PROJECT FOR DIPLOMA IN
GEOTHERMAL ENERGY TECHNOLOGY

REPORT

INTERPRETATION OF TANGKUBAN PERAHU
GEOPHYSICAL DATA
(WEST JAVA - INDONESIA)

by
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Note: This is a project report not a thesis, and has been written in part fulfilment of the Diploma in Geothermal Energy Technology. It represents the student's view and the Geothermal Institute does not accept responsibility for the opinions or accuracy of the statements made herein.
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ABSTRACT

The Tangkuban perahu geothermal field is located in West Java, Indonesia, about 20 kilometres to the North of Bandung.

Geophysical surveys of Tangkuban perahu, particularly using resistivity traversing and VES with schlumberger and Magnetotelluric arrays were made to evaluate the electrical resistivity distribution within the geothermal field. Low concealed resistivity anomalies are encountered in both the Kancah and Ciater area. The interpretation of the magnetotelluric soundings and VES curves by computer modelling indicates that deep outflow zones have a resistivity about 1 to 6 Ohm-m. The outflows are overlain by a high resistivity layer of about 15-65 Ohm-m. The low resistive zone, laterally, is confined by resistivity layer of about 14-42 Ohm-m.

Gravity anomalies over Tangkuban perahu are associated with Caldera structure infilled with less dense Pyroclastics. No detailed interpretation of the anomaly can be given since a major reduction error in the data was detected at the final stage of the project.

A positive self potential anomaly observed in this area can be interpreted in terms of upflowing and outflowing mineralized fluids from the deep Tangkuban perahu system.
1. **INTRODUCTION**

The Tangkuban perahu geothermal area is located about 20 km, North of Bandung, West Java, Indonesia (fig. 1). This area is mainly covered by primeval forest, tea plantations and agriculture areas.

Reconnaissance survey of Tangkuban perahu area had been carried out by Pertamina in 1981. This survey lead to further detailed geological investigations which were carried out in 1986. Other surveys using both schlumberger and magnetotelluric arrays were made in the middle of 1986, and a gravity survey is still being continued.

The assessment of Tangkuban perahu area is based upon geological, geochemical and geophysical data.

Geochemical interpretation is based mainly upon the data of water chemistry of hot springs.

Geophysical interpretation is based mainly on the schlumberger Traversing and Soundings, Magnetotelluric, Self potential and Gravity data.
Fig 1. Location of Tangkuban perahu geothermal field
2. GEOLOGICAL SETTING

2.1 Landsat Interpretation

The study of Landsat Imagery of the Tangkuban perahu area, scale 1:300,000 shows that the Tangkuban perahu crater rim lies near the older, eastern Sunda crater rim. Three circular features of Tangkuban perahu crater imply that these structure shifted eastward (fig. 2).

Lineaments with NE-SW, NW-SE and W-E direction point to a concentric pattern centered on both Sunda and the Tangkuban perahu crater.

The Lembang Fault which transects W-E trending Fault can clearly be recognised. The fault is intersected by both NE-SW and NW-SE lineaments and indicates that the Lembang Fault was formed before these lineaments occurred.

2.2 Stratigraphy and Tectonic setting

Stratigraphy of Tangkuban perahu area is dominated by volcanic rocks which erupted from either the Sunda or the Tangkuban perahu centres. Based upon the characteristics of lithological features and volcanic processes, the stratigraphy of rocks from this area can be differentiated into pre-Sunda caldera deposits and post Sunda caldera deposits.
The initial stage of the Sunda Centre activity, in the lower Quaternary, lead to the formation of laharic breccia that is likely to be widely distributed in the surrounding area. This breccia was recently covered by young volcanic deposits. Over the next period, numerous volcanic episodes produced an extensive, thick andesitic lava.

The formation of the Lembang Fault might have lead to major eruption of the old Sunda Volcano resulting in widespread pyroclastic breccia which are dominantly composed of pumiceous andesitic breccia and tuff. The major activity was followed by a collapse leading to the formation of the Sunda caldera. A consequence of this activity was that volcanic activity shifted to the Tangkuban perahu centre which, then, initially erupted its material to form andesitic pyroclastic breccia containing dominantly black pumice and some charcoal fragments. The following eruption occurred, resulting in scoriuous andesitic lava, andesitic lava, tuff and tuffaceous breccia (fig. 3).
Fig. 2: Landsat IR

Landsat image over Tangkuban Perahu - Bukit Tanggul area
3. GEOCHEMISTRY AND DESCRIPTION OF SURFACE MANIFESTATIONS OF TANGKUBAN PERAHU

Thermal manifestations of Tangkuban perahu area are mainly associated either with faults or rim structures and are encountered in 7 areas, namely: Tangkuban perahu, Kawah Domas, Ciater, Kancah, Cimangu, Maribaya and Batugede (fig. 4). The chemical constituents of hot springs is shown in Table 1.

