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AN EVALUATION OF GROUND MAGNETIC SURVEYS AS AN AID TO PROSPECTING FOR OPAL IN SOUTHWEST QUEENSLAND 1975

by

C.L. Horsfall & B.R. Senior

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SUMMARY

A chemical weathering profile, developed in sedimentary rocks of the Lower to Upper Cretaceous Winton Formation, is the host to precious opal deposits in western Queensland. The profile, consisting of kaolinitic, siliceous, and ferruginous rocks, has a preserved thickness in excess of 100 m, and is widespread in western Queensland. Significant production of precious opal, however, is restricted to a belt about 90 km wide. Precious opal is present in this profile in the voids of ironstone concretions.

Following a promising preliminary investigation, ground magnetic surveys were conducted at three opal prospects northwest of Quilpie to evaluate the suitability of ground magnetometer surveys in locating potentially opal-bearing ironstone. The results of this work suggest that the method is of doubtful usefulness and even in a favourable situation requires careful field work and interpretation with measurements of the magnetic properties of samples. It cannot be used as a simple prospecting aid.

Measurements on samples show that the susceptibilities are low and that there is generally little contrast in susceptibility and remanence intensity between the ironstone and weathered host sediments.

Measurements on oriented samples of ironstone show that their remanent magnetization is sub-parallel to the present direction of the Earth's magnetic field and that both normal and reversed magnetizations occur. For totally normal and totally reversed remanent magnetization, effective susceptibility values were calculated for samples on the assumption that their remanent and induced magnetization was totally induced. These values also show little magnetic contrast between ironstone and country rock. However, it is possible that the method may work in some areas if the country rock has low and homogeneous susceptibility and remanence relative to that of the ironstone.

Anomalies encountered on two opal prospects were related to variations in susceptibility in the weathered country rock, to contacts between clayey alluvium and iron-stained sandstone and possibly to variations in depth to the ferruginous zone of the weathering profile. Some anomalies seem to be related to the affect of lightning strikes on remanence. On two other prospects magnetic anomalies appeared to be related to the subsurface extension of exposed ironstone occurrences, but there are insufficient sample measurements and excavation to support this.

1. INTRODUCTION

Ground magnetometer surveys were carried out in November 1974 by a BMR party consisting of C.L. Horsfall (geophysicist) and B.R. Senior (geologist) on four opal prospects near Quilpie, Qld. The aim of the surveys was to follow up previous magnetometer work by Senior to establish the suitability of ground magnetometer surveys in delineating the presence of underground ironstone which is the host rock to precious opal in this area. The usual method of opal exploration has been random excavation, drilling, or excavation near surface float indications.

Previous work in the application of geophysics to opal prospecting has been done by J.J. Hussin (1965) of S.A. Dept of Mines at Coober Pedy, S.A., using the seismic refraction technique and resistivity depth probing with limited success.

Ground magnetometer surveys were conducted at The Yeppra, Bulgaroo, Nickavilla Station, and Bull Creek prospects near Quilpie, Qld. The location of these survey areas is shown in the geological map, Figure 1, and Figure 4.

Throughout this report the term 'ironstone' refers to a rock heavily charged with iron oxide, usually limonite, and commonly in concretionary form. The term 'country rock' refers to the weathered sediments in which the ironstone occurs.

2. GEOLOGY

A chemical weathering profile, developed in sedimentary rocks of the Lower to Upper Cretaceous Winton Formation, is the host to precious opal deposits in western Queensland. The profile, consisting of kaolinitic, siliceous, and ferruginous rocks, has a preserved thickness in excess of 100 m, and is widespread in western Queensland.

Significant production of precious opal, however, is restricted to a belt about 90 km wide (Fig. 1). Within this belt the weathered profile has been truncated by erosion near folds and faults. In such situations the weathered profile averages only 30 m in thickness and the basal ferruginous portion lies just below the peneplaned landsurface.

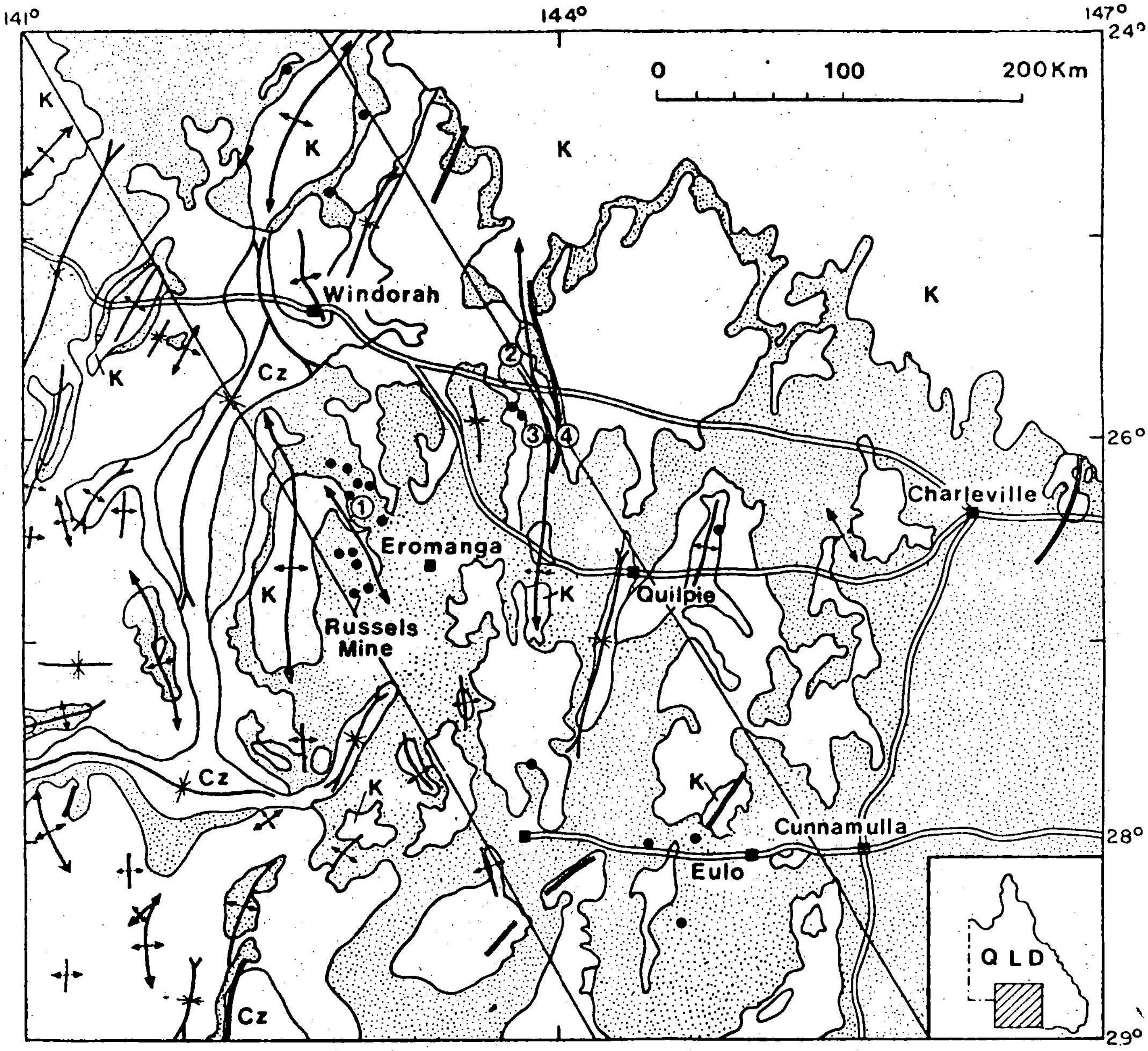
Peneplanation was followed by further prolonged weathering and colluvial disintegration of the Winton Formation profile. Iron-oxide cementation of the colluvium formed a hard crust (Fig. 2) which forms cappings to mesa remnants throughout the zone of significant opal production. Opal is found within the ferruginous portion of the Winton Formation profile by driving shafts into mesas below this crust, or by open-cutting areas where the crust has been partly or completely eroded.

The distribution of ironstone in the Winton Formation profile is in many places strongly controlled by the bedding configuration of the weathered host rock. Iron oxides accumulated in the ferruginous zone as thin beds, or as lenticular or concretionary bodies in bedding structures floored by impermeable rock. Ironstone along the base of palaeochannels, cross-bedding foresets in sandstone, differential compaction faults, and undulatory bedding contacts formed local sites for the deposition of precious opal (Fig. 3). However, deposition of opaline silica occurred only in areas where the Winton Formation profile was truncated, which in effect brought the ferruginous zone closer to the ground surface and hence into the zone of intermittent groundwater saturation. Under these conditions, concentric, radial, and sub-parallel voids in ironstone acted as reservoirs to silica-laden groundwater. Along the basal portions of bedding traps, movement of groundwater was restricted owing to lateral closure, and the ironstone was bathed in silica-rich groundwater for long periods. In these exceptionally quiet zones the colloidal silica formed a gel which hardened by hydration into precious opal.

3. METHOD AND EQUIPMENT

The undisturbed total magnetic field at the survey sites investigated had an intensity between 54 000 and 54 600 nT, an inclination of -57.7^{o}, and a declination of 8.1^{o}E. Anomaly amplitudes ranged up to 70 nT with most anomalies being of the order of 30 nT amplitude. An anomaly due to a higher-susceptibility body in the above magnetic environment will generally have a maximum and minimum, with the minimum on the southern side.

Readings were taken to 1 nT accuracy using a Geometrics G816 proton precession magnetometer with digital readout of total field. The sensor was mounted on a 2.5-m pole. Readings were generally taken on square grids of 6.1-m spacing and follow-up traverses across anomalies of interest were done at 1-m to 1.5-m spacing.



• Precious opal occurrence

(1) Proton magnetometer surveys of opal prospects

1 Gem mine, Yeppra

2 Bulgroo prospect

3 Bull Creek mine

4 Nickavilla prospect

Zone of significant precious opal production.

Cz — Cainozoic sediments

Glendower Formation

K — Rolling Downs Group mainly Winton Formation

Fault

Anticline showing plunge direction

Syncline " " "

Fig.1 Precious opal occurrences and distribution of the potential opal-bearing Winton Formation profile in southwest Queensland.

