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MAGNETIC ANOMALIES OVER THE KAMOJANG GEOTHERMAL FIELD fWEST-JAVA. INDONESIA)

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ABSTRACT

A high level (2500 m) airborne magnetic survey made in 1986 has shown that a broad, negative total force anomaly occurs over the centre of the Kamojang field. The anomaly can be interpreted in terms of demagnetised, andesitic reservoir rocks extending from about 300 m depth to at least 900 m depth. Measurements on cores also indicate that rocks from productive wells are demagnetized where T>150°C (commonly below 300 m depth). Modelling of topographic effects of andesitic flows exposed outside the prospect gives an average magnetization of 2.5 A/m for these unaltered rocks. The magnetic model covers an area of about 10 km^2; all productive wells lie within this area. The study shows that demagnetisation of volcanic reservoir rocks can also take place in a vapour-dominated system.

INTRODUCTION

The geophysical structure of the Kamojang Geothermal Field was first outlined by resistivity and temperature surveys (Hochstein, 1976); follow-up studies, including gravity and ground-magnetic surveys, led to an integrated exploration model (Sudarman and Hochstein, 1983) which strongly influenced siting of exploration and production wells. Interpretation of well data has shown that the prospect is a vapour-dominated system (Hochstein, 1976; Dench, 1980; Grant et al., 1982) which stands in a sequence of young, dominantly andesitic rocks. The reservoir is capped by a thick (about 350 m) condensate layer in which temperatures increase from about 100°C at the top to about 235"C at the bottom. Simple reservoir models have been constructed recently which indicate that the permeability of the volcanic rocks outside the reservoir is anomalously low (Saptadji, 1987).

In 1986 a high level (2500 m height) airborne magnetic survey was made over a large area (400 km^2) centred on the nearby Darajat geothermal prospect which had been discovered after completion of the Kamojang reconnaissance survey (Hochstein, 1976). The high level survey also covered the Kamojang area and the young andesitic complex of Gunung Masigit lying to the E of Kamojang. A preliminary interpretation of the high level magnetic data over the Kamojang Field was attempted by Suranto (1987); his model has been modified recently and is presented in this paper.

THE KAMOJANG MAGNETIC ANOMALY

The original data of the high-level magnetic survey consist of a contoured map showing the total magnetic force values (contour interval 20 nT) at flight level. The anomaly pattern over high standing, young andesite volcanoes (Gunung Masigit-Gunung Picung) is controlled by topography. The magnetic terrain effect was modelled by Suranto (1987) by digitizing terrain contours at 100 m contour intervals and using the algorithm of Talwani (1965) for horizontally stacked polygonal slabs. The topographic effect of most of the terrain lying between Kamojang and G.Masigit could be matched by using an average total magnetisation of 2.5 A/m (d = 0°; i = -35°) for all volcanic rocks. This study allowed a clear separation of the normal magnetic field and also provided a representative value for the average magnetization of volcanic rocks in the greater Kamojang area. Reduction of the normal field, in turn, produced the residual total force magnetic anomalies which are shown in Fig. 1.

The Kamojang magnetic anomaly is centred on the field as delineated by DC-resistivity surveys (Fig. 1); at 2500 m elevation, i.e. about 1000 m above mean terrain, its maximum amplitude is about -100 nT. An anomaly with the same wavelength and in about the same position can also be recognised from an earlier AZ-ground magnetic survey of the area (Sudarman and Hochstein, 1983) if the data are continued upward to 1800 m elevation, i.e. about 300 m above mean terrain. The maximum amplitude of this anomaly attains values of about + 200 nT over the centre of the prospect (see Fig. 4).

Unfortunately, the upward continued AZ-anomaly published previously by Sudarman and Hochstein (1983) contains a sign error and the earlier interpretation model given for the Kamojang magnetic anomaly in terms of a deeper seated, normally magnetized, intrusive body is no longer valid. Further, Suranto (1987) showed that a shallow, demagnetised (or reversely magnetized) body is required to explain both magnetic anomalies.

