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Subsurface geology of the Mataloko geothermal field deduced from MTL-1, MT-1 and MT-2 wells, central Flores, East Nusa Tenggara, Indonesia

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Fredy NANLOHY, Kastiman SITORUS, KASBANI, Sjafra DWIPA and Janes SIMANJUNTAK (2002) Subsurface geology of the Mataloko geothermal field deduced from MTL-1, MT-1 and MT-2 wells, central Flores, East Nusa Tenggara, Indonesia. *Bull. Geol. Surv. Japan,* vol. 53 (2/3), p. 329-336, 6 figs., 1 table.

Abstract: The Mataloko geothermal field is situated east of Bajawa, the capital city of Ngada District. The field is bordered by several volcanoes; Ebulobo in the east, Inelika in the northwest and Inerie in the south-southwest. The local surface geology was affected by volcanic activities of some eruption centers during Tertiary to Quaternary ages. At least two periods of volcanic activities were identified. One is the Tertiary volcanic basement composed of the Maumbawa lava flow and Green Tuff; the other is the Quaternary volcanic rocks characterized by Watumanu, Rotogesa and young volcanic cones.

Based on the lithologic logs of the MTL-01, MT-1 and MT-2 shallow wells, the stratigraphic sequences of the MT-1 and MT-2 are nearly the same, but the well MTL-01 is characterized by dacitic ash tuff. In general, subsurface geology of the Mataloko geothermal field consists of Quaternary ash tuff of dacitic composition, pyroxene andesite intercalated with hornblende andesite and pyroclatic deposits.

1. Introduction

The Mataloko geothermal field, about 15 km east of Bajawa City lies between 121° 00' 00" - 121° 48' 30" east longitude and 08° 48' 30" - 08° 50' 30" south latitude (Fig. 1).

Three shallow wells MTL-01, MT-1 and MT-2 have been drilled in the area. The MTL-01 well was spudded on 14 October 1999 and has a 5 5/8" drill hole diameter. After setting the 4" casing shoe at a depth of 98.0 m, steam discharge occurred while coring from 98.0 to 103.23 m. The drilling was stopped on 25 October 1999 after killing the well with a cement plug. Well MT-1 was the first exploration well proposed by the Five-Year Cooperative Research between Indonesia - Japan (1997-2002). This well was abandoned and the alternative well MT-2 was drilled near the site because the well MT-1 was plugged back with cement due to a steam blow-out around the cellar. Although the MT-1 well was terminated, the lithologic log was completed. The MT-2 well was drilled to a total depth of 180.02 m.

In general, the stratigraphic correlation between MTL-01, MT-1 and MT-2 wells (from south to north) can be made using the lithologic units based on the surface geological map.

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2. Tectonic and geologic settings

2.1 Tectonic setting

Flores Island is a part of the volcanic inner Banda arc (Fig. 2), and is composed of Upper Cenozoic volcanic rocks, which are intercalated with volcanogenic and carbonate sediments (Hamilton, 1979).

The oldest age of the rocks is correlated to Late Miocene (Hamilton, 1979). Koesoemadinata et al. (1994) mapped the regional geology of western Flores (Fig. 3) and reported that the oldest rock exposed in this area is the volcanogenic sediments of the Middle Miocene.

Volcanic rocks of the island are mainly composed of mafic and intermediate calc-alkaline i.e. andesite, basalt and dacite which are typical of island arc volcanism associated with the subduction of the oceanic crust (Hamilton, 1979).

Keywords: geothermal field, geothermal exploration, subsurface geology, exploration well, lithologic log, Mataloko, Flores, Indonesia

