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The comprehensive results of geological, geophysical and geochemical surveys for geothermal resources in the Gou area, Flores Island, Indonesia

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Abstract: The aim of this paper is to identify and describe the possibilities of the utilization of geothermal energy in the Gou area, Flores Island, Indonesia. The general view of the comprehensive results of integrated geoscientific surveys in the Gou area is as follows. Stratigraphy consists of Quaternary volcanic and sedimentary rocks underlain by Tertiary basement rocks. Thermal features on the surface occur along a NE-SW trending fault, namely the Mengeruda fault. These features include hot springs, fumaroles and altered rocks. The temperatures of hot springs at Managara, Watuh Wuti and Tukapela reach 47.5 ℃ while their flow rates are 5 - 7 l/min. All hot springs are characterized by high concentration of acid sulphate water discharges at the surface. Also, surface argillic alteration occurs in the vicinity of hot springs along the Mengeruda fault. The high contour values of soil gas mercury are concentrated around the Managara and Watuh Wuti hot springs, where the maximum concentration of Hg reaches 564 ppb. The lateral distribution of the low resistivity zone (less than 10 ohm-m) at AB/2=1000 m is also concentrated around these hot springs, and the contour is open to the northeast direction. This prospective area covers a minimum of about 2 km^2. The vertical distribution of the low resistivity zone is between 350 - 700 m below the surface.

1. Introduction

The Gou area is located 4 km north of Bajawa City in Ngada District, Flores Island, East Nusa Tenggara (Fig. 1). Ngada District has a population of at least 211,000 people. The installed electric power generated from diesel is utilized for many domestic energy demands such as: lighting, industry, hospitals, official offices, harbour, hotels, houses, restaurants, schools and markets. Many geothermal manifestations appear on the surface in the area like Gou. Surface manifestations consist of hot springs, fumaroles and alteration rocks.

These manifestations are presumably indicating the presence of a geothermal reservoir beneath the Gou area. The direct utilization of geothermal energy or developing small-scale electric power generation from geothermal energy could provide economic growth for the area. However, the Directorate of Mineral Resources Inventory (DMRI), Indonesia, and New Energy and Industrial Technology Development Organization (NEDO) have explored and drilled a few holes for the first small-scale geothermal power generation in the Mataloko area to support its energy demands. The Mataloko geothermal field is approximately 10 km south of the surveyed area.

2. Methods

Geological, geochemical and geophysical surveys have been carried out during the exploration in the Gou area. The geological survey has been carried out in a large area, but geochemical and geophysical surveys are mostly concentrated in a smaller area in the vicinity of the geothermal surface manifesta-

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Keywords: geothermal exploration, comprehensive results, Gou area, Flores, Indonesia, geology, geophysics, geochemistry

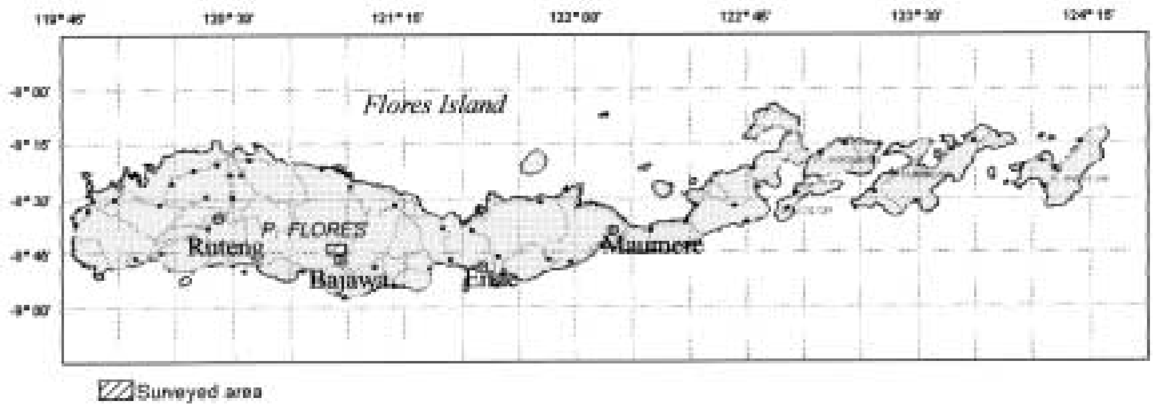

Fig. 1 Location of the study area.

tions. For the geochemical survey, we conducted soil gas mercury measurement. As for the geophysical survey, we conducted Schlumberger mapping and sounding.

