INTERPRETATION OF SELF-POTENTIAL ANOMALIES OVER THE ULUBELU GEOTHERMAL PROSPECT, SOUTH SUMATRA, INDONESIA

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SUMMARY - Self-potential (SP) measurements were carried out along two survey lines (23.5 km total length) across the Ulubelu geothermal prospect (South Sumatra, Indonesia) in 1991 by the Geothermal Division of Pertamina. The results show long wavelength positive and negative anomalies associated with the geothermal prospect. A quantitative interpretation of the data indicated that these SP anomalies can be explained by electrical potentials generated along four dipping planes located at 0.8 and 1.5 km below the ground surface, which probably represent interactions between faults and geothermal activity at depth.

1 INTRODUCTION

Self-potential (SP) anomalies have been observed over many geothermal systems, with a wide variety of amplitudes, shapes and polarity (Corwin and Hoover, 1979). Mechanisms that can generate such anomalies are the flows of fluid, heat, and ions associated with the elevated temperature and fluid convection inside the geothermal systems (Fitterman and Corwin, 1982; Apostolopoulos et al., 1997). Some geothermal prospects are associated with dipolar SP anomalies which can be originated from fault planes separating regions with differing electrokinetic or thermoelectric coupling coefficients (Fitterman, 1979; Fitterman and Corwin, 1982). Broad (long wavelength) positive SP anomalies have also been measured over some other geothermal prospects and appear to be associated with zones of uprising thermal fluids (Zablocki, 1976; Hochstein et al., 1990; Pham et al., 1995).

SP anomalies can also be generated by the flow of groundwater induced by topography, causing a decrease of electrical potential with the increase of elevation (e.g. Ishido et al., 1990). Results of SP surveys across many geothermal systems have also shown that long wavelength SP anomalies associated with deep geothermal zones are often disturbed by shorter wavelength anomalies caused by superficial sources of *streaming* potentials (shallow hydrological or geothermal origin), that can be filtered out during the processing of the data (Apostolopoulus et al., 1997).

In this paper, an interpretation of long wavelength SP anomalies across the Ulubelu geothermal prospect in the Lampung Province, South Sumatra, Indonesia, is presented, which appears to indicate sources associated with geothermal zones at depths.

2. THE ULUBELU GEOTHERMAL PROSPECT

The Ulubelu prospect is located on the eastern side of the Southern end of the Sumatra Fault Zone, a major fault system running NW-SE along the entire southwestern side of the Sumatra Island (Fig. 1). The prospect is situated within a volcano tectonic depression, at elevations between 700 and 800 m a.s.l. (Fig. 1), surrounded by still higher volcanic terrain. Thermal surface manifestations in the Ulubelu area include fumaroles, hot springs, mud and hot pools, and thermally altered ground. Fumaroles are present in the higher terrain in the central part of the area; chloride hot springs occur at lower elevation in the southeastern part.

A geological mapping of the Ulubelu area was carried out by Masd..uk (1990). The mapping showed that the lithology in the Ulubelu area consists mainly of pyroclastics and lava, andesitic to basaltic in composition, with their ages ranging from Pliocene (4.5 Ma) to Pleistocene (1.4 Ma). The Ulubelu prospect is associated with a low residual gravity anomaly, indicating a graben or a small

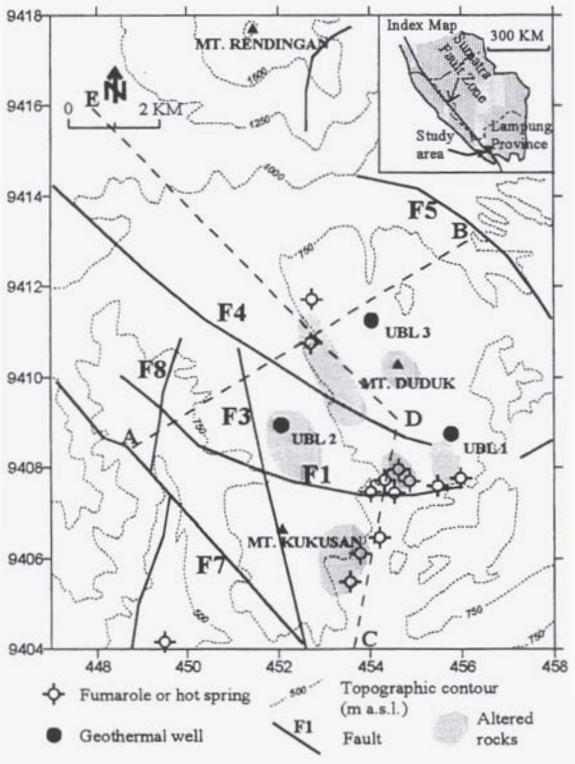

Figure 1. Map of the Ulubelu area showing topography, geological fault lines, surface thermal manifestations (fumaroles and hot springs), thermally altered rocks, geothermal wells, and SP survey lines AB and CDE. The names of faults are according to Suharno (1999).

