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Discrimination of surficial and bedrock magnetic sources in the Cobar area, NSW

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Known mineral deposits in the Cobar area of NSW are magnetic. Hence, the magnetic method is an important tool in the search for mineral deposits in this area. Unfortunately, widespread occurrences of near-surface magnetic mineral accumulations commonly produce aeromagnetic anomalies similar to those expected from bedrock sources. Work by BMR during 1978 and 1979 has shown that the near-surface response is caused by laterite, which contains concentrations of hematite/maghemite minerals with high magnetic remanence and/or susceptibility. These magnetic minerals usually occur in surface layers up to 10 m thick and exhibit large lateral and vertical variations in magnetic properties over small distances. Frequency domain analysis of both model and field magnetic data shows the spectral signatures of bedrock and near-surface sources to be distinctly different. Hence, spectral techniques may be used to separate the responses of bedrock and near-surface sources which occur at the same locality, if high resolution data are available. A comparison of the response of near-surface and bedrock sources by modelling indicates that, with careful survey design, a magnetic target such as Elura could be detected at a depth of 300 m, even in areas of severe surface magnetic noise.

Introduction

In the Cobar area of NSW, surficial deposits of magnetic laterite minerals are widely developed and produce prominent aeromagnetic and ground magnetic anomalies which may mask or be mistaken for anomalies from bedrock sources. During 1978 and 1979 the Bureau of Mineral Resources (BMR) investigated the application of methods able to discriminate between anomalies produced by surface and bedrock magnetic sources, and detect mineral deposits lying beneath surficial sources. Investigations undertaken by BMR included airborne, ground, and downhole magnetic surveys, with laboratory physical property measurements on core samples. Previous BMR work relevant to this problem has been described by Wilkes (1979), Gidley & Stuart (in press) and Gidley (in prep.).

Characteristics of airborne anomalies

Airborne magnetic surveys in the Cobar area are usually flown at 70-150 m above ground level. However, at these heights many surficial and bedrock sources cannot be distinguished by analysis of anomaly shape and amplitude.

Response to bedrock sources

Figure 1 shows the results of an aeromagnetic survey over the Elura lead-zinc deposit flown for the Electrolytic Zinc Co. of Australasia Ltd in 1974 (from Wilkes, 1979). The survey was flown at a height of 90 m above ground level with a line spacing of 300 m. The magnetic anomaly is located directly over the deposit and shows a near-circular anomaly with an amplitude of approximately 40 nT. The results of modelling a north-south aeromagnetic profile flown by BMR across the deposit at a ground clearance of 90 m are shown in Figure 2 (after Gidley & Stuart, in press). A good fit to the observed profile is provided by the response of a magnetic prism comprising a core of moderate susceptibility and a substantial amount of remanence parallel to the Earth's field, and an outer sheath of low susceptibility. This model is reasonably consistent with drilling and physical property measurements, which indicate the deposit contains an inner core of magnetic pyrrhotite with substantial remanence (Gidley & Stuart, in press).

It is important to note that a good fit to the Elura anomaly is also provided by an essentially surface model, as indicated by model 2 in Figure 2. In this model fifteen small three-dimensional blocks with a susceptibility of 150 000 x 10^{-6}SI are used to represent a shallow inhomogeneous source which approximates a surficial accumulation of magnetic laterite minerals. The similarity between the surface and bedrock source aeromagnetic responses is remarkable and illustrates the difficulty in distinguishing between near-surface magnetic sources and bedrock sources in the Cobar area.

Response of surficial sources

A typical example of a near-surface magnetic source occurs in the Shearlegs area, 40 km south of Cobar. The results of an aeromagnetic survey over this area at a ground clearance of 70 m and a line spacing of 400 m are shown in Figure 3 (from Wilkes, 1979). Although flight line spacing and data processing have contributed to the contour pattern in this case, the observed magnetic closures with amplitudes up to 65 nT could easily be interpreted as being due to a bedrock source. However, a substantial program of surface and downhole work (Gidley, in prep.) has shown that the anomalies are produced by upper soil horizons containing up to 40 percent by volume of magnetic minerals.

The results of modelling an aeromagnetic profile flown by BMR across the anomaly at a ground clearance of 90 m are shown in Figure 4. This profile was flown along the line A-B shown in Figure 3. The Shearlegs profile is similar in shape and amplitude to the anomaly observed over the Elura deposit and, again, an Elura-style bedrock source (model 1 in Fig. 4) can provide a good fit to the observed anomaly. The detailed structure of the surface model (model 2 of Fig. 4) was derived by forward modelling a series of twenty discrete magnetic cells to fit ground magnetic data acquired by BMR beneath the aeromagnetic profile along line A-B (see Fig. 3).

Aeromagnetic surveys over other areas with surficial concentrations of magnetic minerals also illustrate this

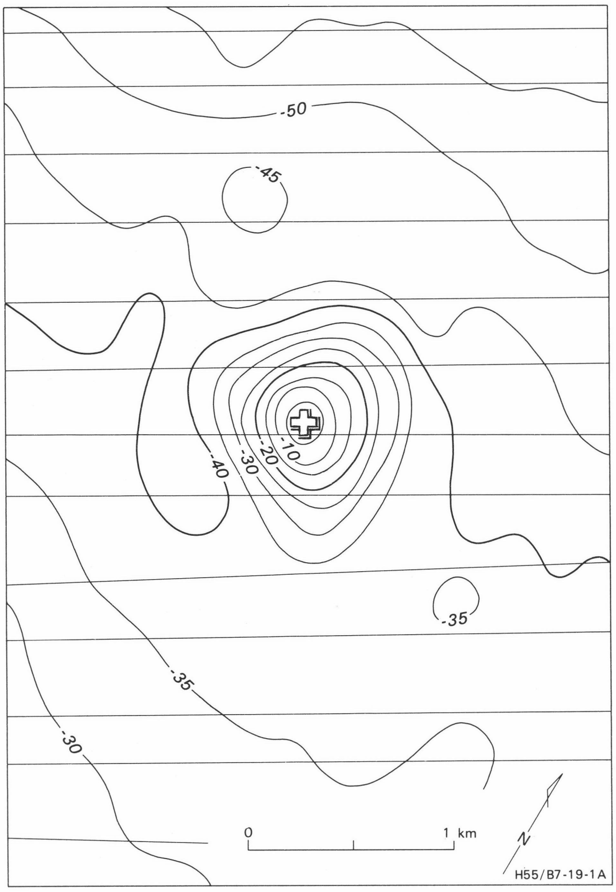

Figure 1. Aeromagnetic contour map of the Elura area obtained from a survey with 90 m ground clearance and 300 m line spacing (from Wilkes, 1979).

