GEOTHERMAL SYSTEM
OF THE
DIENG-BATUR VOLCANIC COMPLEX

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ABSTRACT

This paper is mainly concerned with the evaluation of reports on geophysical and geochemical surveys made by Group Seven Inc. and Truesdell in the Dieng Mountains under contract with the US-AID and on behalf of the Directorate General for Power and Electricity and the Indonesian Geological Survey and partly also with the author's own field observation on geothermy in the Dieng Mountains in Central Java.

All the accumulated data lead to the conclusion that the geothermal system of eastern Dieng originated through the intersection of two major fracture zones.

The high chloride content found in various streams gives good reason to accept that the geothermal system of the Dieng Mountains is a system of hot water and steam rather than a system of dry steam only. The hot springs in the Dieng Mountains might represent surface manifestation of a deep, neutral, hot water "reservoir".

The distribution of geo-electric anomaly which resulted from two dipole mapping surveys delineated a belt of anomalously low resistivity in the eastern Dieng Mountains in which there are three areas of very low resistivity indicating systems of up-welling thermal water. These systems might be connected at great depth.

The area with low resistivity anomaly might indicate a reservoir having a volume of 5 to 6 cubic kilometers at depth of 2 kilometers. An estimate based on geophysical data suggests that a power production rate of 200 megawatts could be supported for 25 years, or of 100 megawatts for 50 years. Based on all those data an exploratory deep drilling work is recommended which is due to start in June 1971.

INTRODUCTION

History of Dieng Geothermal Project

The idea of utilising natural steam for generating electric-power in Indonesia is not a new one. The first was launched by J.Z. van Dijk (1918). Escher (1920) criticised van Dijk's opinion strongly. According to Escher (1920) most solfataric fields in Indonesia are situated rather high, the surface

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areas of these solfataric fields are small, whereas drilling processes in volcanic areas are extremely difficult to execute because of the corosive action of gases. On the other hand, Taverne (1925) was more optimistic. His optimism was based on the good results gained by Italians in Larderello. The most optimistic view however was offered by van Bemmelen (1928) who visited Larderello in 1927.

The first exploratory drilling in the solfataric field of Kawah Kamodjang in western Java was ecxecuted in 1928. The results were considered not very promising. Until the disruptive years of the Pacific war nothing was done to promote further developments of geothermal plants in Indonesia.

In 1966, however, a three men team sponsored by Unesco wrote a favorable report on the possibilities of utilising geothermal energy for commercial purposes (Tazieff et al., 1966), especially the Dieng area.

Attracted to the authors short note and several popular articles on the possibility of utilising geothermal energy for generating electric-power economically, the Institute of Power Research in Djakarta authorised the author to carry out a preliminary survey on geothermy in Java. The purpose of the work was to locate hyperthermal areas in Java and to recommend the necessary plans for action. This preliminary work singled out several areas for further investigation under which the thermal area of Dieng-Batur volcanic complex was placed very high on the priority list (Zen, 1968). Financial difficulties however prevented the execution of a more detailed field operation.

In the same year a French private company (Eurafreb) was attracted to the same problem and sent a two men team to make a survey in Java and Bali. Eurafreb reported (1968) the same findings already reported by the author in 1968. By one of other complication Eurafreb abandoned its plan.

In 1970 US-AID stepped in. By the combined efforts of the Institute of Power Research, US-AID, the Institute of Technology in Bandung and the Indonesian Geological Survey, more systematic investigation including geological, geochemical and geophysical methods were applied to delineate the thermal belt in the Dieng Mountains and to estimate the volume and extent of the reservoir. In January 1971, the Evaluation Team decided to go ahead with the plan and proposed six sites for the exploratory drilling work due to start in June 1971.

Geographic Position and Location

The Dieng-Batur volcanic complex is situated in Central Java, 65 km S. 70° W from the main city of Semarang (Fig. 1). This area can be reached from Wonosobo or from Bandjarnegara through Karangkobar. However the only road access during the rainy season is from Wonosobo.