3. Results of geoscientific surveys.

Flores Island is a part of Banda island arc, which comprises Upper Cenozoic volcanic rocks with volcanogenic and carbonate sediments (Hamilton, 1979). The volcanic rocks are dominantly mafic to intermediate calc-alkaline composition and are unconformably underlain by Tertiary rocks. The oldest rocks are sedimentary strata in the Miocene age, and it is exposed at the Nangapanda village, about 25 km west of Ende (Van Bemmelen, 1949).

The youngest Quaternary lava is derived from Mt. Inie Lika. It is 10 km west of our survey area. Stratigraphic succession from the youngest to the oldest rock consists of alluvium, Mt. Inie Lika lava, Mt. Mataloko volcanic rocks, lacustrine sedimentary rocks and Bajawa syn-caldera rocks. All these rocks are underlain by Miocene Nangapanda Formation, which is also exposed in the Riung village near northern coast. It is about 8 - 9 km north of the study area. All Quaternary volcanic rocks are dominantly andesite to basaltic andesite in composition with one exception of dacitic-rhyolitic rock in the Bajawa syn-caldera rocks (Fig. 2)

Geothermal surface manifestations are exposed along the NE-SW trending normal fault in the Gou area. This geological structure is named the Mengeruda fault. The surface manifestations include hot spring, fumaroles and altered rocks. Three hot springs, Managara, Watuh Wuti and Paida, are characterized by acid sulphate water (Table 1, Fig. 3). The temperatures of the hot springs reach 47.5 ℃, whereas flow rates are 5 - 7 l/min. Surface argillic alteration occurs only at nearby hot springs. An anomaly of Hg soil gas is mostly around Watuh Wuti and Managara hot springs, where the concentration of Hg reaches 564 ppb. This Hg anomaly is open to the northeast direction (Fig. 4).

The lateral distribution of the low resistivity zone (less than 10 ohm-m) is concentrated around these hot springs (Fig. 5). This phenomenon is also concordant to the soil gas mercury anomaly. Both anomalies are clearly open to the northeast direction. This prospective area covers a minimum of about 2 km^2. The vertical distribution of the low resistivity layer (less than 10 ohm-m) beneath these hot springs are at a depth of 350 - 700 m, and the maximum penetration depth of the method is only 700 m below the surface. The apparent resistivity section for lines B, C, D and E indicate the thickness of the resistive overburden layer is approximately 350 - 600 m, and the top of the clay cap layers is probably also between 350 - 600 m beneath the surface (Fig. 6). The layer below the clay cap is assumed to be a liquid or steam reservoir. However, the depth of reservoir could not be identified by this survey.

The comprehensive modeling of the Gou area is shown in Fig. 7. It is considered that the Gou geothermal system is probably an up-flow system, while and out-flow geothermal system is located at the Mengeruda hot spring. It is about 6 - 7 km northeast of the Gou area. The out-flow of the geothermal system in Mengeruda is calculated to be at least 400 - 500 l/s flow rate of acid hot spring discharge.

4. Discussion and Conclusion

The distribution of the surface manifestations indicates geothermal resources beneath the Gou area. Geothermal evidence, such as hot water, fumaroles, altered rocks, high concentration of acid sulphate hot springs and Hg content, and lateral and vertical distributions of low resistivity zone, indicate that they are formed by geothermal fluids (steam, gasses or hot water). Fractures and NE-SW trending structures are responsible for supplying the means for geothermal fluids to be transported to the surface.