ambiguity. For instance, the results shown in Figure 5 (from Wilkes, 1979) were recorded at Burri, 52 km northwest of Cobar in a survey flown at 90 m ground clearance and 300 m line spacing. Interpretation of this near circular anomaly of amplitude 30 nT as having a bedrock source at a depth of approximately 400 m would be entirely reasonable (Wilkes, 1979). However, extensive drilling failed to locate a bedrock source, but indicated surficial lateritic concentrations similar to the Shearlegs case (Gidley, in prep.). A near-surface source, similar to model 2 of Figure 4, can be developed to model the observed data.

Characteristics of ground magnetic anomalies

Normally in mineral exploration, aeromagnetic anomalies are followed up by ground survey techniques. However, the ubiquitous accumulation of magnetic minerals in the soils of the Cobar area produces high-amplitude short-wavelength spikes which may distort or make unrecognisable the response of deeper sources.

The effect of surficial magnetic sources in the Cobar area is illustrated in Figure 6 which shows the results of eleven east-west BMR car-borne magnetometer traverses across the Elura deposit (from Gidley & Stuart, in press). The car-borne survey system consists of a Geometrics G803 proton precession magnetometer, and results are recorded digitally. The detector is carried 20-30 m behind the vehicle to reduce noise and a sampling rate of 1.0s gives a reading interval of approximately 0.3 m for a survey speed of 1.0 km per hr.

The stacked profiles shown in Figure 6 reveal the widespread presence of high-amplitude short-wavelength anomalies at Elura. However, the longer wavelength response due to the Elura deposit centred on 2450E/50800N is still discernible.

At sites such as Shearlegs, where magnetic laterites are strongly developed, very high-ampltiude short-wavelength anomalies are recorded on the ground. These make the detection of possible bedrock sources difficult, and survey design is very important if a true representation of the magnetic field is to be obtained. For example, the two profiles presented in Figure 7 (after Wilkes, 1979) indicate the difference in anomaly shape which may be recorded at Shearlegs when the measurement interval is increased from 5 m to 25 m. The coarse 25 m sampling interval records an apparent long-wavelength component, owing to the inadequate sampling of high-amplitude short-wavelength components. This problem will affect interpretation and further processing procedures.

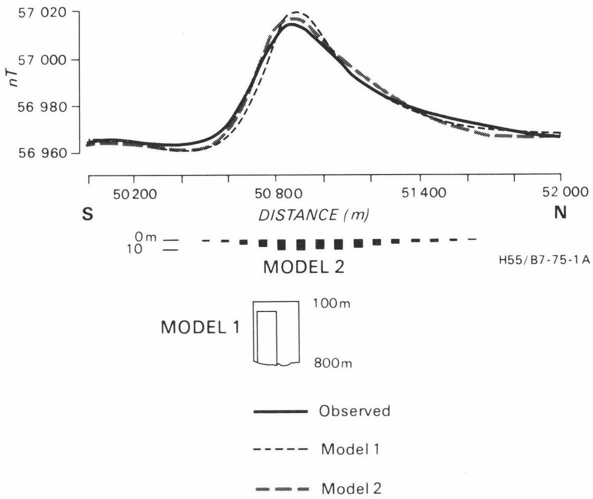

Figure 2. Complex source models for the Elura aeromagnetic anomaly (after Gidley & Stuart, in press).
The outer sheath in model 1 has a magnetic susceptibility of 1000 × 10^{-6} SI and no remanence. The inner prism has a susceptibility of 32 000 × 10^{-6} SI and Koenigsberger ratio of 3.8 with remanent vector parallel to the Earth's magnetic field.

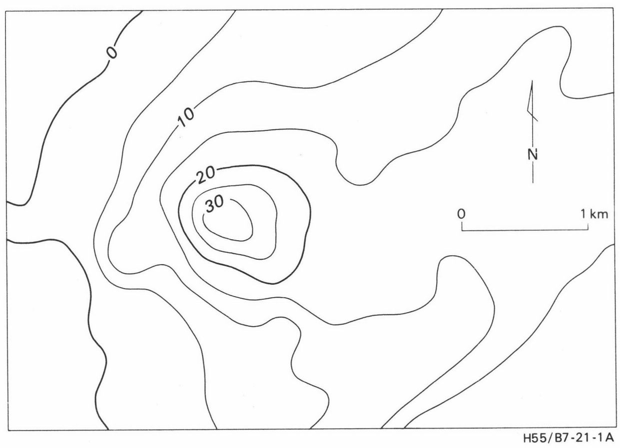

Figure 3. Aeromagnetic contour map of the Shearlegs area, obtained from a survey with 70 m ground clearance and 400 m line spacing (from Wilkes, 1979).