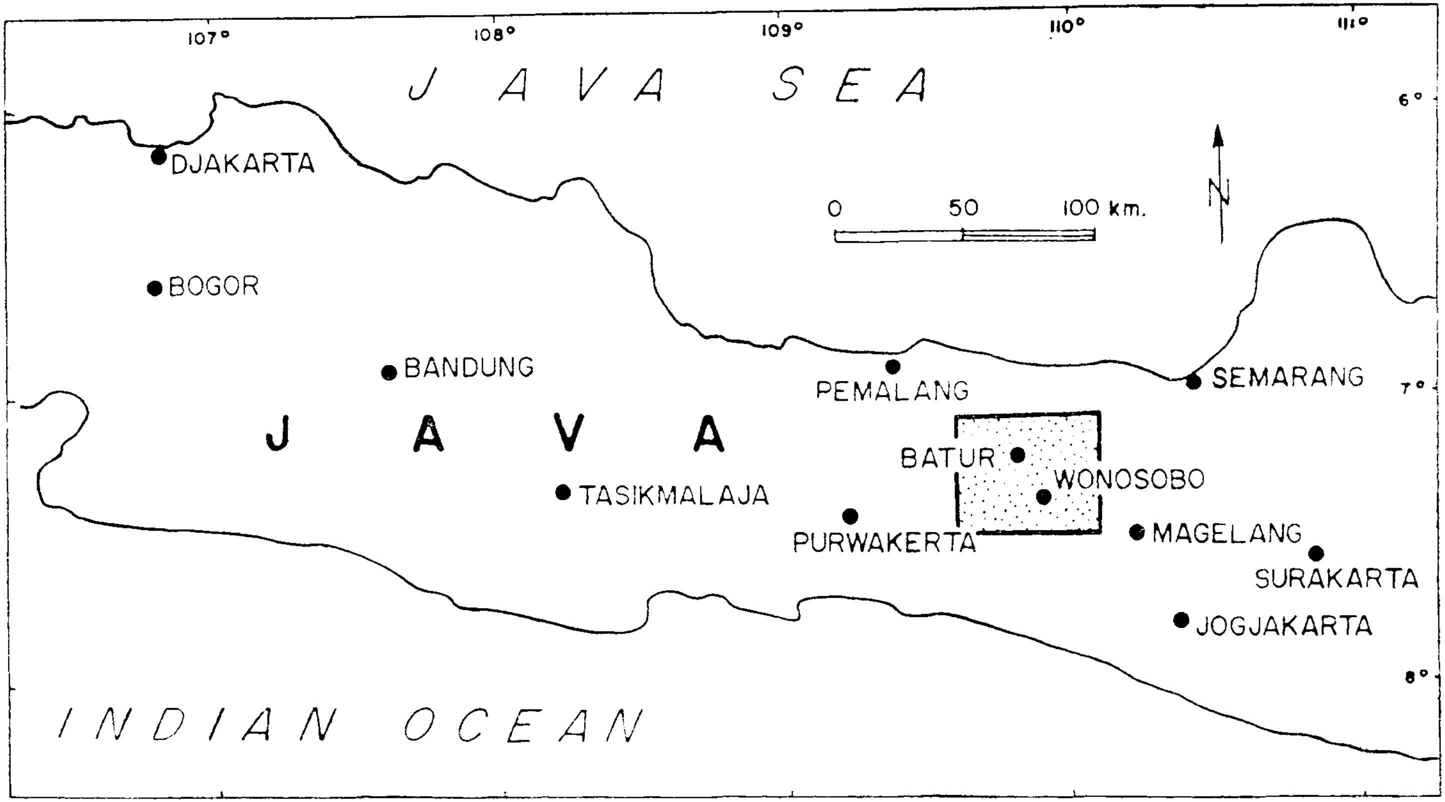


Fig. 1 Index map showing the location of the Dieng Mountains.

The Dieng-Batur Volcanic Complex, better known as the Dieng Mountains, forms part of a chain of Quaternary volcanoes built on top of the east-west trending geanticline of Java. It comprises volcanic peaks which rise to 2200-2565 m above sealevel, enclosing an upland area (1600-2100) of moderate topographic relief. The surface drainage of this upland area (45 km^2) is primarily to the southwest. Rainfall is reported to be in excess of 300 cm per year.

Acknowledgement

The author is very grateful to Drs. Patric Muffler, Montis Klepper, Mr. Dallas Fowler, Mr. Vincent T. Radja and Mr. Djajadi Hadikusumo for the useful discussions carried out during the field trip to the Dieng Mountains in January 1917. The author also wishes to acknowledge all the facilities extended to him by the Institute of Power Research in Djakarta and by the Geological Survey of Indonesia.

VOLCANIC GEOLOGY OF THE DIENG-BATUR COMPLEX

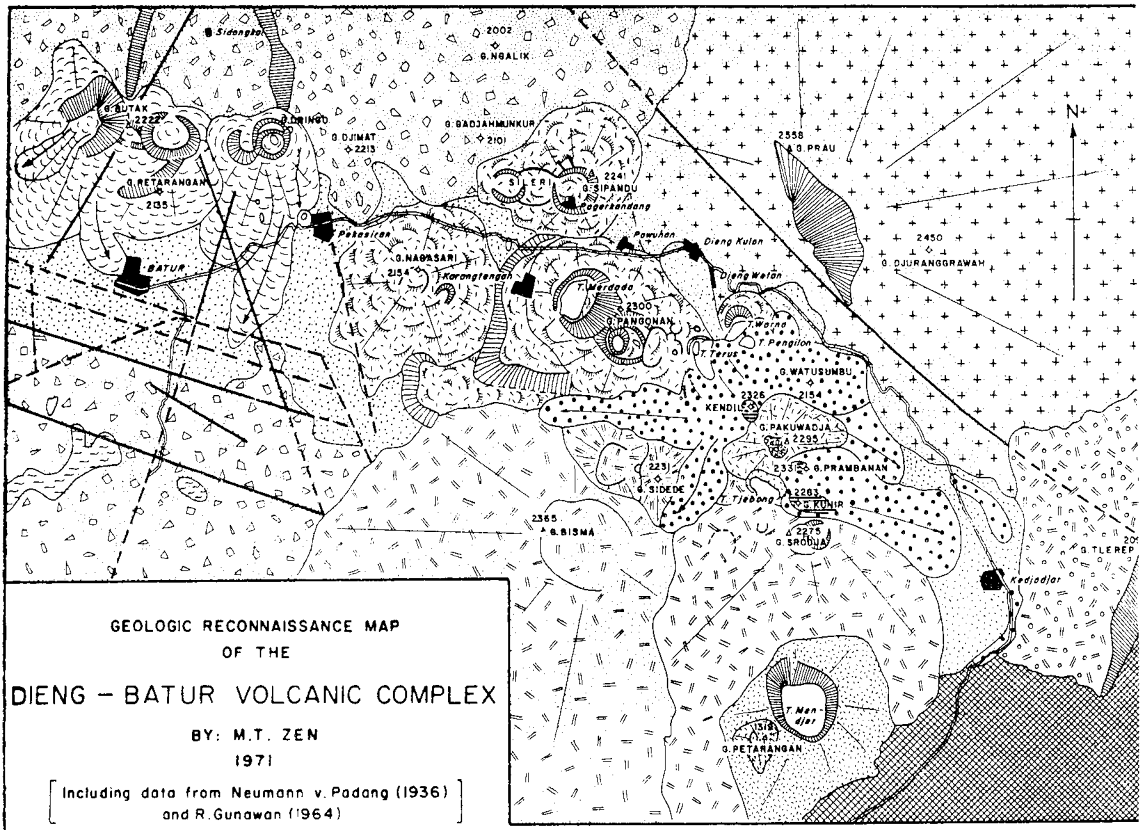
The Dieng-Batur volcanic mountains consist of a complex of late Quaternary volcanic vents which originated at the junction of two major fracture zones; the first one is an east-west trending zone, extending due west from the Dieng Mountains 50 km to the gigantic volcano of Mt. Slamet, and the second one consists of a row of young cones (Sindoro and Sumbing) which extends south-east of the Dieng mountains for 25 km.