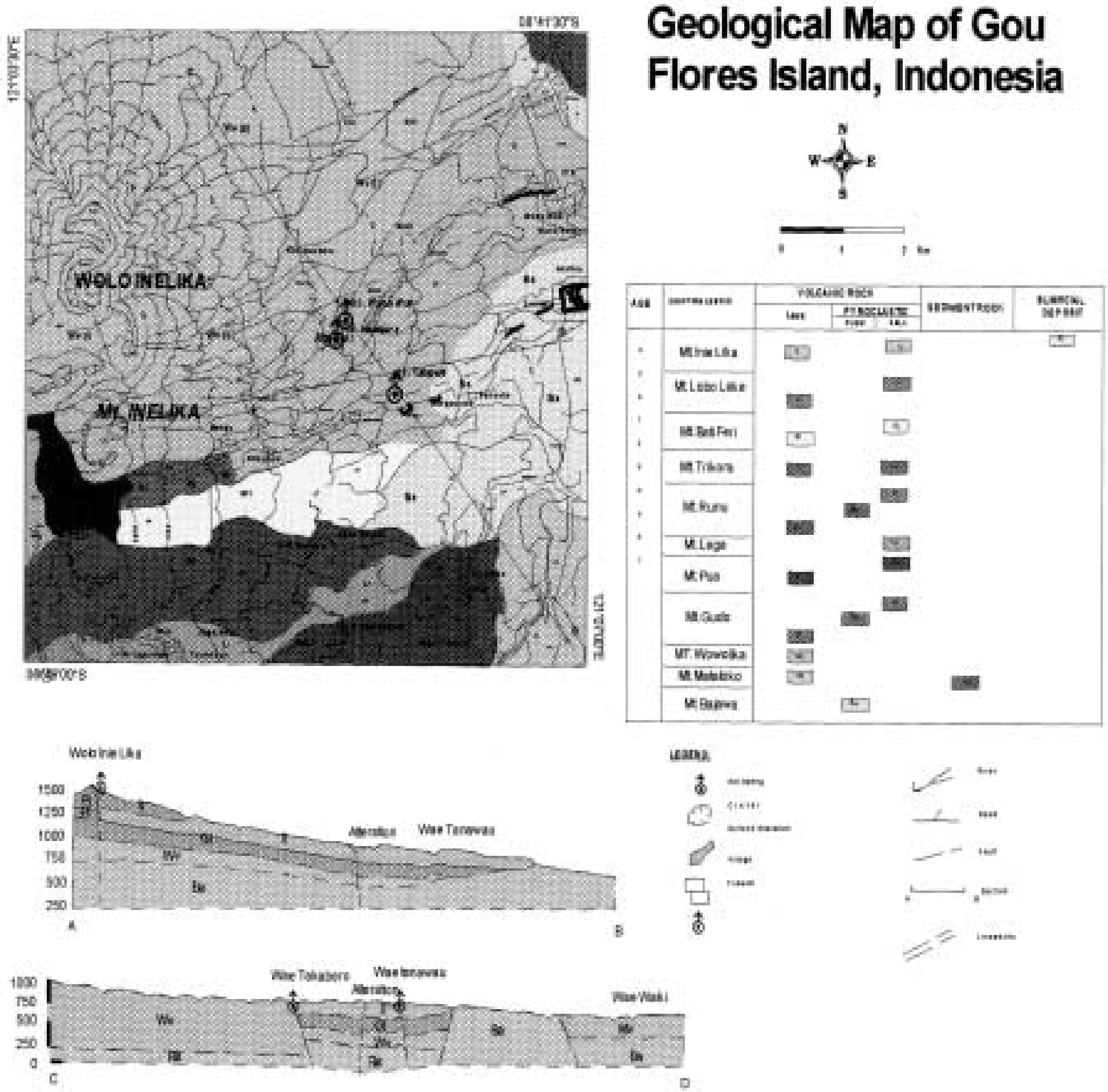

Fig. 2 Geological map of the Gou area.

Table 1 Chemistry data of hot springs in the Gou area, Flores Island.

Constituents	Managara	Watuh Wuti	Tukapela
pH	3.66	2.99	2.66
Cl^-	28.59	120.67	339.95
$SO_4^{=}$	412.24	556.68	794.12
B	1.26	1.00	6.00
SiO_2	88.00	122.00	124.00
Na^+	25.63	35.00	74.04
K^+	7.02	15.32	25.32
Li^+	0.61	1.47	3.11
Ca^{++}	114.79	128.70	163.48
Mg^{++}	6.26	22.96	58.44
HCO_3^-	0.00	0.00	0.00
Fe^{+++}	1.00	4.50	5.50
NH_3	0.05	0.07	0.13
As	0.07	0.13	0.24
F	1.00	1.00	2.00
Conductivity $\mu s/m^2$	1050.00	2600.00	4600.00