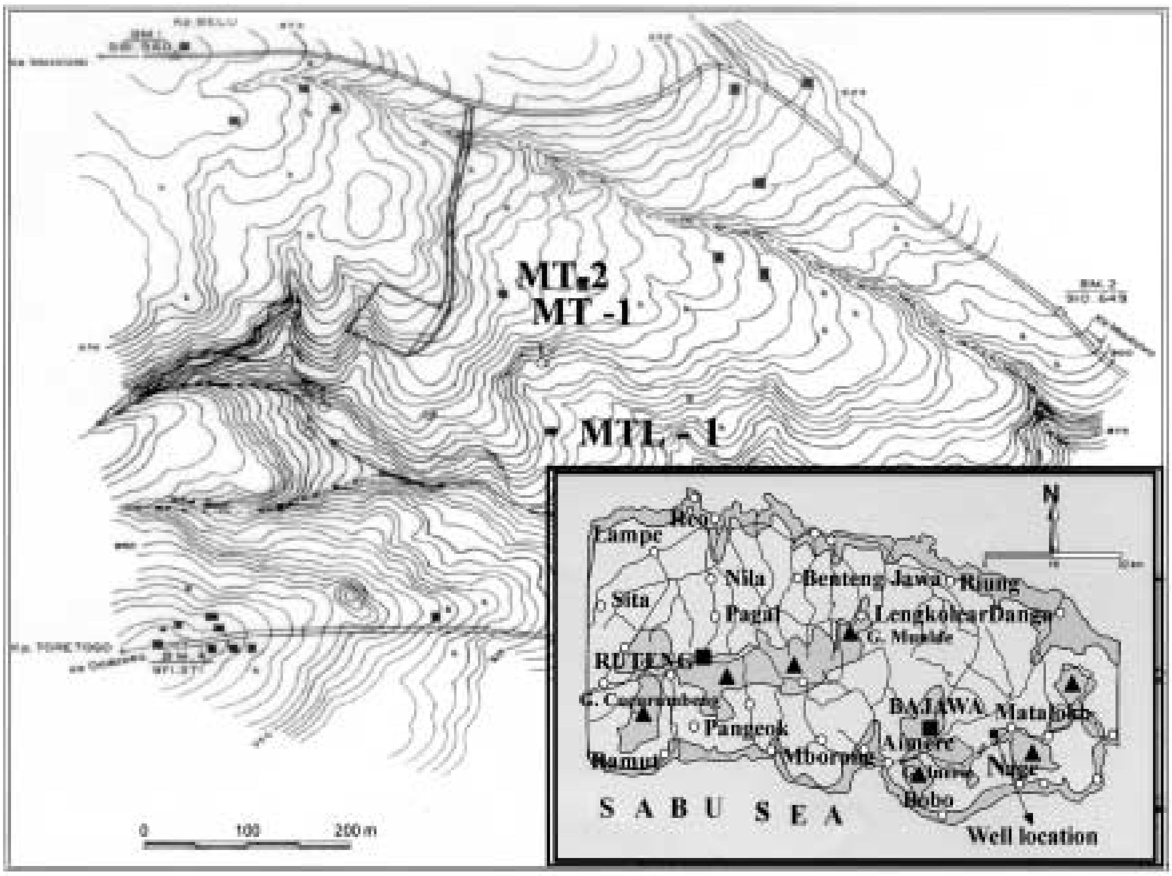

Fig. 1 Location of MTL-01, MT-1 and MT-2 wells.