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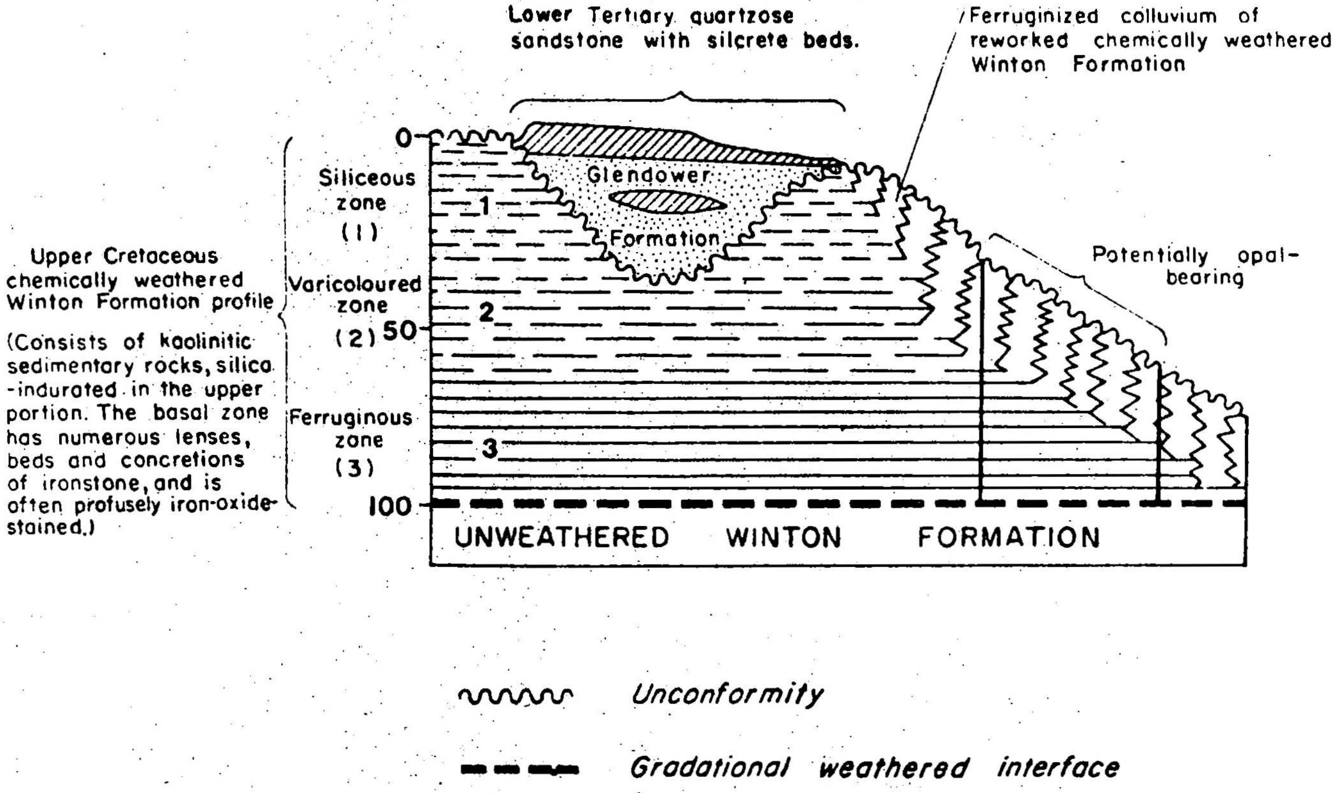

Fig.2 Diagramatic relation of weathered rock units.

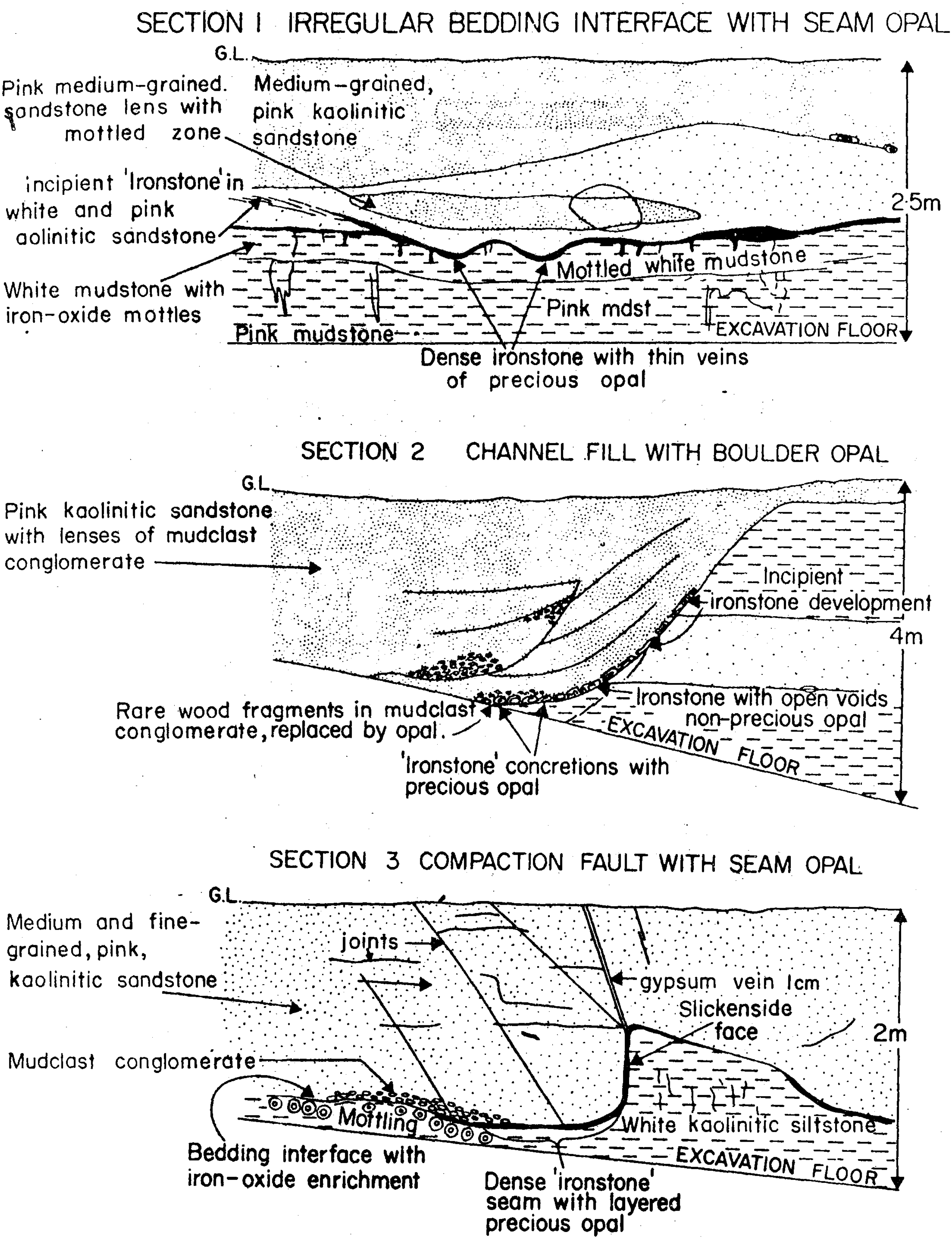

FIG. 3 PRECIOUS OPAL STRUCTURES.

Corrections for diurnal variation were made at 5-minute to 15-minute intervals, depending on the size of the grid, by using tie-lines and returning to a base station.

Vertical gradient measurements were taken on some grids in conjunction with normal measurements. Vertical gradient (or first vertical derivative) values were calculated by measuring the value of total magnetic intensity at two heights above the ground surface at one point and dividing the difference of the magnetic readings by the vertical distance between the readings.

Theoretically the body of higher susceptibility lies under the minimum of the vertical gradient values and the boundary of the causative body is delineated by the zero vertical gradient values (Hood & McLure, 1965). Contour maps and profiles of vertical gradient are useful in determining the position and shape of causative bodies. Vertical derivative values are not affected by diurnal variation, as the two required readings are taken in rapid succession.

Depth estimates were made from the vertical gradient profiles and separately from each of the two total intensity profiles at different heights above the ground. Total intensity profiles were interpreted using the 'Manual of Magnetic Interpretation' of Martin (1966). Depth estimates for the two heights were corrected for their respective heights above ground surface and averaged.

The value of vertical gradient measurements was limited by the low-anomaly intensities in the area. The magnetometer's resolution of 1 nT was large compared with the changes in values of vertical gradient at an anomaly and the 'noise' associated with this relatively low resolution masked the true shape of the vertical gradient contours and profiles. This problem could be partly alleviated by increasing the vertical spacing between readings; however, the theory breaks down if the vertical spacing between readings is not very much less than the depth to the source. Through experimentation with various vertical spacings, the optimum spacing for these conditions was considered to be 0.5 m with the lower height reading taken approximately 2.5 m above the ground.

Samples were collected for susceptibility and remanence measurements from anomaly sites during their excavation, from surface outcrop at the various levels in the weathering profiles, and from surface float ironstone.

4. MAGNETIC PROPERTIES OF SAMPLES

(a) Susceptibility and remanence measurements

Susceptibility measurements were done on all samples collected in the field. Remanence intensity measurements were done on 43 of the 47 samples and *Koenigsberger Q factors calculated. The values with brief sample descriptions are given in Table 1. In general all samples show low susceptibility and remanent magnetization.

X-ray diffraction analysis of an ironstone sample showed the iron oxides to be hematite and goethite. The association of low susceptibility with a higher remanence is consistent with the magnetization of a concentration of single domain hematite grains with a grainsize less than 0.15 cm. The remanent magnetization of the ironstone is considered to be produced by the aligning of single-domain hematite grains with the Earth's magnetic field at the time of chemical precipitation.

Table 2 shows the remanent magnetization, inclinations, and declinations of 11 oriented samples of outcropping ironstone from the weathering profile. The relative locations of these samples and their positions relative to the survey areas are shown in Figure 4. Figure 4 shown that the direction of the normal and reversed magnetizations, shown for each sample by an arrow, are sub-parallel to the direction of the present-day Earth's field. The average of the directions of the normal and reversed magnetizations of the samples in Table 2 is D:013^{o}, I:-62. The pole position deduced from these measurements is consistent with a Middle Tertiary age when plotted on the polar wander curve for Australia. Further study of the directions of remanence in the ironstone is being carried out by the Bureau of Mineral Resources.

The occurrence of both normal and reversed magnetizations in samples of ironstone suggests that chemical weathering and precipitation of ironstones occurred over a period encompassing one or more magnetic reversals of the Earth's field. It is therefore possible that a body of ironstone or even a single concretion may possess both normal and reversed magnetizations. The contribution of remanent magnetization to magnetic anomalies depends on the intensity of the respective magnetizations and the relative proportions of material of normal and reversed magnetization. The effect of both normal and reversed magnetizations in a body of ironstone would be to lower the effective remanent intensity.

*Koenigsberger Q: The ratio of the remanent magnetization to the product of the susceptibility and the Earth's field strength; symbol Q.