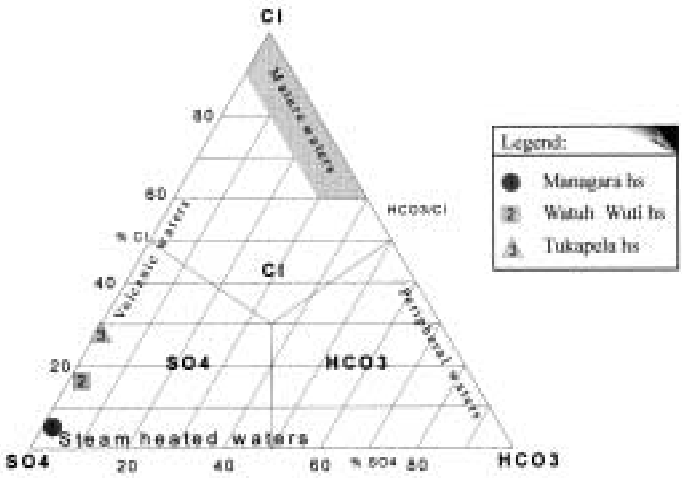

Fig. 3 Anion diagram showing hot spring types in the Gou area.

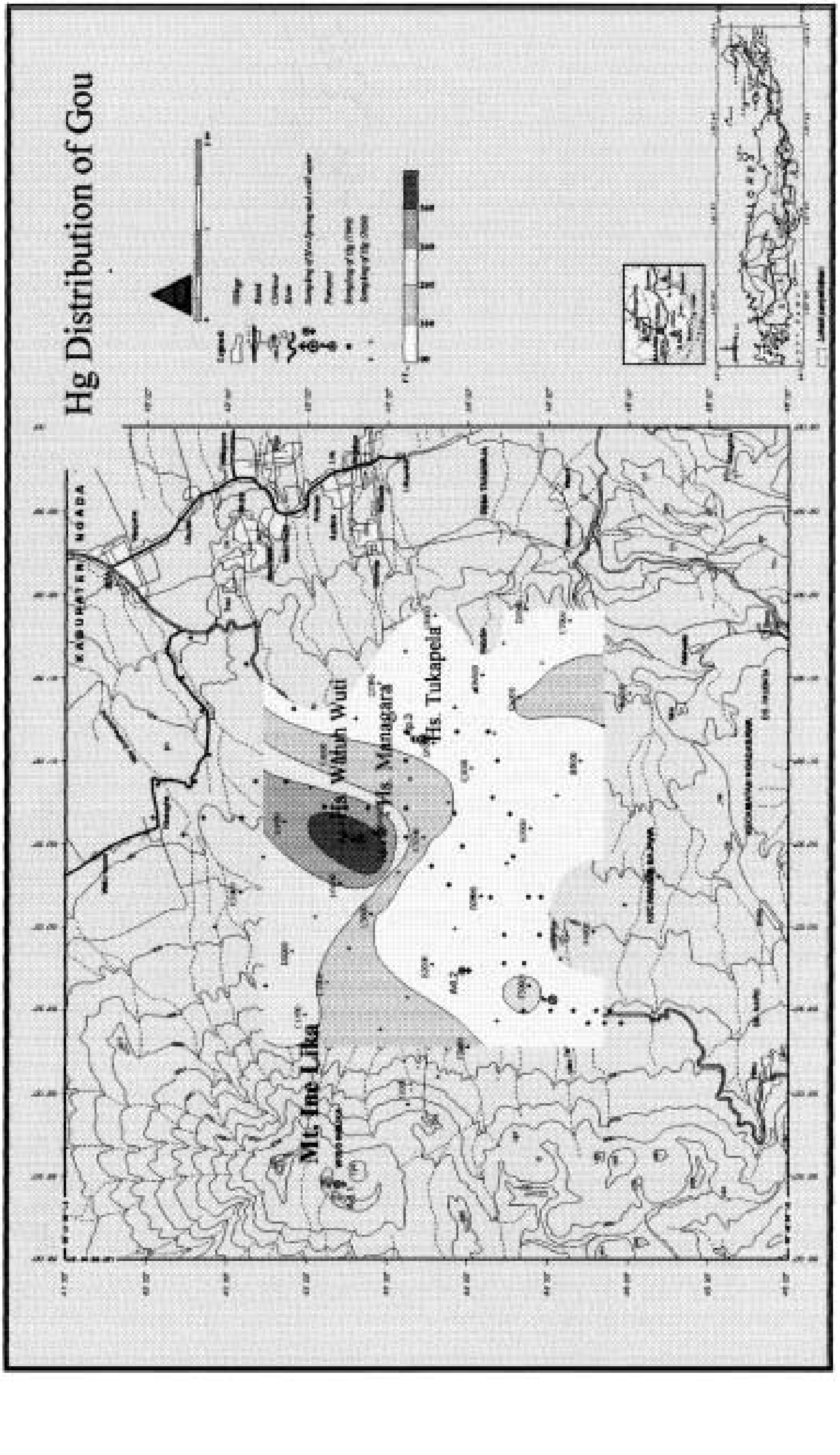

Fig. 4 Contours of the mercury soil gas anomalies in the Gou area.

