Bulletin of the Geological Survery of Japan, vol. 53 (2/3), p. 307-321, 2002

# Exploratory well drilling and discharge test of wells MT-1 and MT-2 in the Mataloko geothermal field, Flores, Indonesia

Yoshikazu SUEYOSHI[1], Koji MATSUDA[1], Tadahiko SHIMOIKE[1], Takehiro KOSEKI[2], Hiroshi TAKAHASHI[2], Masao FUTAGOISHI[3], Kastiman SITORUS[4] and Janes SIMANJUNTAK[4]

Yoshikazu SUEYOSHI, Koji MATSUDA, Tadahiko SHIMOIKE, Takehiro KOSEKI, Hiroshi TAKAHASHI, Masao FUTAGOISHI, Kastiman SITORUS and Janes SIMANJUNTAK (2002) Exploratory well drilling and discharge test of wells MT-1 and MT-2 in the Mataloko geothermal field, Flores, Indonesia. *Bull. Geol. Surv. Japan,* vol. 53 (2/3), p. 307-321, 12 figs., 4 tables.

**Abstract:** Two geothermal exploratory wells have been drilled in the Mataloko geothermal area in the central part of Flores, where geothermal energy is expected to be stored in large quantities. The first well MT-1 was planned to a depth of 1000 m at a site located in the northern side of Wae Luja River. While drilling at a depth of 207.26 m, a high pressure steam zone was encountered, causing steam to flow through the conductor casing. The valve was closed to prevent the steam to flow to the surface, but the steam started to appear at the surface. It was considered that a surface blow-out around the well might have occurred. Under these conditions, consolidation grouting around well MT-1 was carried. After the completion of the grouting operation, well MT-1 was successfully killed with fresh water followed by a cement slurry. Drilling of second well MT-2 was planned to a depth of 230 m at the same drilling site as well MT-1. A steam zone was encountered around 162.35 m during drilling. A temporary flow test was carried out successfully and the total depth was decided. A proper well test was carried out using the Lip-Pressure method (James, R., 1962). The testing included the recording of wellhead pressure, a parameter to calculate the steam flow rate. While fluids were being discharged, samples were taken for chemical and isotopic analyses. Based on the discharge test result, the maximum steam rate of 4.57 kg/sec. (16.5 ton/hr) was calculated.

## 1. Introduction

A five-year international cooperation project on geothermal research between Japan and Indonesia was signed in 1998 by three organizations, New Energy and Industrial Technology Development Organization (NEDO; Japan), Geological Survey of Japan (GSJ) and Directorate General Geology and Mineral Resources (DGGMR; Indonesia). Based on the Agreement, regional and detailed studies including geological, geochemical and geophysical surveys were conducted in and around the Bajawa area in Flores from 1998 to 2000.

The Mataloko geothermal field is the one of most active fields in the Bajawa area, where many indications for the existence of geothermal resources such as fumaroles, hot springs and hydrothermal alteration zones are present. Two exploratory wells (MT-1 and MT-2) were drilled at a site selected based on the results of the geoscientific surveys. Geological analysis of the samples taken from both wells has also been carried out. A proper discharge test was successfully carried out on well MT-2. The well MT-1 was plugged with cement and abandoned because of on uncontrollable steam blow-out to the surface from the well bore. Wellhead pressure, parameters to calculate steam flow rate and sampling of discharge fluids for chemical and isotopic analyses were collected. This paper describes the results of the drilling operations for the two wells (MT-1 and MT-2) including well geology and discharge test of well MT-2.

[1] West Japan Engineering Consultants, Inc., Watanabe-dori 2-1-82, Chuo,Fukuoka, 810-0004 Japan
[2] Mitsubishi Material Natural Resources Development Corp., Nihonbashi Hamacho 3-21-1, Chuo, Tokyo, 103-0007 Japan
[3] New Energy and Industrial Technology Development Organization, Sunshine 60, 30F, Higashi-Ikebukuro 3-1-1, Toshima, Tokyo, 170-6030 Japan
[4] Directorate of Mineral Resources Inventory. Jl. Soekarno-Hatta No.444, Bandung, 40254 Indonesia

Keywords: geothermal fluid, blow-out, well testing, well drilling, Mataloko, Flores Island