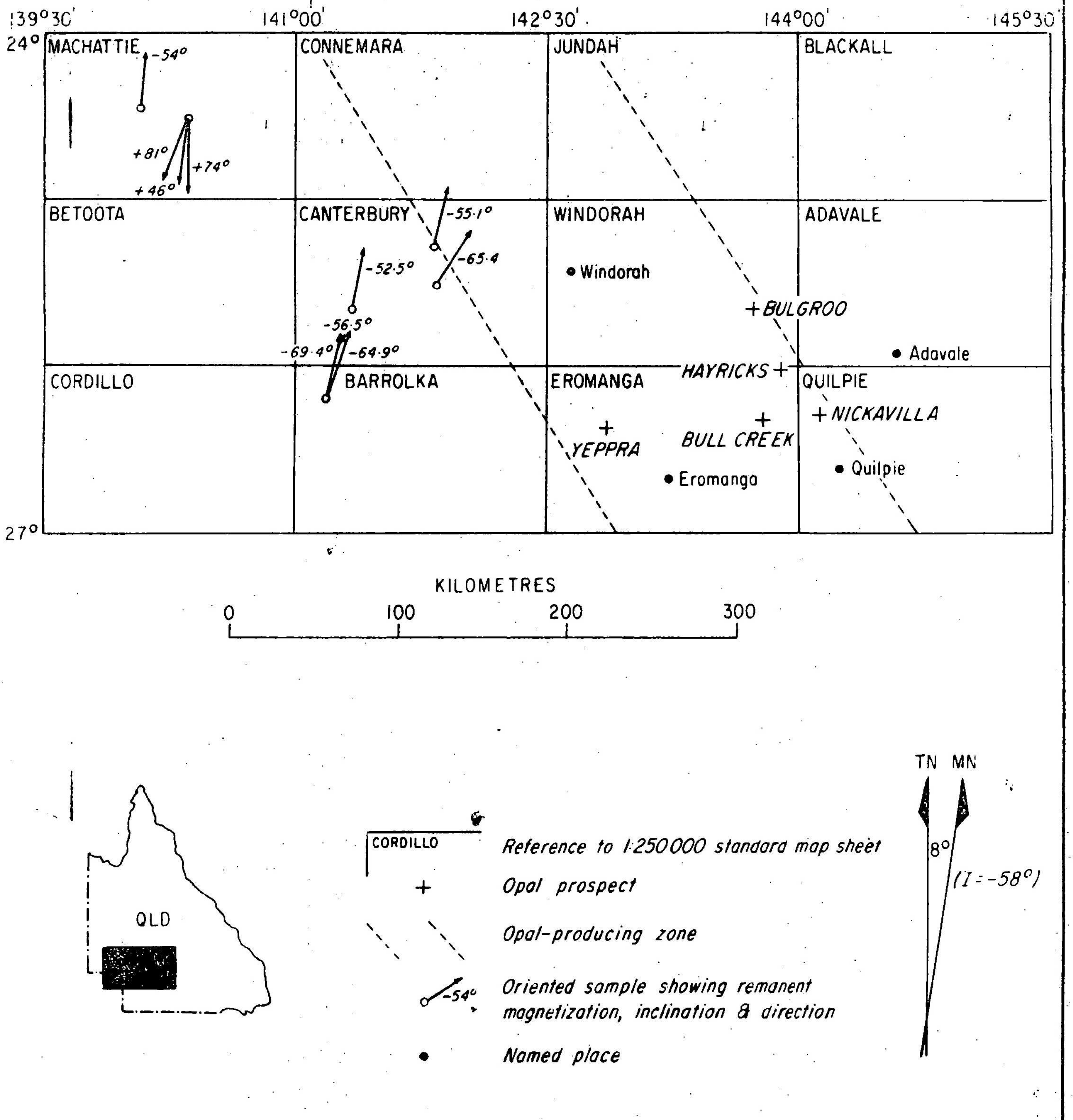

Fig.4 MAGNETIC SURVEY FOR OPAL, SW QLD
LOCALITY MAP

TABLE 1

Magnetic Properties of Samples

LOCALITY	SAMPLE NUMBER	LITHOLOGY	SUSCEPT-IBILITY ($cgs \times 10^{6}$)	REMANENCE INTENSITY ($cgs \times 10^{6}$)	KOENIGS-BERGER Q.	NORMAL Rm EFF. SUSCEPT. ($cgs \times 10^{6}$)	REV. Rm EFF. SUSCEPT. ($cgs \times 10^{6}$)
YEPPRA	37	Opal-bearing concretionary ironstone	70	23	0.608	112	+27
	825-197	Iron-stained sandstone	29	30	1.9	84	-26
	825-197	" " "	35	51	2.7	130	-60
BULGROO	36A	Opal-bearing concretionary ironstone	60	14	0.432	86	+34
	36B	Ironstone	75	29	0.716	129	+21
	36C	Dense opal-bearing ironstone	85	18	0.392	118	+52
	BUL 1	Blackened ironstone float from surface	70	630	16.7	1239	-1100
	BUL 2	Yellowish orange, weathered clayey sandstone at 0.4-m depth	105	410	7.23	864	-654
	BUL 3	Yellowish oatmeal, weathered clayey sandstone	285	485	3.15	1183	-613
	BUL 4	Highly ferruginous sandstone to ironstone at 0.6-m depth	92	160	3.22	388	-204
	BUL 5	Dense-layered opal-bearing ironstone at 2-m depth	85	306	6.67	652	-482
	BUL 6	Red (iron-stained) weathered clayey sandstone	45	360	14.8	711	-621
	BUL 7	Brown clayey sand alluvial	85	-	-	-	-
	BUL 8	Massive ironstone at 0.3-m depth	63	57	1.67	168	-42
	BUL 9	Red-brown iron-stained sandstone	60	684	21.1	1326	-1210
	BUL 10	Highly ferruginous sandstone to ironstone at 0.6-m depth	70	175	4.63	394	-254
	BUL 11	Dense black faintly-layered ironstone	60	31	0.957	117	+2.6
NICKA-	RG 1	Yellowish silicified clayey sandstone (mesa capping)	20	57	5.2	124	-84
VILLA	RG 2	Red-brown iron-stained sandstone	30	43	2.65	110	-50
	RG 3	Opal-bearing concretionary ironstone	50	12,3.3	.44,.12	72, 56	+28,+44
	RG 4	Pinkish red, weathered clayey sandstone	50	15	0.56	78	+22
	RG 5	White, yellowish, red, mottled ferruginous kaolinitic siltstone	70	38	1	140	0

TABLE 1 (Continued)

LOCALITY	SAMPLE NUMBER	LITHOLOGY	SUSCEPT-IBILITY (cgsX10^6)	REMANENCE INTENSITY (cgsX10^6)	KOENIGS-BERGER Q.	NORMAL Rm EFF SUSCEPT (cgsX10^6)	REV. Rm EFF. SUSCEPT (cgsX10^6)
NICKA-VILLA	RG 6	Dense concretionary ironstone float	70	76	2.01	210	-71
	RG 6A	" " " "	65	29	0.826	119	+11.3
	RG 7	Opal-bearing concretionary ironstone	18	16	1.64	48	-11.5
BULL CREEK	DB 1	Greenish silicified siltstone (porcellanite)	2	3.4	3.14	8.3	-4.3
	DB 1A	Pink, red, white, mottled silicified clayey siltstone (porcellanite)	8	66	15.2	130	-114
	DB 2	Tertiary fossil soil profile	10	-	-	-	-
	DB 3	Pink, brown, white, mottled clayey sandstone	55	21	0.707	94	+16
	DB 4	Dense, concretionary upper-level ironstone	78	49	1.16	169	-12.5
	DB 5	Concretionary lower-level sandy ironstone	65	10	0.285	83	+46
HAYRICKS	35A	Opal-bearing concretionary ironstone	80	30	0.69	135	+25
	35B	" " " "	96	23	0.444	139	+53
	35C	" " " "	97	15	0.286	125	+69
	84-5	Pink silicified siltstone to sandstone	12	13	2.01	36	-12
	84-4	Yellowish brown siltstone	9	2.7	.55	14	+4
	84-3	Red-brown clayey sandstone	51	27	.98	101	+1
	84-2	Off-white clayey sandstone	17	2	.218	21	+13
OTHER AREAS	49-1/83	Outcropping concretionary ironstone	55	190	6.4	407	-297
	50-1/83	" " "	60	-	-	-	-
	56-6/263	" " "	40	180	8.33	373	-293
	21-3/175b	" " "	60	-	-	-	-
	42-2/23	" " "	60	260	8.02	541	-421
	43-2/21a	" " "	60	160	4.94	356	-236
	43-2/21b	" " "	60	460	14.2	912	-792
	70-3/37	" " "	60	1	0.03	62	+58
	8-3/181	" " "	50	6	0.22	61	+39

TABLE 2

Remanent Magnetization Directions of Samples

SAMPLE	COORDINATES	SUSCEPTIBILITY (cgs X 10^{-6})	REMANENCE INTENSITY (cgs x 10^{-6})	DECLINATION	INCLINATION
49 - 1/83	141° 51.3' 25°31.1'	55	190	030.6°	-65.4°
8 - 3/181	141° 50' 25°16.8'	50	6	010.8°	-55.1°
56 - 6/263	141° 20.7' 25°40.5'	40	180	008.1°	-52.5°
42 - 2/23	141° 10' 26°12.3'	60	260	012.7°	-56.5°
43 - 2/21a	141° 11' 26°12'	60	160	011.9°	-69.4°
43 - 2/21b	141° 11' 26°12'	60	460	017.9°	-64.9°
M16	140° 21.9' 24°31.3'S	-	-	203°	+81°
M17	140° 22.2' 24°31.0'	-	-	188°	+46°
M18	140° 22.5' 24°31.3'	-	-	184°	+74°
M27	140° 05.0' 24°27.0'	-	-	004°	-54°

Figure 5 shows histograms of the susceptibility and remanence values of the samples in Table 1. The susceptibility values are plotted on a logarithmic scale as susceptibility and remanence intensity values of rocks generally follow a log-normal distribution (Puranen et al., 1968; Irving et al., 1966). Use of a logarithmic scale converts the log-normal distribution to a normal distribution and permits better comparison of the histograms. The histograms are also normalized to frequency percentages of the total number of samples within each group.

Corresponding logarithmic means and logarithmic standard deviations were calculated for each histogram by converting the magnetic values to their logarithms, computing the mean and standard deviations of these logarithms in the usual way, and then taking the antilogs of these values. The logarithmic mean for each histogram is given in Figure 5. The vertical arrow above each histogram indicates the position of the logarithmic mean.

The histograms for susceptibility are based on measurements on 28 samples of ironstone and 19 samples of the country rock. The histograms show a difference of 33 x 10^{-6} cgs units, which is very small within the scatter. These histograms also show that the ironstone has a much narrower range of susceptibilities (20-100 x 10^{-6} cgs units) than the country rock (2-285 x 10^{-6} cgs units). Correspondingly the range of values defined by one logarithmic standard deviation about the logarithmic mean for ironstone (46-88 x 10^{-6} cgs units) is within the bounds of the corresponding range of values (9.7-93 x 10^{-6} cgs units) of the country rock.

A value of 285 x 10^{-6} cgs units was measured on a piece of yellowish weathered clayey sandstone (BUL3). The high susceptibility of this sample is irreconcilable with hematite and is thought to be due to the presence of maghemite in small quanity. Disregarding this sample value, the country rock susceptibility histogram shows a spectrum decreasing from an upper limit corresponding to that in the ironstone susceptibility histogram. This is probably associated with a decreasing concentration of hematite in the iron-stained country rock samples.

The histograms of remanence intensity again show little contrast between the ironstone and country rock. The mean of ironstone remanence (41 x 10^{-6} cgs units) is almost identical to that of the country rock (39 x 10^{-6} cgs units), and the range of one logarithmic standard deviation about the logarithmic mean for ironstone (8.6-198 x 10^{-6} cgs units), is within the range of that for the country rock (6.6-226 x 10^{-6} cgs units).