It is obvious as stated by Umgrove (1929) and Neumann van Padang (1936) that the Dieng-Batur volcanic mountains are not a single volcano but rather a volcanic complex which consists of numerous separate extrusions, either a pyroclastic cone or a tholoid. Laharic as well as tuff breccias are found in great abundance. The elongated appearance of this complex is the result of a continuous shifting of eruption centers.

For the Dieng Mountains there are no analytical ages, neither a fossil control. However, it is very reasonable to assume from their appearance that all the volcanics found in this area are of Quaternary age. Petrologic data (Neumann van Padang 1936), suggest a sequence of magmatic differentiation which agrees fairly well with the age sequence deduced from geomorphologic studies (Umbgrove 1929).

According to their relative ages, the eruption centers in the Dieng-Batur Complex can be listed as follows:

I. Telogo Mendjer
II. Bismo
III. 1. Srodjo
    2. Binem 2134 m
    3. Pangonan 2308 m



GEOLOGIC RECONNAISSANCE MAP
OF THE
DIENG – BATUR VOLCANIC COMPLEX

BY: M.T. ZEN

1971

[Including data from Neumann v. Padang (1936) and R. Gunawan (1964)]

LEGEND

Early Holocene to Recent
- Intervolcanic Tuff Plain
- Undifferentiated products from Mt. Sundoro
- Quartz latites of Pakuwadja
- Rhyodacitic lava domes
- Rhyodacitic lavas
- Labradorite - rhyodacitic products of Butak-Petarangan-Sedringo volcanoes
- Labradorite trachyandesites from Pagerkandang volcano
- Trachyandesites of Young Srodja
- Trachyandesites of Pangonan-Merdada I. Binem and Nagasari volcanoes
- Labradorite andesites of Mendjer and parasitic cone
- Olivine containing andesites of Mt. Bismo

Late Pleistocene to Early Holocene
- Lava-and-tuff breccias, tuffs and Light pigeonite lavas from Mt. Prau
- Undifferentiated products of Butak-Tlerep volcanic Ruin

Pleistocene
- Undifferentiated products from the Eastern Djembangan volcanic complex

Mio-Pliocene (?)
- Shales, shaly-marl and limestone

- Caldera remnants, crater rims, crater remnants, and craterlets
- Volcanic cone (1000m above sea level)
- Lava terraces

Scale.

0 — 2.5 Km

- Structural lineaments
- Direction of flow
- Lake Terus
- Villages
- Road from Wonosobo to Batur

        a. Kawah Sikidang 2050 m
        b. Kawah Sigadjah 2050 m
        c. Kawah Kumbang 2085 m
        d. Kawah Sibanteng 2075 m
        e. Kawah Upas 2000 m
        f. Telogo Terus 2050 m
    4. Merdodo
    5. Pagerkandang 2240 m
        a. Kawah Pagerkandang 2075 m
        b. Kawah Sipandu 2065 m
        c. Kawah Siglagah 1950 m
        d. Kawah Sileri 1875 m
    6. Nogosari

IV. 1. Butak 2202 m
    2. Petarangan 2135 m
    3. Telogo Dringo 2080 m
        a. Kawah Tjokrodimuko

V. 1. Pakuwodjo 2398 m
    2. Kendil
    3. Kunir
    4. Prambanan

The accompanying map (Plate I) of the Dieng-Batur area shows the following conspicuous features:

1. the wide distributions of explosion craters which show a distinct trend in their arrangement.
2. an east-west trending volcanic lineament south of Batur.
3. a lineament extending northwest from Mt. Butak to Pagerkandang.
4. a structural lineament between Batur and Nagasari.
5. another structural lineament trending northwest-southeast which bounds the thermal belt of Pagerkandang-Sikidang.
6. the explosion craters of the Pagerkandang-Sikidang belt running conspicuously northwest-southeast whereas the explosion craters north of Batur runs east-west.