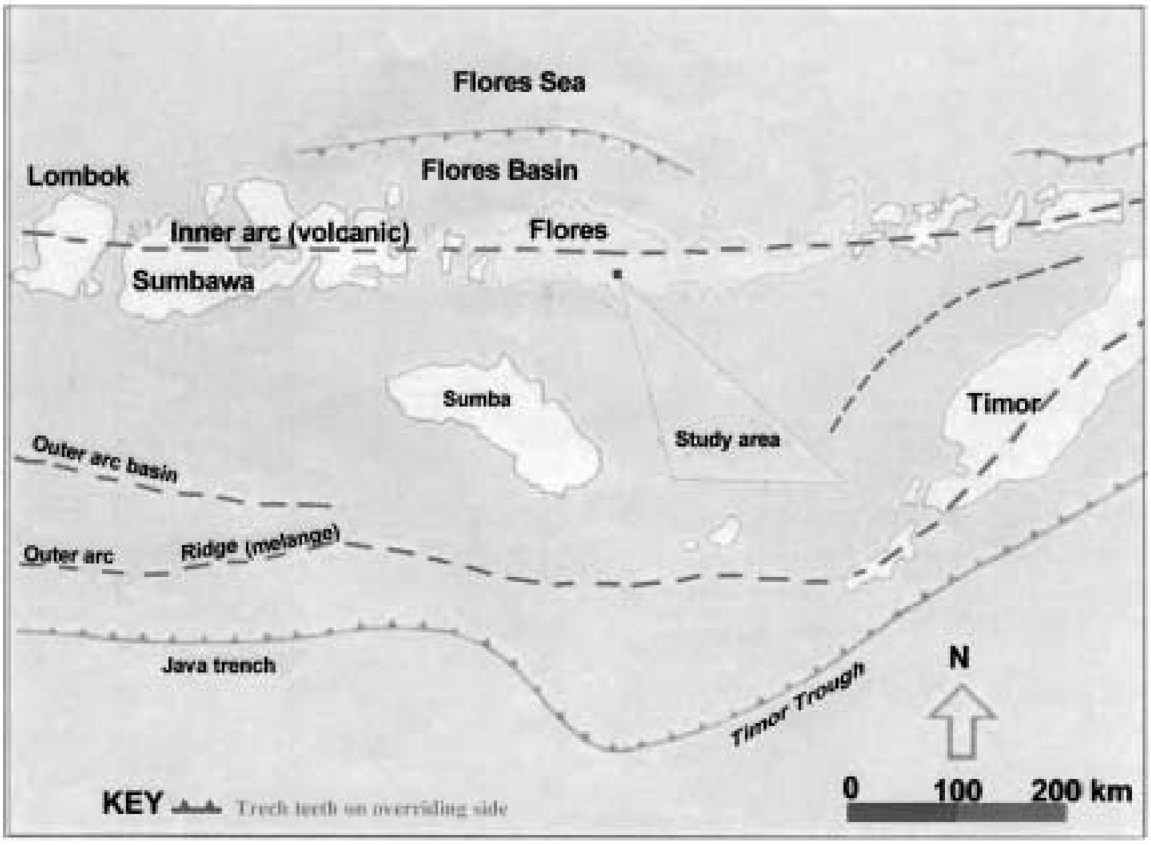

Fig. 2 Tectonic setting of Flores Island (Hamilton, 1979).

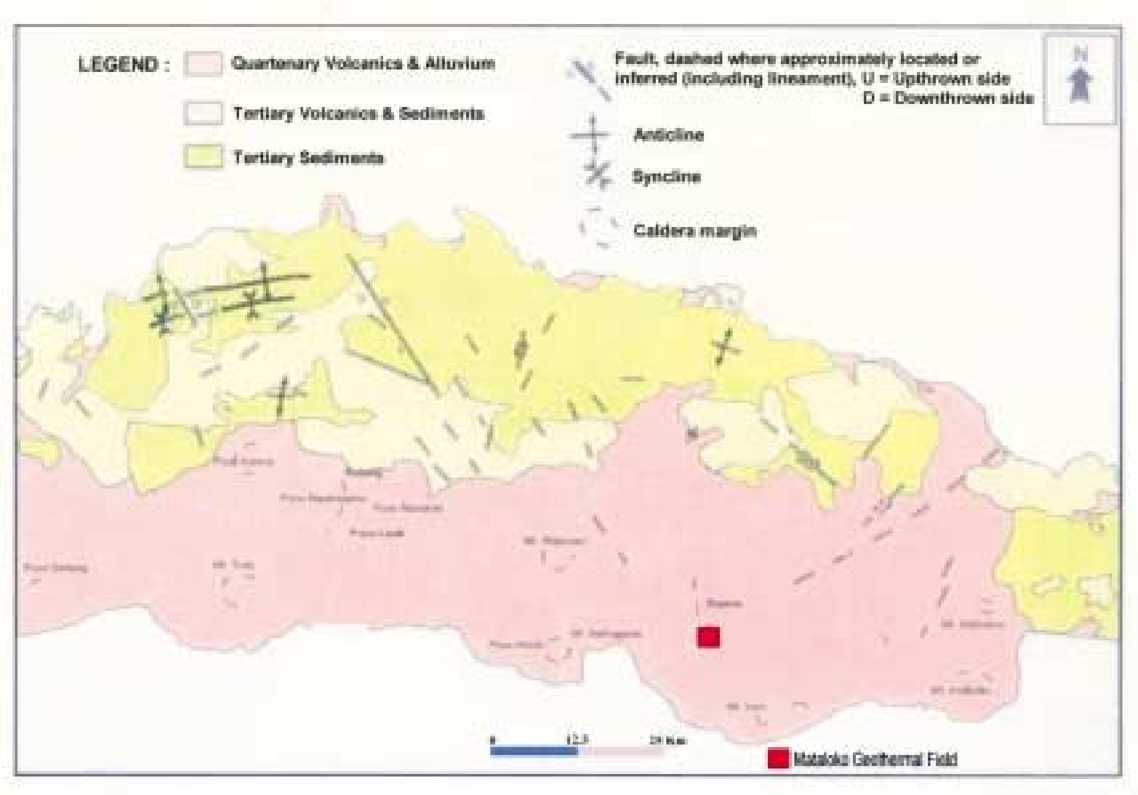

Fig. 3 Regional geology of Western Flores (Simplified from Koesoemadinata *et al.*, 1994).