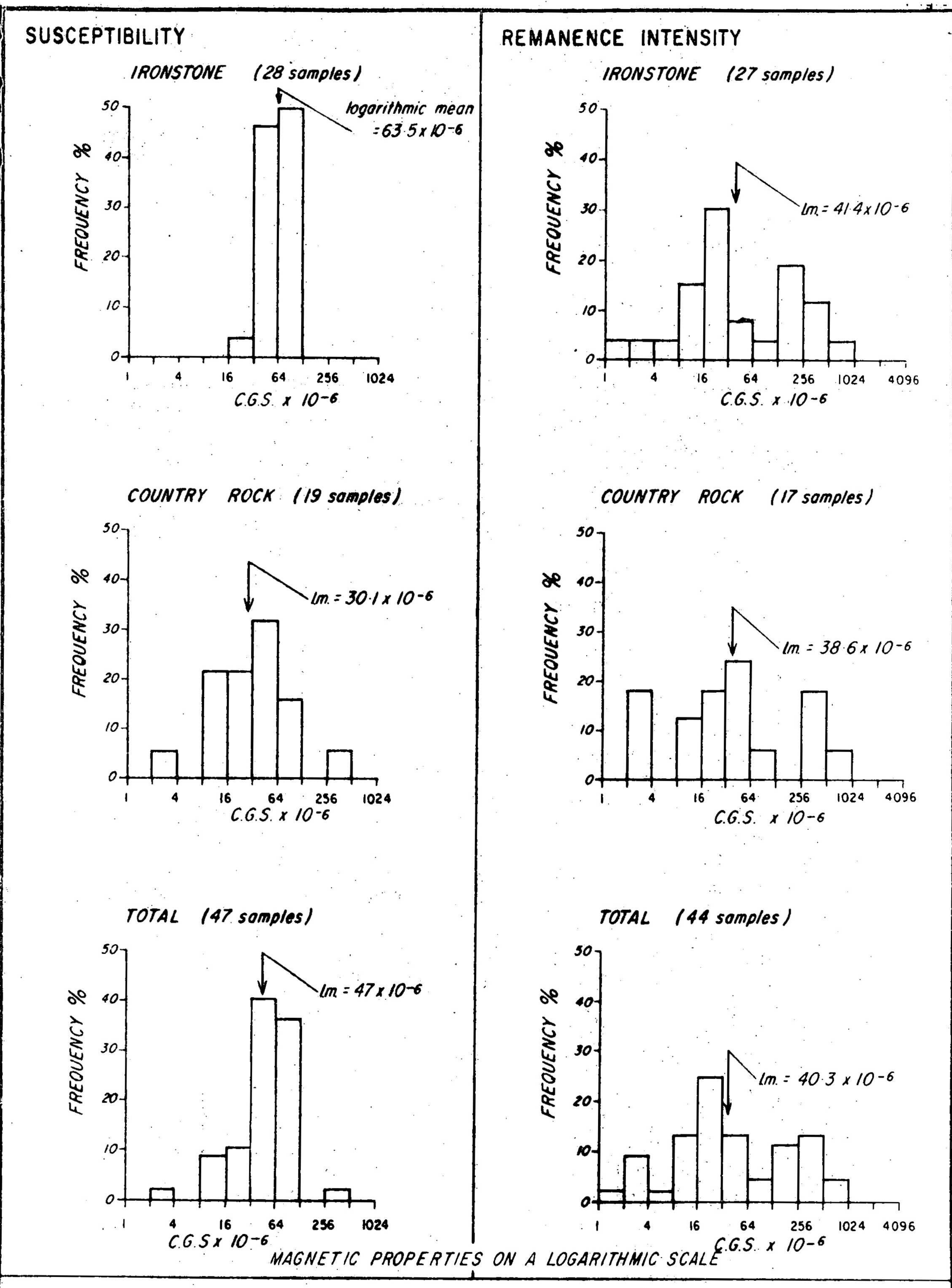

Fig.5 HISTOGRAMS OF MAGNETIC PROPERTIES I

The ironstone remanence intensity histogram shows a bimodal character. Six of the nine sample values above a remanence intensity of 128 x 10^{-6} cgs units are derived from float and outcropping samples or ironstone and a further two are obtained from samples of ferruginous sandstone-ironstone within 0.5 m of the surface. The remaining samples in the histogram were obtained from recent bulldozer cuts and mines at greater depths. Remanent magnetization directions measured on five of these nine samples all show normal magnetization in a consistent direction sub-parallel to the present direction of the Earth's field. It is therefore unlikely that the stronger magnetization is due to lightning strikes on the outcropping rock.

A.D. Haldane (pers. comm.) confirms that geothite can alter to hematite and sometimes maghemite rapidly when exposed to the dehydrating effects of sun and wind at the surface. A possible explanation for the stronger remanent magnetization is that strong dehydration at the surface has converted some of the original goethite to hematite, with further magnetization in the direction of the Earth's field occurring during the transition between crystal lattices. One float sample of ironstone (BUL 1), showing blackening near the surface of the sample (evidenge of chemical change), had a remanence intensity of 630 x 10^{-6} cgs units.

In 50% of all ironstone samples and in 77% of country rock samples, the remanent magnetization is greater than the induced magnetization. If all the outcrop and float samples are distinct from the others on the basis of the previous argument, and are excluded from the calculation, then 28% of underground ironstone has its remanent magnetization greater than its induced magnetization. It would therefore appear that remanence is a more important part of the magnetization of the country rock than it is for the ironstone. The logarithmic mean of the ironstone remanence intensities when dehydrated surface samples are excluded is 19.7 x 10^{-6} cgs units, which is lower than that for the country rock.

(b) Koenigsberger Q and effective susceptibility

If the remanent magnetization direction in a rock is parallel to the direction of the magnetization induced by the Earth's magnetic field then the resultant effect on the Earth's field is the same as if the total magnetization in the sample was totally induced. Hence we can usefully calculate a value of 'effective susceptibility' which would give rise to a totally induced magnetization equal to the magnitude of the remanent plus induced magnetization.

Mathematically:

if k = susceptibility

F_e = Earth's total magnetic field vector

R_m = remanent magnetization vector (assumed to be totally normal)

Q = Koenigsberger Q = $\frac{Rm}{k\ (Fe)}$

then the total magnetization $M_t = k F_e + R_m$

Since the remanent and induced magnetizations are in the same direction.

$$
\begin{aligned}
M_t &= k\,(F_e) + (R_m) \\
&= k\,(F_e) + Q\,k(F_e) \\
&= (1 + Q)\,k(F_e) \\
&= k_{EFF}\,(F_e)
\end{aligned}
$$

Therefore for normal magnetization, effective susceptibility equals (1 + Q) times the susceptibility. Similarly for reversed magnetization effective susceptibility equals (1 - Q) times the susceptibility. Effective susceptibility is negative if the remanent magnetization is reversed and is greater than the induced magnetization.

Figure 6 shows histograms of Koenigsberger Q and effective susceptibility (normal magnetization) for the ironstone and country rock in Table 1. There is little significant contrast in the range of Koenigsberger Q factors for ironstone and country rock. The logarithmic mean of the country rock Q factors is 2.41, but is 1.21 for all the ironstone samples. From this it would appear that remanent magnetization is a more significant factor in the magnetization of the country rock than it is for ironstone. This is even more apparent if the eight of the nine samples with Q factors greater than 3.2 which are surface-outcrop samples are excluded. The logarithmic mean Q of the remaining ironstone values is 0.57.

The effective susceptibility histograms for normal magnetization show the range of values for country rock is wider and envelopes that of the ironstone, i.e. the range of values defined by one logarithmic standard deviation about the logarithmic mean for the ironstone (73-434 x 10^{-6} cgs units) is within the bounds of the corresponding range of values (27-516 x 10^{-6} cgs units) of the country rock. The logarithmic mean of the country rock effective susceptibility values is 118 x 10^{-6} cgs units corresponding to 178 x 10^{-6} cgs units for all the ironstone values. Excluding the 8 surface-outcrop samples the logarithmic mean of the ironstone effective susceptibility values becomes 114 x 10^{-6} cgs units, negligibly different from that of the country rock.

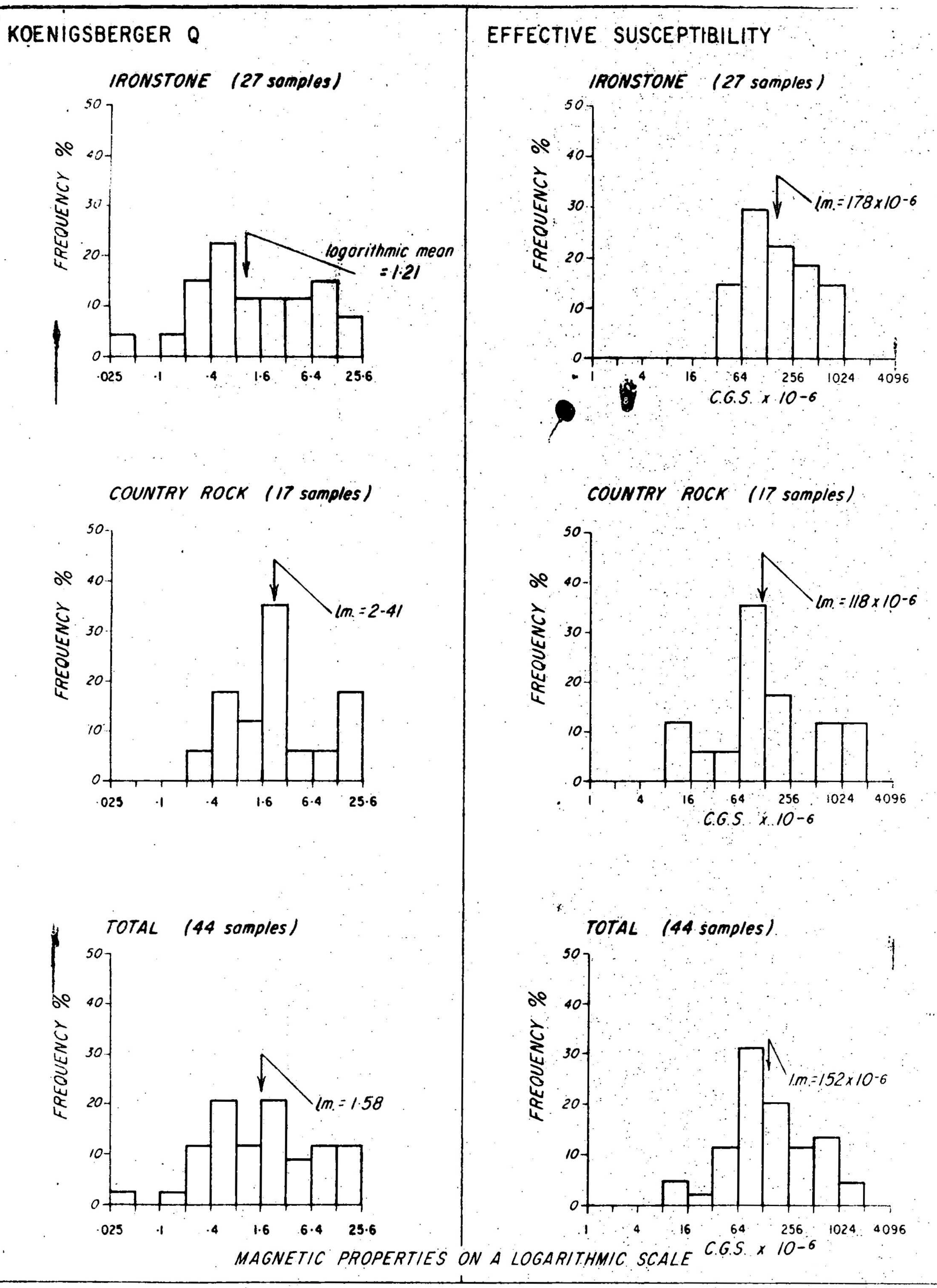

Fig.6 HISTOGRAMS OF MAGNETIC PROPERTIES II

As a test the positive and negative values of effective susceptibility assuming reversed magnetization were plotted on histograms with an arithmetic scale. These histograms are not shown in this report but showed similar results to that for normal magnetization.