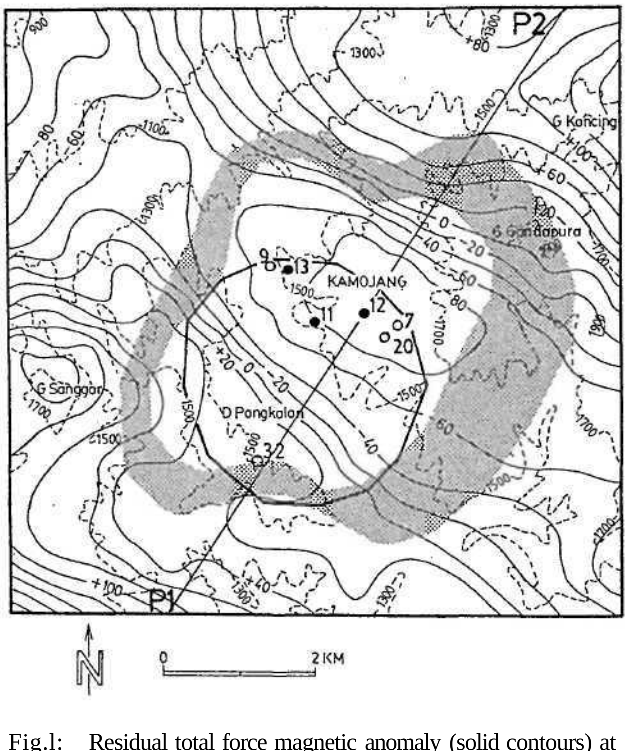

Fig.l: Residual total force magnetic anomaly (solid contours) at 2500 m elevation over the Kamojang Geothermal Field; contour interval is 20 nT. The topography is shown by broken contours (contour interval 200 m). The resistivity boundary of the field is outlined by a stippled pattern. The polygon outlines the demagnetised body below 300 m depth; numbers refer to wells (i.e. 11 = KMJ 11) cited in the text (full circles indicate wells referred to in Fig. 2).