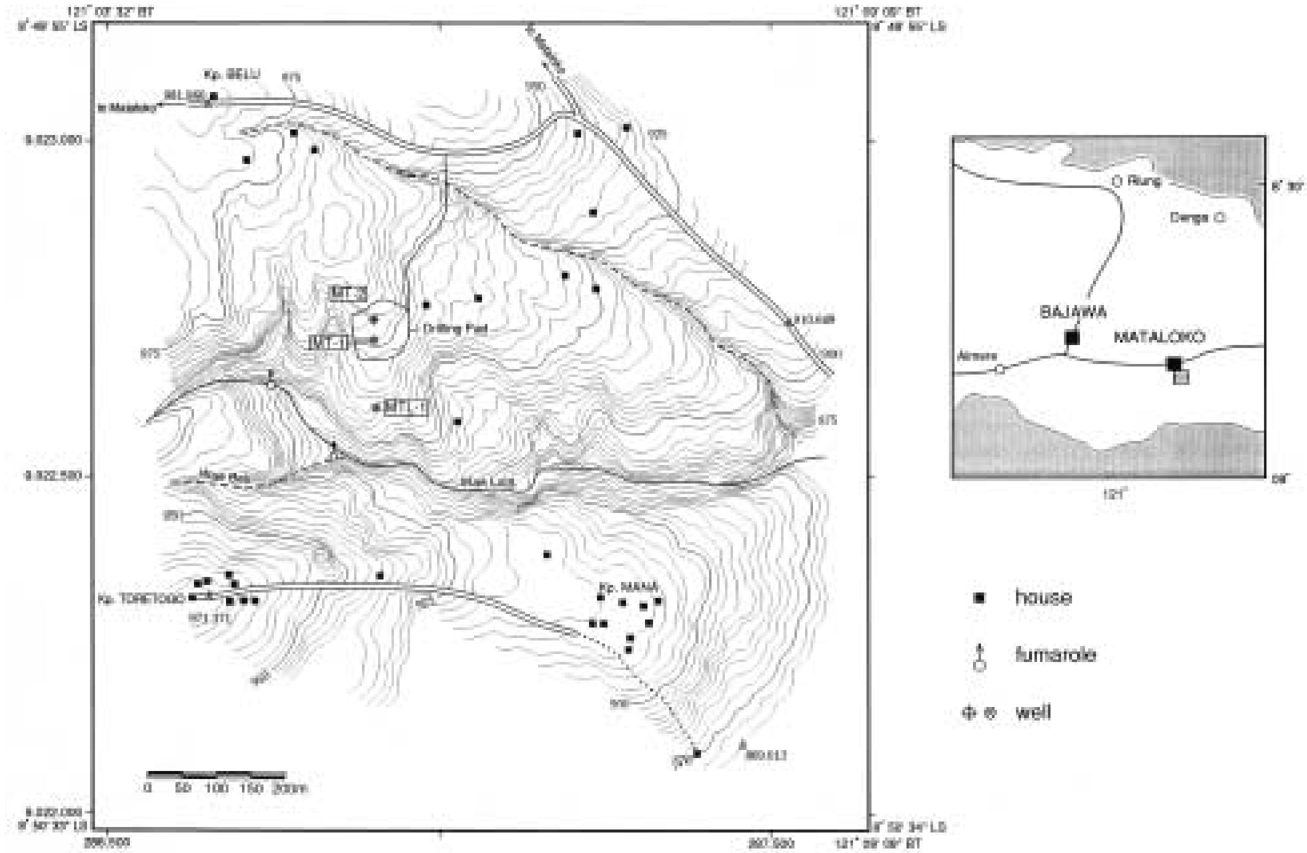


Fig. 1 Location of the exploratory wells MT-1 and MT-2.

## 2. Well drilling

Wells MT-1 and MT-2 have been drilled on the northern side of Wae Luja River. This site was selected based on the results of the geoscientific surveys (Fig. 1). The drilling operation of well MT-1 was started on October 11, 2000 and terminated on October 21, 2000 at a total depth of 207.26 m. The drilling operation of well MT-2 was started on January 5, 2001 and terminated on January 17, 2001 at a total depth of 163.25 m.