5. INTERPRETATION OF GROUND MAGNETIC SURVEYS

(a) Yeppra Prospect Preliminary surveys (Fig. 7)

The location of this survey area is given on the geological map (Figure 1), at locality number 1, and on the locality map (Fig. 4). Three small surveys shown in Figure 7 were done in this area by Senior.

Measurements on area 1 were taken on a 12.2-m by 19.8-m grid. Ironstone was found in a bulldozed cut at the northern end of the grid, which appeared to be the source of the magnetic high indicated there. A notable feature of the results is the apparent trend of a magnetic high from the northern end of the grid south down the western side of the grid. This was interpreted by Senior as possibly representing the effect of ironstone concretions in a paleochannel similar to the environment indicated in Figure 3, Section 2. No further work was done on this grid and no excavation has been carried out on the anomalous area.

Measurements on area 2 were taken on a 12.2-m by 9.1-m grid. Several excavations were made, and Senior reported correlation between magnetic highs and the occurrence of ironstone boulder. The results and locations of excavations are shown on the contour map.

Measurements on area 3 were on a 3.05-m square grid with two perpendicular lines of 1.52-m spacing. The anomaly was located by random traversing before the grid was set out. No excavation has yet been carried out on this anomaly site.

The average of the rapid depth interpretation methods on this anomaly, assuming a thin dyke model of infinite strike extent, gave a depth of 1 m below the surface for the source. The methods used were Demipentes Rule, Sokolov Rule, Peter's Rule, Straight Slope length and half slope length, half width, and one-third maximum to minimum distance. Quantitative interpretation assuming a vertical prism model striking N 105^{o} indicated a depth of 0.4 m above the surface, a strike length of 12 m, a breadth of 7.3 m and an effective susceptibility contrast of 320 x 10^{-6} cgs units. Quantitative interpretation assuming a dipping plate model of limited strike extent indicated a depth of 2.6 m below the surface, a strike length of 12.5 m and a dip of 31°NE. The erroneous depth, and the conflict of the assumption of a vertical model with the 31° dip indicated by the dipping plate model results, indicate that the assumption of a vertical prism model is incorrect. However, the indicated effective susceptibility contrast obtained assuming a vertical prism model is of the order which might be expected considering the effective susceptibility values given for normal remanence direction in Table 1. The associated size of the body is informative.

Samples 825 - 197 (two samples) and 37 at the beginning of Table 1 were collected from the Yeppra area. These three samples are of underground ironstone-ferruginous sandstone and show similar magnetic properties to the other ironstone samples in Table 1. No samples of the country rock (pink and white kaolinitic sandstones and siltstones) were available for measurement.

There is no conclusive evidence that the ironstone which appeared in the excavations on anomaly sites is the source of the anomalies. No magnetic property measurements have been made on samples from the excavations and the magnetic survey data is not of sufficiently close spacing for reliable depth determinations to be made to check whether the interpreted depth corresponds to the top surface of any possible concentration of ironstone boulders. The anomalies may be related to magnetic contrasts within the country rock and the occurrence or ironstone boulders may be coincidental.

(b) Bulgroo Prospect Surveys (Fig. 8)

The location of this area is shown by number 2 in Figures 1 and 4. The surveys were done in a flat scrubby area where the weathering profile had been denuded to the ferruginous and varicoloured zones.

Four grids of 20-ft (6.1-m) square spacing were surveyed and the results related to the magnetic datum of a previous survey carried out on large and variable spacing by the owners of the prospect. The results are shown in Fig. 8. Vertical gradient measurements were taken on all grids on this prospect at variable experimental vertical spacings. Figure 9 shows the vertical gradient measurements and magnetic profiles at close spacing along lines through anomaly centres in these grids.

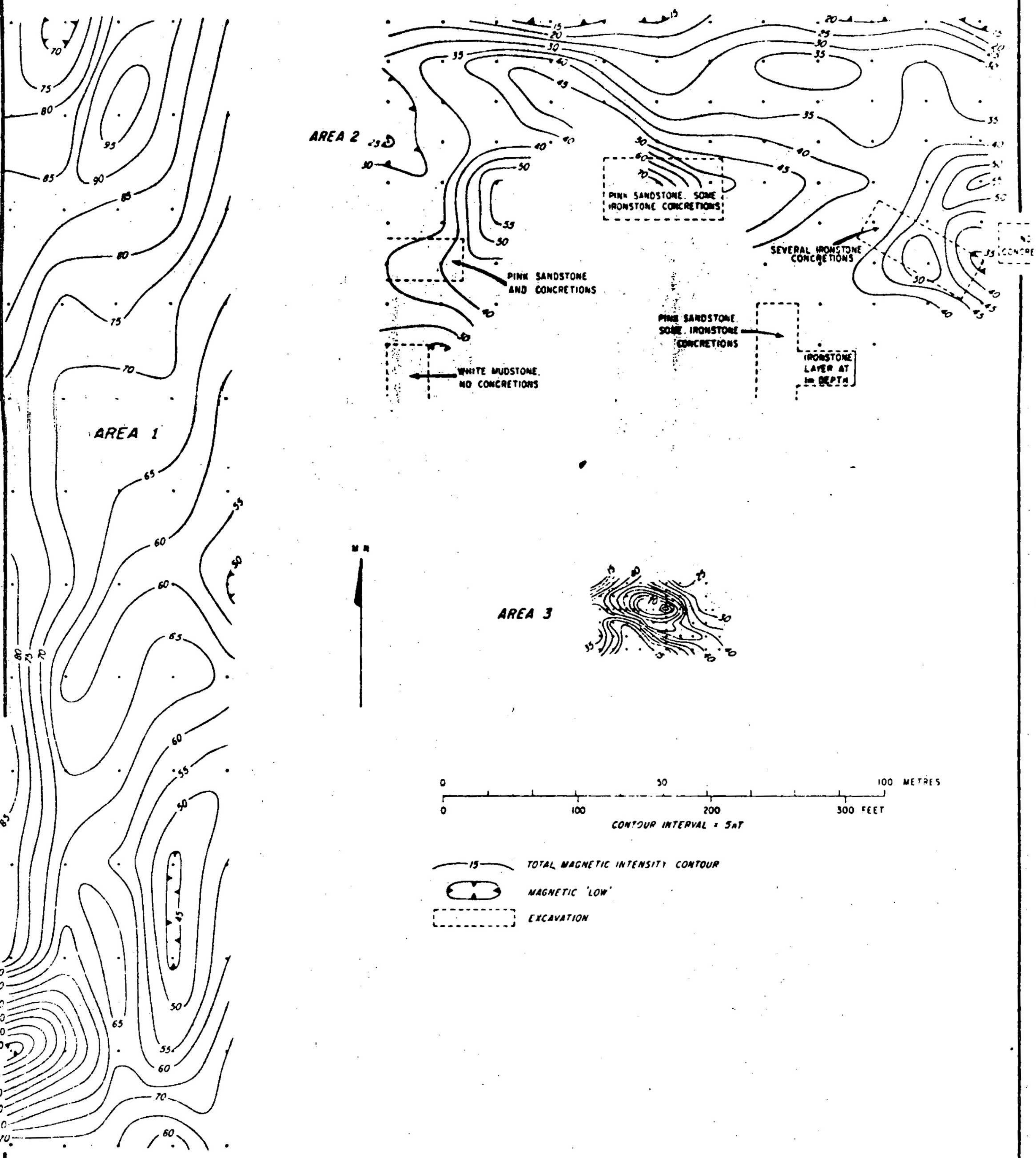

Fig 7 YEPPRA PROSPECT MAGNETIC SURVEYS

(i) Grid 1

The purpose of this grid was to check any magnetic anomalies around a line of float indications of precious opal striking northwest. The grid was set up so that traverses intersected this line of float indications perpendicularly. The position of the float indications was at the centre point of grid 1.

The ground magnetic survey on this grid area shows two anomaly centres of approximately 30-ft diameter and amplitude of 25 nT, neither of which corresponds to the position of the float indications. Excavation of the opal float trace in the north-trending area shown on grid 1 revealed yellowish clayey sandstone with minor ferruginous stained sandstone. At approximately 2-m depth was a horizontal flat band of dense black ironstone 7 cm thick containing potch. This band was widespread throughout the cut and appeared to be deposited at the contact between an overlying sandstone and underlying siltstone-mudstone similar to that shown in Figure 3, Section 1.

Traverse 1 at 1-m spacing was carried out across an anomaly as shown in Figure 8. One of the total intensity profiles and the associated vertical gradient profile is shown in Figure 9. Depths were determined for each of the two total intensity profiles obtained and for two source shape models.

Assuming the model of a dipping plate of limited strike extent, quantitative interpretation indicates an average depth of 16 cm below the surface with the depth values ranging from 5 to 25 cm. The strike length averaged 12.1 m and the dip averaged 60^{o} east. The strike of the 'plate' was taken as N 15^{o}E. For the model of a vertical prism, interpretation indicated an average depth of 0.78 m above the surface, length of 11 m, breadth of 4.6 m and a susceptibility contrast of 190×10^{-6} cgs units. The interpreted depths of both models indicate the depth of the source to be at or just below the surface.

Excavation on the site of the anomaly revealed a soil layer approximately 20 cm thick, followed by some ferruginized sandstone blocks and yellowish sandstone to a depth of 2 m, where an ironstone band approximately 7 cm thick and containing potch was revealed. This ironstone band was an extension of that previously intersected in the bulldozer cut described earlier.

Samples BUL 2 to BUL 5 were collected during the excavation of this anomaly site (see Table 1). The higher values of susceptibility, remanence intensity and effective susceptibility (for normal direction of magnetization) are associated with yellowish samples of clayey sandstone, the lower values of these quantities being associated with the ferruginized sandstone and the opal-bearing ironstone.