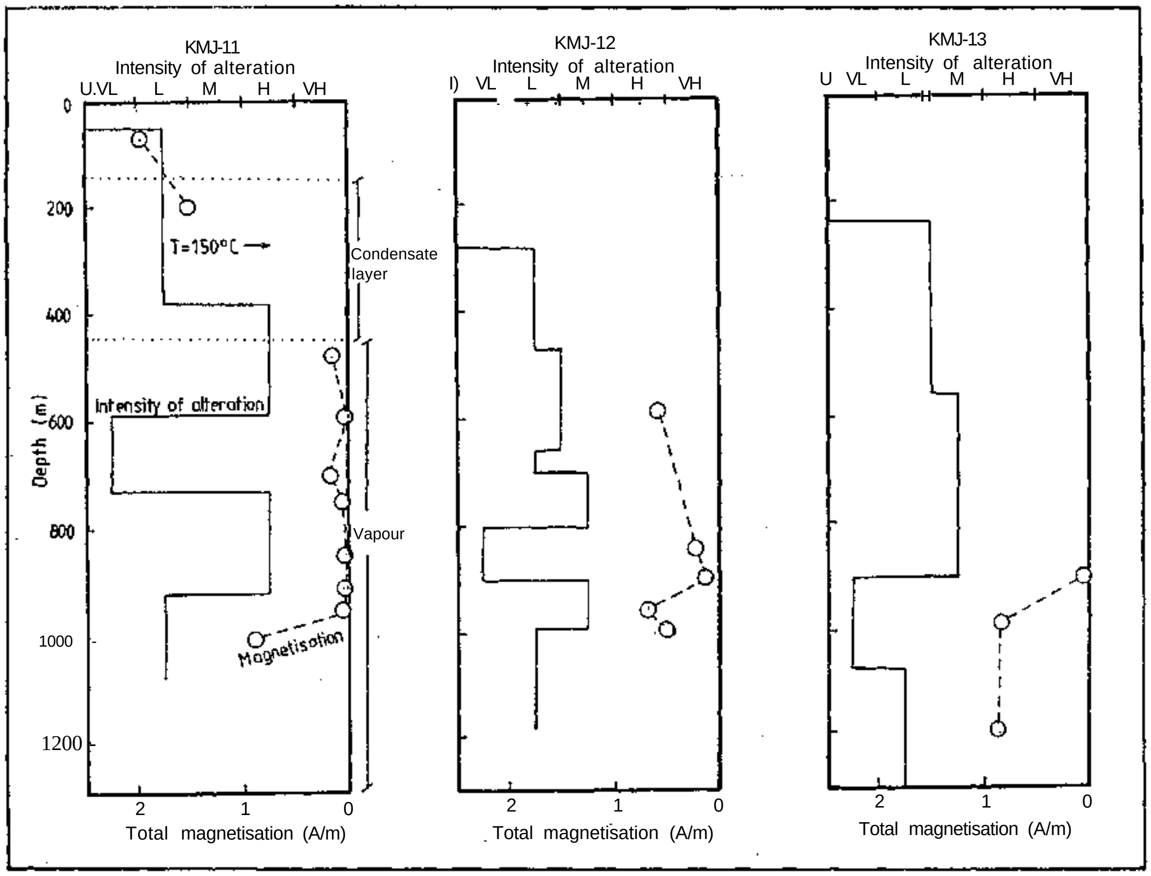

Fig.2: Total magnetisation (A/m) and intensity of alteration of cores from wells KMJ 11,12,13. Total magnetisation was computed from magnetic susceptibility and remanence assuming that the direction of remanence is parallel to that of the present-day field (d = 0°; i = -35°). Remanence was recomputed with respect to a well-known standard. The intensity scale at the top runs from 0 (unaltered = U) to 100 % (completely altered); M stands for a range between 40 and 60 % of altered minerals (all values are gross averages, details not shown).

MAGNETIC PROPERTIES OF CORES

Earlier studies of magnetic properties are cited in Sudarman (1984); the measurements were made on cores from three production wells (KMJ 11,12, and 13) located in the central part of the Kamojang Field as defined by resistivity surveys. The results (Fig. 2) show a rather simplified pattern of changes in total magnetisation and alteration with depth. It can be seen that between about 300 and 1000 m depth the cores are significantly demagnetised; cores above and below this range are normally magnetised ($i \approx -35°$).

Demagnetisation is the result of thermal alteration, and hence replacement, of primary magnetic minerals (titanomagnetite) to almost non-magnetic species (pyrite, for example). Intensity of alteration is a useful parameter to describe the percentage of altered minerals in cores and cuttings. For the three wells shown in Fig. 2 this parameter has been assessed by Sudarman (1984); the figure shows that significant alteration has affected reservoir rocks below about 300 m depth. However, the parameter is not sufficient to describe the phenomenon of demagnetisation which depends upon various stability criteria governed by fluid parameters (activity coefficients of oxygen, sulphur, pH of fluid) as well as matrix permeability. The data in Fig. 2 indicate that below about 1000 m depth magnetic minerals are present and that reservoir rocks below can retain their magnetisation although thermal alteration still occurs at much greater depth (P.R.L.Browne, pers.comm.).

The phenomenon that volcanic reservoir rocks are partly or completely demagnetised within a certain depth range, commonly the upper kilometre, has also been observed in several New Zealand hot water systems (Soengkono,1985; Lampoonsub,1987). Petrological studies by Steiner (1977) have shown that in many NZ systems titanomagnetite is altered and replaced where reservoir temperatures exceed 150°C and it also clearly survives in the upper 300m at Kamojang (see also Fig.2). What causes retention of magnetisation below 1000 m depth in the Kamojang reservoir is not yet known; additional petrology and fluid chemistry studies are required.

