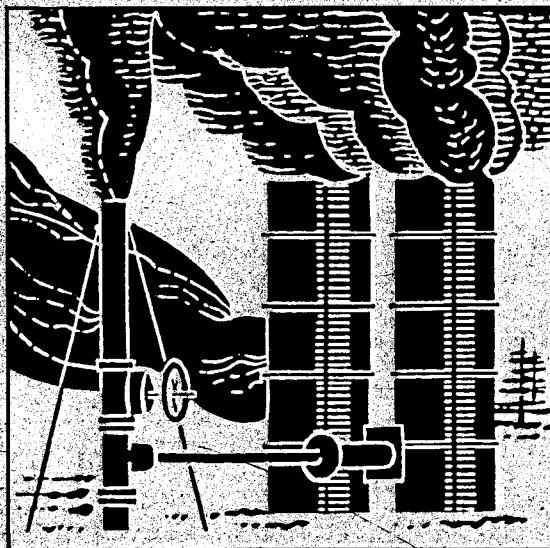


**proceedings of  
THE  
17th NEW ZEALAND  
GEOTHERMAL WORKSHOP  
1995**



**compiled and edited by  
M. P. Hochstein, J. Brotheridge and S.F. Simmons**

**presented by  
Geothermal Institute  
The University of Auckland  
in conjunction with  
The Centre for Continuing Education**

## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

# INTERPRETATION OF GEOELECTRIC STRUCTURE AT HULULAIS PROSPECT AREA, SOUTH SUMATRA

MULYADI

PERTAMINA Geothermal Division, Jakarta, Indonesia

**SUMMARY** - Schlumberger resistivity surveys were conducted in 1993 as part of a combined geological, geophysical and geological program to investigate a geothermal prospect in the Hululais area, Southern Sumatra. These resistivity data resolved the upper conductive layer and were interpreted to define the shallow extent of a possible geothermal system. A follow-up magnetotelluric (MT) survey was carried out to probe deeper than the dc resistivity survey results achieved. However, the resistive sub-stratum below the conductive layer was still poorly resolved. Possible reasons for this include a preferential channelling of the telluric current within the thick shallow very conductive layer, thus limiting the penetration depth of the magnetotelluric signals and poor resolution due to high noise levels caused by significant rain and sferics.

## 1. INTRODUCTION

The Hululais geothermal prospect lies within an area of approximately 100km<sup>2</sup>, located about 80km North of Bengkulu city, Southern Sumatra, Figure 1. Topographically, it is dominated by peaks of Bukit Cemeh, Hululais and Beritibesar, which forms an anticlockwise arc, Figure 2. Bukit Hululais is the highest of these mountains reaching an elevation in excess of 1900m (asl). Much of the area on the northeast slopes of the Bukit Hululais has been cultivated by coffee plantations. A broad valley further northeast lies at an elevation of about 400-500m. At least 15 thermal manifestations, such as, fumaroles, mud pools, and hot springs are observed in the area at elevations ranging from 400m to 1500m.

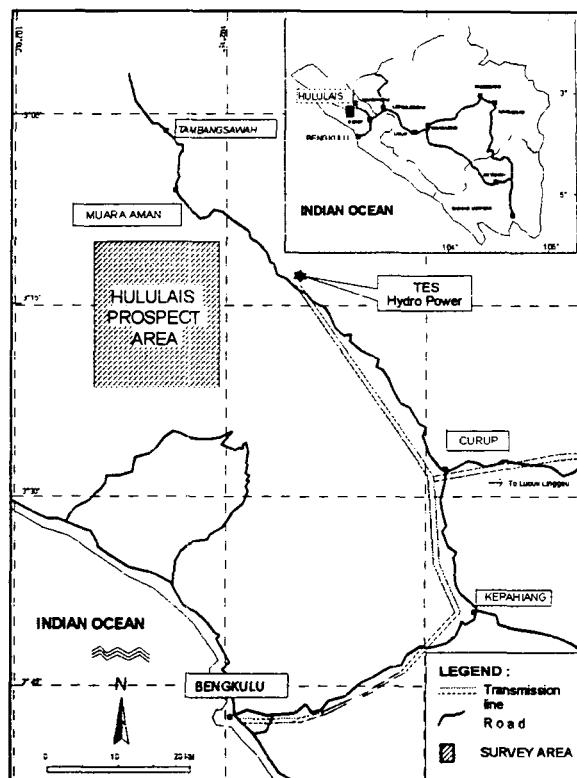
The purpose of an MT survey conducted in the Hululais prospect area was to better define the extent of a Schlumberger resistivity anomaly interpreted to be associated with a geothermal reservoir. Another objective was to detect a deep resistive sub-stratum which was not clearly probed by the Schlumberger survey.