caldera (Suharno, 1999). Results of Schlumberger resistivity mapping show a widespread low apparent resistivity without any clear resistivity boundary of the geothermal prospect. Three explorationwells (UBL 1-3; see Fig. 1) have been drilled in the Ulubelu area. Wells UBL 1 and UBL 3 were drilled to about 1200 and 900 m depths, respectively, and encountered temperatures >200 "C; well UBL 2 was drilled to about 600 depth and has a bottom hole temperature of about 150 °C (Suharno et al., 1999).

3. SELF-POTENTIAL ANOMALIES OVER THE ULUBELU PROSPECT

Self-potential measurements in the Ulubelu geothermal area were carried out in 1991 by the Geothermal Division of Pertamina along two survey lines (AB and CDE; see Fig. 1) with a total length of 23.5 km. The static electrical potentials of the ground were measured relative to point A (the southwestern end of line AB) at every 100 m distance, using a SANWA FD-750C digital voltmeter. Ground contacts were made through non-polarising Cu-$CuSO_4$ electrodes.

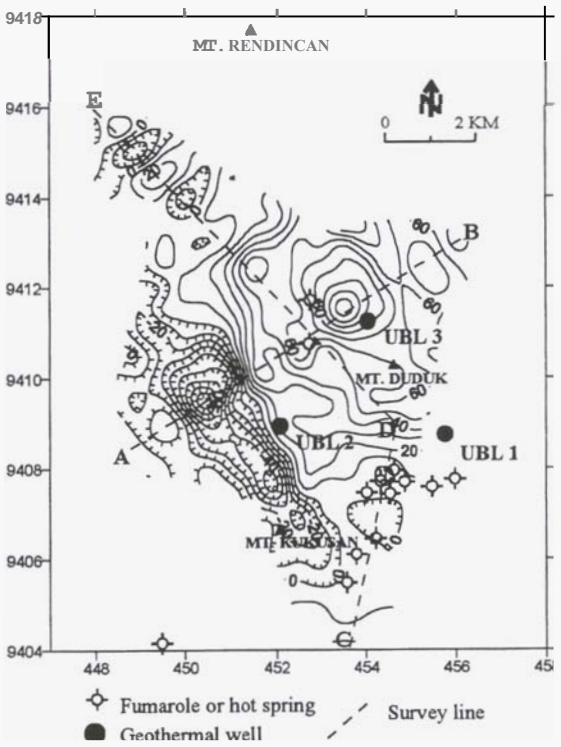

Figure 2. Contour map of SP anomalies across the Ulubelu prospect. Contour values are in mV. The SP anomalies were measured relative to point A (the south-western end of survey line AB).

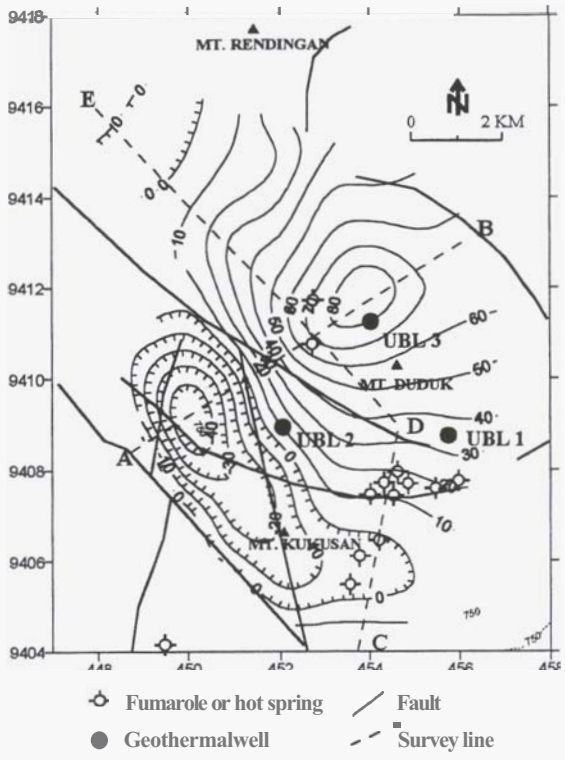

Figure 3. Contour map of smoothed SP anomalies across the Ulubelu area. The smoothing was carried out using a fourth order polynomial fitting along each survey line.