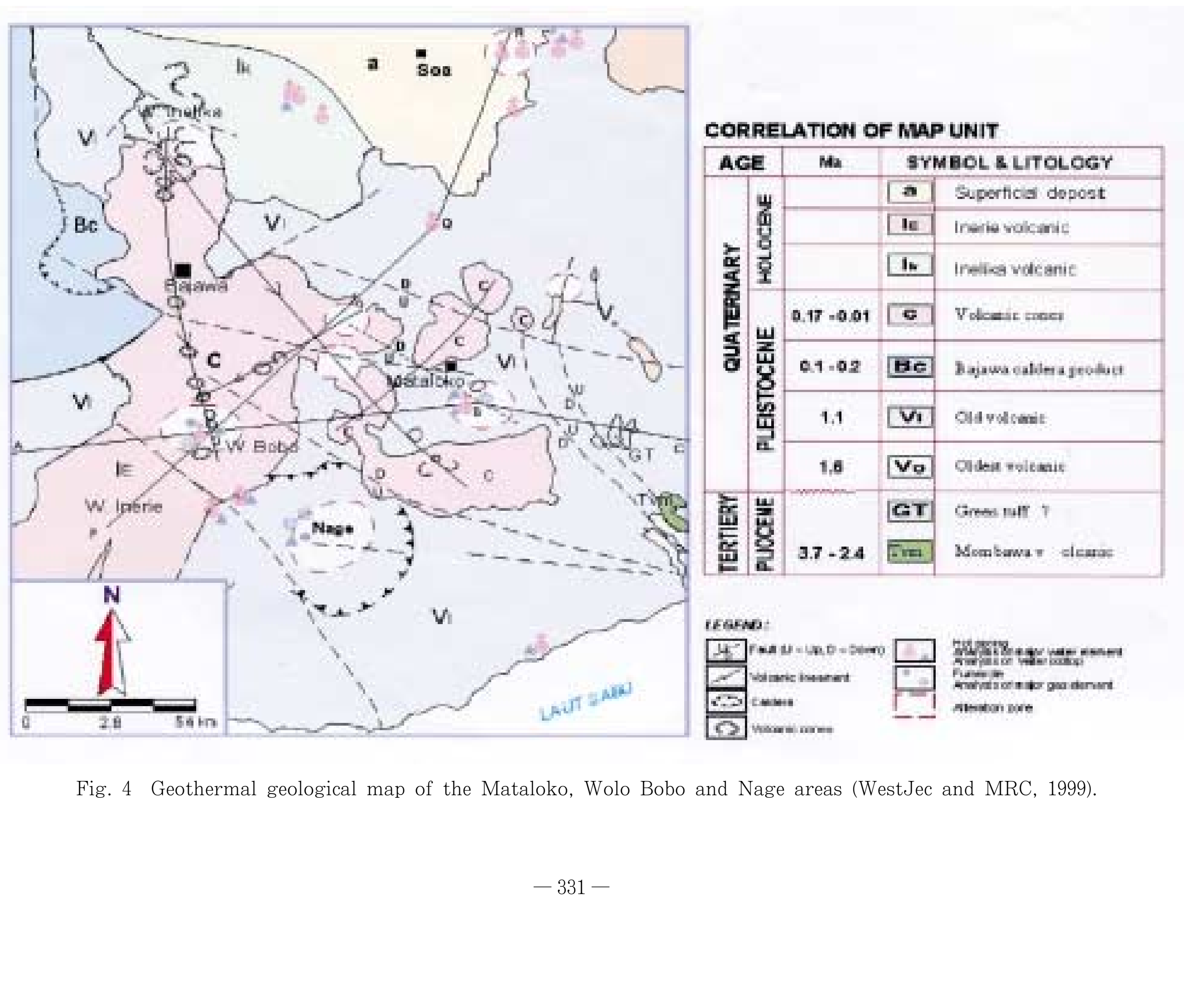

Fig. 4 Geothermal geological map of the Mataloko, Wolo Bobo and Nage areas (WestJec and MRC, 1999).

2.2 Regional geology

The regional geology of Western Flores and geology of the Mataloko, Wolo Bobo and Nage geothermal areas have been mapped by Koesoemadinata *et al.* (1994; Fig. 3) and WestJec and MRC (1999; Fig. 4), respectively.