## 2. PREVIOUS WORK

### 2.1. Generalized Geology

The generalized geology setting and major faults of the Hululais area are shown in Figure 2. The dominating NW-SE trending faults are associated with the Sumatra Fault Zone producing a graben structure.

Along the Sumatra Fault Zone, deposition of marine sediment both in the Bengkulu and Sumatra basins, and deposition of volcanogenic interfingered with marine sediment occurred throughout the Cenozoic.



**Figure 1. The Hululais geothermal prospect area, Southern Sumatra.**

During the Oligocene - Miocene period, andesitic and basaltic volcanism occurred on the Barisan mountain zone, while turbidites were being deposited in the basins.

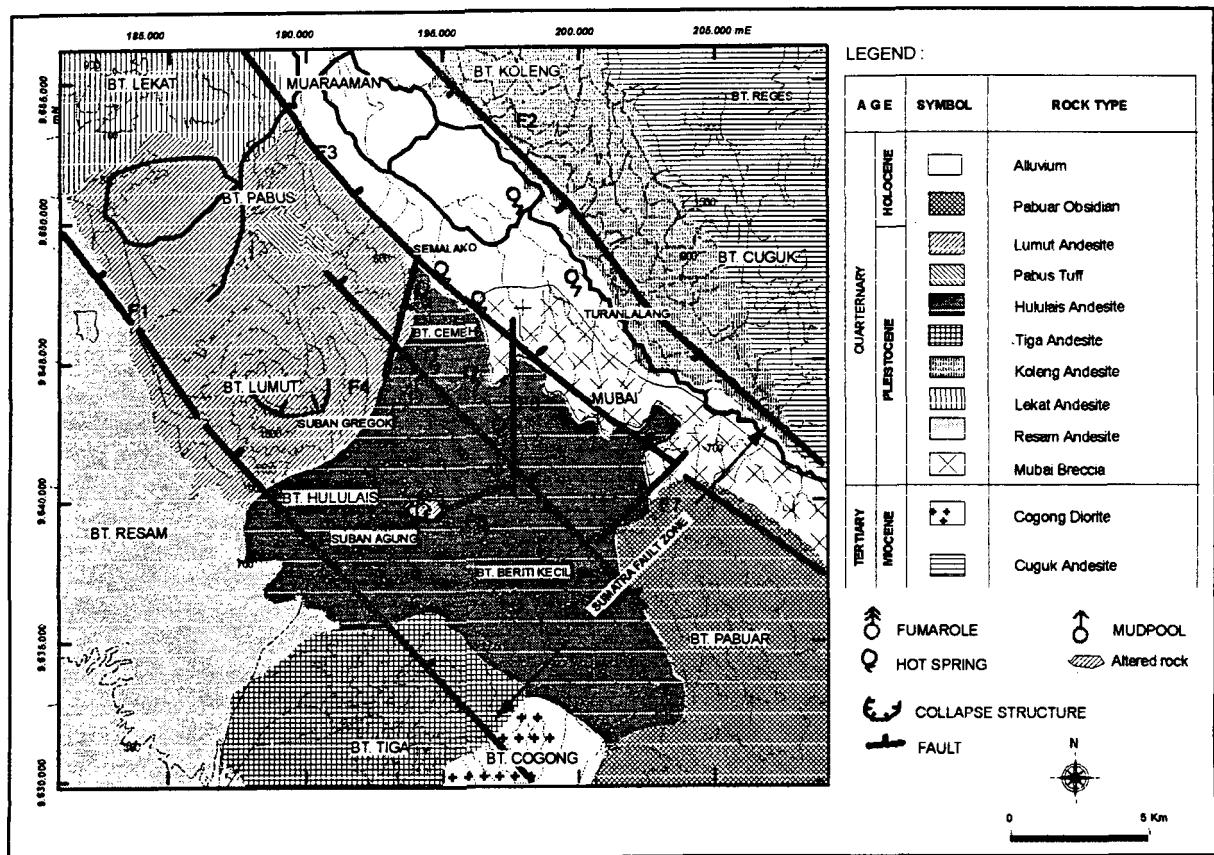


Figure 2. Generalized geology of Hululais geothermal prospect area, South Sumatra.

Uplift along the Barisan mountain was accompanied by acid volcanism along the Sumatra Fault Zone in the Mid-Miocene. Intrusions of granites and diorites followed. Shallow marine sediments were continuously deposited in the Bengkulu basin throughout the Miocene.

Another period of uplift occurred during the Pliocene-Pleistocene period. Basaltic, andesitic and dacitic volcanism along the Barisan mountains have continued through Pleistocene followed by recent (1100 years) activity produced obsidian deposits, which are outcropping at Bukit Hululais. Such recent activity is likely to have been accompanied by intrusion of acidic magma, with localised heating and possible degassing into the flanking geothermal system.