Surface Thermal Manifestation

Strong fumarolic and solfataric activities and phreatic or hydrothermal eruptions which still occur frequently in the very recent time are confined in an area approximately measuring 11 × 4 km wide trending west-northwest.

The existence of numerous explosion craters, maars and craterlakes indicates abundant near surface heat and hot water. Formerly, most explosive activities have been described as phreatic eruptions. Muffler (1971) have shown that similar phenomena at Yellowstone National Park in the US were formed merely by release of confining pressure on the hot water hydrothermal system. These type of activities were called hydrothermal by Muffler (1970).

RESULTS OF THE GEOCHEMICAL SURVEY

Geochemistry has become a method of paramount importance in geothermy. One of the aims of geochemical methods used in geothermy is first of all to establish whether the geothermal system in consideration is a hot water system, i.e. a system of hot water and steam or a system of dry steam, i.e. a system which is solely vapor-dominated.

In a hot water system, the upward transfer of water and heat is caused by the movement of liquid water. In a vapor-dominated system, however, this occurs through the movement of steam. Since chlorides are not soluble in steam with temperatures below 300°C, the existence of a hot water system can be established if the surface springs yield an appreciable amount of chloride to the order of more than 50 mg per liter (Truesdell, 1970).

During the geochemical survey, Truesdell (1970) found 125 mg/l of chloride at Kawah Sileri and 470 mg/l at Pulosari. Since previous experience has established the fact that springs showing a high chloride content could not be associated with a dry-steam system at depth (Muffler, 1971) it is to be concluded that in the Dieng mountains we have to deal with a hot water system.

Further, Truesdell (1970) concluded that at less than 200 m, there might be three geothermal systems in the Dieng mountains, which can be expected to be interconnected at greater depths. Of these presumed systems, the one found at Pagerkandang which has an surface area of 25 m^2 is the largest. Next to this system are the smaller ones of Sikidang near Dieng Kulon and of Tjandradimuka, near Pekasiran. Muffler (oral communication, 1971) is more inclined to think that the chloride-rich water collected by Truesdell at Pulosari represents a discharge from either the Sikidang or Pagerkandang system.

Water samples collected from Kawah Sileri and Pulosari springs have been analysed for their SiO_2 contents by the USGS laboratories at Menlo Park (California). The silica values of both springs are found relatively high, namely, 125 and 177 mg/l respectively (Muffler, 1971). Therefore, subsurface temperatures of 150°C and 170°C respectively can be inferred for both springs (Muffler, 1971). Further Truesdell (1970) concludes that from the low Cl values and the only slightly acid pH values of all the Dieng fumarole condensates and the flowing springs that the hot water at depth beneath Dieng Mountains is not acid, and should present no corrosion problems during exploitation.

RESULTS OF THE GEO-ELECTRICAL SURVEY

General Statement

In July and August, 1970, Group Seven, Inc. (Jacobson et al., 1970) conducted an Electrical Geophysical Survey in the Dieng Mountains under contract to the Agency for International Development and on behalf of the Indonesian Directorate General for Power and Electricity and the Indonesian Geological Survey. This work was planned to delineate the subsurface extent of the hot-water reservoirs feeding the surface hot springs and fumaroles.

The most recommended geophysical procedure to be used in delineating a hot water reservoir up till now would be profiling with the direct current resistivity method, combined with direct current resistivity soundings to depth of the order of 3 km (Banwell, 1970). The first step was profiling with the Schlumberger electrode array along the road running from Dieng Kulon to Batur. Electrode separations of 100 to 500 meters were used which provided a depth of investigation of roughly the same size of 100 to 500 meters.

Instead of a Schlumberger profiling, Group Seven Inc. (Jacobson et al., 1970) has found that detailed mapping of the electric field about a fixed dipole source is a more effective means for mapping a thermal reservoir since Schlumberger profiling is difficult to use in mountainous terrain such as the Dieng Mountains, besides, it provides ambiguous results if there are rapid lateral changes in resistivity, as are frequently associated with geothermal systems.

Accordingly, two dipole mapping surveys were conducted, one about a dipole source located in the meadows south of the village Dieng Kulon, and the other about a dipole source placed along the Dieng-Batur road (Fig. 2).

The measurements were made at a distance of 1 to 5 km from such a dipole source which provided information on an average resistivity to a comparable depth. It is found that dipole mapping surveys are useful in delineating the geographical extent of deep lying hot-water reservoir. However, it provides little information on the variation of resistivity with depth. Once the extent of the reservoir is determined other means must be applied to determine the depth to the top and bottom of the reservoir.