According to Koesoemadinata *et al.* (1994), the oldest rock consists of Tertiary sedimentary rock of *Kiro Formation, Nangapanda Formation and Bari Formation. The* ***Kiro Formation*** was reported as Middle Miocene of andesite lava unit, which is interfingered with the *Nangapanda Formation*. The *Nangapanda Formation* is interfingered with the Bari Formation. The ***Nangapanda Formation*** consists of sandstone and limestone, locally lensed or intercalated with marl. The ***Bari Formation*** comprises limestone, locally interbedded with sandy limestone and calcareous sandstone. These formations are unconformably overlain by the Pliocene ***Waihekang Formation***, interfingered with the ***Kedindi Formation***.

The ***Waihekang Formation*** is composed of tuffaceous clastic limestone, whereas the ***Kedindi Formation*** comprises tuff, in some places interbedded with sandy limestone. These rocks are unconformably overlain by Pleistocene volcanic rocks. The Pleistocene volcanic rocks are unconformably overlain by the Holocene coastal terrace deposits.

2.3 Surface geology

There are many Quaternary eruption centers surrounding the Mataloko geothermal area. During the Tertiary to Quaternary, at least two periods of volcanic activities were identified in the Mataloko geothermal area (Fig. 5), as described below. The Tertiary volcanic green tuff (2.5 Ma ?) is the oldest volcanic rock in this area. Maumbawa volcanic rocks (2.4-3.7 Ma) exposed south of the Mataloko geothermal field is the basement rock of this area (Muraoka *et al.*, 1999; Nasution *et al.*, 1999).

The following volcanic activities are recognized by the oldest and old volcanics (1.1-1.6 Ma) of the Watumanu lava flow, Rotogesa volcanics (lava flow, pyroclastic flow and lahar deposit), Wolo (W.) Pena volcanic cone, W. Roge, W. Sasa and W. Pure volcanic cone. The younger volcanic activities are identified by many young volcanic cones and Wolo Belu lava dome, which are arranged on the NW-SE trending line of the volcanic lineament from Mt.