It is apparent both from the interpreted depths to anomaly sources, the magnetic properties of the ironstone and country rock, and the model shapes which fitted the anomaly profile that the flat-lying band of opal-bearing ironstone at 2-m depth is not the source of the anomaly. This is further supported by the extension of the ironstone into areas where the magnetic field is undisturbed. It is also unlikely that a continuous band of ironstone of that thickness (which is similar to that in productive bands) would be detectable even if the magnetic contrast was great.

It appears therefore that the anomaly is due to magnetic contrast in the weathered sandstone which forms the country rock. The susceptibility value of 285×10^{-6} cgs units (supported by three independent measurements) is regarded as being too high for hematite, especially considering the pale yellowish colour of the clayey sandstone. It is thought that the high susceptibility is due to traces of maghemite.

It is notable that the previously discussed sample BUL 1 of surface ironstone float collected from this prospect has low susceptibility and very high remanence. Noise effects may possibly be caused in some areas by surface float.

The anomaly on Grid 1, Traverse no. 2 (see Figure 9(b)) gave an average depth estimate of 1.36 m length of 9 m, and dip of 85^{o}W, assuming a dipping plate model of limited strike extent striking $N90^{o}$. Excavation could not be carried out on this anomaly.

(ii) Grid 2

This grid was surveyed to obtain further information about an anomaly encountered on a previous survey made by the owners of the prospect. The northwest-trending gradient on the northern side of the anomaly appeared to correspond to an exposure of a contact between a red, ferruginous stained sandstone and clayey alluvium which appeared to have been deposited after development of the weathering profile. The magnetic properties of samples of these rock types (BUL 6 and BUL 7)

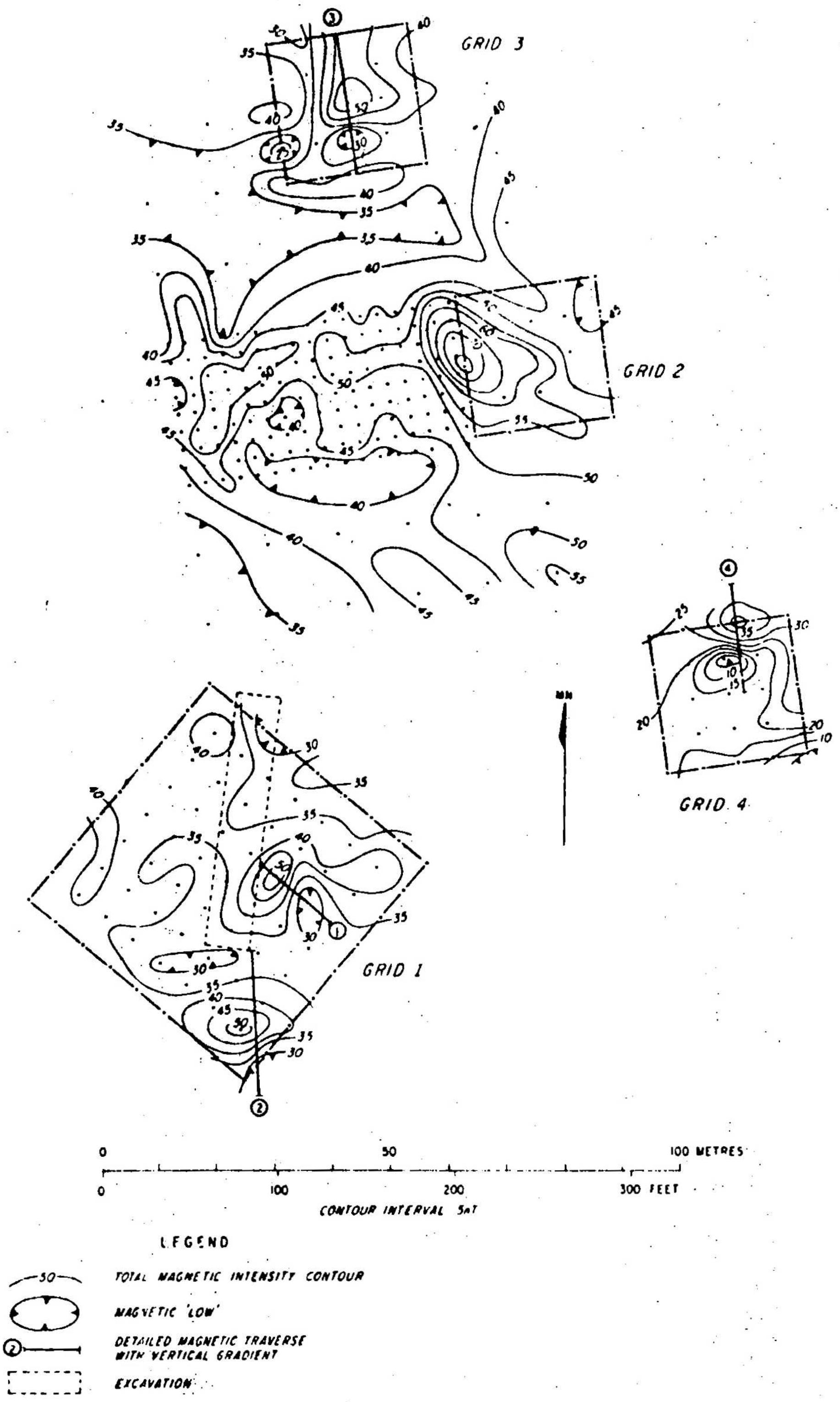

Fig 8 BULGROO PROSPECT MAGNETIC SURVEYS

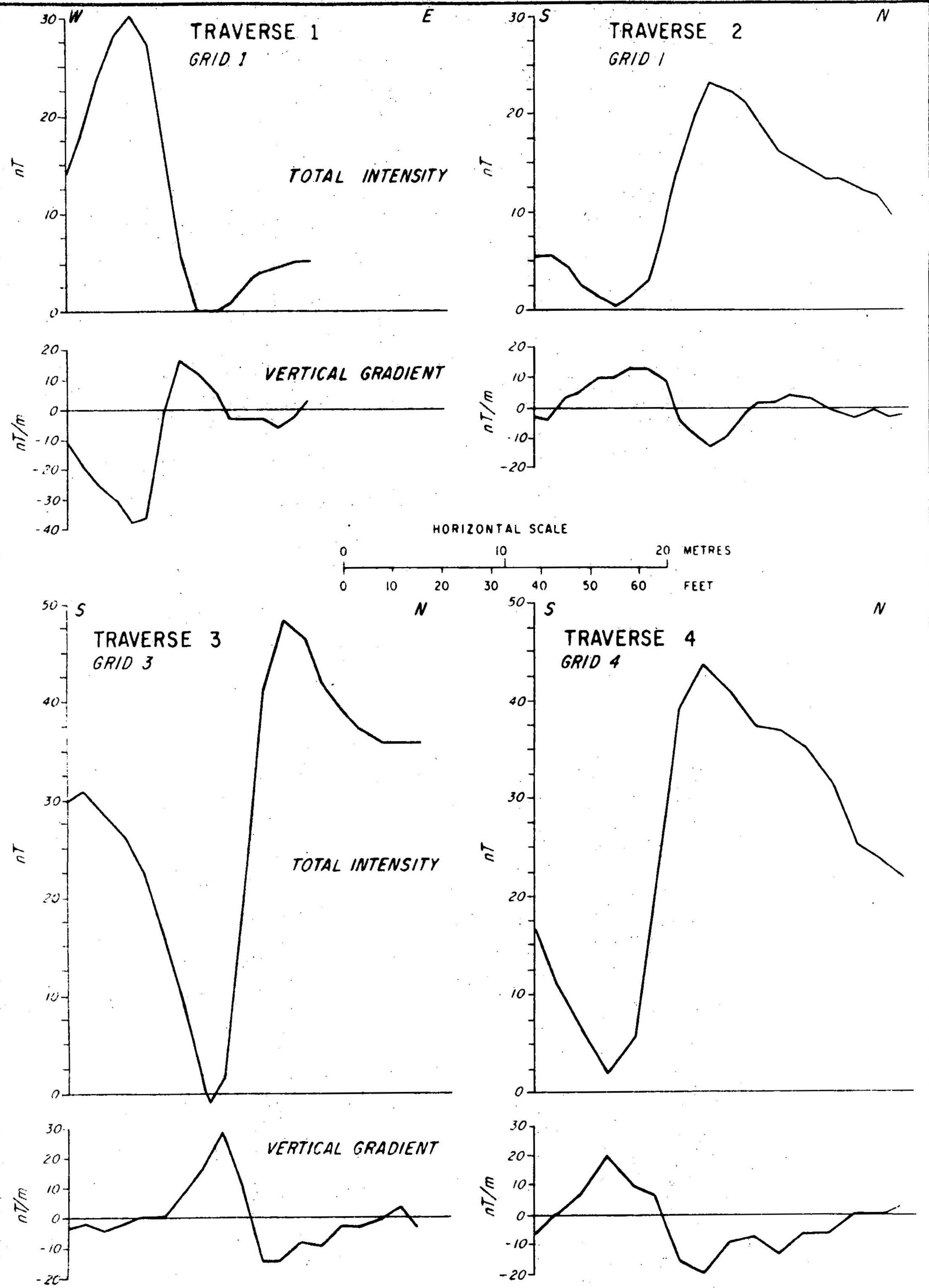

Fig.9 BULGROO PROSECT MAGNETIC PROFILES

is given in Table 1. No depth estimates were made on the anomaly owing to the existence of the bulldozed cut in the line of the traverse. No ironstone boulder was found in the cut, which was excavated to 2.5 m depth, and the ferruginous stained sandstone is regarded as the source of the anomaly.

(iii) Grid 3

This grid was surveyed to detail a magnetic high found on a reconnaissance survey done by the owners of the prospect. The anomaly amplitude was approximately 30 nT. Excavation to approximately 2.5 m below the survey did not reveal any occurrence of ironstone, nor did any heterogeneity in lithology appear which might have indicated the source of the anomaly. Samples BUL 8 to BUL 11 were collected from the cut and their descriptions and magnetic properties are described in Table 1. The susceptibilities of the ironstone and country rock are similar, but the remanence and effective susceptibility of the country rock is high relative to the ironstone. Once again heterogeneities in the magnetic properties of the country rock appear to be the source of the anomaly.

Quantitative interpretation of the profile on Traverse 3 (see Fig. 9(c)) showed that the profile would not fit that of a dipping plate model or prism model. The anomaly profile most closely resembled that of a step contact model, but interpreted for this model it gave an average depth of 1.2 m above the surface, a vertical thickness of the slab of 3.6 m, a dip of contact of 72°S, and an effective susceptibility contrast of 350 x 10^{-6} cgs units. The strike of the step contact was taken to be N 90° with the higher (effective) susceptibility 'step' on the northern side. The interpreted source depth above the surface shows that the model assumptions are not correct and it would appear that the top of the source was at the surface.