3.1 Tangkuban perahu and Kawah Domas Manifestation

The Tangkuban perahu as well as the Domas hydrothermal manifestation consists of Solfataras, fumaroles, mudpools and hot springs, steaming ground and altered rocks.

The Kawah Domas manifestations are confined to a collapse structure.

Sulphur bearing altered rocks which exhibit a yellowish, pale grey colour are widely encountered in both Tangkuban perahu and Domas area.

The temperature of solfatar at Tangkuban perahu is about 172°C and the hot spring temperatures are between 80°C and 96°C. These hot springs consist of acidic condensate with pH less than 2.
The Domas acid springs contain high sulphate (dissociated $\text{H}_2\text{SO}_4$) concentration between 1627 and 2796 ppm and about 77-182 ppm chloride concentration.

Ellis and Mahon (1977) pointed out that in active volcanic areas, high temperature steam rich in $\text{HCl}$, $\text{HF}$, $\text{SO}_2$, $\text{CO}_2$ and $\text{H}_2\text{O}$, may arise from molten rock at shallow depth to condense into surface or near surface water which give rise to high concentration of sulphate chloride and fluoride.

Henley (1984) stated that dissolved constituents in magmatic fluid such as $\text{H}_2\text{S}$, $\text{SO}_2$, $\text{CO}_2$, $\text{HCl}$, $\text{HF}$, etc, will dissociate drastically with the decreasing temperature. $\text{H}^+$, for instance, is formed from dissociation of $\text{HCl}$ and the pH of the solution tends to decrease as temperature falls, and $\text{SO}_2$ and $\text{CO}$ become unstable.

Giggenbach (1975) in an investigation of fumarole at White Island stated that the main volcanic gas species are $\text{H}_2\text{O}$, $\text{CO}_2$, $\text{SO}_2$ and $\text{HCl}$; $\text{CO}_2$ is considered to be unreactive, while the other three species are very reactive and are likely to show considerable variations in their concentrations which respond to variations in temperature and pressure.

Relatively high concentrations of $\text{Mg}$, $\text{Ca}$, $\text{Na}$, $\text{K}$ and $\text{Fe}$ in Kawah Domas, are mainly derived from leaching and decomposition of the rocks due to the acid condensate containing hydrochloric and sulphuric acid. These cation contents reflect the cation composition of the surface
rocks which are being dissolved, and the anion contents are dissociated from magmatic gases.

It can be concluded that the thermal features in Kawah Domas are related to magmatic steam rising from magmatic emanation or are derived from steam heated water containing magmatic gases.

3.2 Kancah Manifestation

Kancah hot springs lie on the southern flank of Tangkuban perahu mountain about 4 km SSW, confined to N-S Lineaments.

The Kancah manifestations comprise Jarosite and residual silica owing to hotspring deposition and acid leaching. These springs have temperature of approximately 30°C to 40°C with pH of about 3 and a debit of about 10-18 l/s.

Hotspring waters containing relatively high comparable sulphate and chloride concentrations are found in most of the springs in this area. The sulphate concentration ranges from 200 to 405 ppm which is somewhat similar to the chloride concentration ranging from 173 ppm to 404 ppm.

The unbalanced sodium and chloride concentration (excess in chloride) exist in these springs with an excess in chloride of approximately 312 ppm. The sodium concentration is about 30-90 ppm. The shallow acid condensate outflows from tangkuban perahu are partly neutralized by rock-fluid
interaction resulting in higher in pH values of Kancah and some dilution with ground water is also taking place. The high content of calcium and relatively high comparable Fe and Na come from dissolved rocks.

The increasing concentration of chloride is probably the result of more condensation of volcanic gases between Tangkuban perahu crater and Kancah, or it might reflect the existence of uplowing condensate from a deeper condensate outflow (fig. 5).

3.3 Ciatar Manifestation

The ciater manifestations lie on the N-E part of Tangkuban perahu crater about 5 km NE.

Manifestations in Ciater represent exclusively hotspring and deposits of Jarosite, residual silica and alunite.

These hotsprings have a temperature of approximately 38°C to 44°C with a pH of about 3 and > 25 l/s debit. Bemmelen (1949) visualized that alunite that he found both at Kancah and at Ciater was the result of hydrothermally, solfatar steam alteration of basaltic rocks. This solfatar alteration today can not be found, but H₂S can still be smelt.

The ciater manifestations apparently are confined to SW-NE trending lineaments which can be inferred to be normal
faults with the downthrown side on the western part.