### 2.1 Well MT-1

#### 2.1.1 Drilling

The mobilization of the drilling equipment and rig-up were completed on October 10, 2000. The drilling of the 12-1/4" hole was started at 10:30 on October 11th. During the drilling of the 12-1/4" hole, no loss of circulation zone was encountered. Drilling formation continued to a depth of 18.1 m and a 10" conductor casing was successfully run and cemented on the bottom. After waiting 20 hours for the cement to set, the 10" conductor casing was cut at the surface and a 10" wellhead valve and 2" kill-line valve were installed.

A 9-5/8" bit was run in the hole after the opening and closing test of the wellhead valves. The top of the cement in the conductor casing was tagged at 17 m and reaming of the cement was started on October 14th. After reaming the cement, drilling of the formation was started with the same bit. During the drilling in this period, especially from 189 m to 207.26 m, a rapid change of the drilling conditions were observed; the rate of penetration was faster than that at shallower depths and flow-line temperature of the returned mud was higher. It was considered that these changes in the drilling condition indicated the existence of high temperature geothermal fluids. Drilling was suspended at a depth of 207.26 m to set a 8" production casing and install a blow-out preventer to drill a deeper zone safely.

#### 2.1.2 Blow-out

After the circulation of drilling fluid to cool the hole and remove the cuttings from the well bore, it was tried to pull the bit out to the surface. However, steam with gases started to enter the well bore from the formation once circulation was suspended. This made it impossible to pull the bit to the surface without having a blow-out preventer installed to kill the well with fresh water. Finally the connection of the drill pipe was broken to allow the 10" valve to be closed and prevent the steam from coming out of the hole. Simultaneously the steam flow started through the conductor casing and 10"

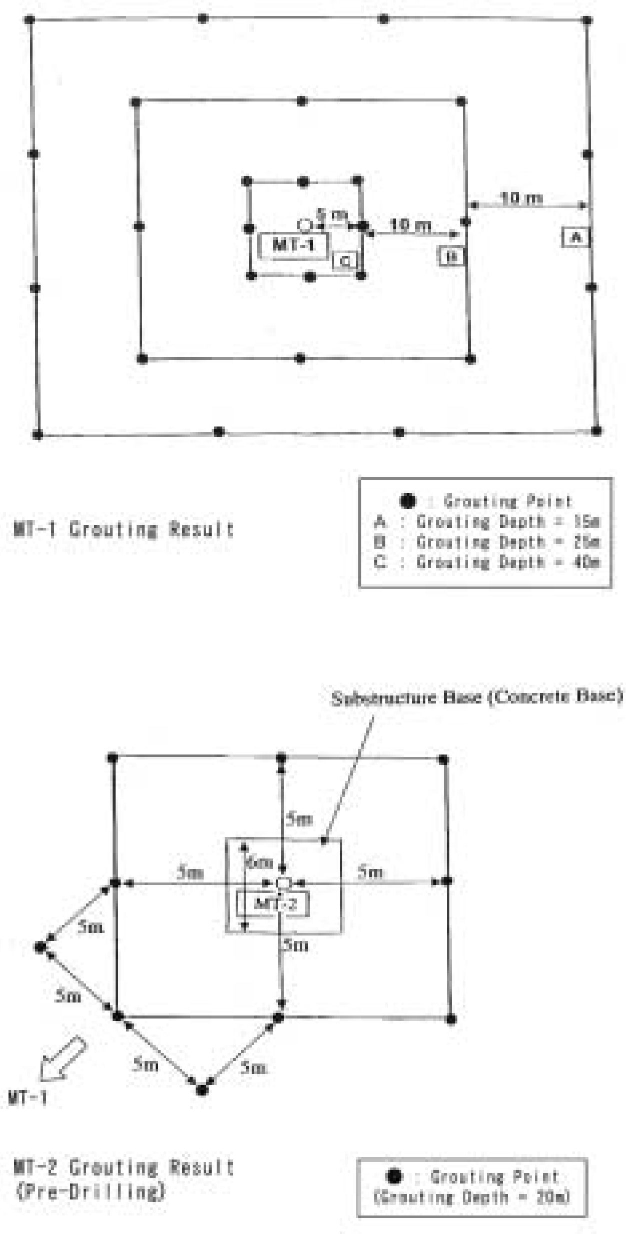


Fig. 2 Distribution of grouting slim holes.

wellhead valve. To prevent the steam flow to the surface and kill the well, an attempt to close the wellhead valve was made, but it was unsuccessful because of a breakdown of the valve. After fixing it, the valve was completely closed. However soon after the valve was closed, steam simultaneously started to pour out around the well. It was considered that a surface blow-out might have occurred. To avoid this, the valve was opened again to release the steam pressure and the well was allowed to continue to flow vertically.