The magnetic measurements on samples imply that a contrast in remanence intensity in the country rock may be the source of the anomaly. Considering that the present land surface has been exposed for many millions of years it is possible that some magnetic anomalies could be related to the effects of lightning on remanence intensity and direction in the country rock. A. Cox (1961) in describing the anomalous remanent magnetization of basalts from Idaho states that the isothermal remanent magnetization caused by lightning strikes 'is due to the intense magnetic field accompanying discharge with a peak current of 22 000 amperes'. This I.R.M. sometimes had an intensity of 10 to 100 times that of the thermal remanent magnetization, with 'cells' of anomalous magnetization having dimensions of the order of 5 to 25 m. The dimensions of all anomalies encountered at the Bulgroo survey area are within the limits of 5 to 25 m. However a lightning discharge may have negligible effect on the remanence of the country rock as the magnetic mineral is hematite and not magnetite.

(iv) Grid 4

A small grid was set up adjacent to a small costean. The survey revealed an anomaly which was detailed by Traverse 4 (Fig. 9(d)). Quantitative interpretation assuming a dipping plate model of limited strike extent and striking N 74^{o} gave an average depth of 1.3 m below the surface, average length of 10 m, and average dip of 60^{o}S on the two profiles obtained at different heights.

Excavation on the site of this anomaly to an approximate depth of 2.5 m again revealed no visible heterogeneity in lithology which might have caused the anomaly. The lithology was a iron-stained weathered sandstone. Considering the interpreted depth, variations in magnetic properties within the country rock are regarded as the source of this anomaly.

(c) Nickavilla Station Prospect survey (Fig. 10)

The location of this area is shown by number 4 on relatively open undulating scrub country where the profile was exposed from a siliceous capping down through the ferruginous zone. Exposures in cuts showed the varicoloured and ferruginous zones, which were strongly mottled and stained and in which were occasional scattered ironstone concretions.

Two large grids were surveyed and the results are shown in Figure 10.

(i) Grid I

This area was surveyed at 6.1-m square spacing and diurnally corrected by tie-lines and a base station reading approximately every 15 minutes. The anomalies have an amplitude of the order of 15 nT and appear to have an east-west elongation.

There appears to be an increased anomaly intensity and frequency in the eastern half of the area. The topography slopes downward from a low mesa of the siliceous zone of the profile (shown in Fig. 10) at the southwestern corner of the area to a northerly-trending creek channel in the eastern portion of the area, shown by a pair of dashed lines.

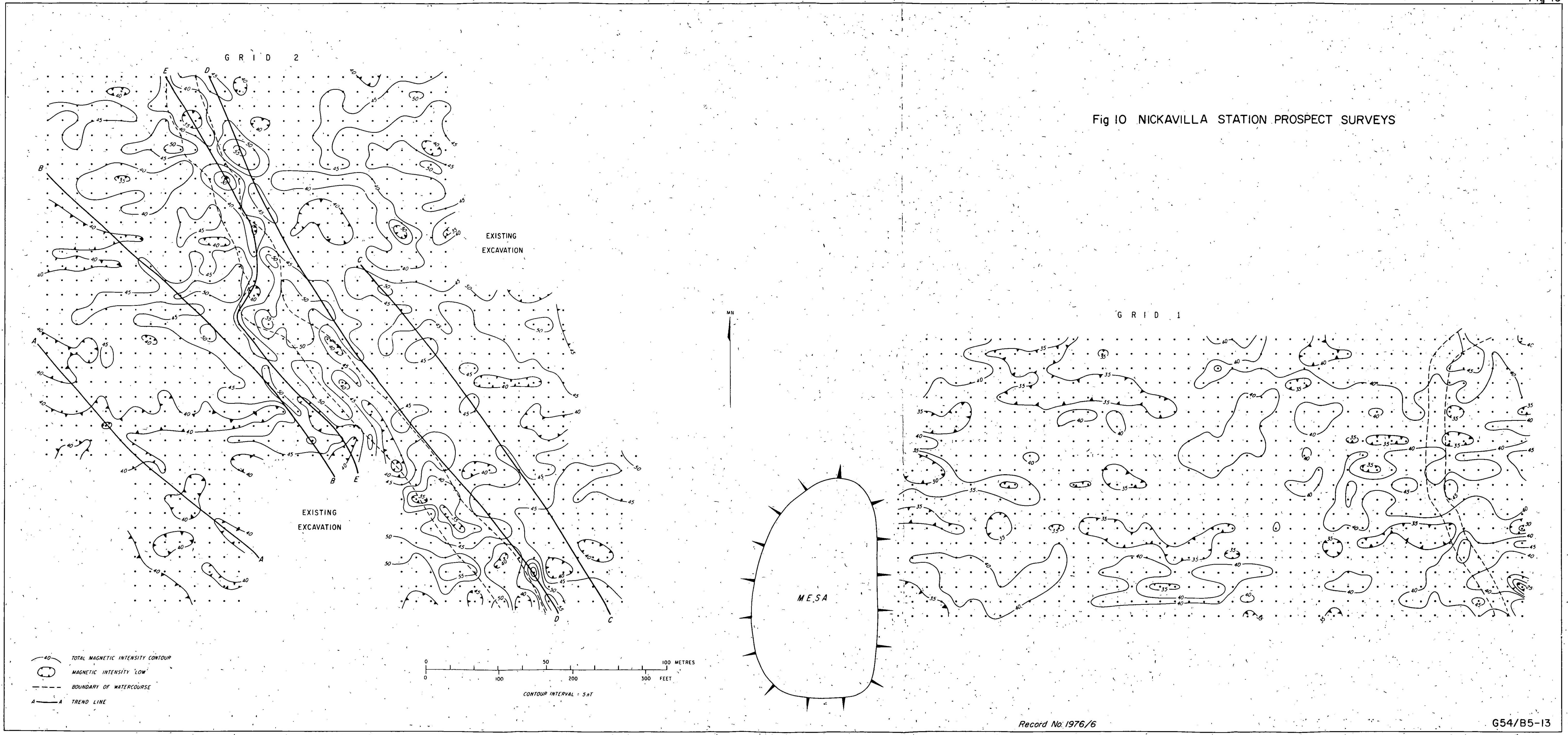
Fig 10 NICKAVILLA STATION PROSPECT SURVEYS
GRID 2
GRID 1
EXISTING EXCAVATION
EXISTING EXCAVATION
MESA
MN
TOTAL MAGNETIC INTENSITY CONTOUR
MAGNETIC INTENSITY 'LOW'
BOUNDARY OF WATERCOURSE
TREND LINE
0 50 100 METRES
0 100 200 300 FEET
CONTOUR INTERVAL : 5nT
Record No. 1976/6
G54/B5-13

One possible explanation for the change in magnetic character across the area is that the weathering profile is differentially denuded across the area, resulting in an associated gradation in depth to the magnetically variable ferruginous and varicoloured zones of the weathering profile. As a consequence, the magnetometer is less sensitive to variations in the magnetic properties in these zones in the western portion of the grid owing to the greater depth under a relatively non-magnetic siliceous zone. It was also possible that the magnetic anomalies in the eastern portion of the grid were related to magnetic minerals in alluvium, but excavation on anomalies revealed hard sandstone with occasional ironstone concretions.

(ii) Grid 2.

This grid was surveyed similarly to grid 1 of this prospect. The area of the grid is relatively flat, the mesa to the southeast dropping more steeply to the 'plain'.

Anomalies in this area are also elongate east-west parallel to the traverse lines. However, across the centre of the grid is a northwest-trending band of relatively high magnetic gradients and high intensities, which corresponds to the position of a watercourse indicated by a pair of dashed lines in Figure 10.

In the immediate vicinity of the watercourse are northwest-trending lines of anomaly maxima DD and minima EE. Note that the bend in line EE corresponds to a bend in the watercourse. The intimate and parallel association of anomalies to the watercourse on this grid contrasts with apparent non-association of the watercourse and anomalies at the eastern end of grid 1. In addition there appear to be parallel northwest-trending anomaly maxima BB, CC, and minima AA, outside the area of the creek on grid 2.

It is possible that the intimate association of anomalies and the watercourse is a consequence of a concentration of magnetic minerals in the creek wash. However the absence of a similar expected association on grid 1 tends to discredit this. The creek in grid 2 is straight whereas that in grid 1 is not. This might lend support to the idea that the creek in grid 2 is associated with a structural feature such as a fault, which has controlled the course of the creek by its associated weakening of the rocks. Magnetic effects may be associated with this fault to give rise to the linear maxima and minima observed.

The prospect owner made approximately 20 bulldozer cuts across the creek, each to a depth of up to 6 m. He reported finding friable sandstone and layered clayey alluvium containing transported ironstone concretions. The alluvium was more than 6 m deep below the creek channel, thinning out 50 m either side of the creek. He reported finding no ironstone concretions on areas of anomaly highs, and several ironstone concretions in some anomaly-free areas. This 'channel alluvial fill' is not prospective like the situation indicated in Fig. 3 section 2, as the channel is a post-weathering profile formation.

It appears therefore that the anomaly pattern may be related to variations in magnetic properties within the alluvium, or to magnetic contrasts at the contacts between the alluvium and the country rock sandstone.

(iii) Measurements on samples

Samples RG1 to RG7 were collected from this prospect. The sample of siliceous mesa capping, RG1, has high remanent magnetization relative to induced magnetization, and an effective susceptibility (normal magnetization) comparable with the other samples. Two samples of ironstone which were taken from below the surface, RG3, RG7, have lower remanence, effective susceptibility (normal inclination) and in the case of sample RG7, a lower susceptibility, than all the samples of country rock from this prospect. Samples RG6 and RG6A of surface float ironstone show higher susceptibility, remanence and effective susceptibility values than the underground ironstone samples RG3 and RG7, and show comparable to high susceptibility relative to the country rock.

The prospect owner has since abandoned this prospect, having found little marketable opal here.

(d) Bull Creek Prospect survey

A grid and a separate magnetic profile were surveyed at this prospect. The location of this area is shown by number 3 in Figures 1 and 4. A siliceous layer (porcellanite) was exposed at the surface through which the prospect owners had to blast in order to arrive at the prospective underlying varicoloured sandstone. The opal is generally found in large ironstone concretions which the miners call 'sandstone boulders', and which occur irregularly and sometimes in bands in the cross-bedded sandstone. The prospect owner reported that the ironstone bands presently worked were approximately 2 m thick and trended in a northerly direction through the prospect at approximately 5 m depth.

(i) Magnetic profile

The profile in Figure 11 was taken in an east-west direction at 1-m and 5-m spacing to the south of an exposure of a large deposit of ironstone in the quarry face. (The grid is north of the quarry). The anomalous zone in the profile between 90 and 190 m corresponds to the southward extension of the ironstone occurrence in the quarry. It appears therefore that the ironstone is the source of the anomaly.

Depth determination on the anomaly at 110 m, assuming a north-south striking dipping plate model of limited strike extent, gave depths ranging from 0.5 m above the surface to 0.5 m below the surface and a dip of between 45° and 60°E. The length of the dipping plate was assumed to be between 0.5 and 6 times the distance between the magnetometer sensor (2.44 m above ground) and the top of the causative body. Depth determinations on the anomaly at 170 m assuming a north-south striking dipping plate model of limited strike extent gave depths ranging from 4 to 5.5 m below the surface and dips ranging from 40° and 55°E. A strike length 0.5 to 5 times the depth to the body from the magnetometer sensor was assumed.