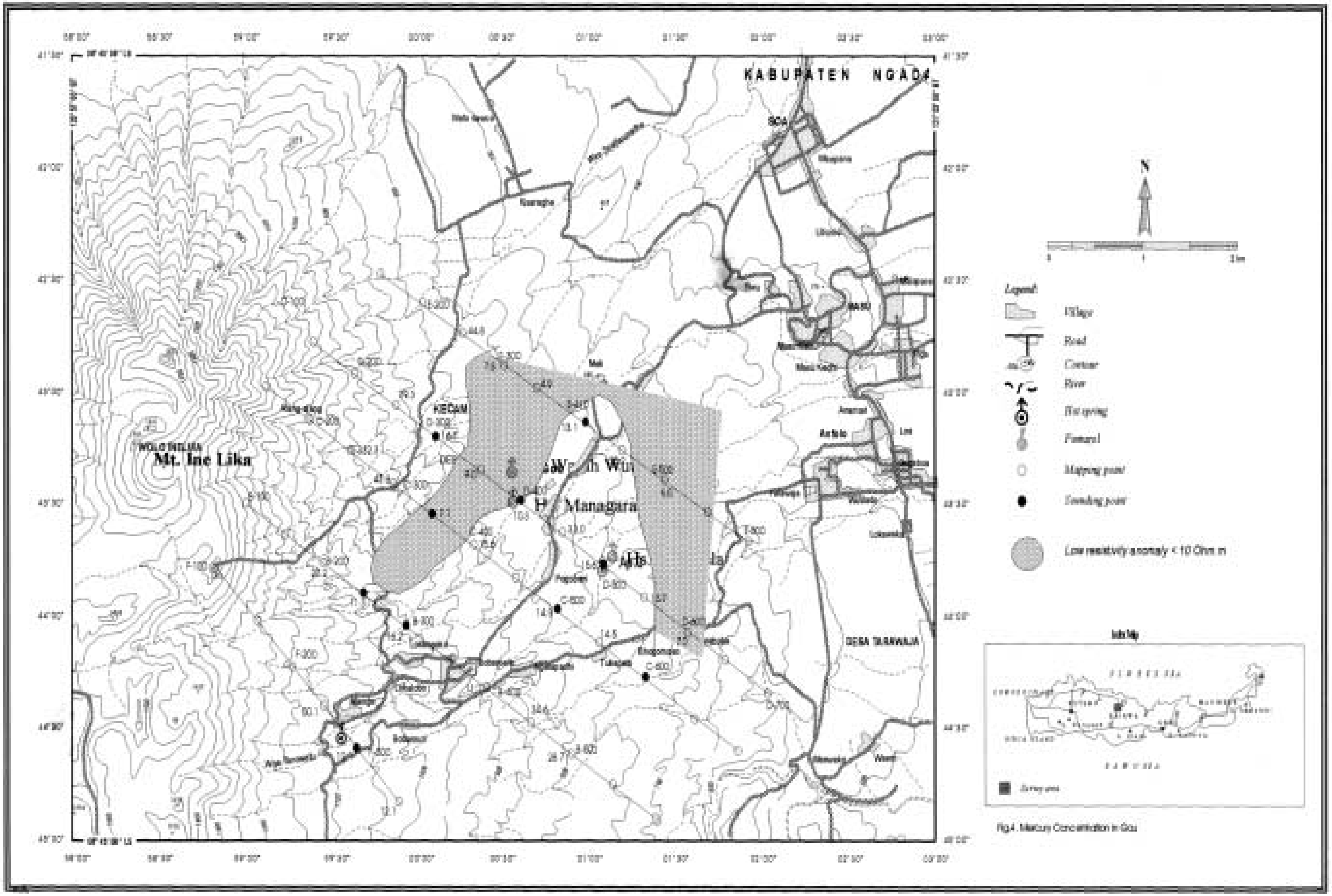

Fig. 5 Schlumberger survey lines and apparent resistivity map of AB/2 = 1000 m in the Gou area.