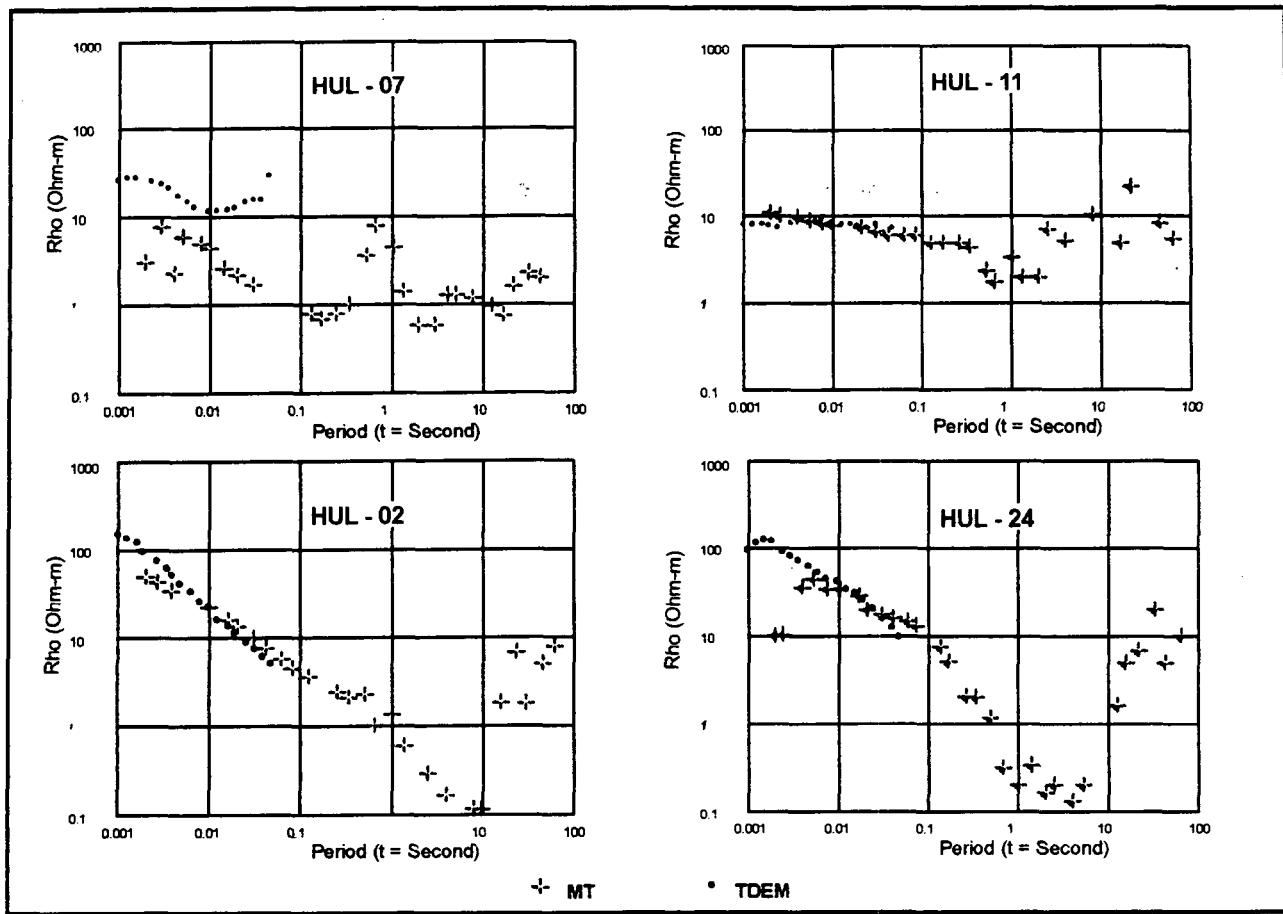
## 2.2. Thermal manifestations

Fumaroles and acid pools occur at relatively high elevations of about 1050m to 1300m (asl). Neutral pH, high chloride springs are found at an elevation of about 1000m (asl), northeast of Bukit Hululais, and to the north, at much lower elevations of about 500m and 400m near Simalako and Pasirlebar village.

Other springs containing  $\text{HCO}_3\text{-SO}_4$  waters with very little chloride are found near Bukit Cemeh (700-1000 m asl) and Turanlalang (400 m asl). Geochemical analysis suggests that the temperature of the deep reservoir probably lies in the range of 250°C to 300°C.

## 2.3. Resistivity Data

Resistivity data for the area consist of Schlumberger resistivity mappings, time-domain electromagnetic (TDEM) and magnetotelluric (MT) soundings. The Schlumberger resistivity data were collected in 1993 by Pertamina as part of an integrated geological, geochemical and geophysical evaluation of the prospect area, ( PT. Cakrabuana Perkasa, 1994 ). The MT and TDEM soundings were carried out in 1995 to follow-up resistivity anomalies detected with the Schlumberger survey. The TDEM was collected at every MT station to check for static shifts and to provide better resolution of the shallow resistivity structure. The TDEM soundings were carried out in the in-loop (INL) mode using 200 meter square transmitting loops. The MT data were measured using standard 2 component electric field ( $\text{Ex}$ ,  $\text{Ey}$ ) and 3 component magnetic fields ( $\text{Hx}$ ,  $\text{Hy}$ ,  $\text{Hz}$ ).