The Ciater hotsprings show a higher concentration than the Kancah hotspring (840 ppm) and 338 ppm chloride. The high concentration of Ca, Na, K, Fe, Mg also come from superficial surface leaching of rocks by acid condensates. These springs are also characterized by the unbalanced concentration of sodium and chloride (excess in chloride).

Similar to the Kancah manifestation, the Ciater manifestation is probably a shallow acid condensate outflow from Tangkuban perahu which is partly neutralized by rock-fluid interaction. The increase in Chloride concentration suggests also the existence of additional concentrations of volcanic gases between Tangkuban perahu crater and ciater. The other possibility is that this acid condensate is mixed with fluids rising up from a deeper condensate layer.

3.4 Maribaya Manifestation

The Maribaya manifestations are associated with the W-E trending prominent Lembang fault. Hotsprings that discharge from basaltic lava have a temperature of about 38°C to 43°C. A thin layer of carbonate deposit (travertine) suggests that these hotsprings are outflow springs with a pH of 6-7.

Relatively high bicarbonate, chloride, sulphate and sodium values with excess in chloride with respect to sodium and
low concentration of Fe, are typical for the Maribaya
hotsprings.

Part of the deeper condensate water contaminated by deep
diluted hotbrine might come to the surface mixing with
surface waters at Maribaya.

3.5 Cimangu Manifestation

Similar to the maribaya manifestation, the Cimangu
manifestations are confined to the Lembang fault as well.
The temperature of hotsprings are about 34°C with neutral pH
(6-7). CO₂ is frequently discharged from these springs.
The flowrates show considerable variations between 5-25
l/s.

The Cimangu hotsprings are characterised by moderate
bicarbonate, low chloride and almost zero concentration of
sulphate.

Plotting the concentrations of magnesium, sodium and
potassium in the water-rock equilibration temperature chart
of Giggenbach (fig. 6) shows that the Cimangu hotsprings
are shallow heated groundwater springs.
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<th>SO₄</th>
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<td>130</td>
<td>32.8</td>
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Table 1: The Chemical Constituents of Hotsprings in Tangkuban Perahu area (ppm).
3.6 Batugede Manifestation

The Batugede manifestations are located to the North of Tangkuban perahu crater (about 11 km), confined to prominent W-E normal fault.

The maximum temperature of the hot springs is 50°C with pH=6 and maximum flowrate is about 5 l/s. Silica and carbonate are the main deposit encountered in this area.

Bicarbonate, sodium and chloride concentrations are 1992 ppm, 1267 ppm and 1246 ppm respectively. The relatively balance of the sodium and chloride concentration indicates that the Batugede water is probably an outflow that might come from a deep brine layer (fig. 5).

The Na/K geothermometer of Giggenbach (1986) indicates T=215°C, and the K-Mg geothermometer indicates T=105°C. Such imbalance in geothermometers for a hot neutral chloride water is typical for an outflow with rapid re-equilibration of K and Mg along the flowpath.
Fig. 5. Predicted model of hydrology based on geochemical interpretation.
Fig 6. Plotting the concentration of Mg, Na and K in water rock equilibration temperature chart of Giggenbach, show that Cimangu and Batugede are shallow water springs.
4. GEOPHYSICS

Geophysical surveys of Tangkuban perahu area have been made, including schlumberger electrical mapping and soundings, magnetotelluric soundings, gravity and self potential surveys. These surveys were made in order to delineate surface and subsurface structures.

The resistivity structure was outlined both by Magnetotelluric soundings and schlumberger electrical soundings.

The traverse network delineating the horizontal distribution of resistivity structure was fairly dense, except for parts of the caldera where high terrain exists.

Gravity surveys have been used to map subsurface structure reflecting density structures.

4.1 Schlumberger electrical mapping

The basic equipment for measuring surface electrical mapping consists of a transmitter with a 10 KVA power source IPT-2 (phoenix), AC to DC converter and a multimeter Fluke 77 (digital) receiver.

Resistivity schlumberger mapping, in Tangkuban perahu, was carried out from 22 October to 18 February 1986 covering an
FIG. 9

APPARENT RESISTIVITY MAP
(Schlumberger AB/2:1000)

Legend:
- Dark Yellow: Apparent Resistivity (Ωm)

Scale:

1987
area of about 784 square kilometres occupying 171 stations.

The main achievement of this survey was in determining the lateral extent of conductive rocks at shallow to moderate depth.

A Schlumberger array with a spacing (from array centre to outside electrode) of AB/2=250M, AB/2=500M, AB/2=750M, and AB/2 1000M was used.

Results of the resistivity traversing surveys are presented in fig. 7, 8 and 9 of AB/2=500M, 750M and 1000M respectively.

