surveys

Magnetic surveys, which record perturbations of the local geomagnetic field, are, in favourable circumstances, very efficient for exploring for heavy-mineral sand deposits.

Magnetic anomalies have been calculated along profiles at right angles to long, heavy-mineral seams containing about 15 per cent magnetite, striking north, northeast, and east, buried by 5 m of overburden, at different magnetic field inclinations (Fig. 2). The field inclinations occur at about latitudes 25°S (inclination of -60°), 10°S (inclination of -30°), and at the equator (inclination of 0°). Ambient field values used in the calculations are those occurring at these latitudes. No anomaly is generated when the seam strikes north in an area where the inclination of the Earth's field is 0°. In all the other instances, narrow anomalies of large amplitude are generated. As magnetometers can measure total magnetic field strengths to a precision of 1 nT, and the vertical component of magnetic fields to a precision of 3 nT, all the anomalies are detectable by ground magnetic surveys, provided adequate spacing between stations is used. Station spacings of no more than 10 m would be appropriate for detection and initial interpretation of the anomalies in Figure 2.

Low concentrations of magnetite can generate anomalies detectable by magnetic surveys. For example at about 25°S (ambient field inclination of -60°) recognisable magnetic anomalies could be produced by east-striking seams with the geometry of the seams in Figure 2 and a susceptibility of 0.0013 SI (5 nT total field anomaly) or 0.002 SI (15 nT vertical component anomaly), which would arise from less than 0.1 per cent magnetite concentration.

The amplitude and size of the magnetic anomaly from a heavy-mineral sand seam vary with the depth to the seam (Fig. 3). For a seam with geometry and susceptibility as in Figure 2, and striking 45° in an area where the ambient field strength is 55 000 nT and inclination is -60°, a survey 100 m above the seam would detect a 30 nT anomaly with maximum and minimum values 150 m apart. Measuring the magnetic field every 50 m would be adequate, and if the seam were near the surface its anomaly would be apparent in a low-level airborne survey.

Some results, reported by Untung & Hanna (1975), from a vertical component magnetic survey over titaniferous magnetite-bearing sands in East Java are illustrated in Figure 4. The field measurements, made at intervals of 25 m, only roughly define the peaks and troughs of the anomalies, which would be more precisely defined if a 10 m interval had been used.

High-sensitivity magnetometers are becoming available, and these have sufficient resolution to detect even very small amplitude anomalies arising from very weakly magnetic heavy-mineral sand deposits. As an example, the results of two high precision magnetic traverses recorded by BMR across the Evans West deposit in the Jerusalem Creek area are shown in Figure 5. The Evans West deposit is a rich heavy-mineral sand seam about 3 m thick and covered by about 3 m of overburden. The deposit has a sharp grade cut-off at its boundaries and averages about 10 per cent heavy minerals, comprising zircon (36%), rutile (35%), 'magnetics' (mainly ilmenite) (25%), minor monazite (4%), and other minerals.

The high-precision magnetic survey used a moving magnetometer with an accuracy of 0.1 nT and a base station magnetometer, also of 0.1 nT accuracy. The weak anomalies of 0.6 nT and 3 nT (Fig. 5) are attributable to heavy-mineral accumulations. Sources interpreted from the magnetic profiles have low susceptibilities of 38×10^{-5} and 113×10^{-5} (SI), corresponding to 0.01-0.05 per cent magnetite, and are partly coincident with the highest heavy-

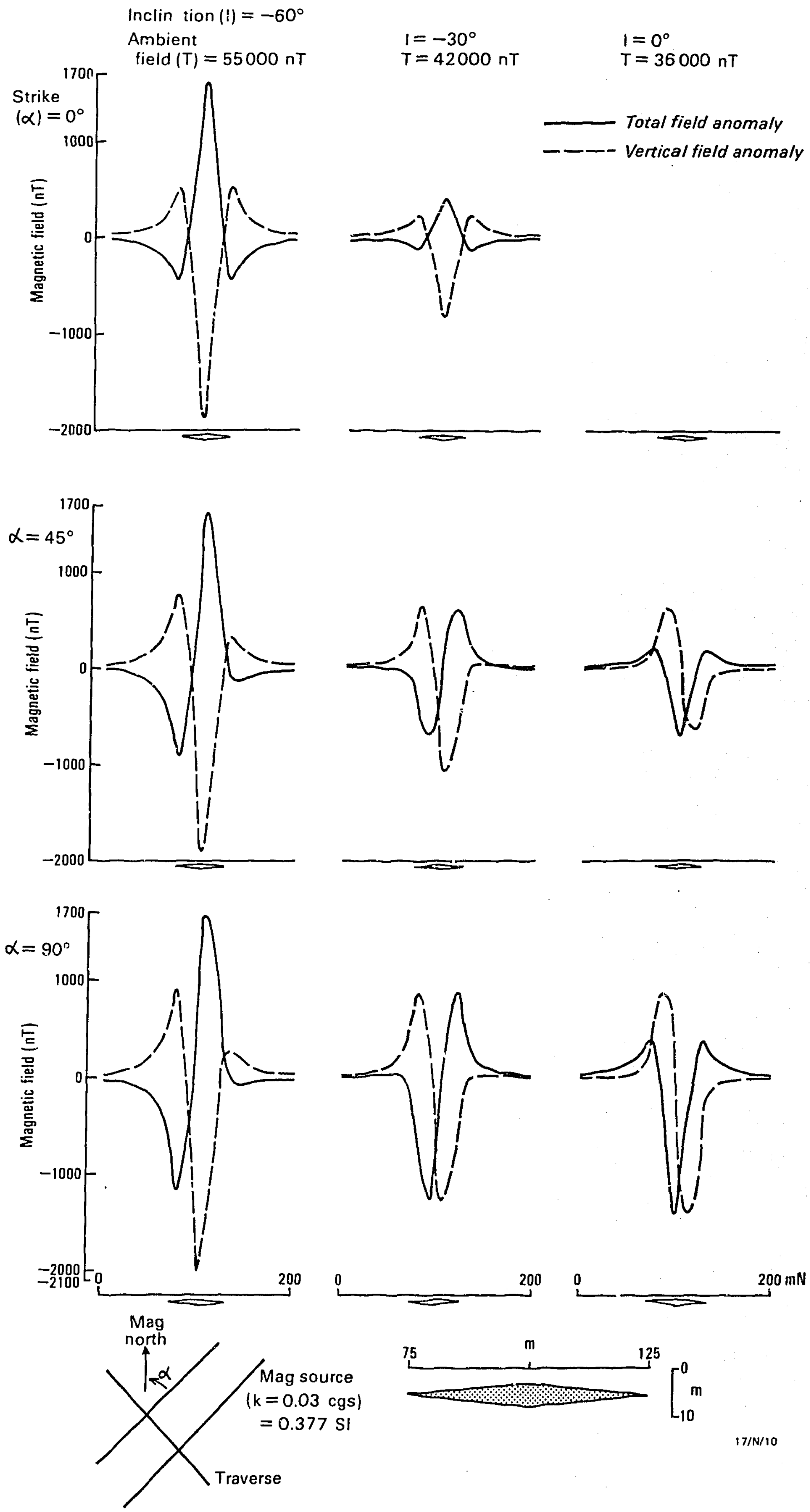
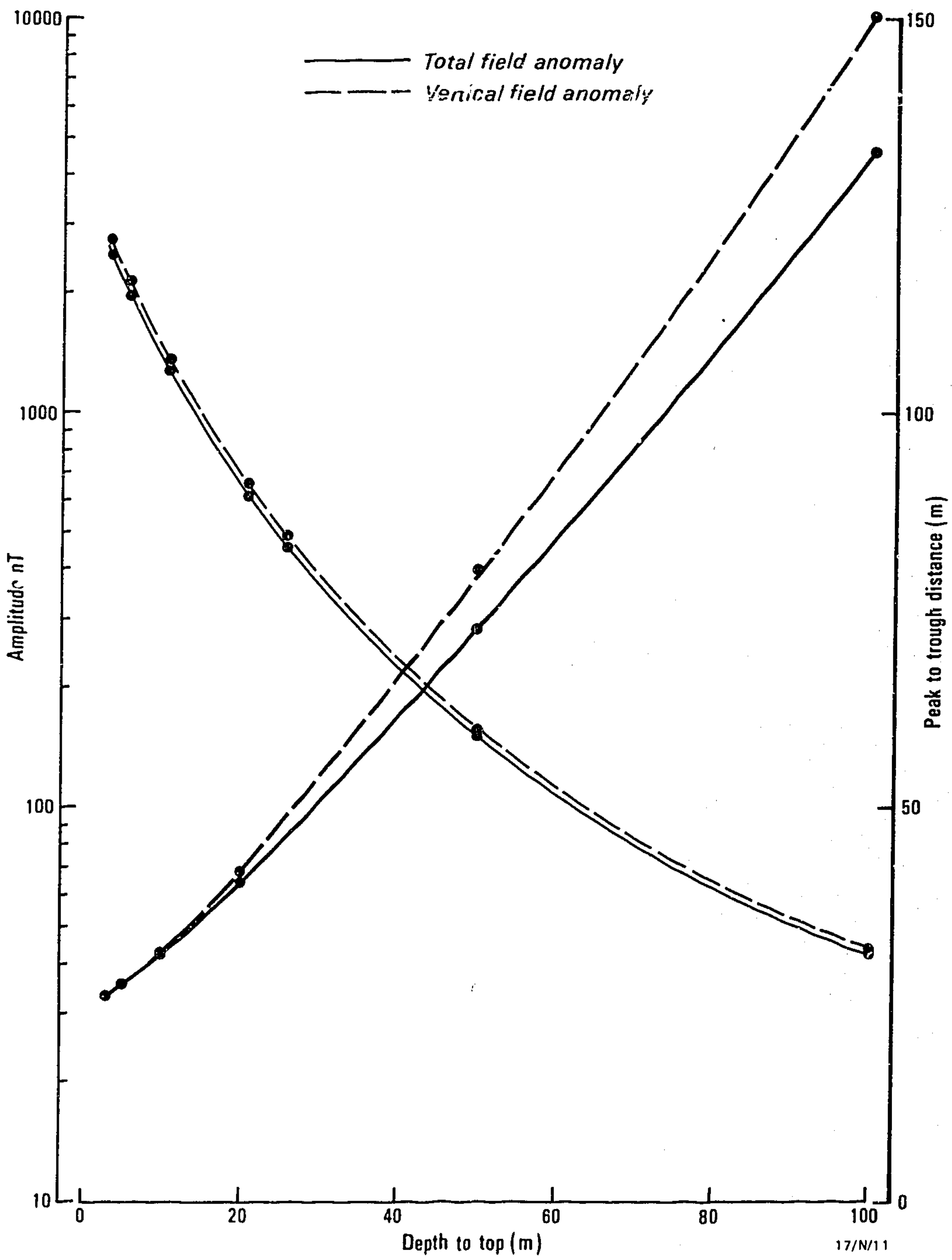
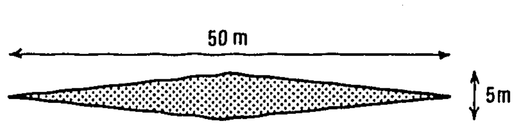