**Figure 3. Examples of TDEM and MT sounding curves for 4 stations.**  
MT soundings plotted on the figures are the Rho- invariant.

The electric fields were measured using pairs of CuSO<sub>4</sub>-porouspot electrodes (MN = 200m) connected through a signal conditioning amplifier to the GDP-32 Zonge receiver. Voltages are measured relative to central reference/receiver ground. Example of the TDEM and MT soundings are shown in Figure 3. Note that the station Hul-07 shows evidence of a static shift between the MT and TDEM soundings. The other three stations, Hul-02, Hul-11 and Hul-24, show a good correspondence between the MT and TDEM soundings. Since most of the MT sounding curves show a good correspondence with TDEM sounding, the static effects are ignored during inverting MT-resistivity sounding curve into resistivity layers. Also note that the MT data are noisy, particularly at frequencies less than 1 Hz. These high noise levels are due to the large amount of rain and sferics (lightening) experienced during the survey.

Computer software written by M. Stark (Philippine Geothermal Incorporated) and Mulyadi (Pertamina) in 1984, was used to invert the MT-resistivity soundings into layered model. The layered interpretations were simplified into 3 layers for most stations. Two cross-sections, S-N and SW-NE, were made to get a clear figure of the sub-surface resistivity distributions, Figure 4.