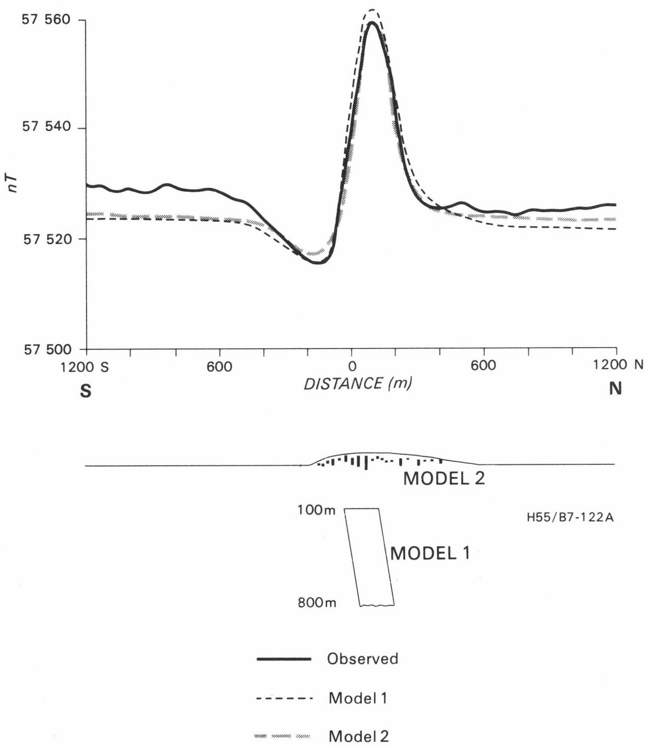

Figure 4. Complex source models for the Shearlegs aeromagnetic anomaly, in profile form along A-B for Fig. 3.
The bedrock source model is a two-dimensional dyke with 80° dip to the south and magnetic susceptibility of 30 000 × 10^{-6} SI.

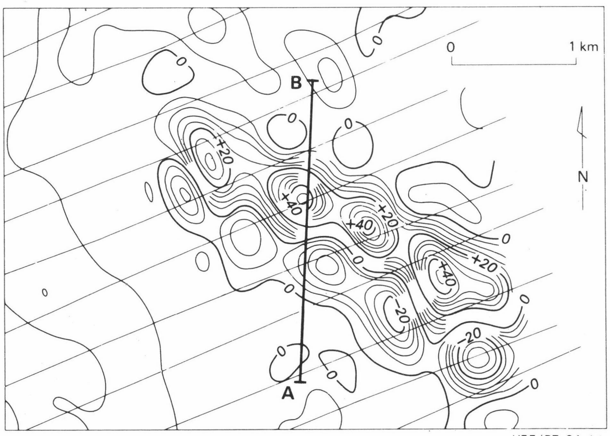

Figure 5. Aeromagnetic contour map of the Burri area obtained from a survey with 90 m ground clearance and 300 m line spacing (from Wilkes, 1979).

The geology and physical character of surficial sources

To study the geophysical behaviour and characteristics of surficial magnetic sources it was necessary to examine drilling results and laboratory analyses from sites where surface accumulations of magnetic minerals are extensively developed. Results of this work from Shearlegs are shown in Figure 8. Shearlegs lies in an area of undifferentiated Cobar Supergroup rocks (Pogson & Felton, 1978), consisting of red and yellow siltstone with some claystones, shales, and argillaceous and quartzitic sandstones. Eleven rotary air-blast holes were drilled by CRA Exploration at 50 m intervals over the main magnetically disturbed zone along the line A-B shown in Figure 3. The holes ranged in depth from 5.5 to 14 m and were logged, as shown in Figure 8, for lithology, magnetic susceptibility and the intensity of the vertical magnetic field.

The geological section reveals a 2-4 m thick layer of iron-rich soil lying upon an east-west trending ridge. BMR X-ray diffraction work indicates that the predominant mineral is quartz, with accessory minerals kaolinite, illite and mica (Gidley, in prep.). Of the iron minerals present, approximately 75 percent is hematite and the remainder is highly magnetic maghemite. To the south of the main maghemite development are low-susceptibility hematitic soils.

The magnetic susceptibility logs were obtained in the laboratory from drilling samples. The maximum susceptibility measured was 250 000 x 10^{-6}SI. The susceptibility in all holes decreases with depth to typical bedrock values of about 400 x 10^{-6}SI. The vertical field magnetic log was measured with a BMR-constructed

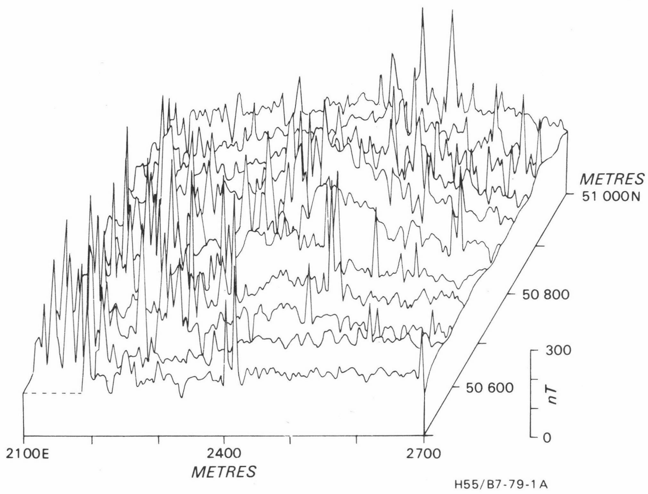

Figure 6. Perspective plot of car-borne magnetometer traverses, Elura (from Gidley & Stuart, in press).

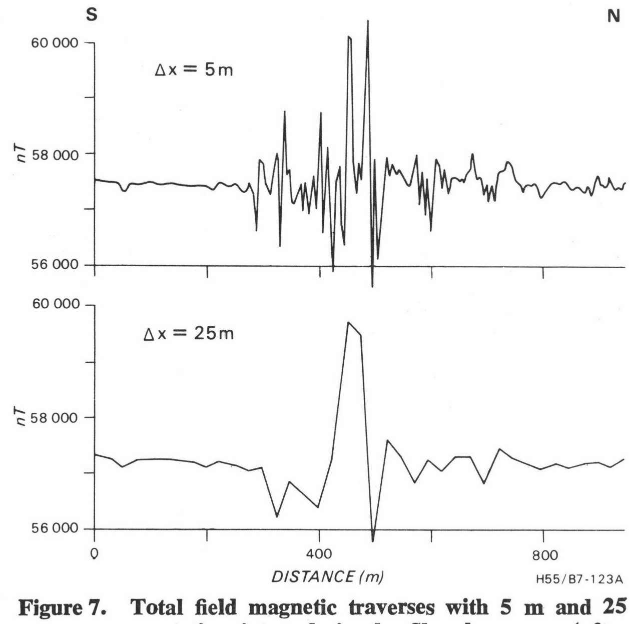

Figure 7. Total field magnetic traverses with 5 m and 25 m station intervals in the Shearlegs area (after Wilkes, 1979).