Evaluation of Results

As stated previously, the electrical geophysical method is aimed at delineating the boundaries of conductive areas associated with the occurrence of a subsurface hot water reservoir. The boundaries are depicted in (Fig. 3). Here the 5 ohm meter contour is considered to be the outer most boundary of the region where the electrical resistivity of the rock has been altered extensively by thermal activities. The main areas of thermal activities are the regions enclosed within the 2.5 ohm meter contour. The results indicate three

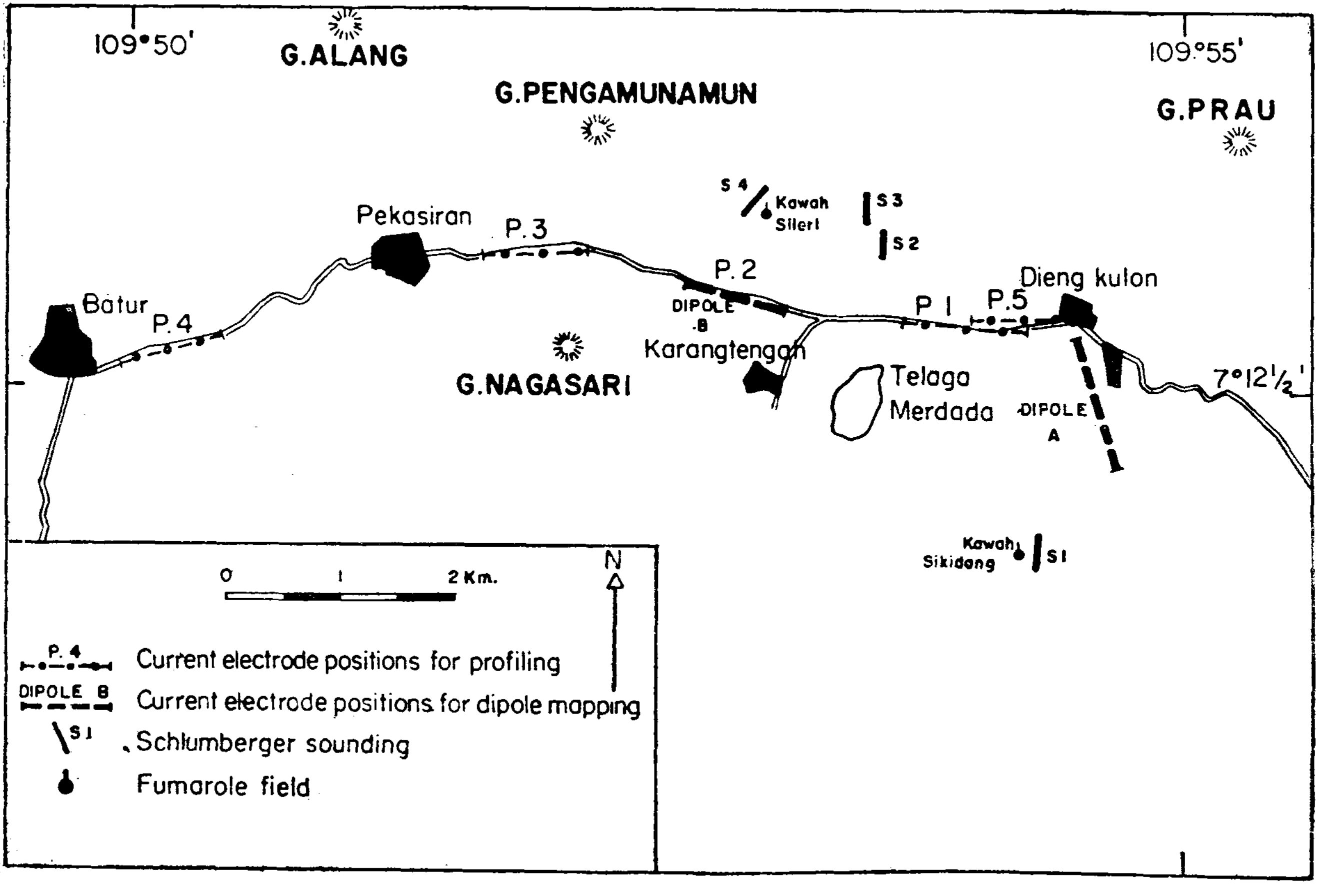


Fig. 2. Location map for electrical geophysical surveys in the Dieng Mountains by Group Seven Inc. (Jacobson, 1970).