### 3. DISCUSSION

Lateral resistivity distribution at shallow depth is illustrated by the Shlumberger iso-apparent resistivity map at AB/2=500m, Figure 5. Although not shown, similar shallow resistivity pattern were observed with TDEM (turn off time of 48ms) and MT (frequency of 3Hz). The conductive area, especially apparent resistivity of less than 10Ωm, shows a general NW-SE trend and may be associated with the similarly trending faults of Sumatra fault systems, Figure 5. The largest conductive anomaly of less than 10Ωm overlies an area with thermal springs. This correlation with thermal area suggests the resistivity anomaly may be caused by shallow clay alteration associated with an geothermal outflow system. Note, the low resistivities are bounded on the western, eastern and southern edges by faults suggesting the faults may be important structural controls for the shallow geothermal system in this area. To the west, a resistive zone occurs suggesting a decrease in percentage of clay at shallow depth due possibly to change in rock type or absence of geothermal outflow in this direction.

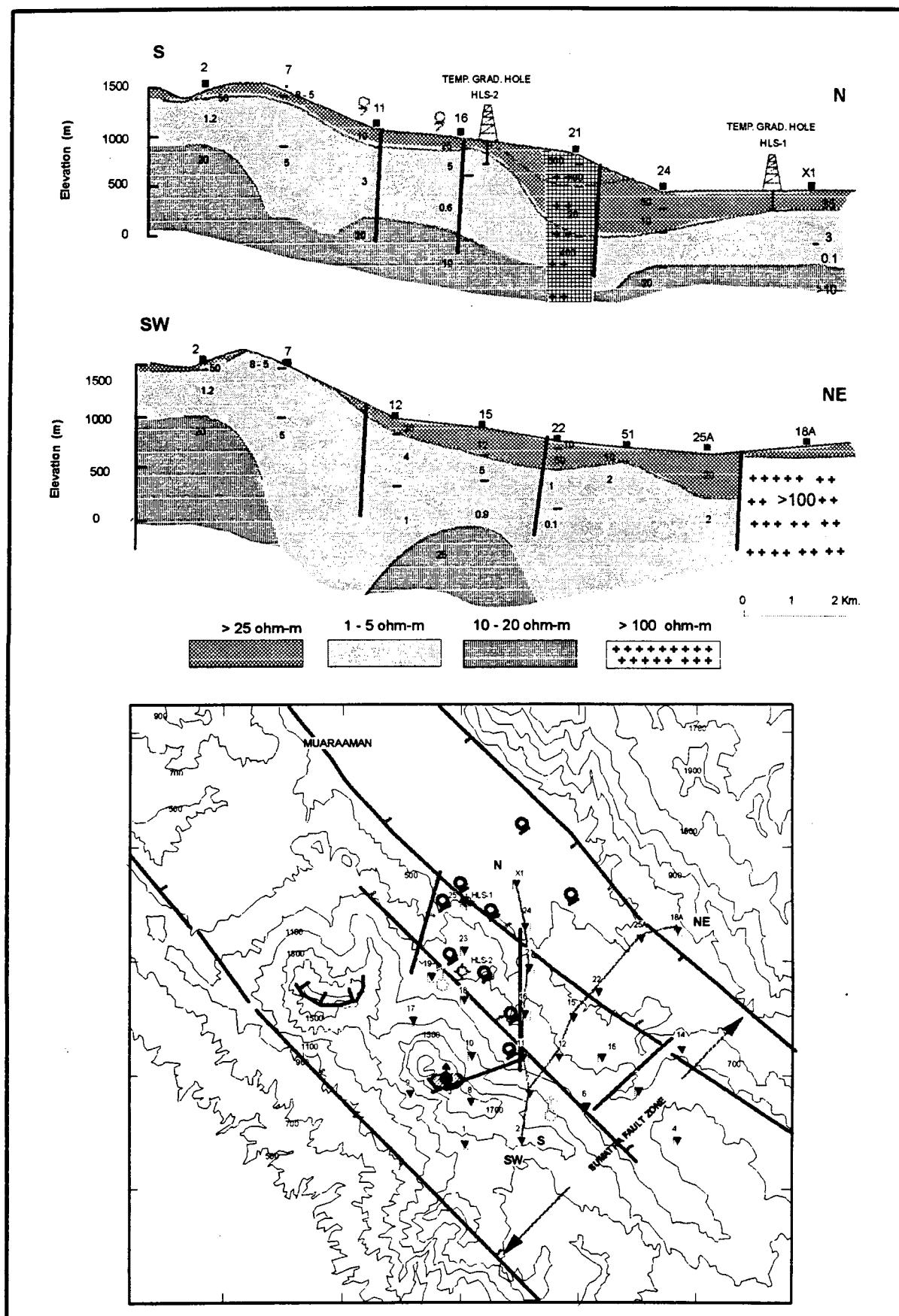


Figure 4. MT-resistivity sections, Hululais, South Sumatra.

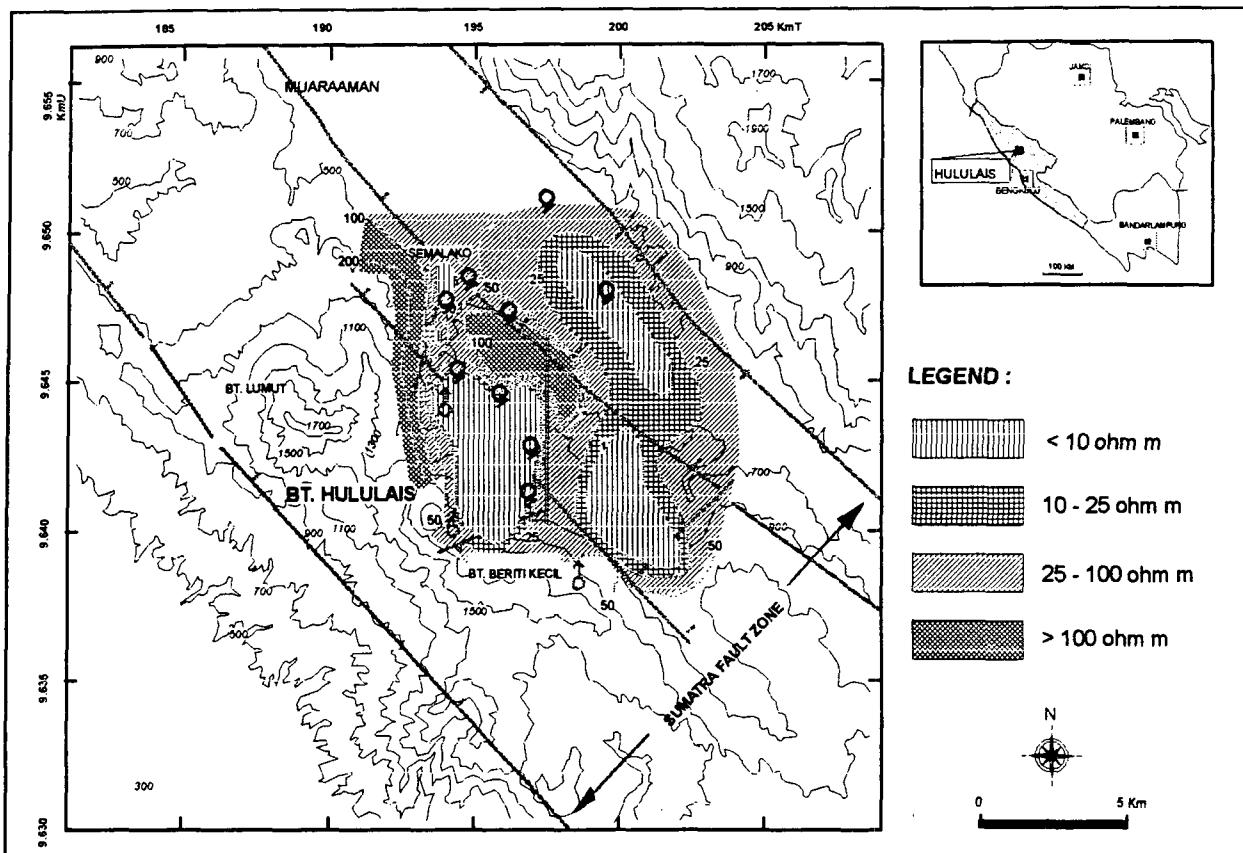


Figure 5. Distribution of the conductive area as defined with Schlumberger apparent resistivities at  $AB/2=500m$ .