Figure 2. Magnetic anomalies arising from heavy-mineral sand seams having various orientations for various inducing field inclinations.





Ambient field 55 000 nT
Inclination −60°
Strike 45°
Susceptibility 0.377 SI (0.03 cgs)

Figure 3. Dependence of amplitude and width of magnetic anomalies on depth to source.

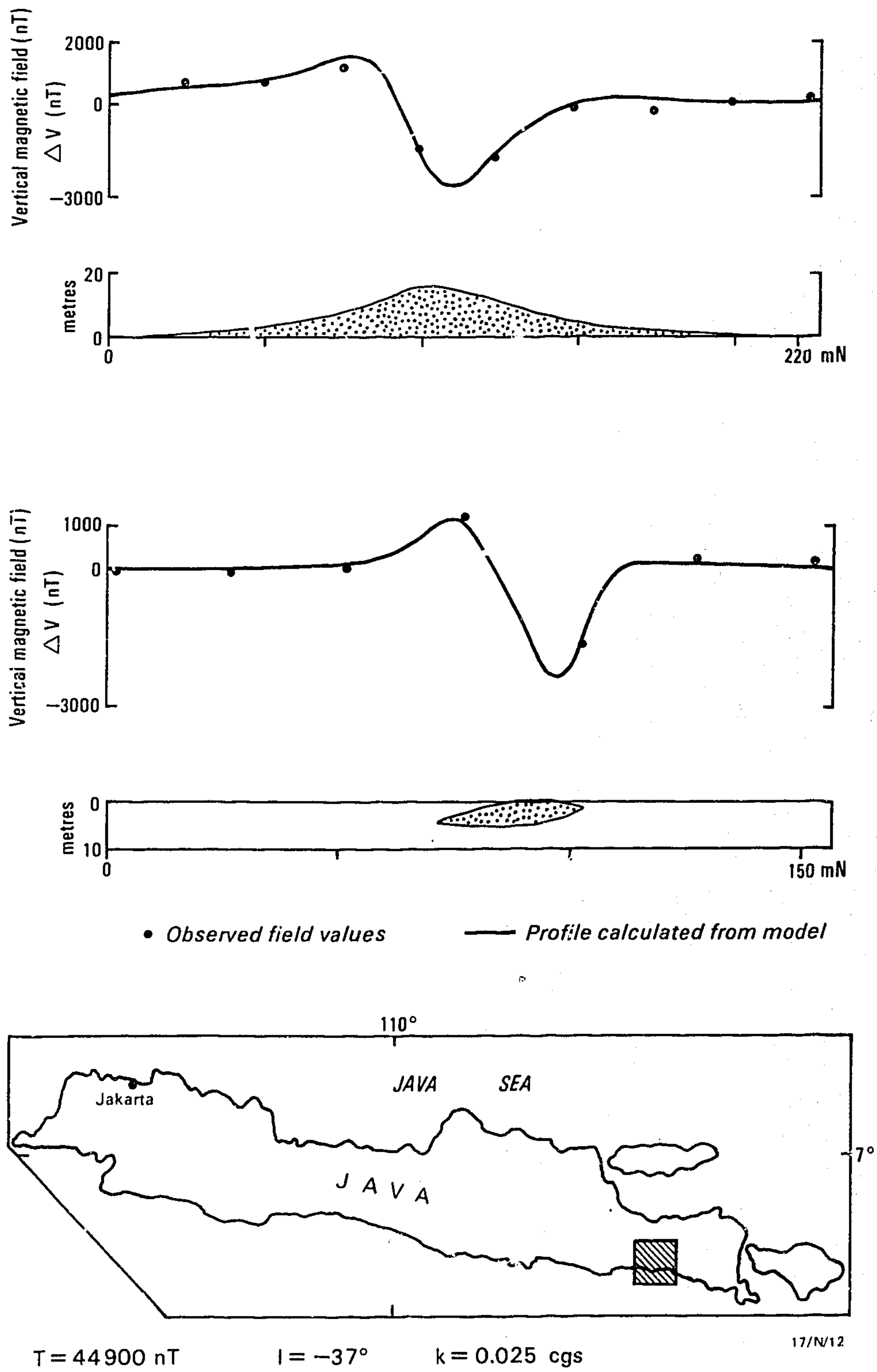


Figure 4. Vertical magnetic field component results, Java, Indonesia. (After Untung & Hanna, 1975).

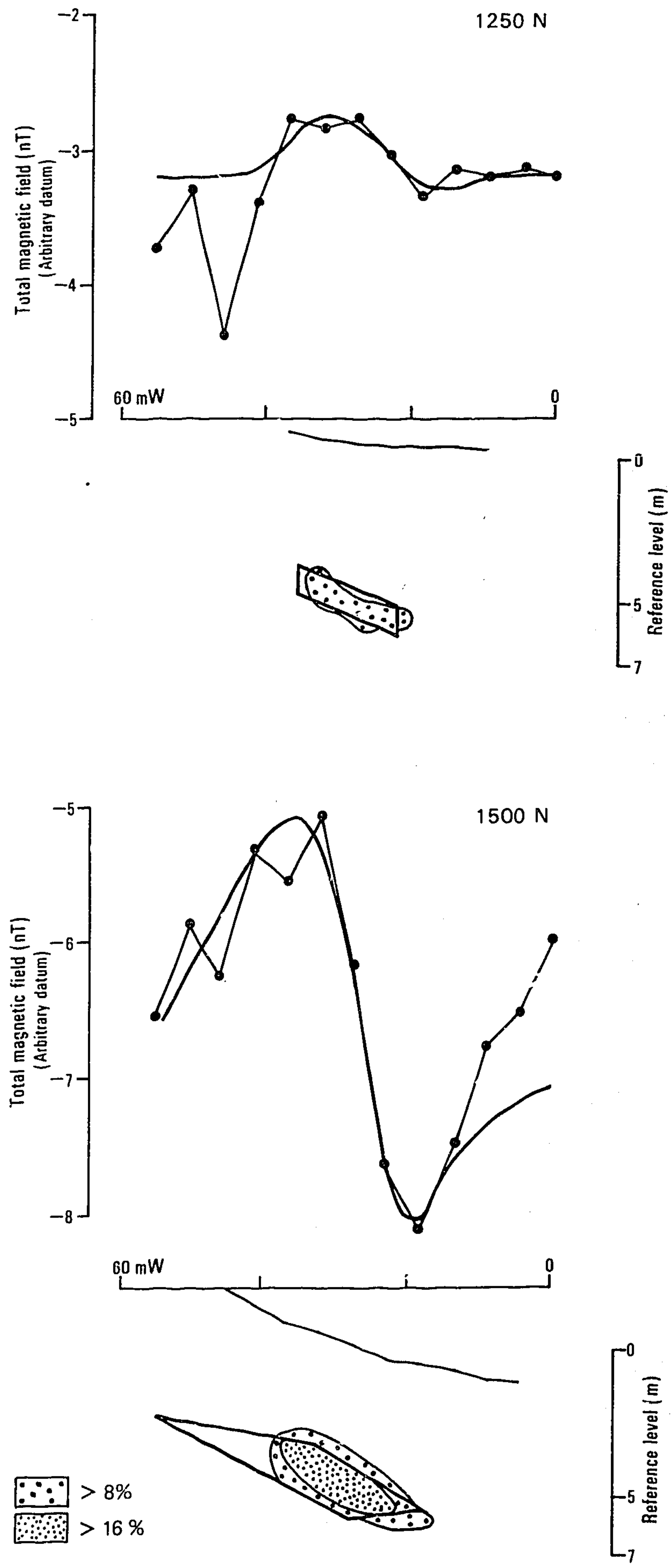


Figure 5. High precision magnetic traverses, interpretation, and heavy mineral grades, Evans West deposit.

mineral concentrations determined from auger drilling, but centred slightly further west (up the beach) than the heavy-mineral sand seam. Magnetite could be concentrated further up the beach because of its higher density (5.18 t/m^3) than the other heavy-mineral constituents of the seam - ilmenite (4.7 t/m^3), zircon (4.68 t/m^3), and rutile (4.18-4.25 t/m^3). Susceptibility measurements (Table 3) show a slight contrast between mineralised and barren sand of 86 x 10^{-5} (SI).