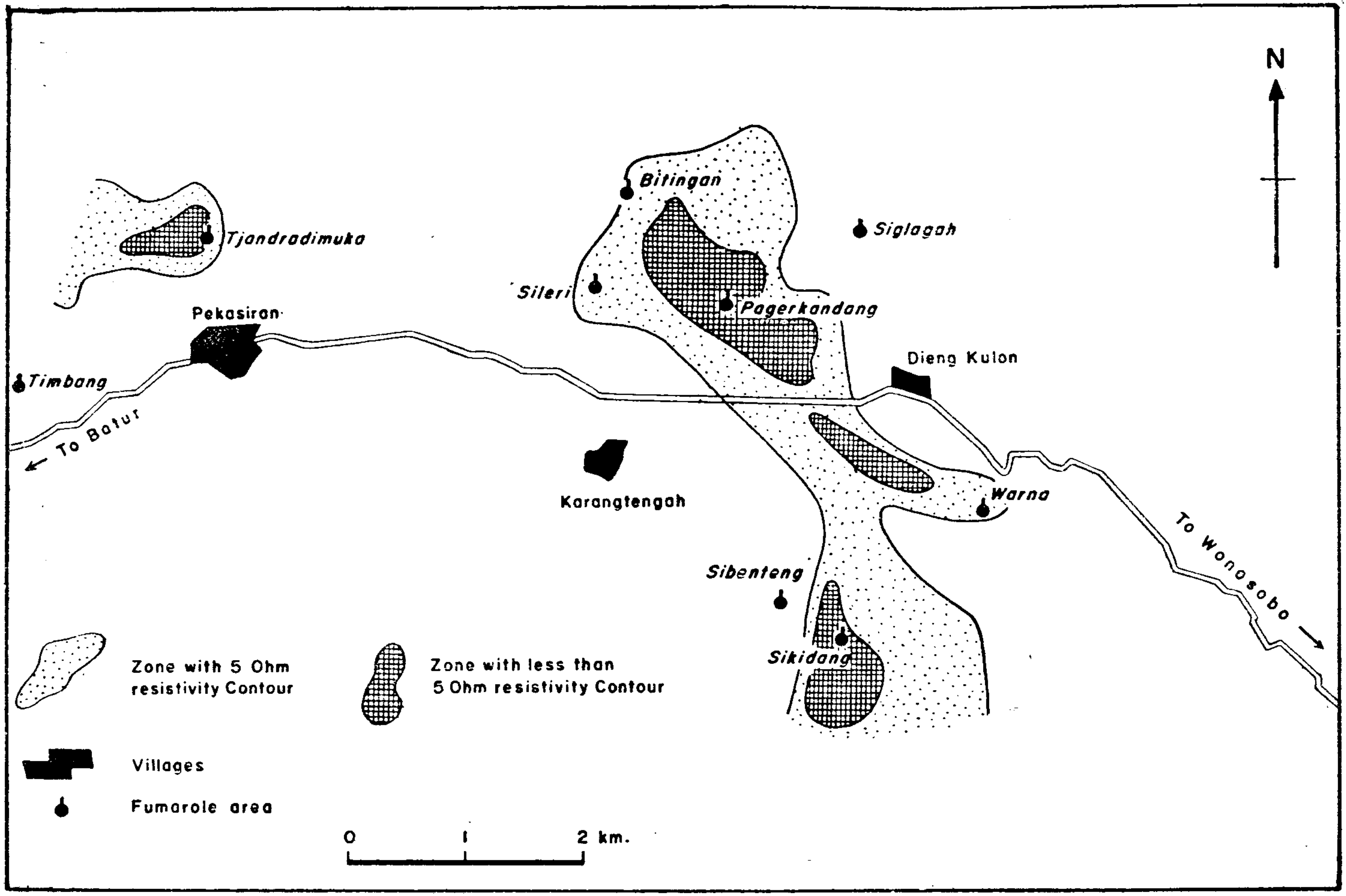


Fig. 3. Map showing low resistivity zones obtained by Group Seven Inc. Survey. (data from Jacobson et al., 1970, modified by Zen).

such areas within the thermal belt: one is centered about the Pagerkandang fumarolic fields, one about the Sikidang crater, and a third is located south of Dieng Kulon. The first two areas show considerable surface thermal manifestations, the central area, however shows very little or no surface manifestation.

It is a wellknown fact that the resistivity of a porous rock is determined almost entirely by the amount of water contained in that rock and the resistivity of the water. The resistivity of water is in turn determined by its salinity and temperature. The variation of the resistivity in volcanic rock as a function of water content which is assumed to be equivalent to its porosity, should be similar to that shown in Fig. 4 [a compilation of data for volcanic rocks from the southwestern US (Keller, 1960)].

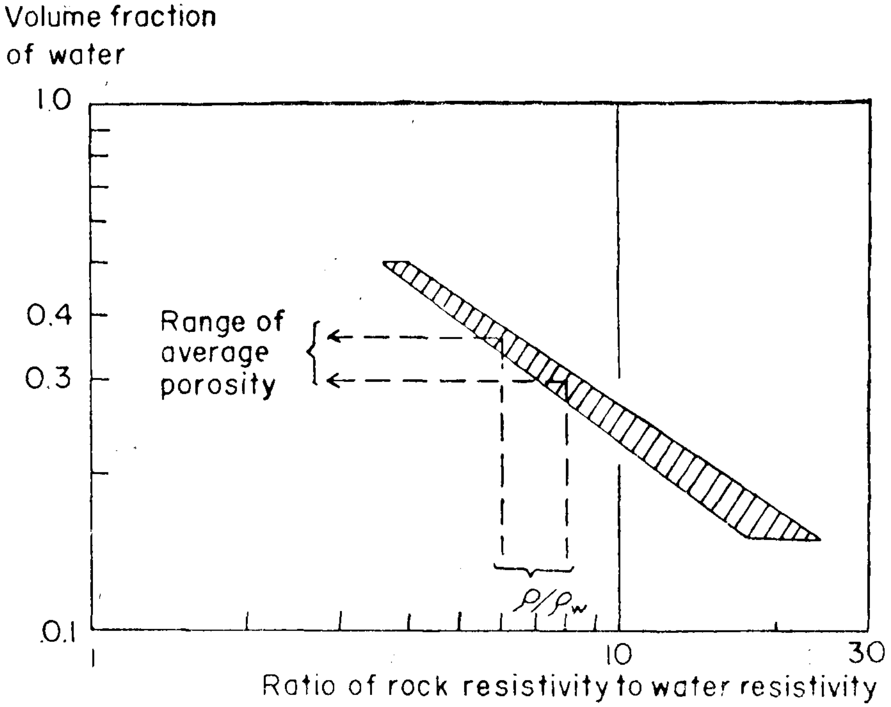


Fig. 4. Empirical relationship between rock restivisity and water content for typical pyroclastic rocks (Keller, 1960).