Low resistive rocks (< 50 Ohm-m) at AB/2=500M occur in the Parongpong area on the southern part of Tangkuban Perahu caldera and in the Ciater area which lies in the eastern part (fig. 7). The other low resistive rocks occur in the S-W part and eastern part of the parongpong anomaly (around the Maribaya manifestations). Small concealed low resistive rock also occur in the southern part of the Ciater anomaly.

Both the AB/2=750M and AB/2=1000M map show the same anomaly pattern, but the low resistivity area increases in size.

A lateral distribution of low resistivity rocks occurs around the Lembang fault. A nearby MT station shows a conductive substratum at about 500M depth.
Because of the thermal features in both Ciater and parongpong (kancah) areas, the low resistivity rocks are more likely associated with hot hydrothermal fluids than different lithology.

4.2 Schlumberger Vertical Electrical Soundings

Only a few vertical electric soundings were carried out. They are restricted to areas with good access.

Fig. 10 and 11, show the results and the interpreted sounding curves across the main low resistivity area of parongpong and Ciater.

Interpretation of the VES curves was made by curve matching procedure and trial and error calculation of theoretical sounding curves using the Ghosh method in terms of one dimensional models (i.e. horizontally layered structure assumed).

The ID interpretation is difficult to correlate across the Kancah - Tangkuban perahu crater - Ciater since only 5 soundings were made.

A simplified correlation of ID resistivity section from VES data in terms of true resistivity cross section is shown in fig. 12.
Fig. 10. Resistivity model of station M.9 and E.4.
Fig. 11. Resistivity model of station M6.7 and F.4.
Fig. 12. Subsurface resistivity structure of VES data across Kancah - Tangkuban perahu crater - Ciater (Section C-D, fig. 22).
The low resistive substratum of 18-34 Ohm-m extends across the whole profile in Ciator, overlain by an upper resistive layer of 70-100 Ohm-m at 200-250M depth.

In Kancah, the conductive substratum (18 Ohm-m) is only seen at station M9, while station M6 shows a mere resistivity substratum of 50 Ohm-m. A near surface, high resistivity layer of greater than 300 Ohm-m, in the Ciator area is found at the depth of 2-20M. In Kancah, it is encountered at 1-50M depth.

4.3 Magnetotelluric Sounding

4.3.1 Introduction

The magnetotelluric method uses the natural variations of the earth's magnetic field as a signal source.

The telluric currents are induced in the earth by the time variations in the magnetic field which produces a secondary magnetic field that modifies the primary magnetic field. The electromagnetic wave travels vertically downwards into the earth.

The amplitude of the wave decreases with depth which is depending upon the resistivity distribution within the rock
and the frequency. An approximate penetration depth (skin depth) for a homogenous substratum is given by:

\[ D \approx 500 \sqrt{\frac{\Gamma}{f}}, \quad (D \text{ in M}) \]

where \( \Gamma \) and \( f \) are average resistivity and frequency of field.

The one dimensional (ID) resistivity structure is determined by plotting the apparent resistivity versus the square root of the period of the signal on a log-log scale. The ID interpretation involves comparison with master curves (as is done with schlumberger sounding) but also trial and error solution.

4.3.2 Basic theory of MT

A theoretical outline of MT was first formulated by Caignard (1953) and has since been developed by Porstendorfer (1975) and Kauflmann, A.A, and Keller, G.V. (1981).

Two components of the electric field (Ex, Ey) and three components of magnetic field (Hx, Hy, Hz) are measured in the field over a selected frequency range. These electric and magnetic field for a particular frequency and a given orientation are related by:

\[
\begin{align*}
Ex &= Zxx Hx + Zxy Hy \\
Ey &= Zyx Hx + Zyy Hy
\end{align*}
\]

\[
\begin{bmatrix}
Ex \\
Ey
\end{bmatrix} =
\begin{bmatrix}
Zxx & Zxy \\
Zyx & Zyy
\end{bmatrix}
\begin{bmatrix}
Hx \\
Hy
\end{bmatrix}
\]
For isotropic (1D) layered earth, $Z_{xx} = Z_{yy}$ and $Z_{yx} = Z_{xy}$, 
($Z_{xx}, Z_{yx}, Z_{xy}$ and $Z_{yy}$ are components of the Impedance tensor).