Table 3. Field susceptibility measurements, Evans West deposit, Jerusalem Creek

Material	Susceptibility Mean SI ($\times 10^{-5}$)
Background and overburden	59
Orebody, in situ, after overburden stripped	145
Ore dumps	102
Concentrate dumps	267

There are a number of examples from Australia and around the world of where heavy-mineral sands have a magnetic expression, and the magnetic method has helped or could help in exploration. Magnetic anomalies occur over heavy-mineral deposits in Western Australia (Rowston, 1965; Baxter, 1976) and titanomagnetite sands in New Zealand (Lawton, 1979). Magnetite sands occur in Egypt and southeast Papua New Guinea. Heavy-mineral sand deposits along the east coast of Australia are not very magnetic, and most magnetic surveys generally would not detect them. Magnetometers could be easily adapted for offshore surveys - if need be, the sensor could be towed along the seabed.

Radiometric surveys

Radiometric surveys record gamma radiation from the disintegration of atomic nuclei belonging to the thorium, uranium, and potassium decay series. Spectrometers record the intensity of radiation through three energy windows, each one relating to a decay series (Table 4), and a total count window.

Scintillometers record all incident gamma radiation above a (low energy) threshold.

Table 4. Typical spectrometer specifications

Channel	Radioelement/daughter detected	Energy peak (MeV)	Channel limits (MeV)
K	K^{40}	1.46	1.36 - 1.56
U	Bi^{214}	1.76	1.66 - 1.86
Th	Tl^{208}	2.62	2.42 - 2.82
Total	-	-	0.4

Results of radiometric surveys are often presented as units of counts per second. However, as different instruments have different characteristics, measurements made by one frequently cannot be compared with measurements made by another. To facilitate comparison between instruments, they are calibrated, and field readings converted to a measure of the intensity of incoming radiation (total-count channel in spectrometers and scintillometers) and apparent abundance of radioelements potassium, uranium, and thorium.

Most Australian heavy-mineral sand deposits are radioactive. Mineral sand environments typically contain little clay, and hence little potassium; thus, most of the gamma radiation arises from the thorium decay series. Therefore, a scintillometer, which is cheaper and faster to use than a spectrometer, is usually adequate for radiometric surveys. However, if it is necessary to separate the effects of clay accumulations from mineral sand accumulations, a spectrometer should be used. As natural gamma-rays are almost completely absorbed by 0.5-1 m of rock and soil, deeply buried deposits may be difficult to detect.

Radiometric recordings along two traverses over moderate and high-grade heavy-mineral sand seams at North Stradbroke Island, Queensland, are shown in Figures 6 and 7. The total intensity profiles are similar to the apparent thorium profiles, indicating that a scintillometer would be an adequate prospecting instrument in this environment, which contains almost no clay. Radiometric anomalies correlate well with the accumulations of near-surface heavy minerals. Note in Figure 7 that, where a rich accumulation of heavy-mineral sand is covered by overburden, no anomaly attributable to the rich accumulation occurs - surface material is the source of the radiometric anomaly.

At Bridge Hill South, in New South Wales, the heavy minerals are much more disseminated than at North Stradbroke Island, averaging 0.5 per cent in the seams. A profile across a typical part of the deposit (Fig. 8) indicates a clay-free environment, so a scintillometer is adequate for radiometric prospecting. Anomalous radiometric recordings occur where near-surface concentrations are highest, and, as drilling shows that the average concentration of heavy minerals over a considerable depth is similar to that near the surface, which is causing the radiometric response, the radiometric survey therefore highlights the richest accumulations of heavy minerals.

The North Stradbroke Island and Bridge Hill South examples show that radiometrics can successfully detect near-surface heavy-mineral sand deposits or buried deposits that have a radioactive halo cutting the surface. In areas where deposits are covered by barren material, exploration could be carried out by the measurement of gamma-radiation in shallow auger holes.

Surveys by BMR over a number of mineral sand deposits along the east coast of Australia indicate that concentrations of monazite of 0.1 per cent are sufficient to generate an observable radiometric anomaly in favourable circumstances. Offshore heavy-mineral sand deposits could be located by towing a water-tight sensor along the seabed.

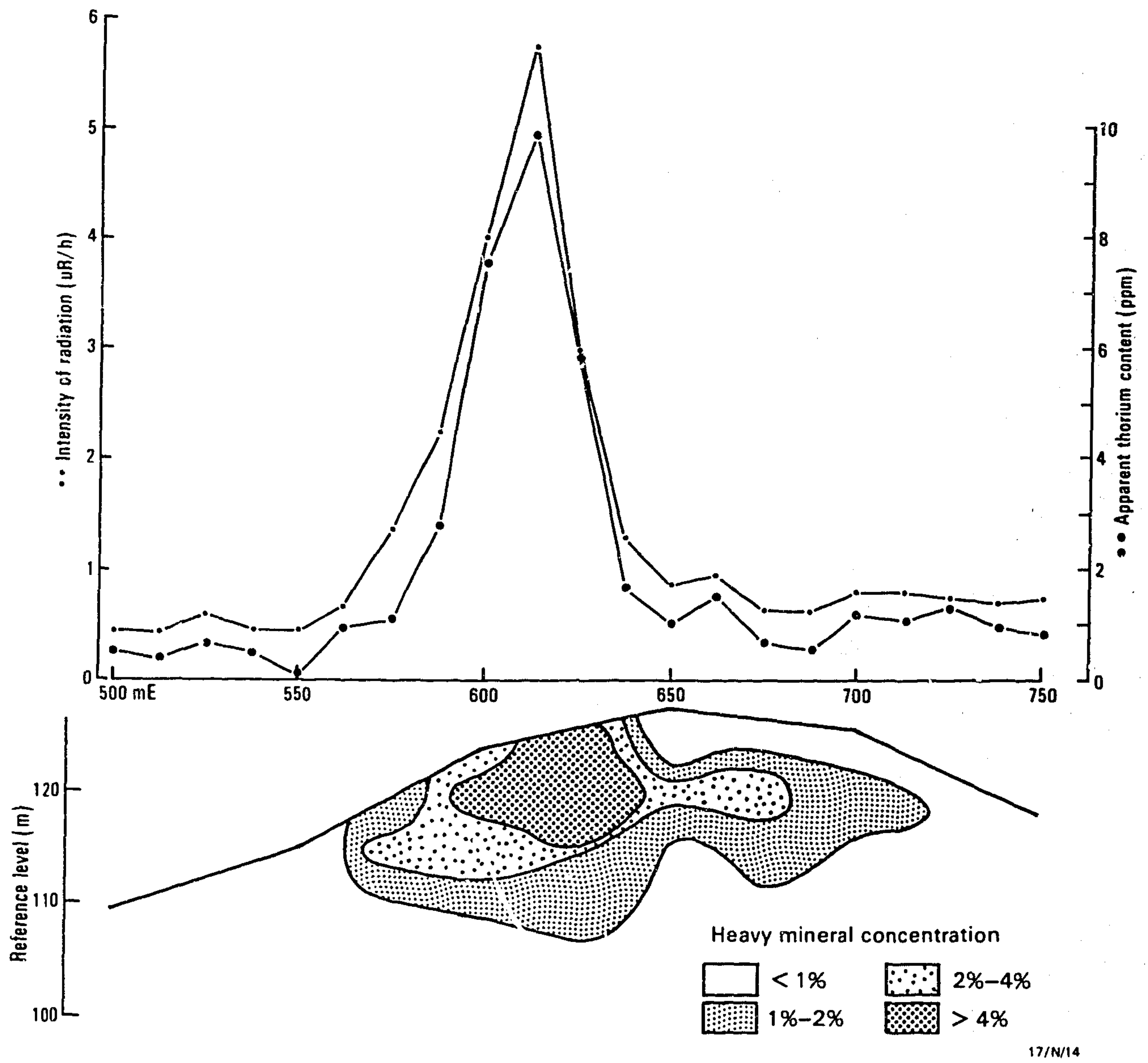


Figure 6. Radiometric traverse and geological section, Dampier, North Stradbroke Island. (Geological section from Consolidated Rutile Pty Ltd)