**2.1.3** Grouting

In order to kill the well effectively, consolidation grouting operations around well MT-1 was started. Before grouting, a horizontal steam flow line was installed from the MT-1 wellhead to direct the steam to a newly built rock silencer to minimize the noise of the steam flow. Twenty-eight slim holes were drilled around well MT-1 to a depth ranging from 15 m to 40 m. Figure 2 shows the distribution of these slim holes used for grouting. A cement slurry was injected to the formation through each slim hole to consolidate the shallow formations. After completion of grouting, the wellhead valve was successfully closed without any steam escaping around the well. It was confirmed that the grouting operation for well MT-1 was successfully completed. A second well, MT-2 was then planned. The pre-drilling consolidation grouting was carried out around the proposed new location to prevent the problems experienced in well MT-1.

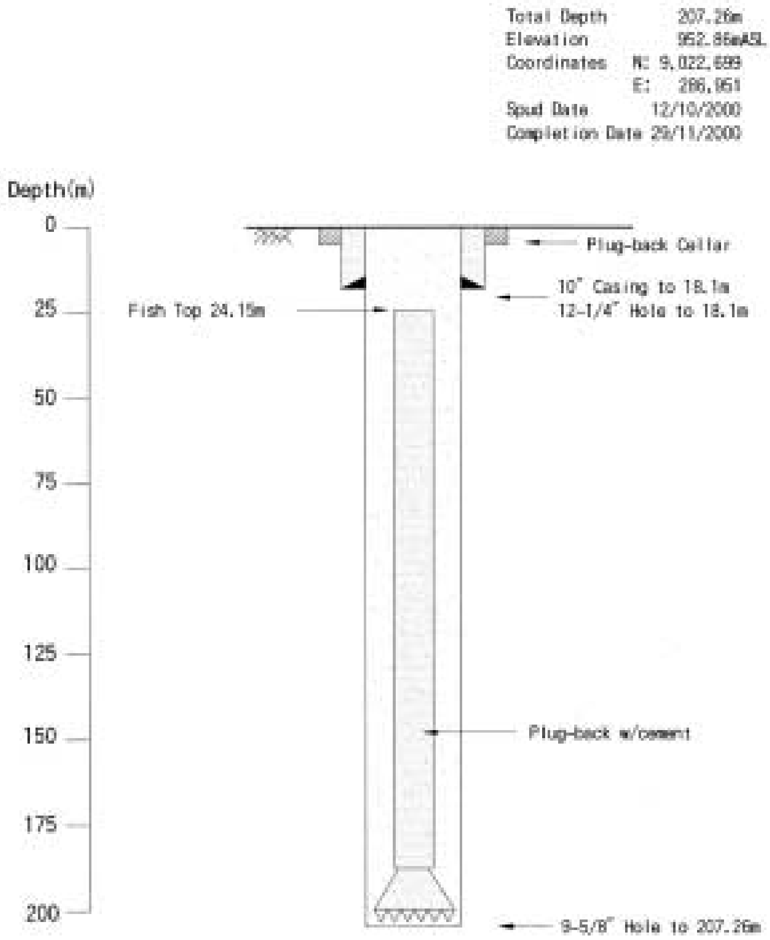


Fig. 3 Well MT-1 final profile.

**2.1.4** Killing well

After the completion of the grouting operations, the 10" wellhead valve was gradually closed while 200 liters/minute of fresh water was pumped into well MT-1. The pumping of fresh water was continued for 6 hours without any problem, thus it was considered that the well had completely cooled down. Afterwards 31 $m^3$ of cement slurry was successfully pumped to plug the well bore from the bottom to the surface. Finally the 10" conductor casing was cut at the ground level and a steal cap was welded to avoid a future steam blow-out (Fig. 3).