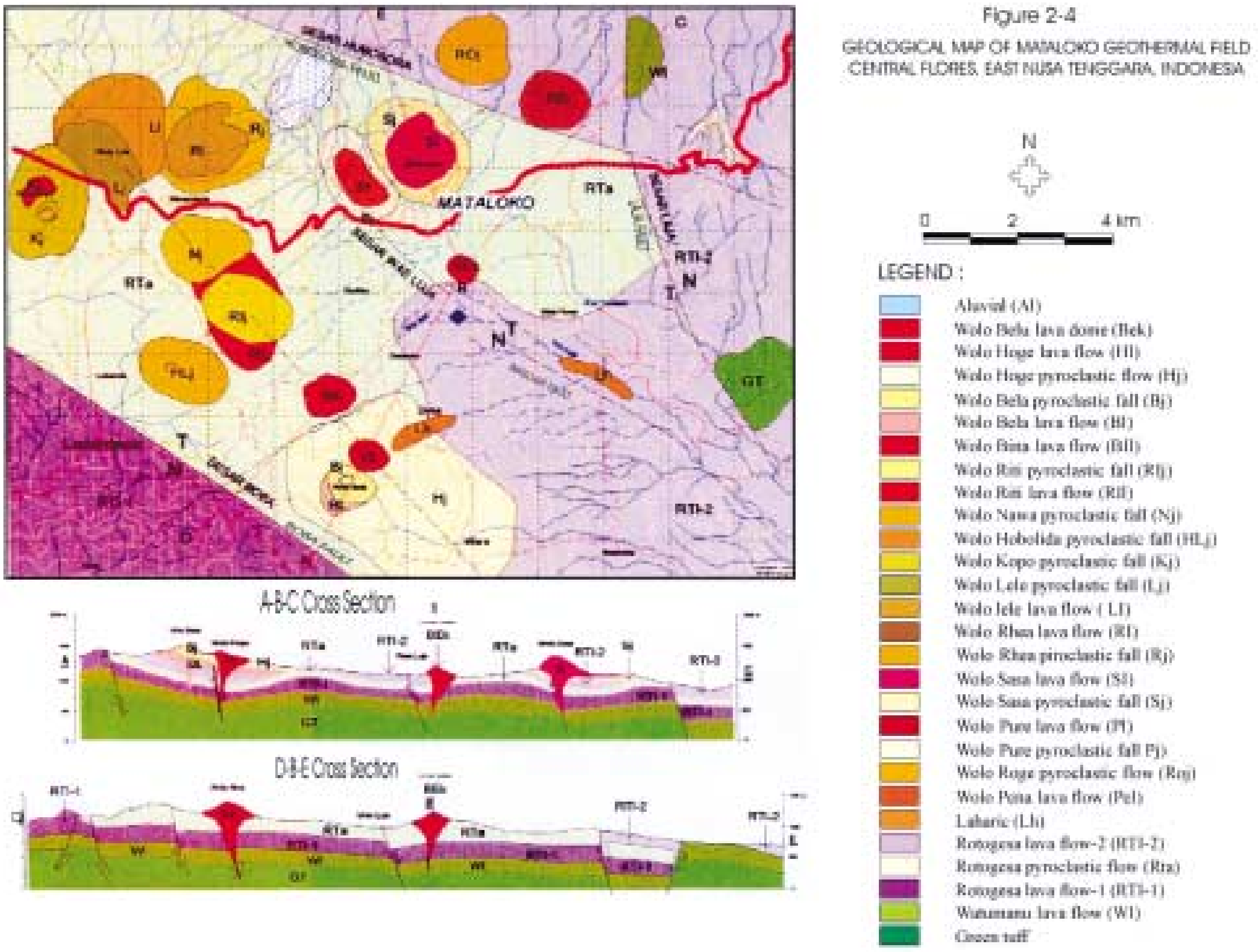

Fig. 5 Geological map of the Mataloko geothermal field.

Inelika to south of the Mataloko area. These young volcanic centers are regarded as heat sources of the Mataloko geothermal field. The Tertiary volcanic green tuff and the Watumanu lava flows are assumed as reservoir rocks. The young volcanic cones surrounding the Mataloko geothermal field is the products of the younger tectonic activities. The summit craters of young volcanic cones range between 100 to 500 m in diameter. Most cones are controlled by fractures or a fault system. At least four normal fault structures found in the Mataloko geothermal field are characterized by a lineament of hot springs, triangular facets and scarps. The most important fault in which thermal manifestations occurred is the NW-SE trending Wae Luja normal fault. Other fault structures are inferred from the NW-SE and NE-SW volcanic lineaments (Fig. 5). These volcanic lineaments are characterized by the development of eruption centers, suggesting the subsurface distribution of heat sources in the Mataloko geothermal area.

3. Subsurface geology

3.1 Subsurface stratigraphy

Subsurface stratigraphy was done based on three wells, MTL-01, MT-1 and MT-2. The deepest well, MT-1 (207.26 m depth) penetrated into the Quaternary volcanic rocks. A more complete subsurface stratigraphy of the MT-1 well is shown. It comprises four main lithologic units: Quaternary dacitic ash tuff, tuff breccia of pyroclastic deposit to 10 m depth, pyroxene andesite lava flow from 10 to 100 m depth, and intercalation of hornblende and pyroxene andesites with pyroclastic deposits from 100 to 207.26 m depth. A schematic subsurface stratigraphy in the Mataloko geothermal field is presented in Table 1, Figs. 6a and 6b.

The Quaternary tuff breccia seems to be a part of the Mt. Sasa volcanic product, whereas pyroxene andesite, and intercalated hornblende and pyroxene andesites with pyroclastic deposits probably belong to the Quaternary Rotogesa lava and pyroclastic flows (Sitorus *et al.*, 2000a, 2000b; Nanlohy *et al.*, 2001). In Fig. 5, Mt. Rotogesa volcanic product is divided into two rock units, Rotogesa pyroclastic and lava flows. The Rotogesa pyroclastic flow is characterized by an intercalation of thinly bedded hornblende and pyroxene andesite lava flows (3-17 m thick), tuff breccia and ash tuff (3 - 18 m thick). The Rotogesa lava flow consists of andesite lava flow (34 - 98 m thick) with a thin bed of tuff breccia pyroclastic deposit (3 - 6 m thick). The other cone of Mt. Sasa comprises of tuff breccia as pyroclastic air fall deposit with a range of thickness between 10 and 30 m. In the MTL-01 well, there is a thin layer of dacitic tuff (± 6 m) that is not present in the MT-1 and MT-2 wells. The source of this rock is not clear yet, but it probably belongs to the Wolo Bena volcanic cone. In this report, the thin layer of dacitic ash tuff is grouped into the Bena pyroclastic fall deposit.