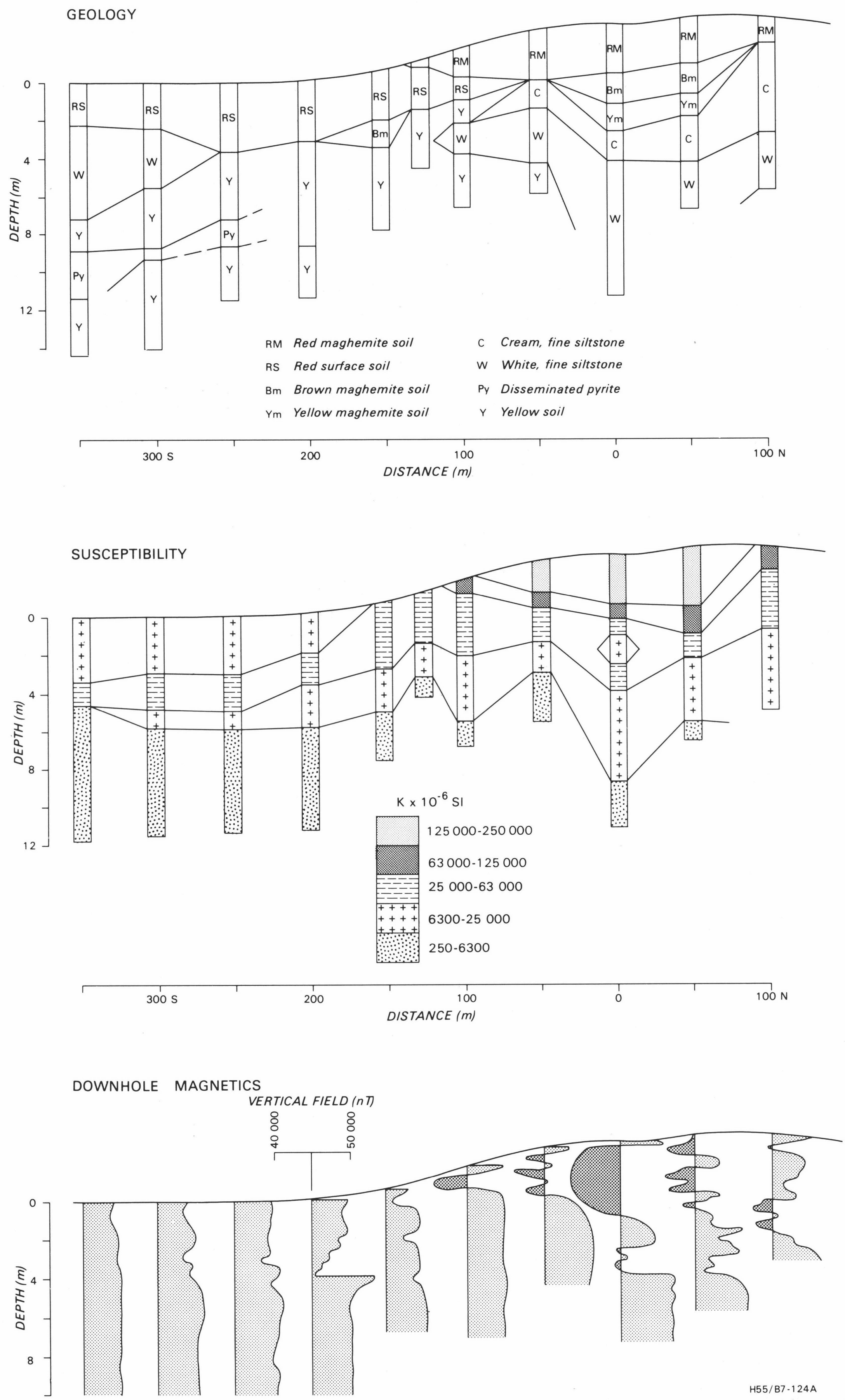

Figure 8. Drilling and physical property logs, Shearlegs.

downhole fluxgate magnetometer. Measurements were recorded at 0.25 m intervals and showed extremely high magnetic gradients over small distances, which indicate the rapid vertical variations in magnetic properties. A good correlation between boundaries observed in the susceptibility, geological and vertical magnetic field logs is demonstrated in Figure 8.

Remanence measurements made on soil samples collected 1-2 m below surface from auger sample holes resulted in Koenigsberger ratios up to 92, indicating that remanence, as well as high susceptibility, is very important in producing disturbed magnetic fields associated with the near-surface magnetic sources (Gidley, in prep.).

Based on the geological control afforded by these studies along line AB (see Fig. 3), a three-dimensional magnetic model was developed for the Shearlegs area. As shown in Figure 9 the response of this model at ground level, 20 m and 60 m above ground level fits closely to the results observed by BMR along AB. It is important to note that for a source of this type the high-frequency component is evident in airborne surveys below 20 m altitude. Above this altitude the individual elements of the model are not seen, and the long-wavelength bulk effects dominate the spectrum.