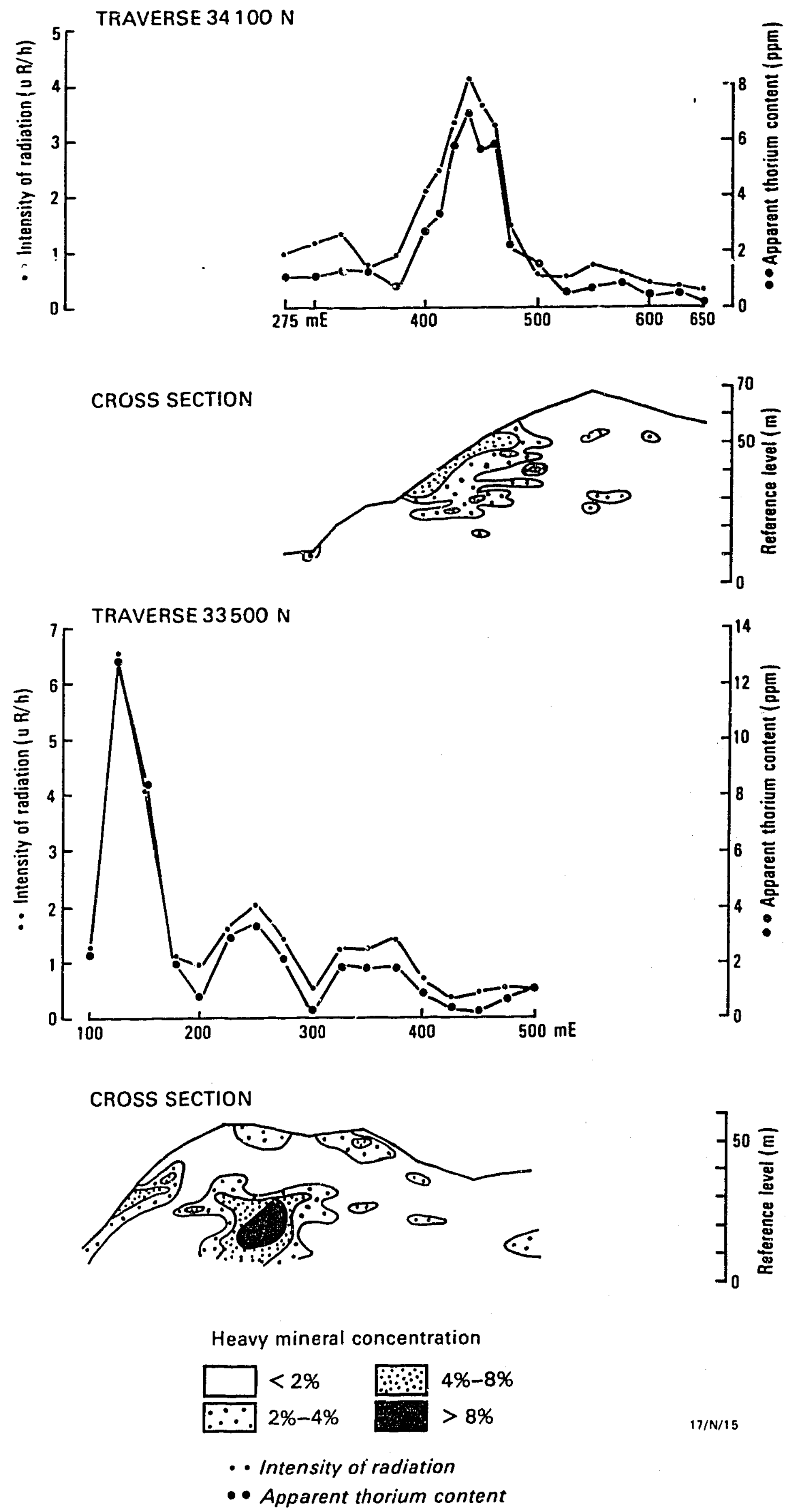


Figure 7. Radiometric traverses and geological sections, Amity Point, North Stradbroke Island. (Geological sections from Consolidated Rutile Pty Ltd)

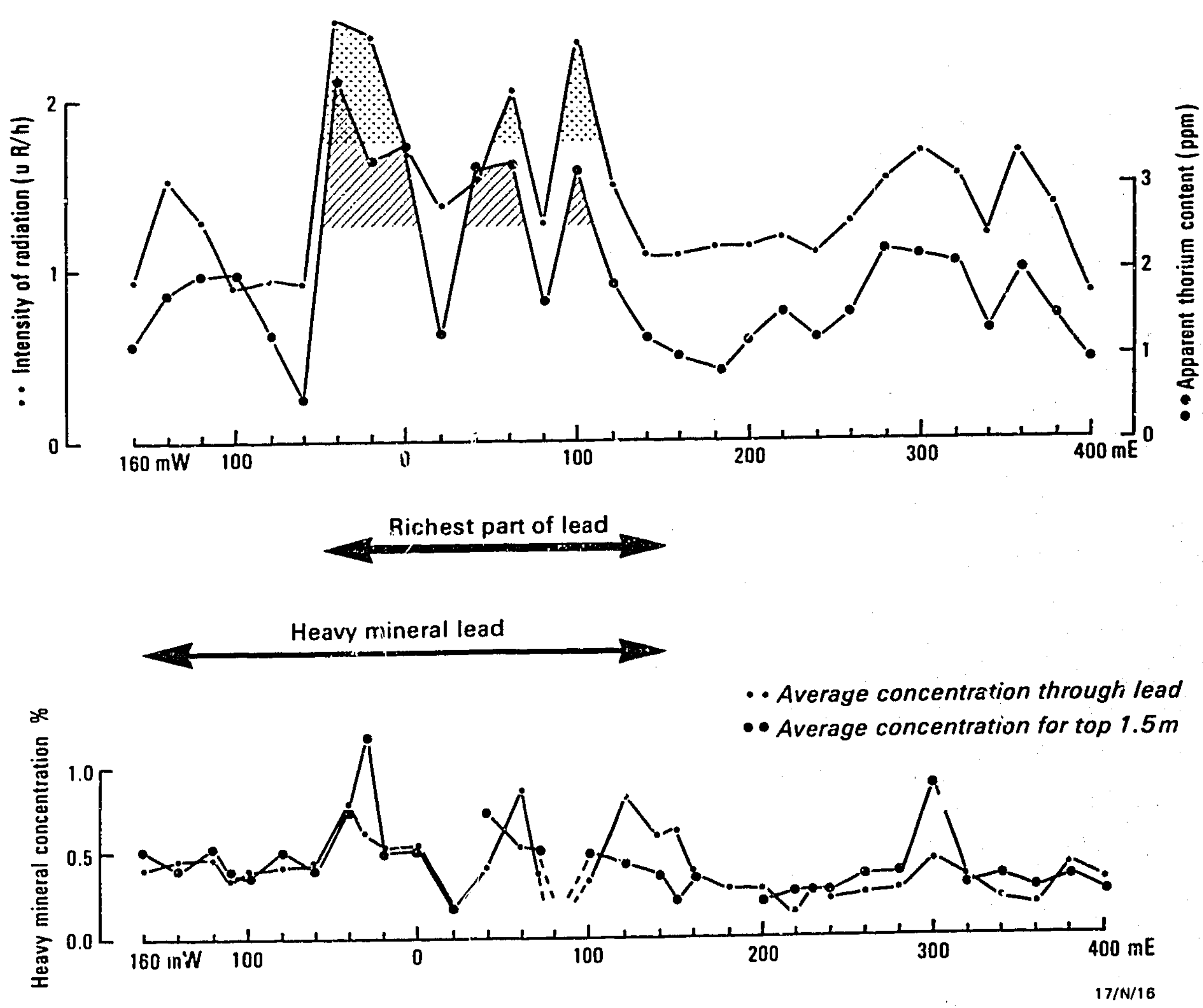


Figure 8. Radiometric traverse and concentrations of heavy minerals, Bridge Hill South. (Drilled by Mineral Deposits Ltd. The area is to be included in the Myall Lakes National Park).

Induced polarisation surveys

The induced polarisation (IP) method measures the decay of electric currents transmitted through the ground. Decay is measured directly, or indirectly by way of changes in resistivity with frequency of the transmitted current. When the measuring system uses two 'receiver' or monitoring electrodes the method is called electric IP. When it uses a magnetometer the method is called magnetic IP.

BMR has investigated the response of the IP method to heavy-mineral sand seams in the Jerusalem Creek area. Much of this research, from over the Evans West and GL 10 deposits, has been reported by Robson & Sampath (1977). Heavy-mineral concentrations for the Evans West deposit, averaged over a depth of 10 m, are shown in Figure 9. The gap in the orebody between 600N and 300N is due to the presence of a large sand dune, which prevented drilling of the deposit. The GL 10 deposit comprises several parallel leads of similar mineral composition to the Evans West deposit, but having an average grade of 1-5 per cent. It is buried by 0.5 m of cover.

The results of a gradient array electric IP traverse across the Evans West seam, using a 235 m current electrode separation, and 5 m and 10 m receiver electrode spacings are shown in Figure 10. A small IP anomaly was recorded over the richest part of the seam, when a receiver electrode spacing of 5 m was used, but when a 10 m spacing was used, the anomaly from the heavy minerals was indistinguishable from background readings. In IP surveys using a particular array geometry, small-size arrays are more strongly influenced by shallow sources and are more sensitive in resolving small sources. For these reasons the 5 m receiver electrode spacing appears more appropriate than the 10 m spacing for highlighting the seam. A small current electrode separation of, say, 100-150 m could have been used so that the seam was preferentially illuminated. Small-amplitude electric IP anomalies can be generated by high-grade heavy-mineral sands, but the Evans West results indicate that, for a survey to successfully detect a target seam, the size of the array needs to be selected or tuned to generate the biggest possible amplitude anomalies from the target.