Eventhough, a collapse structure exists in this area as part of volcanic activity, no geothermal prospect area is defined in this area, since there are no geophysical and geochemical data available. Another shallow high resistivity area was located in between these low resistivity zones.

Lateral resistivity distribution at deeper level ( $t=30s$ , MT) shows a conductive zone of less than  $20\Omega m$  within the Sumatra Fault Zone producing graben structure, Figure 6. This shows that the conductive layers spread widely at deeper level and may not be controlled by the step faults system. Two very conductive areas of less than  $2\Omega m$ , consists of eastern anomaly and western anomaly which are located over thermal features separated by ridge of high resistivity. This high resistivity between step faults is located at relatively at the same area as high shallow resistivity, Figure 5. As noted above those resistive features may reflects either changing in rock type or growth less clay alteration. The western boundary of the high conductive zone is not known due to the limitation of MT stations.

But to the east, the lateral conductive distribution was bounded at the location of MT-18A (Figure 4), which is far to the East at the foot-wall of the Sumatra Fault Zone.

The very conductive layers of  $0.1\Omega m$  to  $5\Omega m$  on the MT cross-sections, Figure 4, may be due to the Bukit Hululais altered andesite rocks abundant in clay mineral and

containing hot fluids. This is consistent with results concluded by the geochemical survey, which suggest the area is underlain at depth by a neutral sodium chloride water (pt. Cakrabuana Perkasa, 1994). The thickness of low resistivity layer and depth to top of the higher resistivity substratum are poorly resolved due to noise and possible very low resistivity for the conductive layer, Figure 3 and 4. However, the resistive substratum of about  $10-20\Omega m$  was obviously indicated underneath of MT-2, MT-11, MT-16 and MT-21. This increasing resistivity in the substratum could be caused by increasing of silica content due to increasing temperature with depth.

The substratum is shallowest (about 1000m asl) in the south then dips downward to the north to a level of about 250m (asl).

HLS-2 was drilled deep enough to encounter the conductive layer, at which depth the intensity of alteration increased and the encouraging temperature gradient of about  $11^\circ C/100m$  was observed. HLS-1 with depth of about 250m did not drill deep enough to get into the top conductive layer, Figure 4. It shows moderately cool temperature of about  $25-35^\circ C$  throughout most of its depth.