Spectral characteristics of sources

The results of ground and airborne studies indicate that the magnetic response of surface and bedrock sources, and consequently the spectral responses, are distinctly different at low flying altitudes provided sufficient resolution of the data is obtained. The one-dimensional spectral character can be obtained by transforming the magnetic data from the spatial domain to the frequency domain by Fourier transform. The result of this spectral analysis can be plotted as a power spectrum as shown in Figure 10 (from Gidley & Stuart, in press), where frequency is plotted in cycles per km

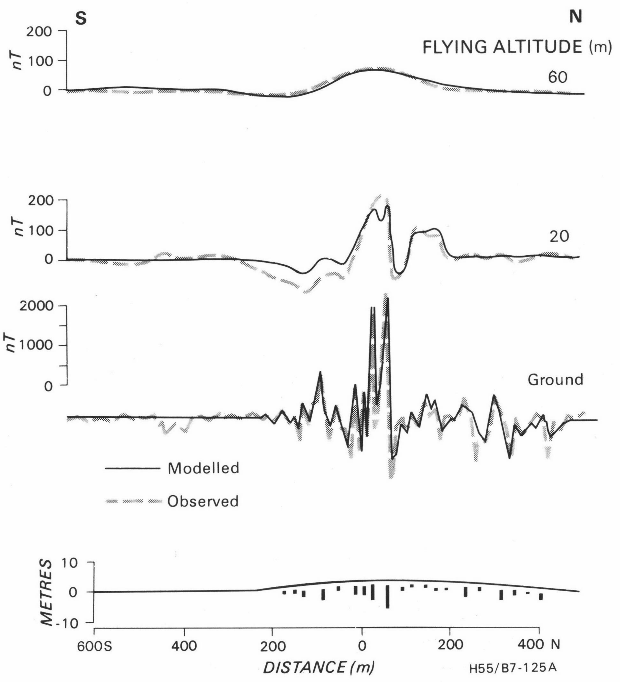

Figure 9. Surficial source magnetic model, Shearlegs. Twenty near-surface discrete bodies were used to model the ground profile and then the profiles were calculated for 20, 40 and 60 m altitudes.

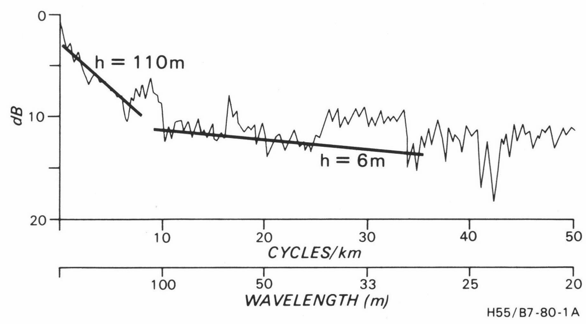

Figure 10. Spectral analysis of car-borne magnetic data, Elura (from Gidley & Stuart, in press).

along the horizontal axis and the normalised power in decibels is plotted on the vertical axis. Examination of power spectra presented in this form shows the relative contribution of different wavelength signals to the original magnetic data. The analyses of frequency domain data can provide information on depth to source, number of sources present, and, possibly, the size and spacing of magnetic cells. As explained by Spector (1968) and Spector & Grant (1970), the attenuation of spectral power with frequency depends on a number of factors including the depth of the source. For tabular sources the plot of log spectral power versus linear wavelength is commonly a straight line, the slope of which can be directly used to estimate the depth to the magnetic source. For spectral analysis to be carried out, the magnetic anomaly must be adequately sampled. As was illustrated in Figure 7, inadequate sampling of high amplitude, short wavelength components of the anomaly will introduce erroneous long wavelength components into the data.

An illustration of the use of spectral analysis is seen in the power spectra derived from Elura and Shearlegs data. The power spectrum of Elura obtained from car-borne magnetometer data is shown in Figure 10 (from Gidley & Stuart, in press) and suggests two gradients and, therefore, two magnetic ensembles. The first of these occurs in the low frequency part of the spectrum, from 0.5 to approximately 9 cycles per km, and is represented by a steep gradient indicative of a source approximately 100 m deep. The similarity between this estimate and the known depth of the Elura deposit is remarkable and indicates that this part of the spectrum is largely due to the magnetic field anomaly in this area caused by the Elura deposit. The second gradient is less well defined, but is observed between

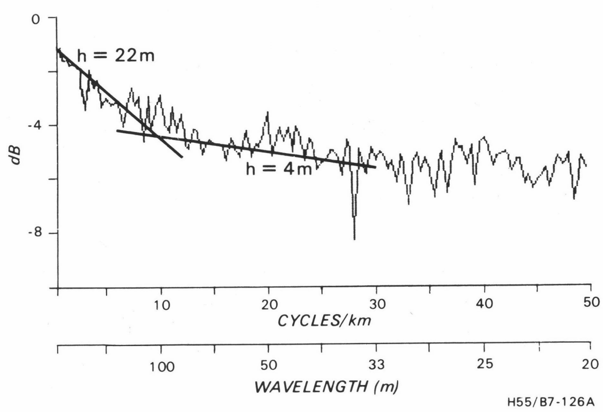

Figure 11. Spectral analysis of observed ground magnetic data, Shearlegs.