In the magnetic IP chargeability profiles across the Evans West deposit (Fig. 11), anomalous values show a good overall correlation with concentrations of heavy minerals. The anomalies average -3 mT/T, and the background level is 2-3 mT/T. The chargeability profiles indicate that the ore zone is continuous between 600 N and 300 N, where auger sampling was not possible. Weak but persistent anomalies occur over the heavy-mineral sand seams at GL10 (Fig. 12).

Even though magnetic IP and electric IP measure the same physical property - polarisability - the magnetic IP survey was more successful in delineating the Evans West deposit than the electric IP survey. There are two reasons: first, in a magnetic IP survey the signal is measured at a point, so the size and geometry of the array are better tuned to produce a larger signal from the deposit, which is small and shallow; secondly, in magnetic IP surveys the array is more favourably located with respect to the deposit, the transmitting electrodes being placed so that the current running directly between them runs along the strike of the seam. In electric IP surveys the transmitting electrodes are placed so the current running directly between them is perpendicular to the seam.

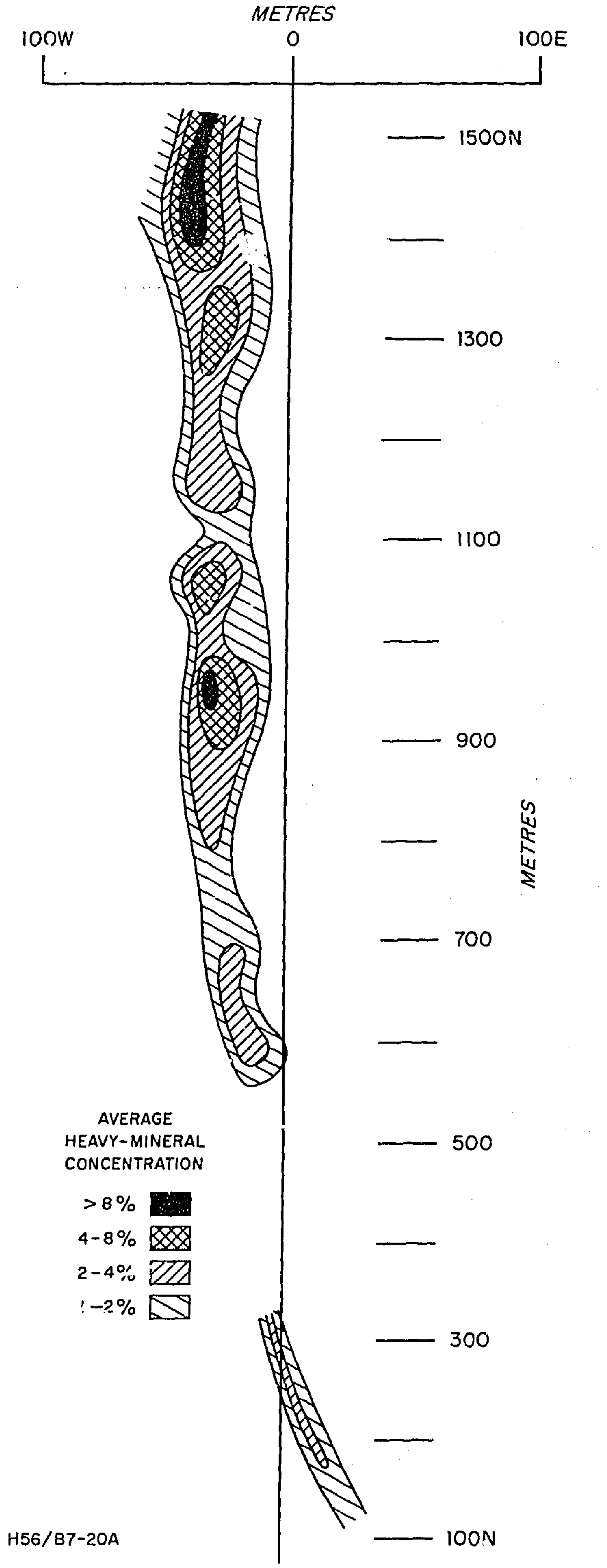


Figure 9. Average heavy-mineral concentration, Evans West deposit.

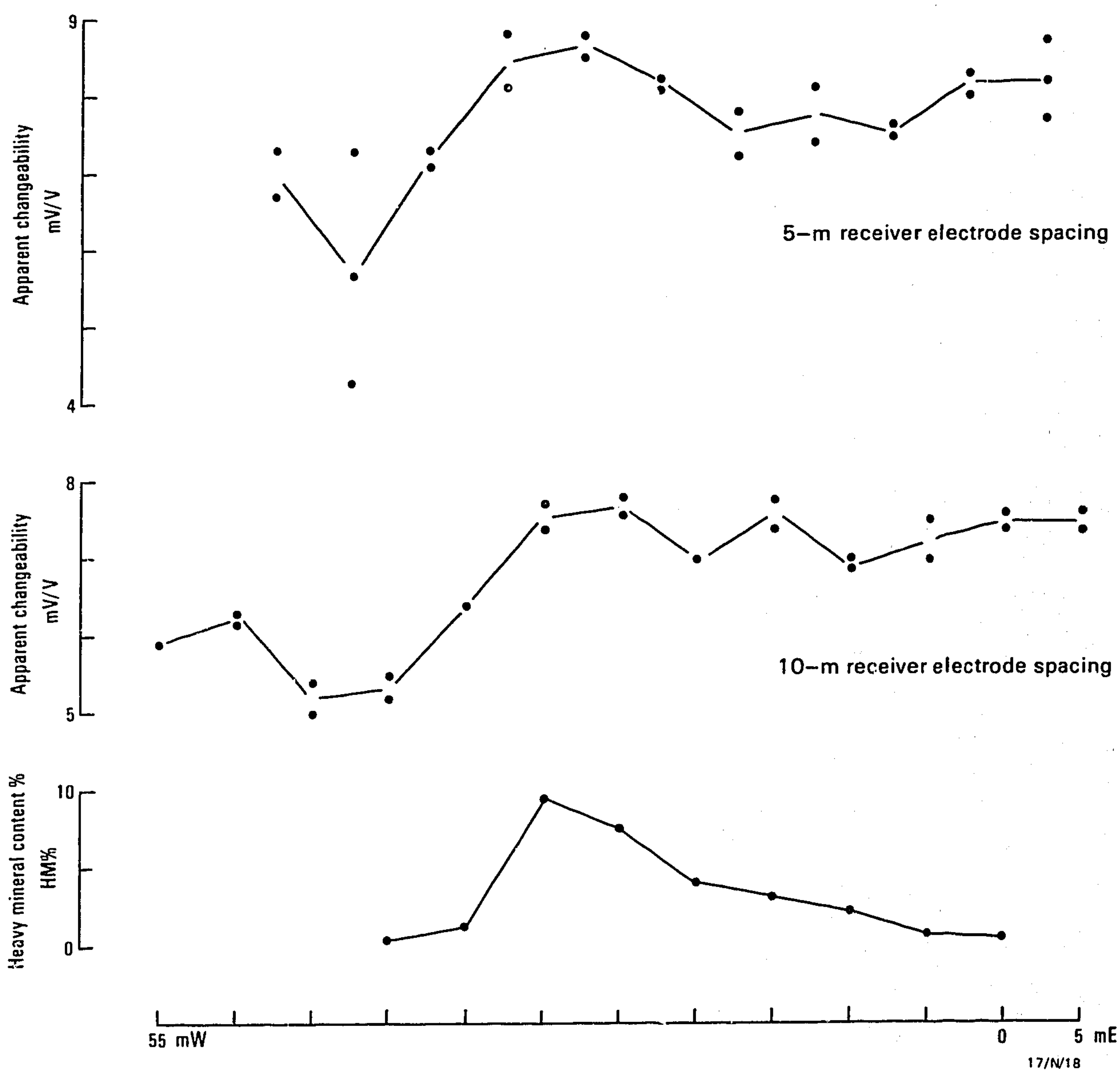


Figure 10. Electric IP gradient array results, traverse 950N, Evans West deposit. The current electrodes are at 135W and 100E. (Geological information from Australian Minerals Consolidated).