## 2.2 Well MT-2

**2.2.1** Drilling

The mobilization of the drilling equipment and rig-up operations were completed on January 4, 2001. The drilling of a 12-1/4" hole was started at 8:00 on January 5th. Drilling formations continued to a depth of 20.0 m, then a 10" conductor casing was successfully run to 17.6 m and cemented. After waiting 20 hours for the cement to set, the 10" conductor casing was cut at the surface and a 10" wellhead valve and 2" kill-line valve were installed.

A 9-5/8" bit was run in hole after the opening and closing test of the wellhead valve was done. The top of the cement in the conductor casing was tagged at 16 m and reaming of the cement was started on January 7th. During the drilling of the 9-5/8" hole, no loss of circulation zone was encountered. Drilling formations continued to a depth of 104.56 m, and a temperature and pressure survey was run from the surface to bottom hole. After the temperature survey was completed, a 8" production casing was successfully run to 100.12 m and cemented. The 8" production casing was cut at the surface and a 8" wellhead valve, 8" blow-out preventer and 2" kill-line valve were installed.

A 7-5/8" bit was run in hole after the pressure test of the wellhead valves and blow-out preventer. The top of cement in the production casing was tagged at 90 m and reaming of the cement was started on January 13th. After reaming the cement, the drilling of the formation was started with the same bit. During drilling at a depth of 155 m, the

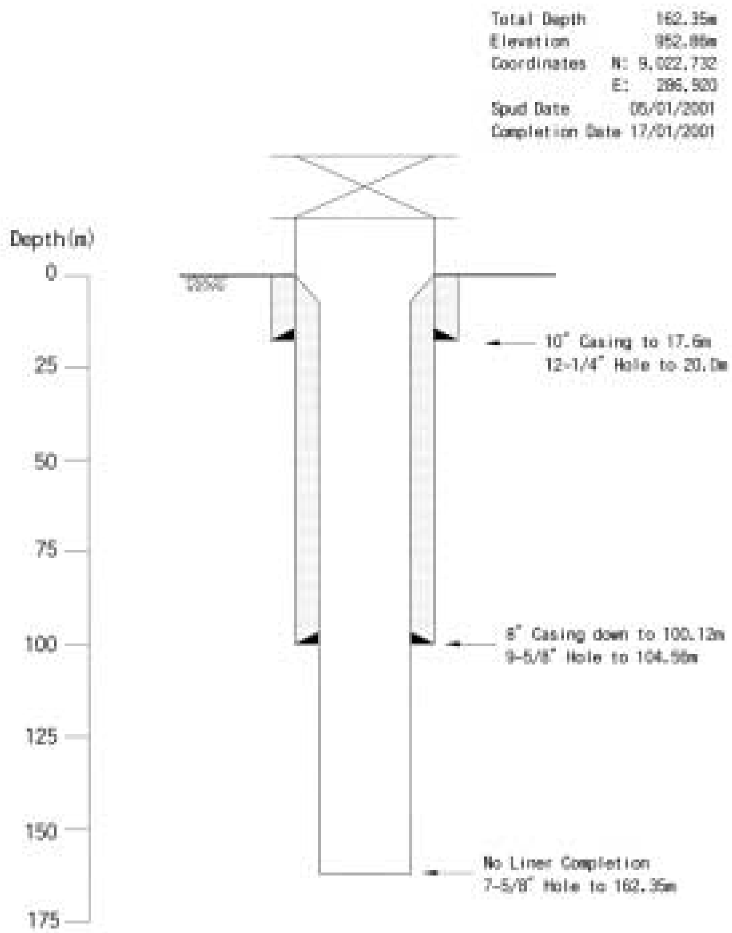


Fig. 4 Well MT-2 completion diagram.

flow-line temperature of the returned mud started to rise similarly to what occurred when drilling the steam zone of well MT-1. It was considered that this change in mud temperature indicated the existence of high temperature geothermal fluids. Drilling was carefully continued to a total depth of 162.35 m. Well MT-2 was completed at this depth to carry out a discharge test (Fig. 4).