The porosity of a volcanic rock may be estimated from its resistivity if the resistivity of the water contained in the pore space is known.

The geochemical results (Truesdell, 1970) indicate that the geothermal fluid at depth contains 770 mg/l of chloride in solutions. This corresponds to a resistivity of 1.5 to 2.0 ohm meters at 20°C (Keller et al., 1966).

To appraise the significance of these data representative values of resistivity from the field measurements must be selected. To do this, Jacobson et al., (1970) made use of a histogram of the measured values (Fig. 5). Based on this, Jacobson et al., (1970) concluded that the median value of 1.3 ohm meters applies to the hot water saturated rock in the centers of thermal activity, the median value of 6 ohm-meters applied to the moderately altered and heated rock in the belt containing these centers of thermal activity, and the median value of 12 ohm-meters applies to "normal" volcanic rocks outside the area appreciably affected by the thermal activity.

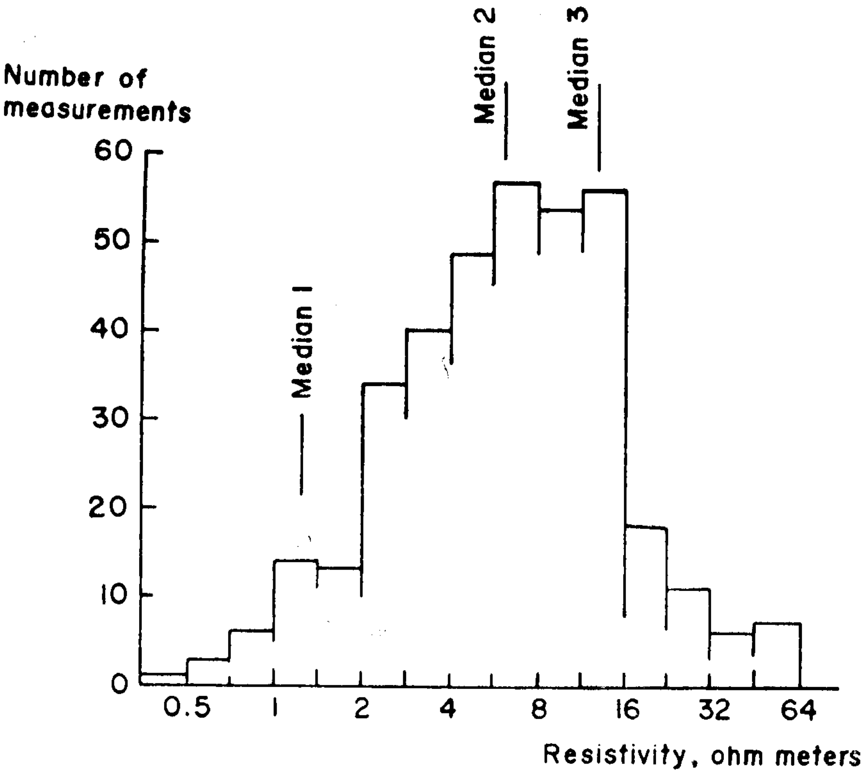


Fig. 5. Histogram of apparent resistivity values determined by dipole mapping. Resistivity scale is log normal (From Jacobson et al., 1970, Group Seven Inc. — Report).

THE GEOTHERMAL SYSTEM OF MT. DIENG

The thermal areas outlined by surface manifestations and the belt of anomalously low resistivity delineated by the geophysical survey by Group Seven Inc. (Jacobson, et al., 1970) are obviously related to the major northwest-southeast trending lineament zone indicated in Plate I. The scant geochemical data and the rather incomplete geophysical information allow quite a room for speculation. Nevertheles it is quite reasonable to suppose that those manifestations are connected at depth to form the Dieng Geothermal system. Besides, this thermal belt coincides with the zone of volcanic lineaments which extends from Pakumadja to Pagerkandang whereas the Tjandradimuka thermal system is confined within the zone of structural lineaments west of Gn. Nagasari.

From air photos interpretation and field observation it seems justified to assume that both geothermal systems which show most intense thermal manifestation are at the junction of two lineament zones, namely, the northwest-trending lineaments found on the crest of the Dieng-Batur Mountains trending east-west.

Based on the model of Larderello, Tazieff et al. (1966) and Facca and Tonani (1961, 1966) considered the existence of a cap-and-reservoir rocks beside a heat source as an absolute condition for the existence of a commercial steamfield. This model seems to break down for the Dieng Geothermal system. During his short visit in the Dieng Mountains, Tazieff et al. (1966) placed a too much emphasis on the possibility that the lacustrine sediments of Dieng Plateau proper would play the role of a cap rock. In fact the distribution of the lacustrine sediments at Dieng Plateau proper is very limited in extent whereas the thermal belt with the anomalous low resistivity delineated by electrical-geophysical means reaches far beyond the limit of Dieng Plateau proper. In the area on Pagerkandang as well as in the area of Tjandradimuka this lacustrine sediments, expected to play the role of a cap rock by Tazieff, are completely missing.