3.2 Hydrothermal alteration

Most horizons of the MTL-01, MT-1 and MT-2 wells have been affected by moderate to very intense hydrothermal alteration (Secondary/total minerals = 30 - 90 %). Alteration is shown by argillization, pyritization with or without carbonatization, oxidation, silicification, devitrification, anhydritization and illitization. Rank of alteration is characterized by clay minerals (kaolinite, smectite/montmorillonite), quartz and illite.

Clay minerals (20 - 70 % from total minerals) occur from the argillization process of primary minerals,

Table 1 Summary of subsurface stratigraphy of the Mataloko geothermal wells.

THICKNESS (m)	ROCK UNITS	LITHOLOGY	PERMEABILLITY	AGE
6	Wolo Bena Pyroclastic Fall	Ash tuff (pyroclastic fall)	Good	Quaternary
10 - 30	Sasa volcanic product	Tuff breccia (pyroclastic fall)	Poor	Quaternary
34 - 98	Rotogesa lava flow	Intercalated andesite (3-6 m) with tuff breccia (pyroclastic fall)	Poor	Quaternary
33 -107	Rotogesa pyroclastic flow	Intercalated tuff breccia with hornblende lava flow	Intermediate - Good	Quaternary

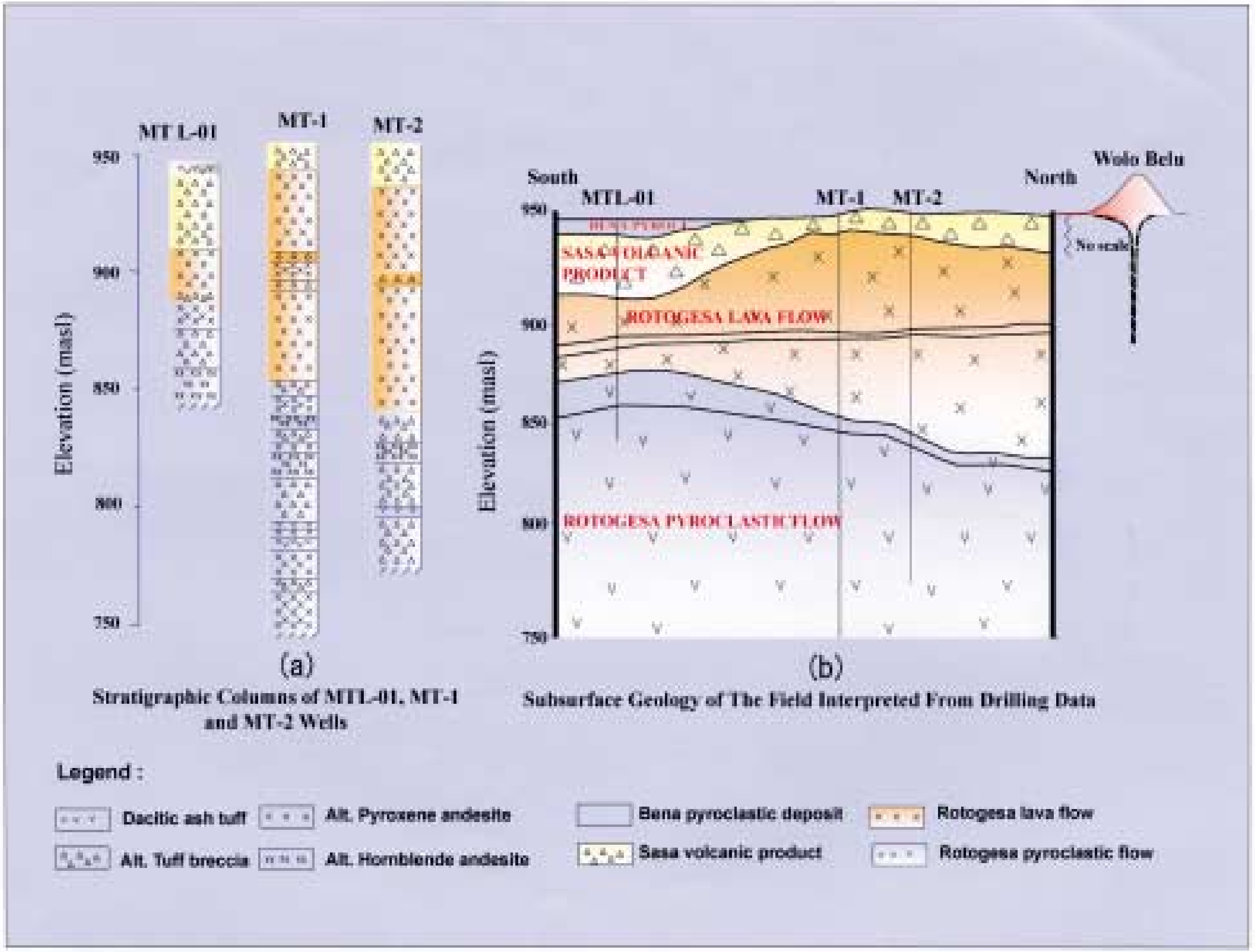

Fig. 6 Stratigraphic columns of MTL-01, MT-1 and MT-2 wells and subsurface cross section model. (a) Stratigraphic columns and (b) Subsurface cross section model.

plagioclase, pyroxene and groundmass of volcanic glass.

Pyrite (2 - 20 % from total minerals) exists from surface to the bottom in the three wells, fine to moderately, and concentrates in some fragments as a replacement of pyroxene and groundmass of volcanic glasses. In some fragments, pyrite is shown as veinlets or vugs.

Carbonate/Calcite (0 - 20 % from total minerals) is not present throughout the wells, but as an alteration/replacement of plagioclase and volcanic glass of groundmass.

Anhydrite (0 - 5 % from total minerals) is present in some intervals as an altered phase of plagioclase and groundmass.

Secondary Quartz (0 - 5 % from total minerals) is present as an alteration/replacement of plagioclase, volcanic glass and also as veinlets in some fragments.

From the alteration intensity and rank of alteration, it is concluded that the subsurface rocks down to about the 207.26 m depth have been affected by *argillic alteration*.

3.3 Subsurface structures