A contour map of the SP anomalies across the Ulubelu prospect is shown in Fig. 2. The contours are disturbed by short wavelength components of SP anomalies that are probably of shallow origins (hydrological or geothermal). To identify long wavelength anomalies, data along each survey line were smoothed using two different procedures, i.e. a polynomial fitting and a low-pass filtering by the "moving average" technique. It was found that results of a fourth order polynomial fitting are very similar to outputs from low-pass filtering using a five-point "moving average". Fig. 3 shows contours of long wavelength SP anomalies obtained from the fourth order polynomial fitting.

The results in Fig. 3 show that a broad positive anomaly of about 80 mV occurs near UBL 3 to the northwest of Mt. Duduk, together with a negative SP anomaly of about -40 mV to the southwest of the Ulubelu prospect, which extends to the east of Mt. Kukusan. The positive anomaly is located over a broad, high topography (see Fig. 1) and the negative anomaly is associated with both a valley and a ridge. Hence, these two long wavelength anomalies are not topographic effects.

4. INTERPRETATION OF THE SELF-POTENTIAL *ANOMALIES*

There are some apparent relationships between long wavelength SP anomalies and geological faults shown in Fig. 3, suggesting the possibility of the SP anomalies being generated by sources associated with the faults. Hence, a quantitative interpretation was carried out using the method of Fitterman (1984) which can be used to compute SP effects generated by dipping plane sources in a 3-D ground with a homogeneous electrical resistivity. A Schlumberger resistivity mapping had shown that the subsurface resistivity at Ulubelu is almost constant (Suharno, 1999).

The SP modelling was carried out by a "trial and error" approach. Models for the SP anomalies were constructed with different combinations of source intensity (F_o), position (E, N), depth (D), strike length (L), dip extent (T), dip (δ) and strike orientation (α) of dipping plane sources (see Fig. 4). The source intensity (F_o) is a parameter representing the discontinuity of electrical potential across the source region, related to temperature and contrast of thermoelectric coupling coefficients (Fitterman, 1984; Fitterman and Corwin, 1982).

A reasonably good fit between computed anomalies and the long wavelength SP anomalies in Fig. 3 was obtained from a final model consisting of four

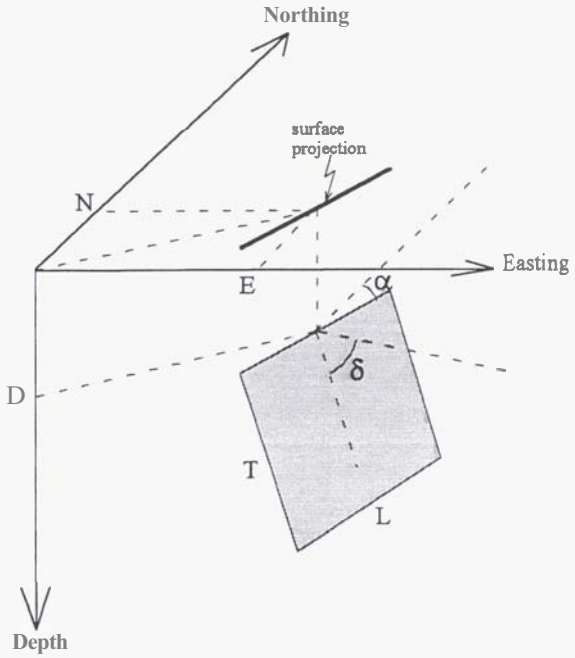

Figure 4. SP source model parameters of a dipping plane (Fitterman, 1984) (modified from Apostolopoulos et al., 1997).

Table 1. Parameters of the SP model in the Ulubelu area.

SP Source	F_o (mV)	E, N (km)	D (km)	L, T (km)	α (°)	δ (°)
S1	230	451.2, 9410.0	0.8	4.0, 5.0	350	90
S2	260	452.8, 9410.8	0.8	2.0,	310	80

dipping planes, whose parameters are listed in Table 1. The Surface projections of S1, S2, S3 and S4, together with contours of the computed SP anomalies, are presented in Fig. 5.

The SP contours in Fig. 5 reproduced the long wavelength positive and negative SP anomalies shown in Fig. 3. Profiles of the computed SP effects of the model and the unfiltered SP data along the two survey lines AB and CDE are presented in Fig. 6, which shows that the computed anomalies match the long wavelength trends of the observed SP anomalies.