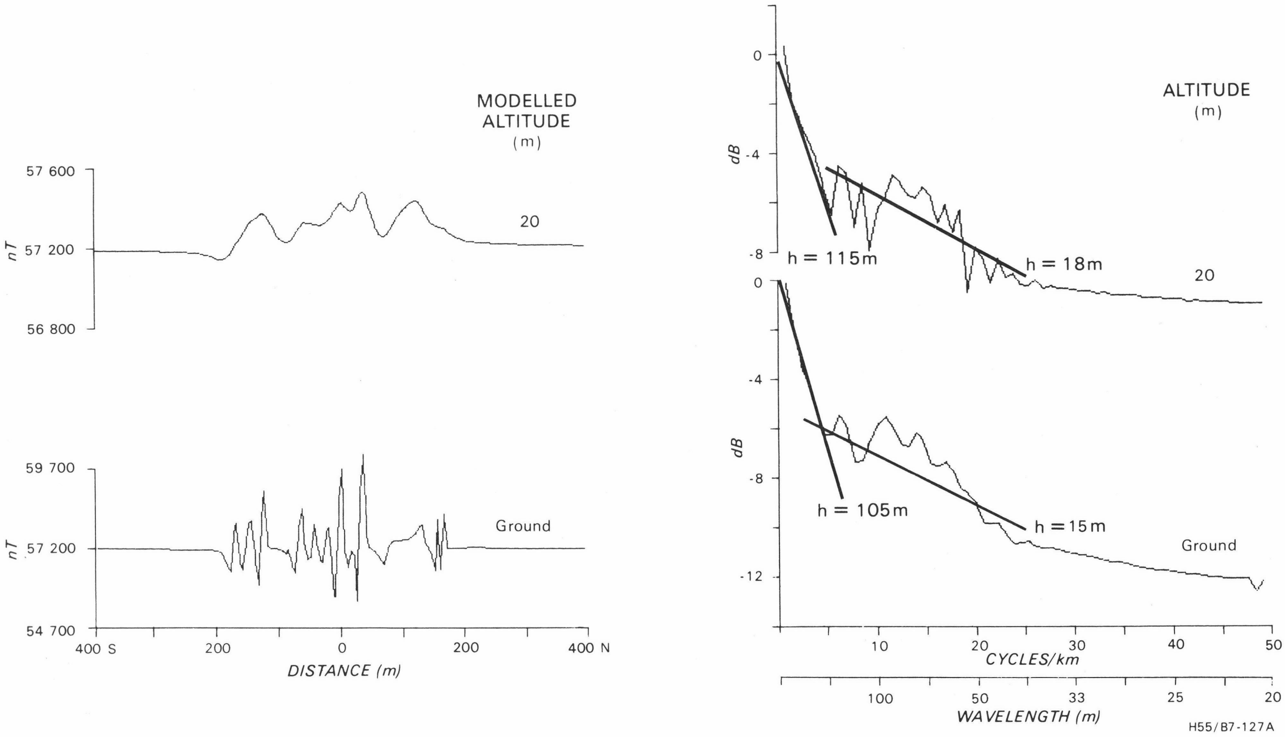

Figure 12. Profiles and spectral plots of the response of a Shearlegs surface model combined with an Elura-type bedrock model.

9 cycles per km and about 36 cycles per km. The depth to the source or sources producing this part of the power spectrum is certainly shallow, and is estimated to be approximately 6 m. Hence, this gradient would appear to characterise the near-surface source at Elura, and the peaks at 9, 17, and approximately 30 cycles per km may indicate the size of individual near-surface magnetic cells. Beyond 40 cycles per km the power spectrum degenerates into noise and cannot be meaningfully interpreted.

The Shearlegs ground spectrum presented in Figure 11 is indicative of a spectrum obtained from a combination of near-surface sources. The spectrum can be fitted by a series of straight lines whose gradients represent a depth range between 4 and 22 m which is consistent with the presence of a near-surface source. The advantage of making depth estimates in the frequency domain rather than the spatial domain is related to the fact that in the frequency domain all data are used simultaneously in the analyses. In the spatial domain, depth interpretation of long wavelength features is likely to be less reliable, owing to the need to remove high frequency components before analyses.

Discrimination of combined surface and bedrock sources

Model data

The spectral characters of anomalies due to surface and bedrock sources in the Cobar area appear to be markedly different. Hence, methods of spectral analysis may solve the problem which exists when a surface magnetic source overlies a bedrock source. An example of this problem is shown in Figure 12 where a surface model of the Shearlegs area is combined with a bedrock model of Elura centred at 0. At and below 20 m ground clearance the short wavelength components due to the presence of the surface magnetic sources dominate the spatial domain data, and it is almost impossible to identify the response of the bedrock source.

A spectral analysis of the combined sources for each modelled altitude is also presented in Figure 12. The spectra for ground and 20 m ground clearance data show a change in gradient, indicating two magnetic sources contribute to the data. For the ground spectrum, the gradient of the long wavelength feature, from 1 to 6 cycles per km, indicates a depth to source of approximately 105 m, which is similar to the depth to the modelled bedrock source. The second ensemble becomes prominent at about 7 cycles per km and the slope of this ensemble response indicates a near-surface source. At approximately 18 cycles per km the power due to the near-surface source decays rapidly to a smooth low-noise response.

As modelled height increases, the slopes of both ensembles increase and merge. The results of this analysis highlight the need for both high spatial resolution and low-level data for the successful discrimination of sources.

Field data with severe noise

The final test of this discrimination method was to apply the spectral analysis technique to field data. The observed profile and drilling evidence suggest that the Shearlegs area represents a concentration of maghemite as severe as found anywhere in the Cobar region. A spectral analysis was undertaken of the observed ground data from Shearlegs combined with a model of Elura. These results are shown in Figure 13. The spatial domain profiles are also shown for the ground traverse over Shearlegs, the Elura model, and for the sum of these two profiles.

The frequency domain spectra shown in Figure 13 reveal the nearly flat gradient of the Shearlegs ground data and suggest a combination of near-surface sources. The Elura model suggests a single source about 100 m deep.

The spectrum derived from the combined profiles shows a noticeable change in decay rate at 4 cycles per km and thus indicates two sources at different depths. Depth interpretation based on the two gradients indicates the source manifest in the low frequency part of the spectrum is about 100 m deep, while the other gradient indicates a shallow depth of approximately 6 m. This result demonstrates the capability of spectral analyses to discriminate between surficial and strong bedrock sources.

Discrimination of weak bedrock sources in the presence of strong surficial sources

The limit of detection of a bedrock source beneath a surface magnetic source by spectral analysis was determined by modelling the combined Shearlegs and bedrock models with different physical constraints of bedrock depth and susceptibility. In Figure 14 the three spectra shown were produced by combining the ground magnetic response for the Shearlegs near-surface model with the Elura-type bedrock model at depths of 100, 200, and 400 m. As depth to the bedrock source increases, both the slope of the bedrock response in the frequency domain plot and the relative power of the surficial source response increase. Finally, for a bedrock depth of approximately 400 m the two responses merge and interpretation of the data suggests that only a single shallow source is present.