(ii) Survey grid

The grid shown in Figure 11 was pegged at 6.1-m square spacing on an area north of the quarry due to be excavated in 1975. The contours show high anomaly intensity up to 70-nT amplitude in the northern portion of the area. The trend of the two apparent lines of anomaly highs is however approximately west-southwest. Excavation on this site is still being carried out.

(iii) Measurements on samples

Samples DB1 to DB5 were collected from this prospect (see Table 1). The samples DB1 and DB1A were collected from the siliceous porcellanite which lies at the surface at this prospect. These show a wide range of remanence intensity and effective susceptibility which appears to be related to the amount of ferruginous and other staining in the rock. Sample DB2 is from a remnant of a Tertiary fossil soil profile which was too friable to core for remanence measurement. Sample DB3 was a varicoloured non-silicified sandstone similar to the silicified sample DB1A and showing similar effective susceptibility though higher susceptibility and lower remanence. Samples DB4 and DB5 were collected at the surface and may have an increased susceptibility and remanence from being exposed for a long period (see page 7). These ironstone samples have comparable to greater susceptibility and effective susceptibility (normal magnetization) than the samples of country rock.

(e) Hayricks Prospect

The opal deposit here is of the 'sandstone boulder' type, the concretions occurring in a bed of light-coloured kaolinitic sandstone some 35 m below the top of a mesa. The boulders occur as irregularly distributed elongated concretions 0.6 to 3 m long and 0.3 to 1.2 m wide. The majority are disposed with their axes lying north-south.

No ground magnetometer survey work was done on this prospect. Samples 84-2 to 84-5 and samples 75170035 A to C were collected from this prospect (see Table 1). The susceptibilities and effective susceptibilities of the ironstone samples 35A, 35B and 35C are all greater than those of the country rock samples 84-2 to 84-5. The stratigraphic order of the samples is from 84-5 at the upper part of the profile down to 84-2 toward the bottom. Ironstone concretions containing precious opal are mined from the white kaolinitic sandstone typified by sample 84-2. It is therefore possible that in an area where the profile was denuded to the level of the sandstone ironstone boulders may be detectable with the associated approximate effective susceptibility contrast of 100×10^{-6} cgs units for totally normal remanent magnetization, or 35×10^{-6} cgs units for totally reversed remanent magnetization, or 80×10^{-6} cgs units for no remanent magnetization contribution.

6. DISCUSSION

The successful application of ground magnetic surveys to prospecting for precious opal depends on the ability of the method to detect and distinguish ironstone bodies associated with structures conducive to precious opal formation. Ferruginous staining and ironstone are widespread and are not necessarily associated with such structures. Senior reports that sites conducive to precious opal formation have a much greater than normal concentration of ironstone concretions. One prospector, however, reported that in general large concentrations of ironstone concretions tended to yield potch whereas small deposits of ironstone tended to yield precious opal.

The detectability of ironstone masses depends on their size, shape, and their magnetic contrast with the country rock, the depth to the ironstone body, the sharpness of the boundary of magnetic contrast, and the presence or absence of other magnetic 'noise'.

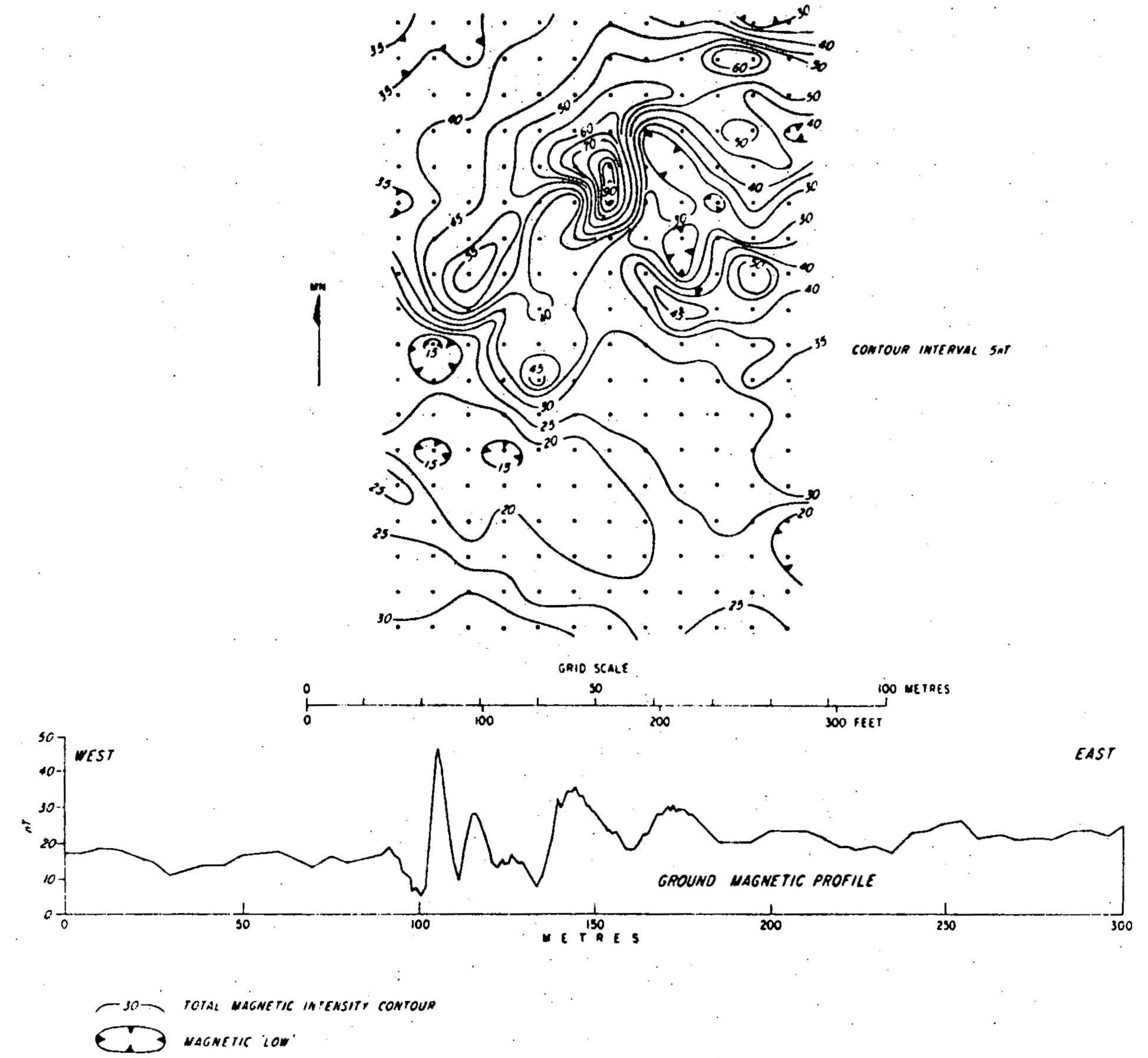

Fig 11 BULL CREEK PROSPECT SURVEYS

The Hayricks and Bull Creek prospects, where the concretions tend to occur as scattered single concretions rather than as concentrations of concretions, may be unsuitable areas for the application of magnetic surveying owing to the small mass of each concretion.

The Bulgroo and Nickavilla prospects, where there was no correlation between magnetic anomalies and ironstone occurrence, are areas of red and yellow iron-staining and mottling of the country rock. The Bull Creek and Yeppra prospects, where the magnetic anomalies correlate with ironstone occurrences, are characterized by less iron staining and the country rock is pink and white sandstone. These results suggest that resolution of ironstone concretions by magnetic surveys is unlikely in areas of red and yellow staining and mottling of the country rock, but is possible in areas of pink and white staining and mottling. However this is not confirmed by sample measurements. Samples of the pink and white mottled sandstones from the Bull Creek prospect (DB1A, DB3, 84-5) show no greater contrast in the magnetic properties of the ironstone and country rock than samples from the Bulgroo and Nickavilla prospects to explain the apparent success in the Bull Creek area. However the number of samples collected in the Bull Creek area may not be sufficient to be representative of the bulk magnetic properties of the pink and white country rock.

Considering the special environments of precious opal formation (Fig. 3) the associated ironstone in these structures may not be distinguishable because:-

1. In the case of Section 1 and Section 3 (Fig. 3), magnetic noise may arise from the underlying 'white mudstone with iron oxide mottles'. In addition there may be little magnetic contrast between the ironstone and the underlying mudstones.

2. In the cases indicated in Section 1 and Section 3 (Fig. 3), the ironstone band is often quite extensive over the sedimentary bedding contact between the sandstone and mudstone. Thus the ironstone in the depressions in the bedding contact may be magnetically indistinguishable from the background magnetic effect of a nearly continuous ironstone band. If the ironstone band is thicker in the depressions, then its magnetically effective thickness is equal to difference in thickness between the prospective and non-prospective areas.

3. In all cases given in Figure 3, noise effects due to variations in magnetic properties, thickness, and lensing of the overlying mottled sandstones may mask magnetic variations due to the prospective ironstone.

Further investigation of the suitability of this method may best be directed to areas where precious opal bearing structures were known to be present and any magnetic response evaluated. Susceptibility measurements could be made in the field in bulldozer cuts and mines using instruments like the Bison Model 3101 susceptibility meter with the accessory in situ coil. Approximate remanence intensity and direction measurements can be made using a fluxgate magnetometer.

7. CONCLUSIONS

Measurements of susceptibility and remanent intensity on samples collected from prospects near Quilpie indicate that there is in general insufficient magnetic contrast between the ironstone and country rock to enable delineation of ironstone occurrences by ground magnetic surveys. However the method may work in areas where the susceptibility and remanence of the country rock is homogeneous and low relative to the ironstone, if such areas exist. The maximum expected effective susceptibility contrast between ironstone and country rock for normal remanent magnetization is of the order of 250×10^{-6} cgs units, Favourable areas would have little iron staining of the country rock but actual measurements of magnetic properties should be made in the field.

Ground magnetometer surveys at the Nickavilla Station and Bulgroo Prospects show that anomalies may be related to: (1) magnetic contrasts within alluvium deposited after formation of the weathering profile, (2) contrasts between such alluvium and the country rock, (3) variations in magnetic properties in the country rock, (4) variations in the depth of the ferruginous portion of the weathering profile, and (5) the effect of lightning strikes on the remanence of the country rock.

At the Yeppra and Bull Creek prospects anomalies appeared to be related to the subsurface extension of exposed ironstone occurrences but there are insufficient excavation and sample measurements to support this.

Even in promising areas application of the magnetic method to prospecting for opal would require: (1) familiarity with magnetic surveying procedure and interpretive techniques, (2) A knowledge of the local magnetic properties of the ironstone and country rock from sample measurements, and (3) knowledge of sources of anomalies other than ironstone. Some system of continuous magnetic recording with chart paper readout would be desirable for rapid and economic coverage. Such a system would be required to have a very small noise level.

If the magnetic method is to be economically successful, the savings from any increased probability of finding marketable opal must exceed the expense of successful and unsuccessful ground magnetic surveys. Insufficient data are available to form an opinion on this.

8. ACKNOWLEDGEMENTS

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