For this study there is sufficient evidence to infer that demagnetisation has occurred in the Kamojang reservoir between about 300 and 1000 m depth. There is no evidence that rocks within or outside the reservoir are reversely magnetised. Since the average total magnetisation of high standing andesitic rocks outside is about 2.5 A/m, the demagnetised reservoir exhibits a magnetisation contrast of about -2.5 A/m with respect to its surrounds. The lateral extent of the demagnetised reservoir can be obtained from modelling the observed anomalies.

MODELLING OF THE KAMOJANG MAGNETIC ANOMALY

Magnetic effects of three-dimensional bodies were computed by using the algorithm of Barnett (1976); for this, each body was approximated by a set of polyhedrons with triangular facets. The first bodies were constructed by assuming that all reservoir rocks enclosed by the resistivity boundary shown in Fig.1 were demagnetised; the computed anomalies, however, showed too large wavelengths. The cross-sectional area of the demagnetised body was then reduced until the cylindrical body with polygonal cross-section was obtained (see Fig.1) whose magnetic effects fits closely the observed total force residual anomaly shown in Figs.1 and 3. Although bodies with a lensoidal section also provide good fits (Suranto,1987), we adopted a demagnetised body with vertical boundaries as the best fit model (Fig.3) because of its simple shape. The fit was improved when it was assumed that all rocks at the surface in the NW part of the field, which are associated with active surface manifestations (steam discharge), are partly demagnetised (0.8 A/m, see section in Fig.3).The effect of a deeper seated, normally magnetised body lying to the SW but outside the field.which causes a positive anomaly at the SW end of the profile at PI in Fig.3, was not modelled.

If the demagnetised body which explains the total force anomaly at 2500 m height were shallow,-it should also reproduce the AZ-magnetic anomaly observed at ground level. This anomaly, however, is highly disturbed by near-surface inhomogeneities and

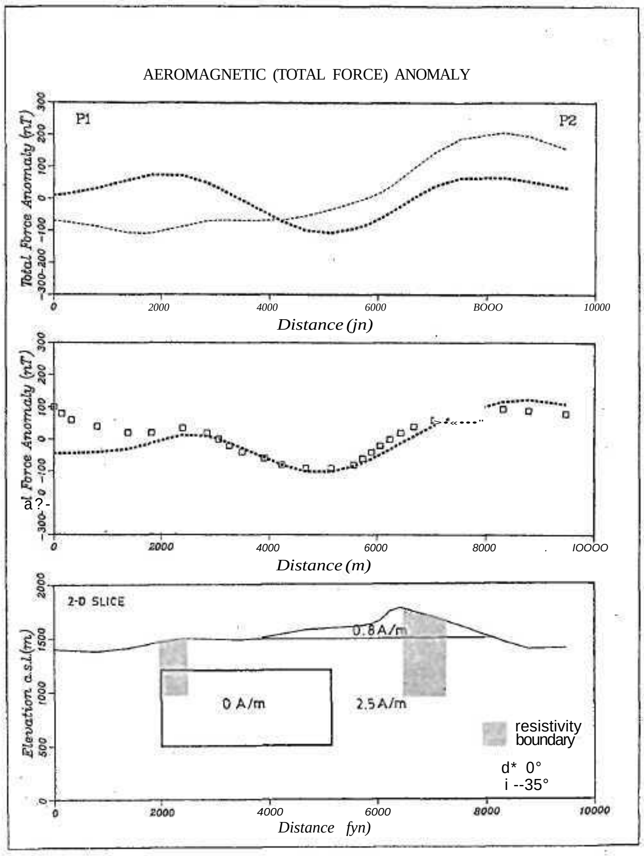

Fig.3: Observed and computed AF-anomalies (at 2500 m elevation) along profile PI - P2 shown in Fig.l. The topographic effect based on an inferred homogeneous magnetisation (2.5 A/m) of the terrain is shown by the thin, broken curve in the upper part of the figure. The thick broken curve in the upper part is the magnetic effect of the demagnetised body and the partly demagnetised terrain shown in the section at the bottom. The broken curve in the central part of the figure is the combined effect of topography and demagnetised bodies (box symbols denote the observed anomaly).