Figure 15 shows a second set of spectra generated by combining the response of a Shearlegs-type surface model and an Elura-type bedrock model, where the depth to the bedrock source is kept constant at 100 m, but magnetic susceptibility varied from 30 000 x 10^{-6} SI. When the bedrock model has a susceptibility of 30 000 x 10^{-6} SI the existence of two sources is apparent. Such discrimination remains possible until the bedrock source susceptibility is reduced to about 10 000 x 10^{-6} SI. Note that as the susceptibility has been altered, the frequency content has remained constant and only the relative power of the two responses has changed.

Conclusions

Widespread occurrences of near surface magnetic mineral accumulations provide a source of ambiguity

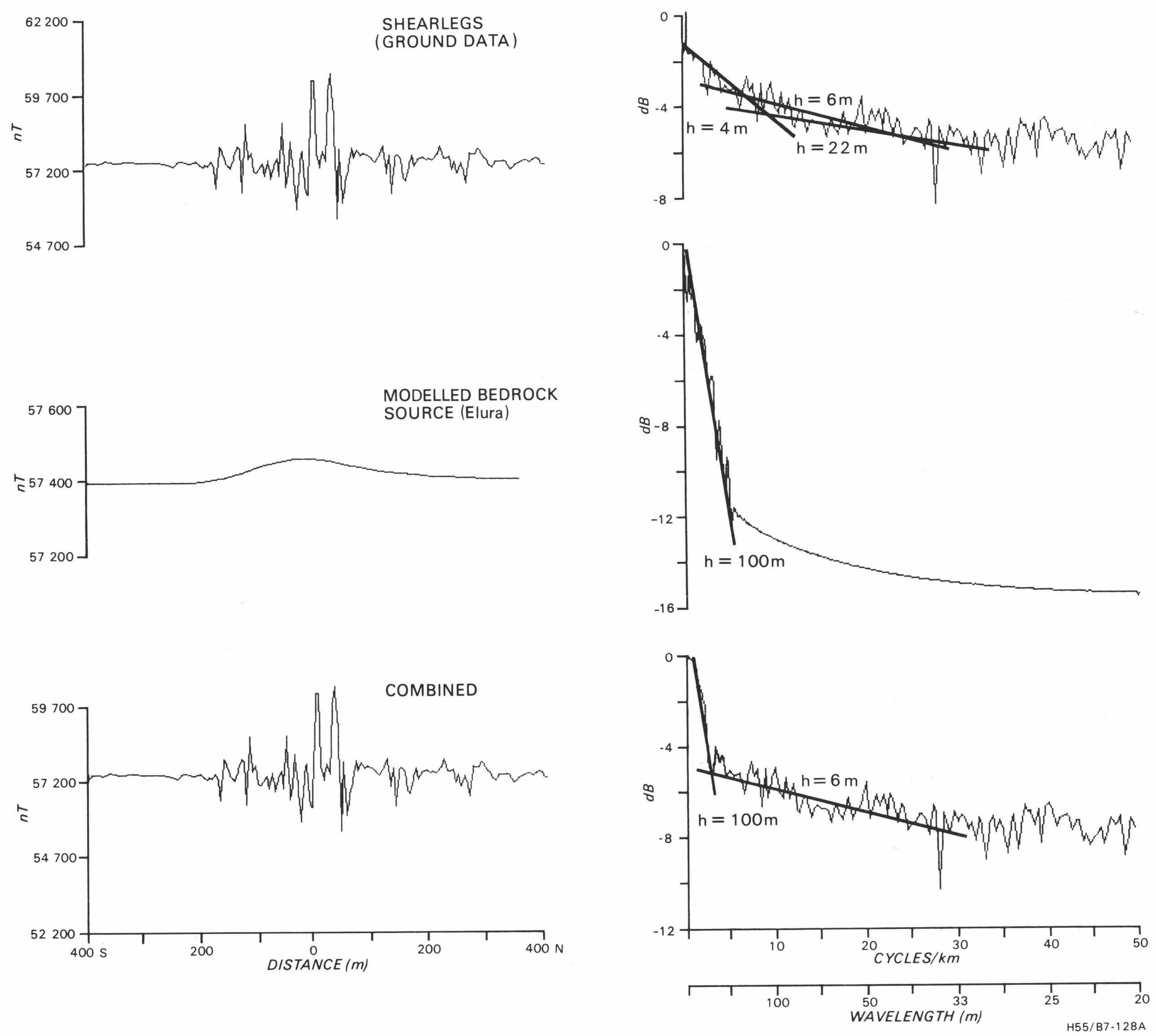

Figure 13. Profiles and spectral analysis of Shearlegs field data combined with the response of an Elura-type bedrock model.