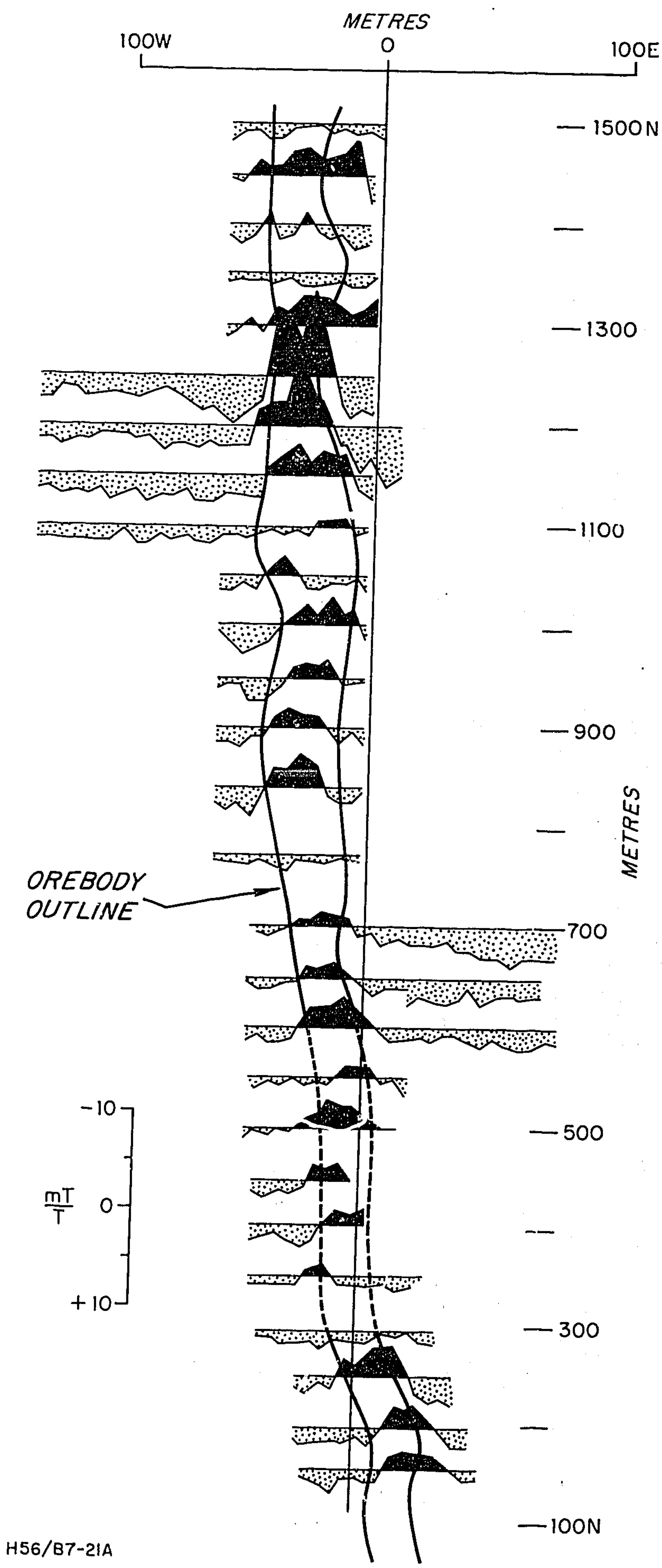


Figure 11. Magnetic IP chargeabilities, Evans West deposit. (After Robson & Sampath, 1977).

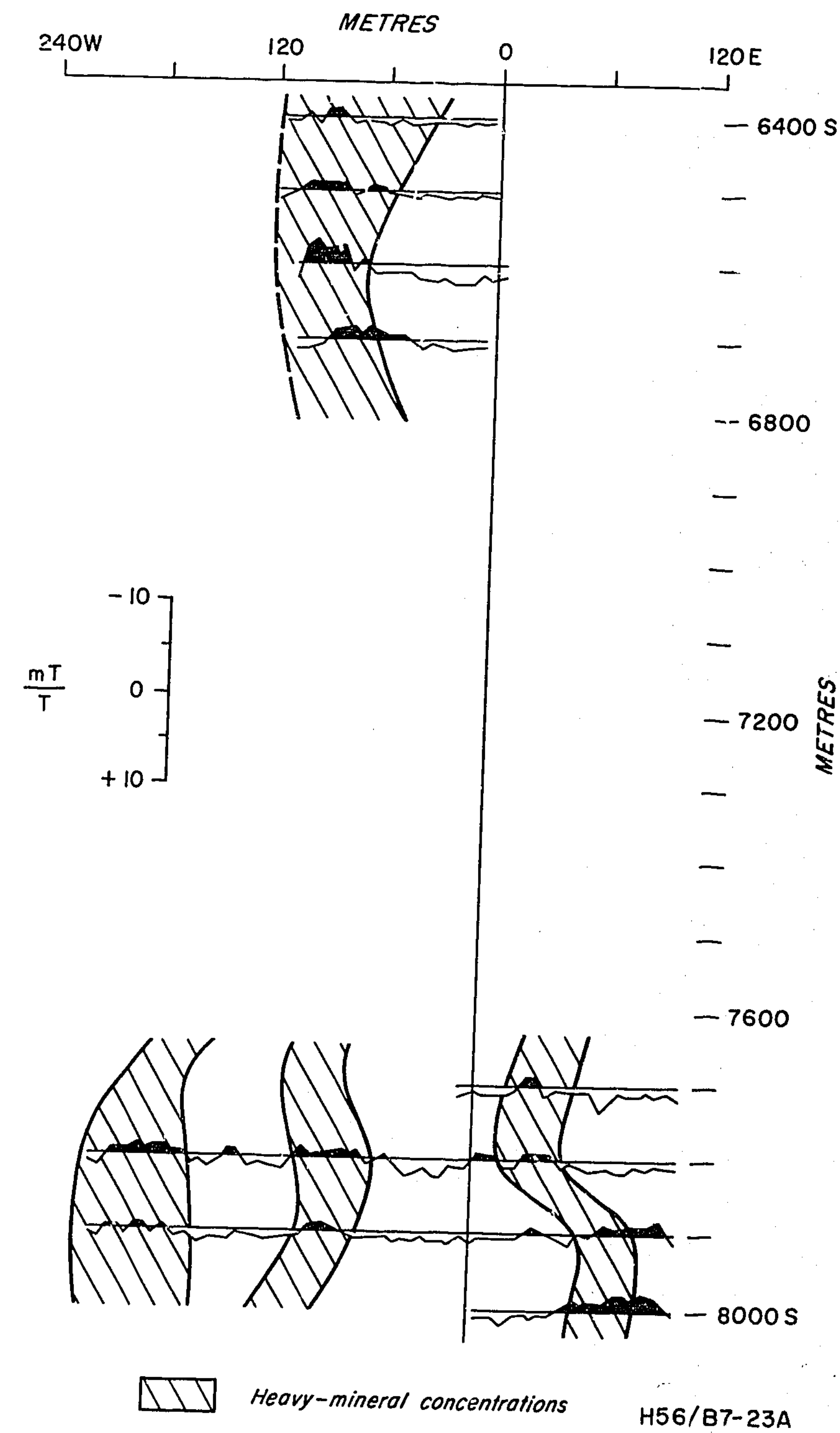


Figure 12. Magnetic IP chargeabilities, GL10 deposit. (After Robson & Sampath, 1977).

Short IP traverses over mineral sand stockpiles from the Evans West and GL10 deposits show that the induced polarisation effects are due to the fraction of heavy-mineral sand separated out during processing as magnetic. This magnetic fraction consists of over 70 per cent ilmenite.

Induced polarisation surveys are slower and require more expensive equipment and more manpower than magnetic and radiometric surveys. Magnetic IP surveys, in particular, require great care and attention to field techniques to produce reliable and valid results. In addition, disseminated heavy-mineral deposits generate only weak anomalies. Consequently, IP surveys are likely to have a more limited role than magnetic and radiometric surveys in the exploration for heavy-mineral sand deposits. In most instances, exploration by auger drilling would be much cheaper, faster, less ambiguous, and more effective than IP surveys. Only in unusual circumstances, such as when drilling was not possible and rich seams were being explored for, would IP surveys have a place in a heavy-mineral sands exploration program. Even then, they would most likely only be used to define occurrences over small areas.

RESOURCE ASSESSMENT

Geophysical surveys can assist mineral sands exploration by locating areas likely to contain heavy-mineral sand deposits and hence be favourable for intensive exploration, and by assisting in the evaluation of total heavy-mineral sand resources.

In the reconnaissance stage of exploration, the surveys can indicate areas having a geochemical environment favourable for the presence of heavy-mineral sand deposits, locations where basement topography and geological structure are likely to facilitate the formation of deposits, and regions where depth of host material is sufficient for economic deposits to be present. Airborne magnetic and radiometric surveys and offshore seismic reflection surveys can rapidly cover large areas and are useful in this reconnaissance stage. Gravity, resistivity, and seismic surveys can indicate the depth and geometry of the base of the host sands. If magnetic sources are present in the basement, magnetic surveys can provide information on basement depth.

Airborne surveys

A reconnaissance airborne survey was flown by BMR in the Jerusalem Creek area to seek broad changes in the radioactivity and magnetic intensity of the sand ridges associated with heavy-mineral sand deposits (Robson & Sampath, 1977). The survey was flown at an altitude of 100 m, a traverse spacing of 400 m, and a speed of 180 km/h. The radiometric survey was made with a 4-channel gamma-ray spectrometer containing a 3700 cm^3 crystal, and the magnetic survey employed a magnetometer having a sensitivity of 1 nT. Survey specifications were adequate to locate the broad sources sought, but were not suitable for detecting small isolated sources.