In this case, the electric field is a function of the orthogonal magnetic field only:

$$E_x = Z_{xy} H_y$$
$$E_y = Z_{yx} H_x$$

The apparent resistivity is given by:

$$\Gamma_a = \frac{0.2}{\mu^2} \left| \frac{E_x}{H_y} \right|^2 = \frac{0.2T}{\mu^2} \left| Z_{xy} \right|^2 \quad \Gamma_{ayx} = \Gamma_{ayx}$$

$$\Gamma_a = \frac{0.2}{\mu^2} \left| \frac{E_y}{H_x} \right|^2 = \frac{0.2T}{\mu^2} \left| Z_{yx} \right|^2$$

For a 2-dimensional resistivity structure, the electric field is influenced both by the orthogonal and parallel magnetic fields. However, by rotating the coordinate system ($X', Y'$), a direction can be found where,

$$Z_{x'x'} = Z_{y'y'} = 0$$
$$Z_{x'y'} \neq Z_{y'x'}$$

In this case the two apparent resistivities can be defined by

$$\Gamma_{TM} = \Gamma_{ax'y'} = \frac{0.2}{\mu^2} \left| \frac{E_{x'}}{H_{y'}} \right|^2 = \frac{0.2T}{\mu^2} \left| Z_{x'y'} \right|^2$$

$$\Gamma_{TE} = \Gamma_{ay'x'} = \frac{0.2}{\mu^2} \left| \frac{E_{y'}}{H_{x'}} \right|^2 = \frac{0.2T}{\mu^2} \left| Z_{y'x'} \right|^2$$
Where $\Gamma_{TM}$ and $\Gamma_{TE}$ are the resistivity of the transverse magnetic and transverse electric mode and $\mu$ is the magnetic permeability.

The so-called invariant apparent resistivity $\Gamma_{aINV}$ can be defined by:

$$\Gamma_{aINV} = 0.2T |Z_{xx'}Z_{yy'} - Z_{xy'}Z_{yx'}|$$

In this case $\Gamma_{ax'y'}$ and $\Gamma_{ay'x'}$ are influenced by lateral inhomogeneity and do not reflect only the resistivity structure beneath a station. Interpretation in terms of a 1D structure is often possible for smaller periods (i.e. shallower depth). A complex 2D modelling is required together with denser stations to interpret deeper structures.

For a 3D resistivity structure, $Z_{xx}$ and $Z_{yy} \neq 0$ for any direction of rotation. The direction for the minimum of $Z_{xx}$ and $Z_{yy}$ changes with frequency and location.

In this case, the apparent resistivity equations do not apply, and quantitative interpretation is difficult, if not impossible.
4.3.3 Data discussion

MT sounding curves are strongly affected not only by lateral homogeneties (2D or 3D bodies), but also by topography. As in case of DC resistivity survey the electric field (E) is affected by topography but the topographic effect on the magnetic field (H) is small.

For the interpretation of MT curves shown in this project, the pair of sounding curve based on Ex, Hy and Ey, Hx data were grouped into three classes which also include tipper and skew effect.

Class I: Both curves are close together and tipper and skew are close to zero which reflect a 1-D structure. 1-D interpretation is justified (MTC 23, fig. 13); if curves are close together at high frequency and split into two separate but parallel branches. This indicates probably a 2D-structure.

Both observed curves can, by rotation of coordinate system, be interpreted in terms of a structure perpendicular to the 2D-structure (example MT CO2, fig. 14).
Class II: The transverse magnetic and transverse electric curves show an early split but are otherwise parallel which is probably due to a 2D structural effect or caused by anisotropy of surface layers. The 1-D interpretation is justified until where tipper and skew become non-zero. The T INV curves is interpreted similar to Class I curves but with lower confidence (MT CO5, fig. 15).

Class III: The Class III sounding curve shows early split curves with parallel curves for higher frequencies usually up to 1 second. At lower frequencies, the branches of both curves are not parallel due to pronounced 3D- structural effects (fig. 16). These curves are not suitable for interpretation.

A 1D interpretation of the MT soundings is given which only applies to the shallow part of sounding curves.

In the inner radius of about 2 km from Tangkuban perahu crater, the MT curves are strongly affected by topography indicated by Class III quality data. In the outer area, the topographic effect does not strongly affect the MT data which is indicated by Class I and Class II type curves, except for station MT p.15.
Fig. 13. Class I MT Sounding. Both TM and TE curve show a small early split with parallel branches.

Fig. 14. Class I MT Sounding shows small early split and split into two separate and parallel branches.
Fig. 15. Class II MTS shows large early split but parallel curves.

Fig. 16. Class III MTS show small early split, and split into two separate and not parallel branches.
4.3.4 Data Interpretation

Interpretation was done by a computer program "MTCURV" developed by GENZL, from theoretical formulae in Porstendorfer (1975).

The 1D interpretation is somewhat limited since only 4 MT soundings have Class I quality.

A simplified correlation of 1D resistivity sections from MTS data in terms of true resistivity cross section is shown in fig. 17. This profile is located through Kancah, Tangkuban perahu crater and Ciatr.