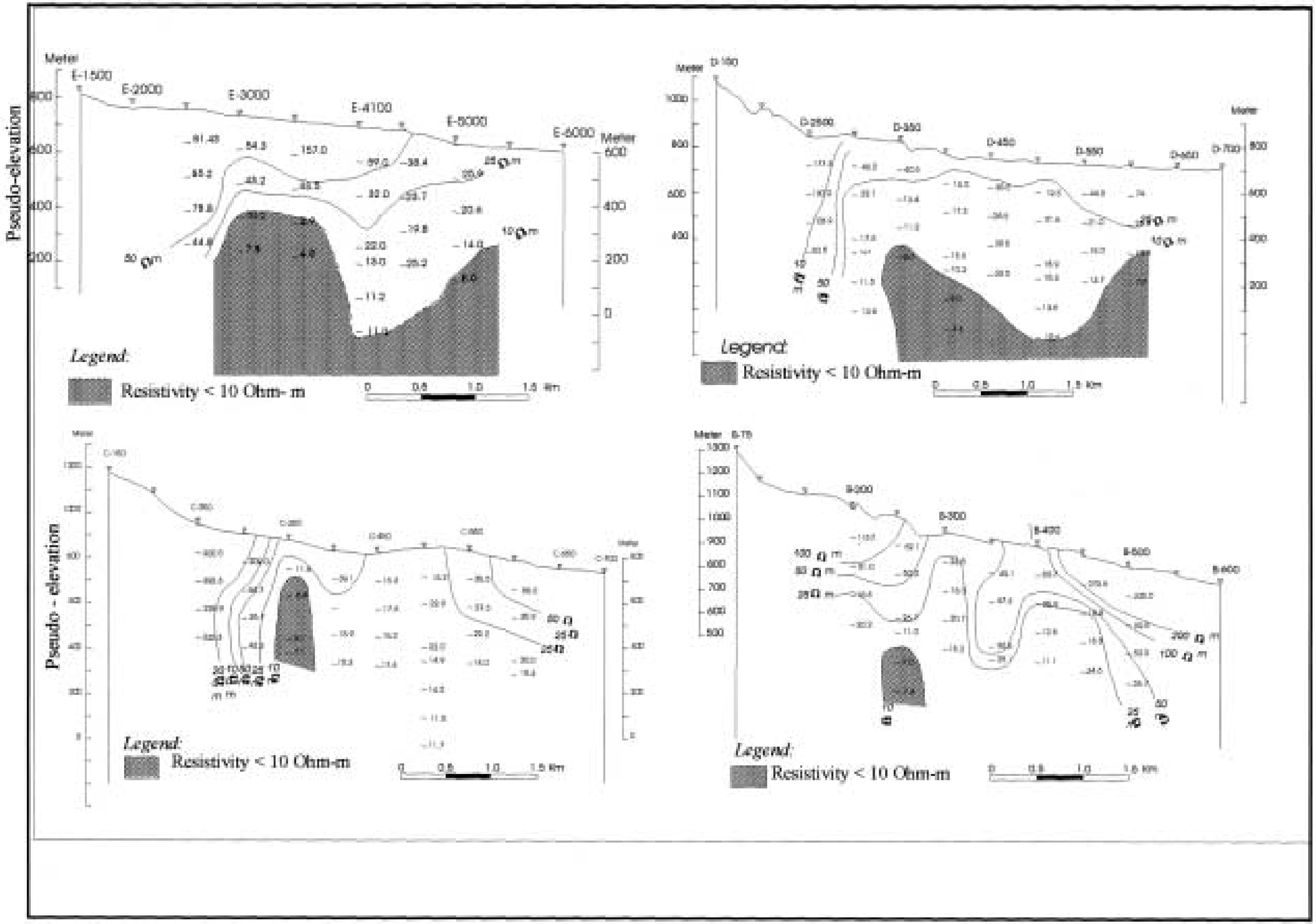

Fig. 6 Apparent resistivity pseudo-sections of the Schlumberger data in the Gou area.