A few large and some small radiometric anomalies occur on a low background of less than 3 μR/h (Fig. 13). Thorium anomalies with radioactivity up to 20 μR/h were recorded over heavy-mineral stockpiles, and smaller anomalies were observed over mining sites and along some sand ridges in the outer barrier sands. Areas that would warrant further work are those sandy regions having

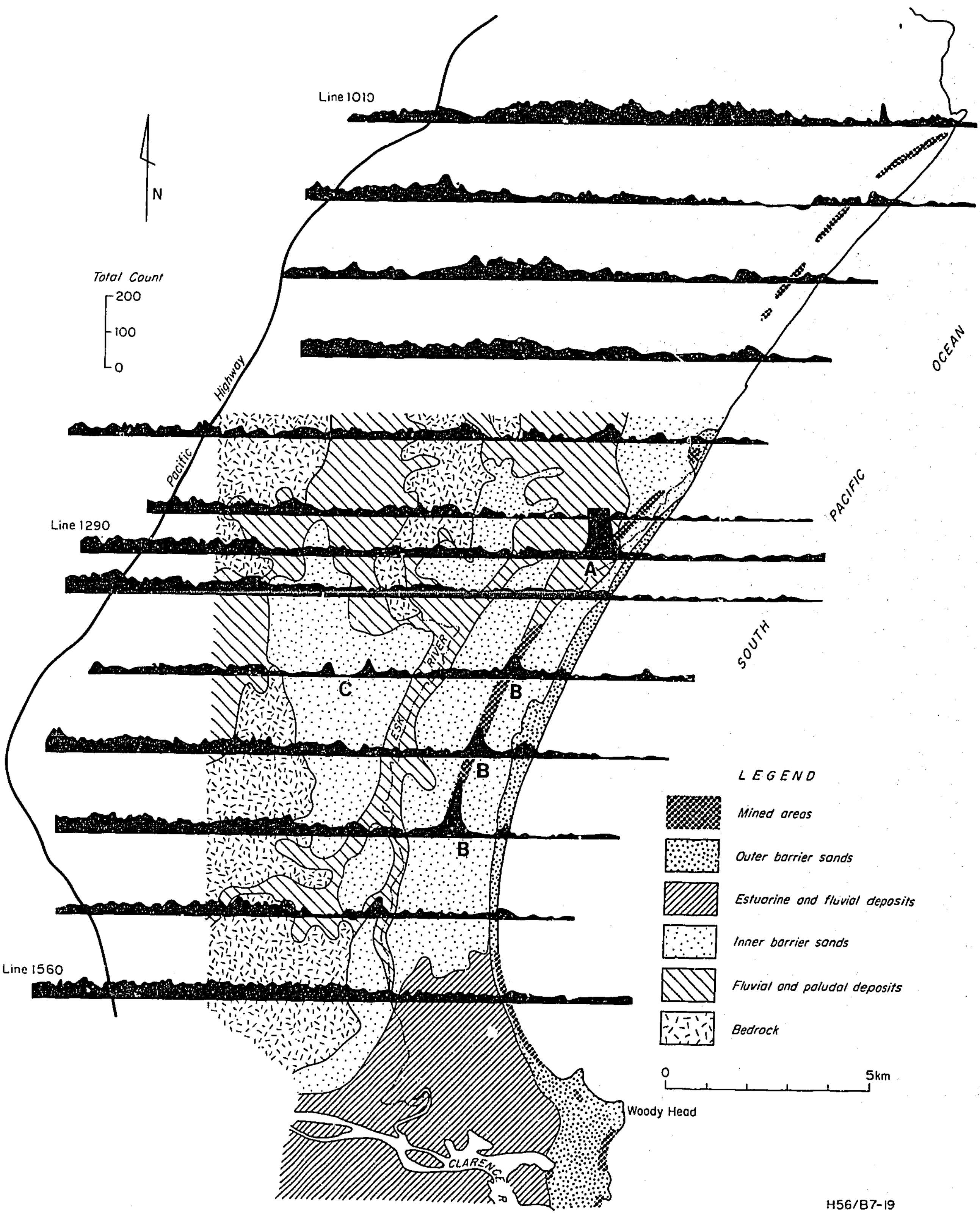


Figure 13. Airborne radiometric results, Jerusalem Creek, NSW. (After Robson & Sampath, 1977; geology from Nicholson, 1974).

abnormal radioactivity. They would occur as areas having very low background radioactivity with superimposed thorium anomalies. In the area covered in Figure 13, the outer barrier sands may be an area that should be followed up with detailed prospecting.

Gravity surveys

Gravity surveys can be used to ascertain the basement shape and the total mass of the host sands. The host sands are usually only partly consolidated and are less dense than basement rocks. Hence, negative gravity anomalies often occur over thick sand masses. Heavy-mineral sand seams themselves are seldom evident in the results of gravity surveys, because the anomalies they produce are too small - the seam in Figure 3 would produce an anomaly of only $2 \mu m/s^2$, even if it was totally composed of heavy minerals.

The shape of the gravity profiles calculated over sand-filled depressions in bedrock is controlled by the shape of the depressions (Fig. 14). The density contrast between the sand and bedrock is taken as $0.7\ t/m^3$. If the gravity readings are made on a grid the mass of the host sand can be calculated using anomalous mass calculations described by Hammer (1945) and Lafehr (1965).

Resistivity surveys

Resistivity surveys can determine basement configuration by mapping the discontinuity in electric impedance between low resistivity unconsolidated sands saturated with salt water and high resistivity basement, using, for example, the Schlumberger array (Fig. 15). In the soundings, the apparent resistivity of the ground is measured for different array sizes, which are in turn measured by the transmitting electrode spacing. The depth at which apparent resistivity is being measured increases with electrode spacing. Results are plotted as sounding curves, which can be interpreted by comparison with master curves or by computer analysis to give the depth to basement. By combining the depths to basement interpreted at each array location, the shape of the basement depression can be derived (Fig. 15).

In heavy-mineral sand environments, conduction of electricity through the ground is almost entirely by pore water, and resisitivity of heavy-mineral sand deposits is generally similar to that of the host material. As a result resistivity surveys are unlikely to directly detect heavy-mineral sand deposits.

Seismic surveys

Seismic surveys can determine basement configuration by mapping the discontinuity in acoustic impedance between the host sands and underlying bedrock. Shallow seismic refraction surveys can be used onshore. Some uncertainties in interpretation can occur because of ambiguities in arrival times, owing to variations in energy absorption characteristics within the sand and seismic noise associated with wave action on beaches (Untung & Hanna, 1975). Shallow seismic reflection surveys can be quickly carried out offshore.

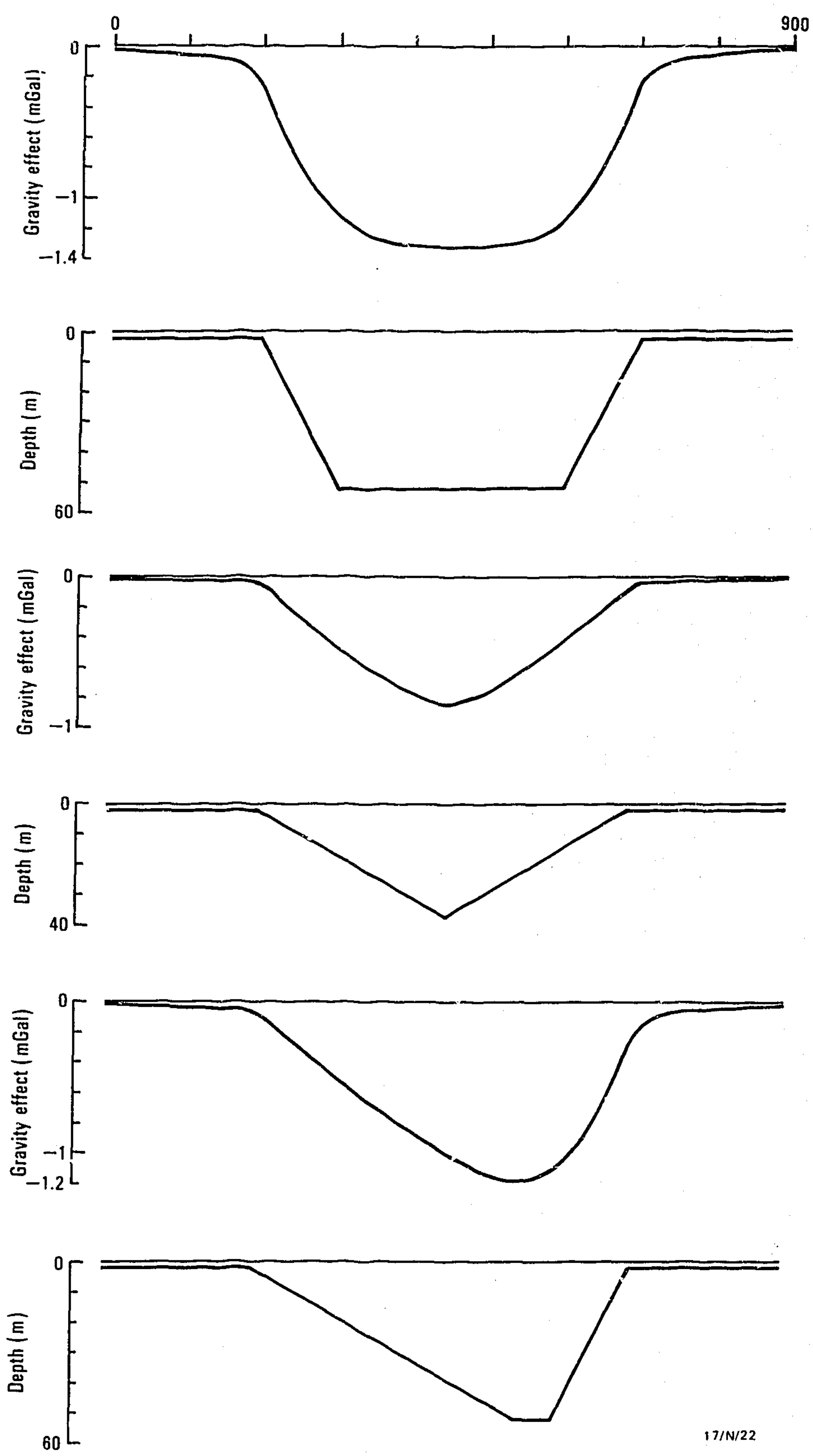


Figure 14. Gravity anomalies over sand-filled depressions in bedrock.