The low resistive substratums of less than 10 Ohm-m extends across the whole profile except for station MT.p16 and MT.C5 showing an intermediate resistive substratum of about 19 and 14 Ohm-m respectively. The very conductive substratum is overlain by a higher resistive layer of about 15 to 65 Ohm-m at Kancah and about 14-42 Ohm-m at Ciatr.

Underneath Tangkuban perahu summit to Kancah, shallow, thin, low resistive layers of 20-24 Ohm-m encountered at about 300m depth are interpreted as acid condensates.

The resistive layer overlying the conductive substratum is interpreted in terms of low permeable rocks. Near surface resistive layers (2-20m depth) of greater than 100 Ohm-m
Fig. 17. Composite geophysical cross section over Tangkuban perahu area.
detected by VES are interpreted as dry pyroclastics.

The deeper resistivity structure of system beneath Tangkuban perahu is still unknown, the nearby MT stations are all disturbed by 3D effects (i.e. p4 and p9).

A crosscheck of the apparent resistivity in terms of resistivity pseudosections from resistivity traversing data show a relatively good agreement in terms of conductive substratum (fig. 17).

4.3.5 A Comparison between MTS and VES

A comparison between MTS and VES data is rather difficult, due to the separation of stations. Five VES points (M6, M9, H4, F4, E4) and five MTS points (p10, p6, C9, C25, C5) are used for comparison (C9 is less reliable, due to Class III quality).

The comparison between the two resistivity sections is shown in fig. 18. Both VES and MTS stations are projected onto the Kancah - Tangkuban perahu crater - Ciater cross section.

The 1D resistivity structure of stations M6 and p10 is totally different although both stations are only of few 200 M apart. However, in Ciater, both sections show slightly better agreement in terms of depth of the
Fig. 18. Comparison between VES and MTS data.
conductive substratum, but with different resistivity values. Various near surface resistivity layers detected by VES cannot be detected by MTS. It seems that MTS cannot detect details in the resistivity structure at depths of less than 200 metres.

The calculation of the total conductance (fig. 10) of VES and MTS data at the depth of less than 500 m does not show agreement, except for stations p6 and M9. Since the VES raw data show good agreement with the schlumberger traverse data, it is unlikely that the shallow resistivity structure as shown by the VES soundings is much affected by anisotropy: i.e. the shallow resistivity structure of VES soundings is real. Since the MT soundings cannot reproduce the VES structure at depth ≤ 200-300 m, the MT sounding interpretations, even of Class I type curves, are open to some criticism.

4.4 Gravity Survey

Gravity surveys can map the changes in mass structure beneath mineral prospects. The method is often used for geothermal prospecting since it allows definition of concealed basement structures and sometimes structure within a geothermal reservoir (densification by mineral deposition in porous reservoir rocks).
In volcanic terrain the method often allows definition of volcanic centres and concealed caldera structures. A gravity survey was made of the Tangkuban perahu prospect to detect such regional and local structures, caused for example by thick low density infills of older subsidence centres.

4.4.1 Data Collection

A gravity survey has been made across the prospect along the Lembang - Ciater road. An almost drift-free Lacoste-Romberg gravity meter owned by PERTAMINA was used for this survey; station heights were established by a single paulin altimeter whose drift was corrected from frequent base station readings.

The stations were about 500 m apart and all gravity readings were tied into the international gravity base (D6.0 with \( g = 977.976.38 \) mgal) at Bandung. A total of 44 stations were occupied. The survey is still being continued.

4.4.2 Data reduction

For this project I obtained originally a set of Bouquer anomalies which has been reduced at Jakarta and for which station location, station height, terrain effect, and Bouquer anomalies reduced with respect to a terrain density of \( 2.67 \times 10^3 \) kg/m\(^3\) were listed (see last column in Table
2). These Bouger anomaly values are plotted as dotted line in fig. 19 which shows a significant residual anomaly of about -36 mgal centred on Tangkuban perahu (distance = 10 km in fig. 19).

It was assumed that the anomaly was real since the anomaly curve is rather smooth to each side of the crater; the rather large jumps in the anomaly curve (i.e. at km 2, km 7, km 13, km 18) were assumed to be caused by errors in station height and therefore were neglected.

The quoted (old) Bouger anomalies were then interpreted in terms of a 3D structure by trial and error methods assuming various thicknesses for the old sunda Caldera and the recent Tangkuban perahu caldera. But even allowing for a less dense magma body, the anomalies near the Tangkuban perahu crater showed a too steep gradient which could not be modelled. This was the first indication that there might be an error in the older data reduction.