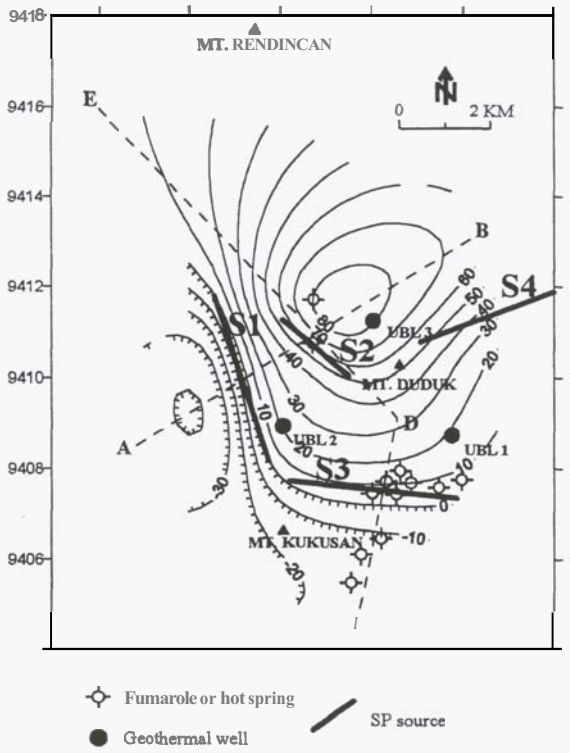

Figure 5. Computed SP anomalies of the dipping planes whose surface projections are indicated by the thick lines.

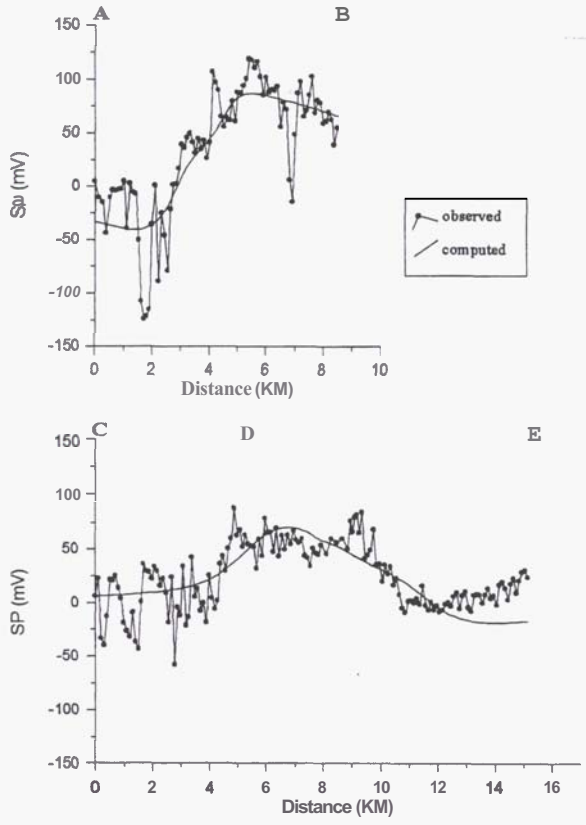

Figure 6. Plots of observed and computed SP anomalies along survey lines AB and CDE.

5. DISCUSSION AND CONCLUSIONS

No data are available to assess directly the source intensity (F_o) of our SP model for the Ulubelu prospect, but the values listed in Table 1 (180 to 260 mV) are compatible to F_o values estimated from similar SP modellings conducted over some other geothermal fields. F_o values of 200 to 500 mV are indicated across the East Mesa geothed prospect in the USA (Fitterman, 1984). In the Cerro Prieto field in Mexico, measured SP anomalies can be explained by a plane source with a F_o value of 349 mV (Fitterman and Corwin, 1982). A more recent SP study by Apostolopoulos et al. (1997) over some geothermal zones in Greece indicated F_o values of 190 to 818 mV.

The SP source S3 is clearly associated with a segment of faults F1 southwest of UBL1 (see Fig. 5 and Fig. 1), whereas S1 and S2 appear to be associated with a segment of faults F3 and F4, respectively. No fault line was mapped at the surface close to S4. However, a modelling of residual gravity anomaly (Suharno, 1999) suggested that buried fault structures may exist near the locality of S4. Hence, results of the quantitative SP interpretation suggest that across the Ulubelu prospect, a relationship exists between long wavelength SP anomalies and geological faults.

S2 and S3 are associated with surface thermal manifestations, i.e. with groups of hot springs and fumaroles to the west of UBL 3 and to the southwest of UBL 1, respectively (see Fig. 5). No surface manifestations appear to be associated with S1 and S4, but thermal activity is likely to exist at depth beneath them, as indicated by high temperatures measured at UBL 3 and UBL2. Hence, it can be inferred that the four SP plane sources listed in Table 1 represent interactions between faults and geothermal activity at depth.

6. REFERENCES

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