**2.2.2** Well survey

Temperature and pressure surveys were done down to a depth of 104.56 m. Table 1 shows the result of temperature surveys at standing times of 2 hours 20 minutes, 4 hours 59 minutes. Figure 5 shows the temperature profile. After a second survey, the recovery temperature was detected at the 104 m depth. The maximum temperature at the recovery zone was 130.4 ℃ with standing time of 6 hours 50 minutes while the temperature was continuously increasing at the end of the measurement. The pressure survey indicated a maximum pressure of 1.08 MPa at the 104 m depth.

## 3. Well geology

The stratigraphic units of volcanic rocks in the Bajawa area can be divided into 5 units (Koseki, 2000): Older Volcanics (V1), Bajawa Caldera Volcanics (Bc), Cone Volcanics (C1, C2) and Inerie Volcanics (Ie) in ascending order (Fig. 6). Two wells, MT-1 and MT-2 were drilled entirely within the Bc unit. This unit extensively distributed in the central to northern part of the Bajawa area and accumulates mostly within the Bajawa caldera depression.

The geology of wells MT-1 and MT-2 is mainly composed of andesite lava and andesitic tuff breccia (Figs. 7 and 8). The shallow part of these wells (down to about 140 m in depth) is mainly composed of andesite with minor intercalations of andesitic tuff breccia. White alteration with argillization is found at the top of this zone. Andesite is dark gray and contains phenocrysts of plagioclase, augite and hypersthene, however most andesite is argillized and changed to greenish gray to gray. The deeper part of these wells (from about 140 m to 200 m in depth)

Table 1 Temperature survey data of well MT-2.

First Temperature Measurement MT-2 (Run-1)
Date : Jan 8,01
Start : 16:05
Finished : 16:30

| Depth (m) | Temperature (°C) |
|---|---|
| | |
| 0 | 28.8 |
| 5 | 34.0 |
| 10 | 37.0 |
| 15 | 37.7 |
| 20 | 38.7 |
| 25 | 39.2 |
| 30 | 39.2 |
| 35 | 41.2 |
| 40 | 42.8 |
| 45 | 45.6 |
| 50 | 47.7 |
| 55 | 48.7 |
| 60 | 49.4 |
| 65 | 51.3 |
| 70 | 53.0 |
| 75 | 53.7 |
| 80 | 52.0 |
| 85 | 45.0 |
| 90 | 44.4 |
| 95 | 44.0 |
| 100 | 44.3 |
| 101 | 50.0 |

Circulation 13:15
Stop : 13:45

| Depth (m) | Time | Temperature (°C) |
|---|---|---|
| | | |
| 104 | 16:30 | |
| 104 | 16:35 | 75.8 |
| 104 | 16:40 | 81.2 |
| 104 | 16:45 | 84.7 |
| 104 | 16:50 | 87.5 |
| 104 | 16:55 | 89.7 |
| 104 | 17:00 | 91.7 |
| 104 | 17:05 | 93.5 |
| 104 | 17:10 | 94.8 |
| 104 | 17:15 | 96.0 |
| 104 | 17:20 | 97.6 |
| 104 | 17:25 | 99.0 |
| 104 | 17:30 | 99.5 |
| 104 | 17:40 | 102.5 |
| 104 | 17:50 | 104.3 |
| 104 | 18:00 | 106.9 |
| 104 | 18:10 | 108.7 |
| 104 | 18:20 | 110.6 |
| 104 | 18:30 | 112.0 |

Second Temperature Measurement MT-2 (Run-2)
Date : Jan 8,01
Start : 18:44
Finished : 19:00

| Depth (m) | Temperature (°C) |
|---|---|
| | |
| 0 | 24.6 |
| 5 | 38.7 |
| 10 | 40.0 |
| 15 | 39.9 |
| 20 | 40.7 |
| 25 | 41.6 |
| 30 | 41.7 |
| 35 | 45.6 |
| 40 | 49.8 |
| 45 | 53.4 |
| 50 | 57.4 |
| 55 | 58.1 |
| 60 | 53.8 |
| 65 | 55.9 |
| 70 | 57.2 |
| 75 | 56.0 |
| 80 | 55.9 |
| 85 | 55.2 |
| 90 | 57.0 |
| 95 | 58.4 |
| 100 | 65.4 |
| 101 | 66.1 |
| 102 | 69.5 |
| 103 | 71.2 |
| 104 | 78.1 |