In a first step, the terrain effects for selected stations (underlined in table 2) were recomputed and it was found that the terrain effect near Tangkuban perahu had been underestimated by up to 5 mgals. The terrain effect was then revised (see data in table 2) which made it easier to interpret the structure beneath Tangkuban perahu, since the Bouger anomaly could be reduced by up to 5 mgals.
However a late check of Bouquer anomaly reduction at the draft stage of this project report showed that an unknown error had occurred during the reduction process. The recomputed Bouquer anomalies are shown in table 2 and have been plotted by a solid line in fig. 19.

It can be seen that the recomputed anomaly values are much smoother than the old data (except for one data point near km 14) and that the residual anomaly near Tangkuban perahu crater has decreased to about -20 mgals.

The interpretation models obtained with the old Bouquer anomalies are therefore invalid and had to be withdrawn at the last minute. Because of time restraints, no interpretation of the recomputed Bouquer anomalies can be given.

4.4.3 Likely Caldera structure

At this stage only a qualitative discussion of the new Bouquer anomalies shown in fig. 19 can be given. It appears that the older sunda Caldera accounts for a residual gravity anomaly of up to about -13 mgal (wavelength 6 km) and that the younger Tangkuban perahu caldera accounts for about 1-10 mgal (wavelength about 2-5 km).

Without further modelling no discussion can be made about the depth of these calderas.
Table 2, Gravity Data over Tangkuban perahu

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recalculated Bouquer anomaly
---------------
old Bouquer anomaly

Sunda Caldera $\varnothing = 6$ km $\Delta g = -13$ mgal. anomaly
Tangkuban perahu $\varnothing = 2.5$ km $\Delta g = -10$ mgal. anomaly

Fig. 19. A comparison between recalculated and old Bouquer anomaly.
4.5 Self potential

This method measures the natural potential difference between two potential electrodes on the ground surface. Potential differences are expressed with respect to an assumed undisturbed potential outside the survey area. The mechanism by which the self potential anomaly over thermal system is generated is not clearly understood. However, self potential anomalies that appear to be related to geothermal activity are likely to be due to the physical properties of the geothermal fluid such as mobility of the ionized fluids through the rock, temperature of the fluid and ionic strength of the fluid. Most geothermal systems studied so far are associated with a significant SP anomaly. The likely mechanism that may generate such anomalies have been termed thermoelectric coupling and electrokinetic coupling.

Thermoelectric coupling relates SP anomalies to temperature gradient that corresponds to a voltage gradient. This is likely to be due to differential thermal diffusion of ions in the pore fluid and electrons and donor ions in the rock matrix (Corwin and Hoover, 1979).

Corwin (1979) cited that self potential anomalies generated by thermoelectric coupling are characterized by smaller amplitudes than usually observed in geothermal areas. The upflowing mineralized fluid with high temperature at shallow depth may result in short wavelength and high
amplitude anomalies. The long wavelength with large amplitude anomaly is likely to be generated by thermoelectric coupling as well. The electrokinetic coupling or streaming potential is caused by the fluid flow through a porous rock, resulting in ion absorption by the rock. Angelus, R (1984) stated that an excess of positive ions is found in upflow zone and deficiency of ions is found near outflow zone.

The other possibilities causing such anomaly are oxidation reduction, electrofiltration and topographic effect which usually produce rather small anomalies.

For SP measurement a "leapfrog" was used in which a dipole of fixed length is stepped along the survey line. The SP survey was carried out at the same site as the resistivity and gravity survey, across parongpong (Kancah), Tangkuban perahu crater and Cieater.

The quality of SP data is relatively good, except that the data in Cieater area show a sharp jump of +150 mV within a distance of less than 200 m. These data appear to be not reliable and need to be checked.

The positive self potential anomaly that appear in Kancah has a wavelength of about 3.5 kilometres with the maximum amplitude of about 150 mV (fig. 17). This anomaly is located within an area of low resistivity values from AB/2 = 500 m, 750 m and 1000 m surveys. In the Rotokawa
geothermal field (NZ), the SP anomaly occurs also within the low concealed resistivity anomaly which is thought to be associated with an upward moving fluid (Boedihardi, 1987, Rotokawa field trip report).

In the northern part of Kancah, a pronounced positive anomaly is located over Tangkuban perahu crater. Closely surface measurements reveal steep gradients in the vicinity of the steam vents. In general, most steam vents in the Tangkuban perahu crater are under high pressure; they are heated appreciably above boiling point. The two kilometres wavelength feature within the crater with a maximum amplitude of 120 mV is probably related to fluid movement beneath the crater which constitute pathways that guide the mineralized fluid to the surface.