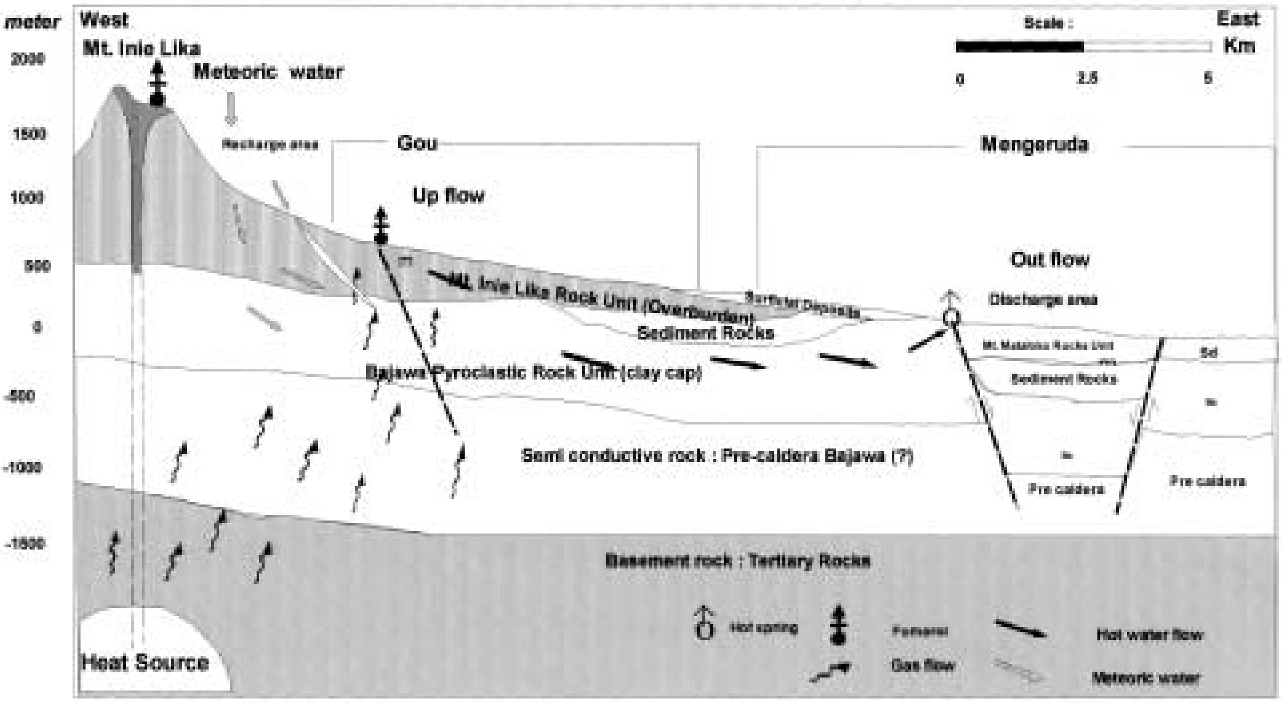

Fig. 7 Tentative geothermal model of the Gou area.

The next surveys using CSAMT, MT and head-on resistivity methods are suggested for identifying deep structures and formations in the Gou area. These surveys are very important for selecting the drilling location.

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インドネシア，フローレス島ゴウ地域の地熱資源に関する地質学・地球物理学・地球化学探査の総合結果

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要　旨

本論文の目的は，インドネシアのフローレス島ゴウ地域における地熱エネルギー利用可能性を確認し記述することである．ゴウ地域における地球科学総合調査の結果を概観すると以下の通りである．地質層序は火山岩類および堆積岩類からなり，その下位に第三紀の基盤岩類がある．地表地熱徴候は北東－南西方向のメンゲルーダ断層に沿って分布し，温泉・噴気・変質岩などからなる．マナガラ，ワトゥ・ウティ，トゥカペラの各温泉の温度は最高 47.5 ℃で，湧出量は毎分 5 〜 7 リットルである．温泉はすべて高濃度の酸性硫酸塩泉であることが特徴である．また，メンゲルーダ断層に沿った温泉近傍の地表では粘土化変質がみられる．土壌ガス水銀濃度の高い場所はマナガラ温泉およびワトゥ・ウティ温泉の周辺に集中しており，最大 564 ppb である．AB/2=1000 m での低見掛比抵抗（10 Ωm未満）の水平分布もこれらの温泉周辺に集中しており，北東方向に開いた形状である．この有望地域は少なくとも約 2 km^2 に及ぶ．低比抵抗帯の垂直分布は深度 350 〜 700 m である．

（要旨翻訳：水垣桂子（地圏資源環境研究部門））