The association of the two geothermal systems with zones of weakness which is manifested clearly at the surface by fracturing and volcanic activity suggest that effective permeability at depth in the geothermal system will be due to interconnected fractures rather than by the existence of a reservoir and a cap rock. This has also been the case with the Geysers in California pointed out by Muffler (1971).

It seems that the caprocks in the sense of Facca & Tonani (1961, 1964) provides an ideal condition, however, it is not a conditio sine quanon for the existence of a geothermal field. In general, the high pressure fluids of a geothermal field are confined by the weight of the overlying water in interconnected pores and fractures. This implies that the pressure measured in geothermal fields in general follow the hydrostatic pressure curve of a column of water everywhere at the boiling points.

On the other hand, volcanics (tuff, tuff-and-laharic-breccias) could be weathered more easily through the action of solfatara and fumarolic gases which might result a self-sealing process after an elapse of time and produce the so called ''cap rock'' overlying a thermal field.

In petroleum engineering problems, a reservoir is defined as "that portion of a trap which contains oil and gas as a single hydraulically-connected system" (Craft et al., 1959). Whether we can speak of a reservoir in this sense for the geothermal system of Mt. Dieng is still questionable.

It is regretful that the geo-electrical measurements have not been extended far enough to the northwest to see whether the belt of low resistivity found northwest of Batur is connected with the low resistivity belt of Pagerkandang-Sikidang. If that was the case the geothermal system of Mt. Dieng has a much larger "reservoir".

The area enclosed by the three main resistivity lows of the Pagerkandang-Sikidang belt has been estimated by geo-electrical methods (Jacobson, et al. 1970) to be 2.5 to 3.0 kilometers. The depth extent of the reservoir beds appears to be at least 2 kilometers. So the volume of the reservoir can be expected to be 5 to 6 cubickilometers. Of this volume about one-third probably is water through which heat may be produced to the surface. The heat energy which would be available on cooling this liquid to 50°C would be 3500 megawatt-years per cubic kilometers of resevoir. Because of the inefficiencies in conversion it is not possible to have all this energy in the form of electrical energy. A more realistic figure would be 900 megawatt-years per cubic kilometer of reservoir (Banwell, 1970). So, the energy available in the eastern Dieng geothermal system with a reservoir of 5 to 6 cubic kilometers can be expected to produce electricity of 4500 to 5400 megawatt-years theoretically. Jacobson et al., (1970) however estimated that the eastern Dieng geothermal system can support a power production of 200 megawatts for 25 years, or of 100 megawatts for 50 years.

The most fundamental question is of course how fast the liquid can be withdrawn from the reservoir, provided that the forementioned geophysical inferences are correct. Our experience in this field is based on oil field production. Volcanic rocks, however, might be different as far as production performances are concerned. The author of this paper is more inclined to think that the conditions prevailing for each geothermal field might be unique which requires unique solution and answers.

EXPLORATORY DRILLING WORK

Drill Sites

Based on all these data the geothermal project of Mt. Dieng has been recommended to proceed to phase II, namely the exploratory drilling work which will drill to a depth between 200 and 600 meters. Therefore, six drilling sites have been selected. These are in the areas of:

1. Pagerkandang
2. Telaga Terus

3. Pawuhan
4. Sekunang
5. Sidolok
6. Dieng Wetan.

The purpose of this exploratory drilling work is to test the geologic, geophysical, and geochemical indicators, determine temperature gradients from 100 to 200 meters, collect samples of fluids and gases at various depth and finally to collect core samples at 5 meter intervals as the work progresses.

If the temperature and chemical indicators of the 200 meter holes were found favorable, one or two of the holes will be deepened to 650 meter. The purpose of this work is to find out the base temperatures which is mostly important, determine whether we have a system of dry steam or a system of hot water, collect fluids at greater depths and finally to determine the physical characteristics of the "reservoir" rocks.

Hazard of Recent Activities

One question worth considering in establishing this thermal project in the Dieng area is of course the fact that this volcanic complex is still unstable. Eruptions, phreatic or hydrothermal in character as well as seismic tremors occur rather frequently. It is of course possible that the seismic tremors and the eruptions in the crater lakes are due to the hot water system itselft rather than of "volcanic" in origin.

The Pakuwadja volcano erupted in 1826, strong phreatic or hydrothermal eruptions occurred in 1786 at Tjandradimuka solfataric fields, in 1928 and 1939 in the Timbang explosion craters, and in 1944 in the Sileri explosion craters of the Pagerkandang volcano. A minor eruption occurred in the same crater in 1964. Solfatares are most strongly developed in the Sikidang field of the Pangonan volcano, in the Sileri explosion crater of Pagerkandang, and in the Tjandradimuka field of the Sedringo volcano. They are associated with fumaroles, mudwells and hotsprings. Fumaroles are most widespread along the southern and southeastern craterwalls of Pagerkandang and along its outer slops. Strong mofettes occur at the bottom of the southern Djimat crater, in the Timbang crater and in Gua Upas explosion crater of the Pangonan-Merdada volcano.

Precaution must be taken to prevent unnecessary lost of human lives and destruction to valuable structures.

While the exploratory drilling is in progress the author is of the opinion that it is highly necessary and strongly recommended to install a seismograph or portable seismoscope to detect earthquake tremors in this area.

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