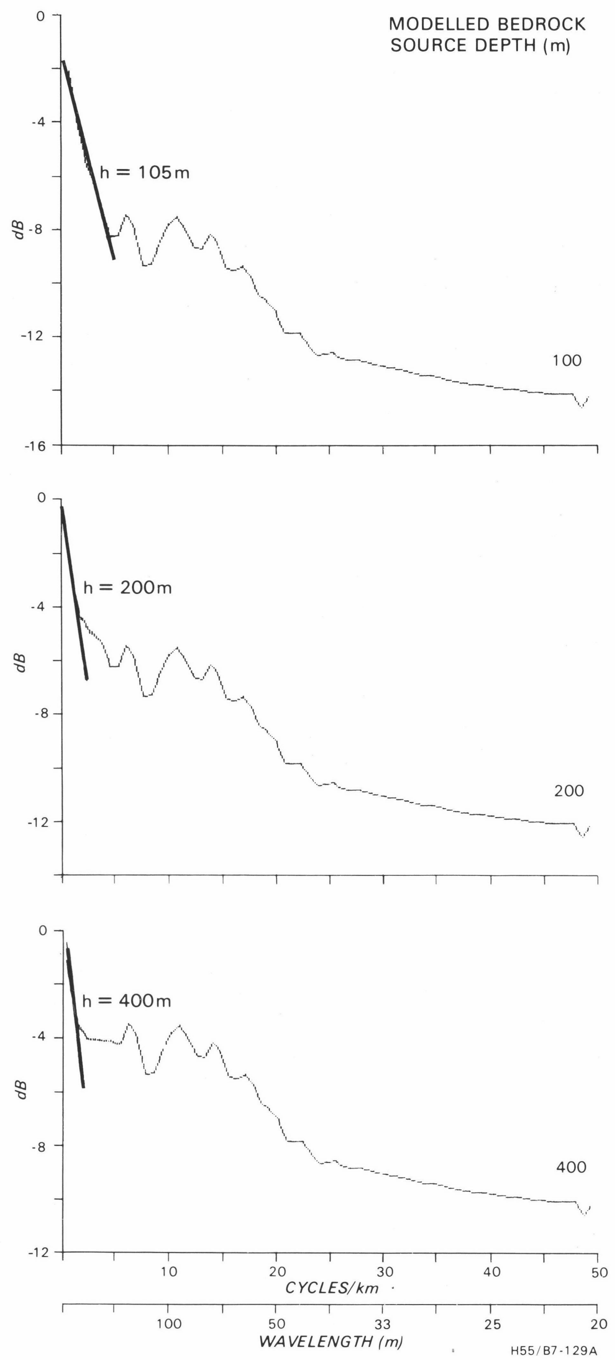

Figure 14. Spectral analysis of the response of a Shearlegs surface model combined with Elura-type bedrock model at depths of 100, 200 and 400 m.

in interpretation of magnetic data in the Cobar area. Airborne, ground, laboratory and downhole magnetic studies have defined the character of the surface magnetic sources and shown them to be due to accumulations of maghemite and hematite which have a high susceptibility and remanence. These magnetic sources usually occur in surface layers up to 10 m thick and exhibit rapid lateral and vertical variations in magnetic properties and concentration over small distances.

Frequency domain analysis shows the spectral signatures of bedrock and surface sources to be distinctly different. Hence, spectral analysis can be used to separate the response of bedrock and surficial sources. The results of these investigations suggest that a target such as Elura can be recognised amid even severe noise by the spectral analyses of high-resolution ground surveys or very low-level aeromagnetic surveys. However, limits to the applicability of the method do exist, and these may be determined by modelling. For example, it may not be possible to detect the presence of a bedrock source such as Elura beneath a near-surface magnetic source if the deposit were at a depth of 400 m. Similarly, a surface source could preclude the detection of an Elura-type bedrock source at a depth of 100 m if the bedrock source susceptibility was as low as 10 000 x 10^{-6} SI.

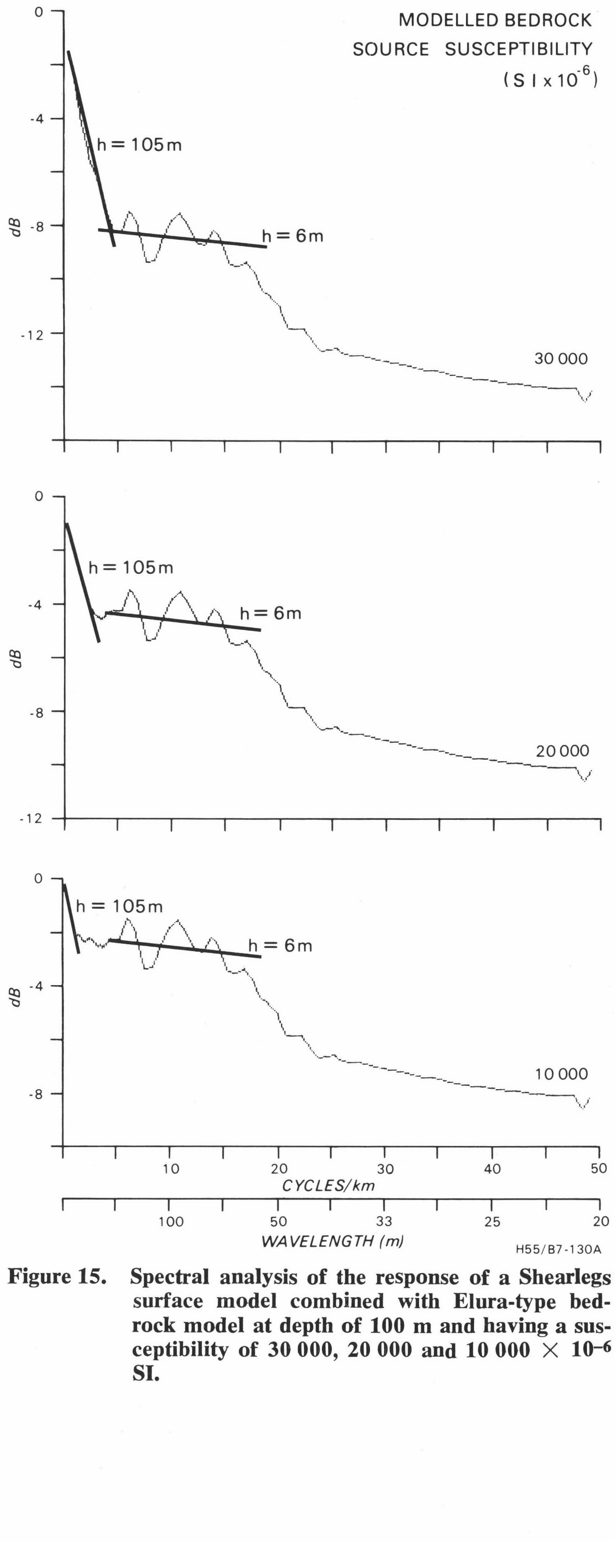

Figure 15. Spectral analysis of the response of a Shearlegs surface model combined with Elura-type bedrock model at depth of 100 m and having a susceptibility of 30 000, 20 000 and 10 000 × 10^{-6} SI.

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