The large displacement of SP anomaly in Ciater is not clearly understood.
FIG. 20

LOCATION MAP

- SP and gravity station
- Resistivity mapping (Schlumberger) gravi
- Self Potential station.
- M.T station (station C2 data quality 4)
- V.E.S (Schlumberger) station
A-B Composite geophysical cross section
5. DISCUSSIONS AND CONCLUSIONS

Inner Zone: Tangkuban perahu is most likely a volcanic geothermal system. Tangkuban perahu crater and Tangkuban perahu caldera (Sunda Caldera) are underlain at shallow depth by thick acid condensates leading to decomposition of rocks at Kawah Domas, through the condensate layers, minor magmatic gases still ascend with high temperature at Kawah Domas, indicating that Tangkuban perahu is still an active volcano.

The deeper resistivity structure of the system beneath Tangkuban perahu is still unknown, the few nearby MT stations are all disturbed by 3D effects (i.e. P4 and P9).

Schlumberger traverses indicate high apparent resistivities in the upper few hundred metres (see AB/2 - 1000 m map).

The only other information for the inner zone comes from gravity anomalies indicating a residual gravity anomaly of at least -20 mgals; the recomputed Bouquer anomaly seems to reflect a pronounced caldera structure which has the same diameter as the older sunda Caldera.
Intermediate Zone: Shallow radial outflow from acid condensate layer occurs at Kancah and Ciator just outside the buried Sunda Caldera. The shallow resistivity structure just upstream from both springs is known from resistivity sounding (M9 and E4 respectively) showing that a condensate layer occurs most likely at depths of 50 and 200 m respectively (true I Ohm-m).

The thickness of condensate layer which still contains acid fluid (pH ~ 3) is unknown. Near both springs the deeper resistivity structure is known from a few less disturbed MT soundings (i.e. P10 near Kancah and C5 at Ciator) pointing to very low resistivities at 2 km depth. The speculative nature of these low resistivity rocks are:

a) Deeper thermal alteration from neutralized condensates.

b) Presence of deeper chloride waters from inferred brine layer.

The greater Kancah hotspring area is also associated with a significant SP anomaly (3 km wave length). A significant jump in SP
occur near the buried Sunda Caldera rim.

Both Kancah and Ciator area are associated with a low resistivity anomaly showing up in the traverse maps.

**Outer Zone:**

This zone consists of two parts, namely: Southern part and Northern part.

**Southern part:** The Maribaya and Cimangu springs have a distance, from Tangkuban perahu crater, of 8 km and 11 km respectively. Both springs discharge diluted waters. Because of Chloride excess over Na at Maribaya, this might be a neutralized mixed condensate waters. A deep diluted brine appears to contaminate the neutralized condensate outflow rising up at Maribaya springs. The Cimangu springs are heated ground water or a very diluted deeper outflow.

Resistivity traverses indicate that the Lembang Fault is associated with low resistivity rocks at depth (thermally altered rocks?), but both prospects are probably not associated with a separate geothermal system.
Northern part: Although geophysical data are not yet available for the North flanks, there are hotsprings at Batugede about 11 km from Tangkuban perahu crater. Batukapur springs lie about 12 km away. Both springs discharge neutral Na Cl waters. The Na/k geothermometer of Batugede waters discharged at 400m elevation indicates T=215°C, but the K-Mg geothermometer indicates about 105°C. It can be concluded that the Batugede springs are fed by an outflow which has a very long path for partial re-equilibration; it possibly originates from a deeper brine layer beneath Tangkuban perahu.

A schematic model of Tangkuban perahu volcanic geothermal system which explains most of the data discussed in this report is presented in fig. 21.
Fig. 21. Schematic model of hydrology of Tangkuban perahu volcanic geothermal system.
REFERENCES

Angelus, R. 1984; An Interpretation of the Self Potential data over the Aluto Geothermal prospect (Ethiopia), geothermal project, 84.02.


Boedihardi, R.M., 1987; Rotokawa fieldtrip report, Unpub.


El-Batroukh and Zentani; Gravity Interpretation of Raguba field.


Giggenbach, W.F., 1974; Variations in the Carbon, Sulfur and Chlorine Contents of Volcanic Gas Discharge from White Island, New Zealand.

Giggenbach, W.F., 1986; Graphical techniques for the evaluation of Water/Rock Equilibration Conditions by Use of Na, K, Mg and Ca Contents of Discharge Waters. Geothermal Workshop.


Hochstein, M.P., 1982; Introduction to Geothermal prospecting. Geothermal Institute, University of Auckland.


Lubis, L.I., 1986; Assessment of patuha Geothermal project West Java, Indonesia. Geothermal project, 86.12.

Mayhew, I.D., 1982; Field Investigation of Self Potential at The Mokai geothermal field New Zealand. Geothermal project, 82.11.


Suryadarma and Boedihardi, R.M., 1986; The Geology of Tangkuban perahu area and its vicinity, West Java. Geothermal Division, Pertamina.

APPENDICES