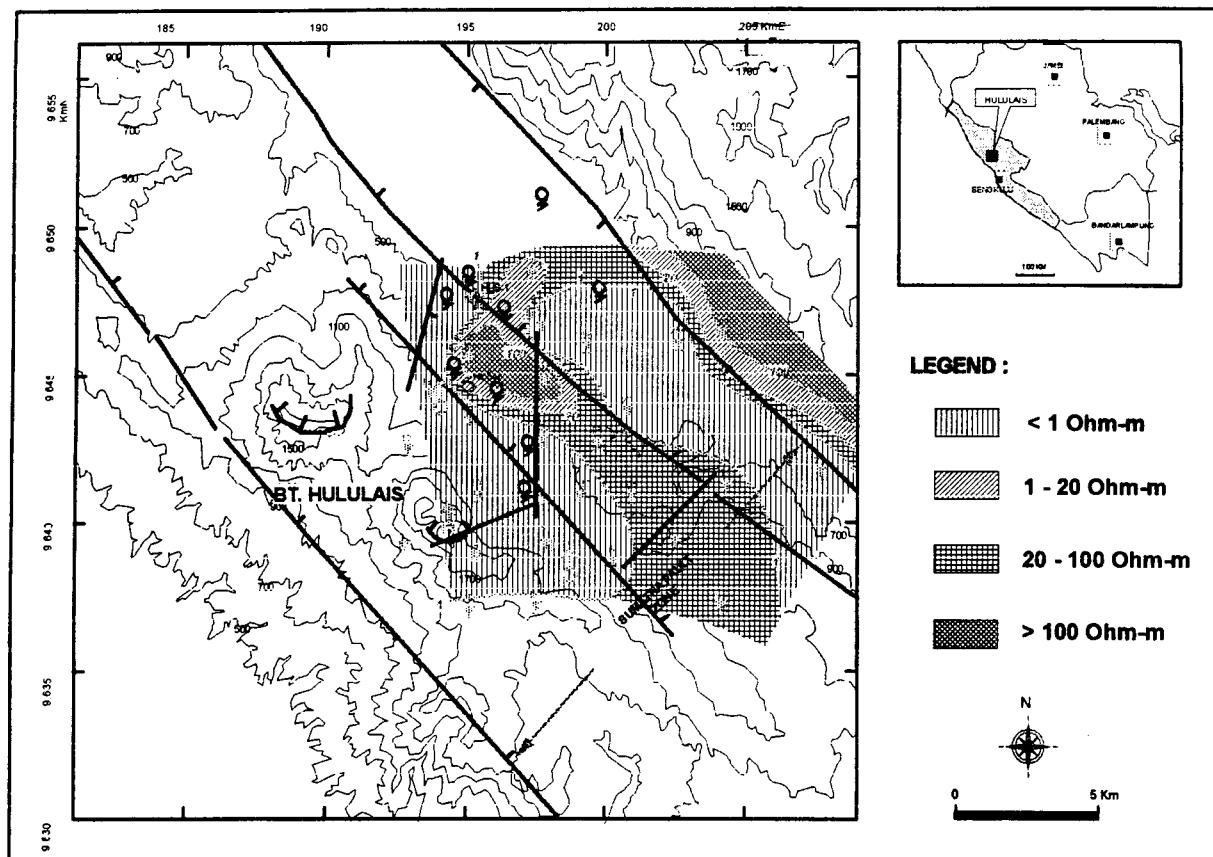


Figure 6. The deeper distribution of conductive structure as defined with MT at a period of 4 seconds.

#### 4. CONCLUSION AND SUGGESTION

The low resistivity patterns at shallow depth suggest hot fluids outflowing to the N-NE and associated with the step faults system, while at deeper depth the conductive area distributes widely within the graben structure formed by NW-SE Sumatra faults.

The resistivity data was only marginally successful at penetrating through the shallow conductive layer. Even, the MT survey, which has the ability to probe deep enough, was not able to resolve very well the resistive sub-stratum which often contain the geothermal reservoir. This was due to in part to the very low resistivities of the conductive layer limiting the probing depth and the high noise levels caused by heavy rain and sferics. Reprocessing the MT data with Robust techniques may increase the data quality and help to better resolve the resistivity layer. Where, the resistive substratum was detected (MT-2, MT-11, MT-16 and MT-21), it showed the top resistive substratum to be shallowest in the south beneath the high elevation thermal features then deepening to the north.

Temperature gradient holes are advised to be drilled at the MT-2, MT-11 and MT-12 for about of 1000m, 1500m and 1500m depth to investigate the reliable deeper reservoir.

#### 5. ACKNOWLEDGEMENTS

Reviews of the paper were kindly made by Gregg A. Nordquist (Chief Geophysicist of UNOCAL-INDONESIA). Permission to publish the work presented here has been given by The Managements of geothermal Division, Pertamina.

#### 6. REFERENCES

PT. Cakrabuana Perkasa, 1994. Scientific model of the Hululais geothermal resources. Unpublished report, Dir. E dan P, Div. Panasbumi, Pertamina, Jakarta.

Rachman, A.R., 1993. Compilation of resistivity, gravity and ground magnetic measured over the Hululais geothermal prospects. Unpublished report, Dir. E dan P, Div. Panasbumi, Pertamina, Jakarta.