During the drilling operation, fault structures or fractures can be recognized by the presence of mylonitization, brecciation and other parameters such as a drilling break and loss circulation zone. The subsurface structure of the MTL-01 well is shown by the occurrence of a total lost circulation (TLC) at a depth of 13.8 m, which is also indicated by surface fractures (Sitorus *et al.*, 2000a, 2000b). No surface fractures are found at the MT-1 and MT-2 well sites. The partial lost circulation (PLC) in the MTL-01 well occurred at the 98.3 m depth and continued to a depth of 103.23 m. The presence of the lost circulation zones (TLC and PLC) is interpreted as the same as fracture zones in which the Mataloko surface discharges occurred as the hot spring, mud pool, fumarole and solfatara.

During the drilling of the MT-1 and MT-2 wells to the depth of 207.26 m and 180.02 m, respectively, mud circulations were fully returned on shale shaker, but the mud properties became hotter with increasing depth. Steam discharges occurred at depths of 207.26 m (MT-1) and 162.35 m (MT-2). Steam flowing from MTL-01, MT-1 and MT-2 wells were mostly related to the Wae Luja fracture zone.

4. Conclusion

Surface geology of the Mataloko geothermal field has been derived from the Tertiary and the Quaternary volcanic activities on and around the field. The Wae Luja normal fault seems to control the presence of surface thermal manifestations and steam flowing that originated from the shallow wells of MTL-01, MT-1 and MT-2.

Subsurface geology consists of four main units, the Quaternary dacitic ash tuff, tuff breccia of pyroclastic deposit, pyroxene andesite lava flow, and an intercalation between hornblende and pyroxene andesite lava flows with pyroclastic deposit.

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インドネシア，ヌサテンガラ東部，フローレス島中央部マタロコ地熱地帯の坑井 MTL-1，MT-1 および MT-2 による地下地質

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要　　旨

マタロコ地熱地帯はンガダ郡の郡都バジャワ市の東にあり，東方をエブロボ，北西方をイネリカ，南－南西方をイネリエの各火山に囲まれている．本地域の地表地質は第三紀－第四紀の火山噴出物を主とする．火山活動には少なくとも 2 回の活動期が識別できる．1 回目は第三紀のマウンバワ溶岩と緑色凝灰岩からなる基盤で，2 回目は第四紀のワトゥマヌ，ロトゲサおよび円錐火山群を特徴とする火山岩類である．

浅部井 MTL-1，MT-1 および MT-2 の坑井地質によれば，MT-1 および MT-2 の層序はほぼ一致するが，MTL-1 はデイサイト質の火山灰を特徴とする．全体として，マタロコ地熱地帯の地下地質は，第四紀のデイサイト質火山灰と，火砕岩類および普通角閃石安山岩を挟む輝石安山岩からなる．

（要旨翻訳：水垣桂子（地圏資源環境研究部門））