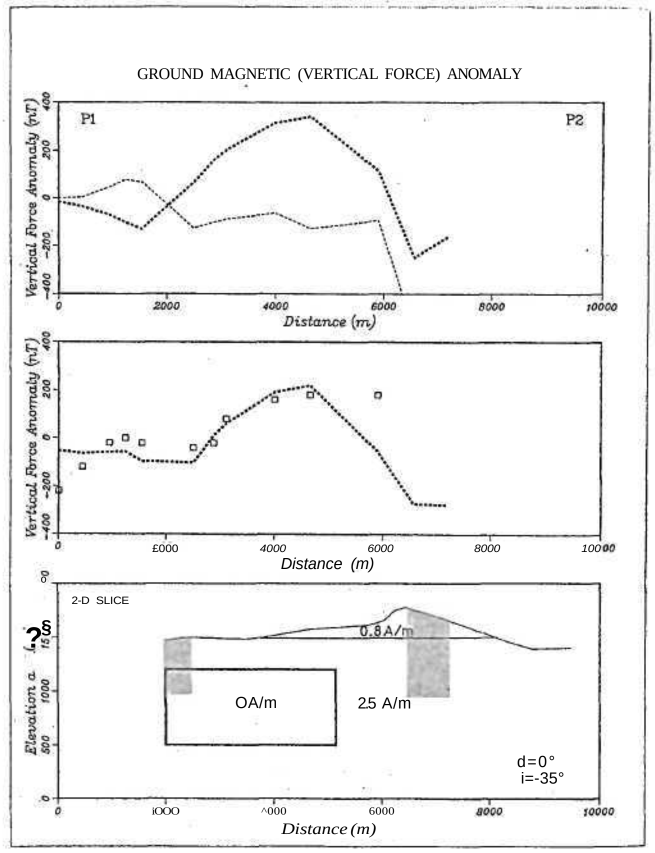

Fig.4: Upward continued and computed AZ-anomalies (at 1800 m elevation) along profile PI - P2 shown in Fig. 1. Explanation of diagrams is the same as for Fig. 3.

topographic effects.To reduce these effects, the anomaly was reduced (height of 1800 m) by upward continuation (Sudarman,1984). However, only a few stations were occupied N of the northern resistivity boundary shown in Fig.l and the upward continued AZ-data in this area are distorted by artifacts of the reduction process. This explains why the AZ-anomaly computed for the same body shown in Fig.3 provides a poor fit to the NE end of the profile shown in Fig.4, although the fit of AZ-anomalies in the SW part of the profile is acceptable. It confirms that the magnetic anomalies are of shallow origin.

IMPLICATIONS OF THE MAGNETIC MODEL

Since modelling has shown that the Kamojang magnetic anomaly is caused by demagnetised reservoir rocks,confirming results of an earlier study of cores, implications of the magnetic model for reservoir studies can be discussed.

Let us assume that for bulk demagnetisation of a certain part of the reservoir some significant matrix- and fracture permeability is required and that fluid characteristics remain about constant at the same level throughout the whole reservoir, i.e. demagnetisation at a given level is essentially controlled by a certain permeability structure. Lack of significant demagnetisation in other parts of the reservoir would then imply either a reduced matrix permeability or a lower fracture permeability.

If one looks at the productivity of Kamojang wells which have been drilled either outside or near the boundary of the demagnetised body as shown in Fig.l, one finds that most of these wells have indeed low productivity or are non-productive, namely KMJ 9 and 13 in the N part, KMJ 7 and 20 in the NW, but also KMJ 32 at the S boundary (see Fig.l). It is therefore possible that parts of the Kamojang reservoir which lie outside the demagnetised body but still within the resistivity boundary exhibit a lower fracture permeability. If this inference is correct, the extent of the demagnetised reservoir could be used for reservoir modelling. The magnetic model could also be applied to the yet unsolved problem whether at economic depths the reservoir might extend beyond the resistivity boundary.

ACKNOWLEDGMENTS

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