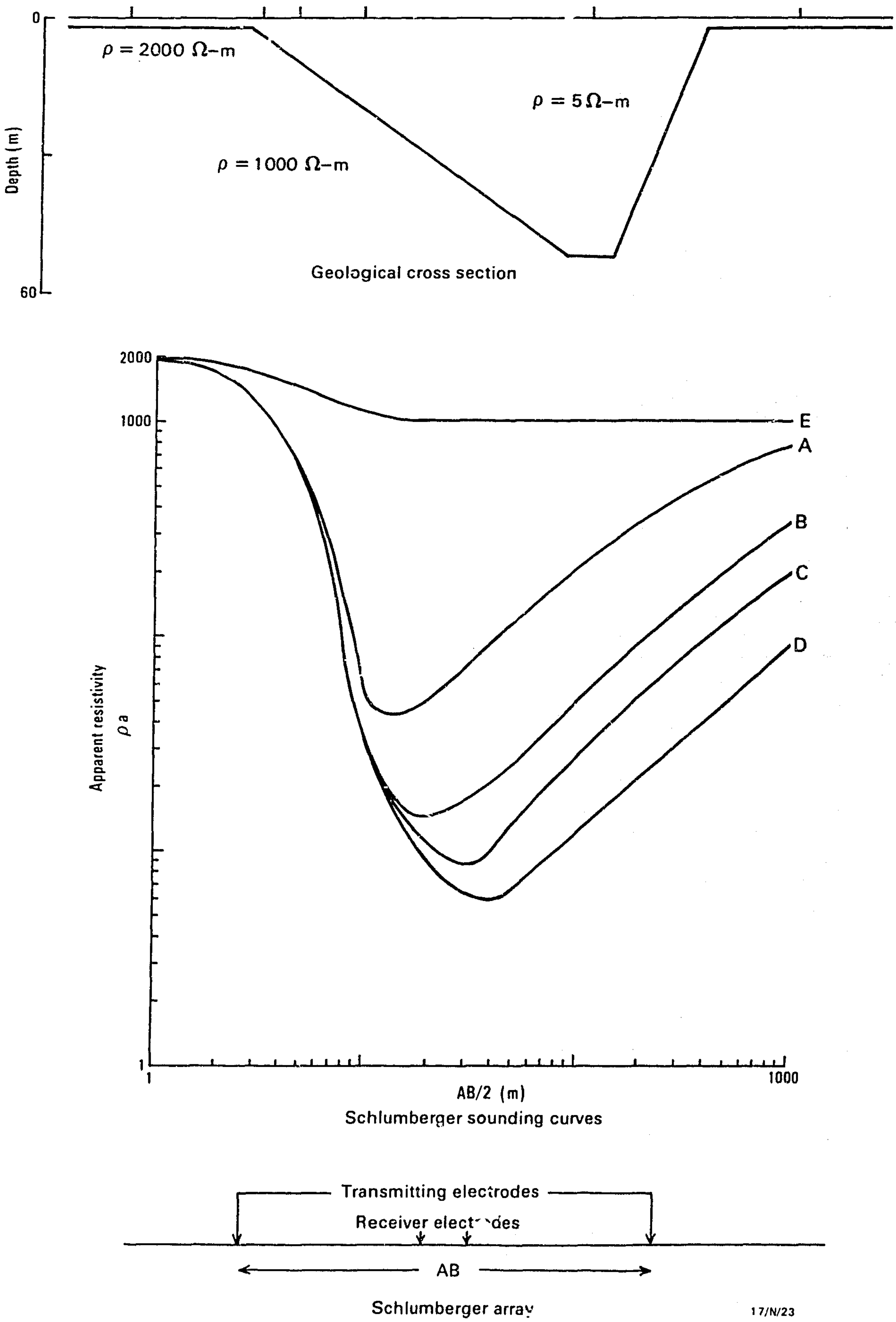


Figure 15. Schlumberger sounding curves over a sand-filled depression in bedrock, and Schlumberger array. 2 m of dry sand (2000 ohm-m) overlies wet sand (5 ohm-m) and bedrock (1000 ohm-m).

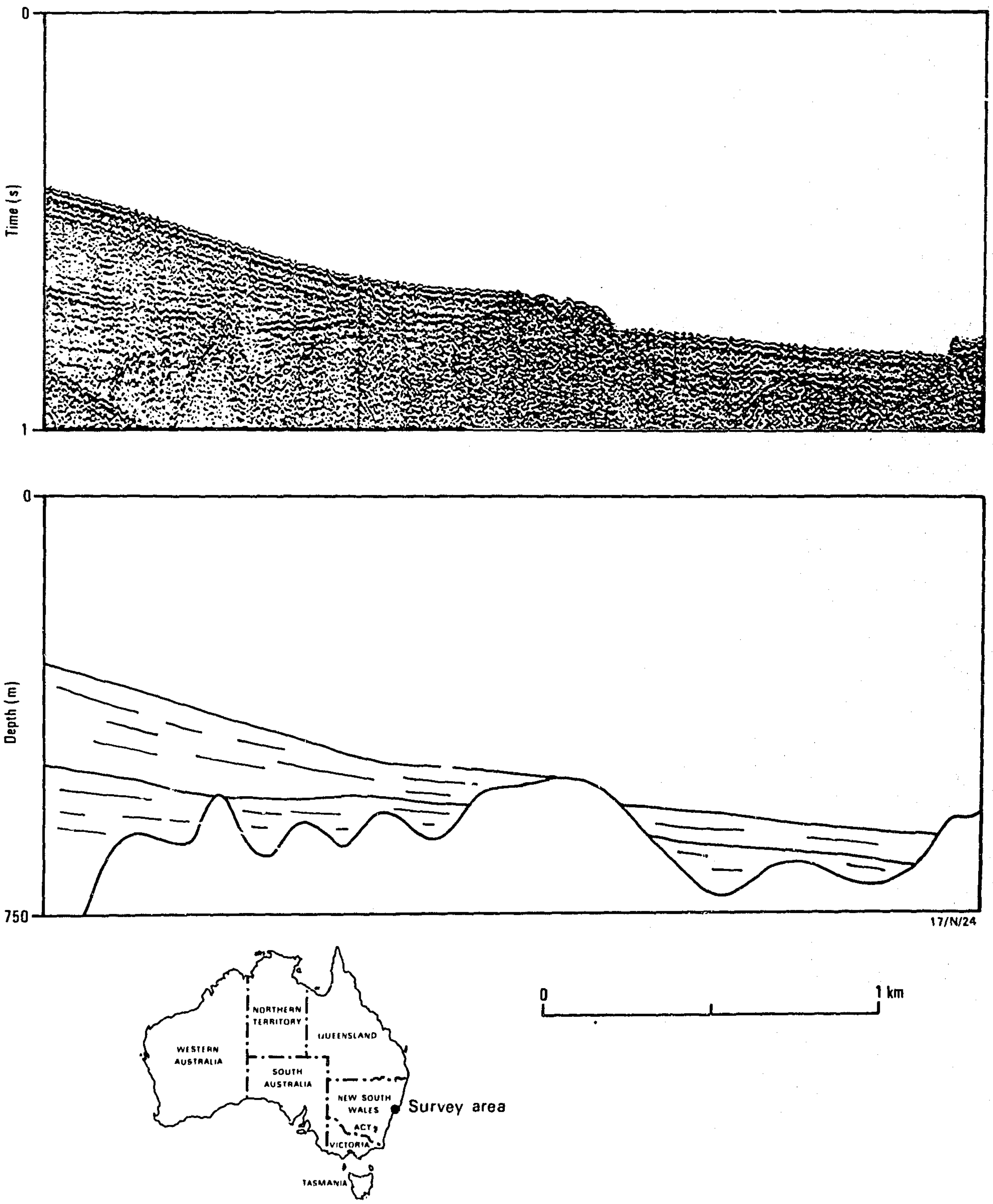


Figure 16. Shallow seismic reflection results and interpretation, offshore eastern Australia. (Sections from J. Colwell, Division of Marine Geosciences & Petroleum Geology, BMR).

Data from part of a BMR offshore shallow seismic reflection survey off eastern Australia were interpreted by J. Colwell (BMR) as basement and two major sand horizons showing layering, some of which is distorted (Fig. 16). Drilling near the survey area has shown that heavy minerals are concentrated between the two sand horizons.

CONCLUSIONS

Up until now, the role of geophysics in the exploration for heavy-mineral sands has been mainly of an experimental nature. However, geophysics can assist by directly detecting deposits, indicating prospective areas, and assessing resources.

For direct detection, a sufficiently large physical property contrast is needed between the deposit and the surrounding material. This contrast mainly results from the presence of magnetite, monazite, and ilmenite. Magnetic and radiometric surveys are fast and easy to carry out. The former can detect deposits containing only a minor amount of magnetite, and the latter can detect deposits not covered by more than a metre of overburden.

Experimental studies have shown that IP surveys can detect high-grade deposits. However, care must be taken to ensure that the array size is appropriate for the size and depth of the target being sought. Generally, IP surveys are much slower, more expensive, and usually less effective than exploring by auger drilling.

Airborne surveys can locate areas favourable for more intensive prospecting and gravity, resistivity, and seismic surveys may also indicate favourable areas. Gravity, resistivity, and seismic surveys can then be used to calculate the size and geometry of host material.

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