| Depth (m) | Time | Temperature (°C) |
|---|---|---|
| | | |
| 104 | 19:00 | 97 |
| 104 | 19:05 | 100.9 |
| 104 | 19:10 | 109.2 |
| 104 | 19:15 | 114.7 |
| 104 | 19:20 | 117.5 |
| 104 | 19:25 | 119.5 |
| 104 | 19:30 | 120.9 |
| 104 | 19:35 | 122.0 |
| 104 | 19:40 | 123.1 |
| 104 | 19:45 | 123.9 |
| 104 | 19:50 | 124.7 |
| 104 | 19:55 | 125.4 |
| 104 | 20:00 | 125.7 |
| 104 | 20:05 | 126.1 |
| 104 | 20:15 | 127.6 |
| 104 | 20:25 | 129.0 |
| 104 | 20:35 | 130.4 |

mainly consists of andesitic tuff breccia with minor intercalation of fine tuff. Tuff breccia is gray to light gray with argillization and contains of andesite fragments. The fine tuff is bluish gray with strong argillization.

The alteration found by wells MT-1 and MT-2 is characterized by a strong argillization, developed in tuff breccia. Six alteration zones can be recognized by the distribution of clay and zeolite minerals analyzed by X-ray diffraction (Figs. 7 and 8 and Table 2). The Montmorillonite (Mo) zone is present and abundant at each well. The Chlorite/Montmorillonite (Chl/Mo) mixed-layer zone is present at the deeper part of well MT-1 and characterized by chlorite/montmorillonite mixed-layered minerals. The Kaolinite (Ka) zone is present at each well and the surface around the Wae-Luja River, and characterized by abundant kaolinite. It is considered that the Ka zone has been formed by interactions with near surface acid fluids. This acid fluid formed through oxidation of rising $H_2S$ gases upon mixing with surface water. The Alunite (Al) zone is present

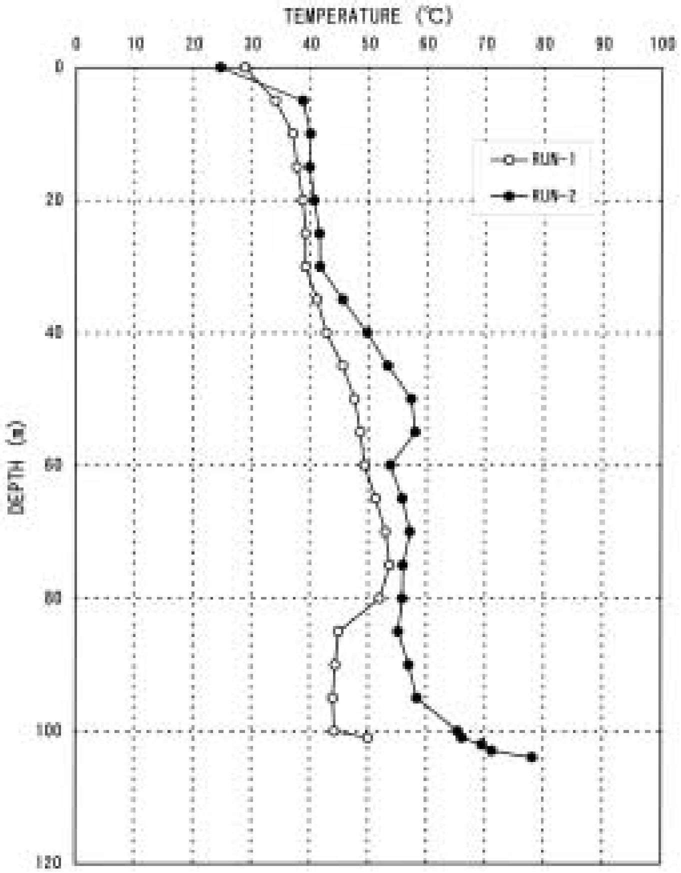


Fig. 5 Temperature results of Well MT-2 (at 104 m).

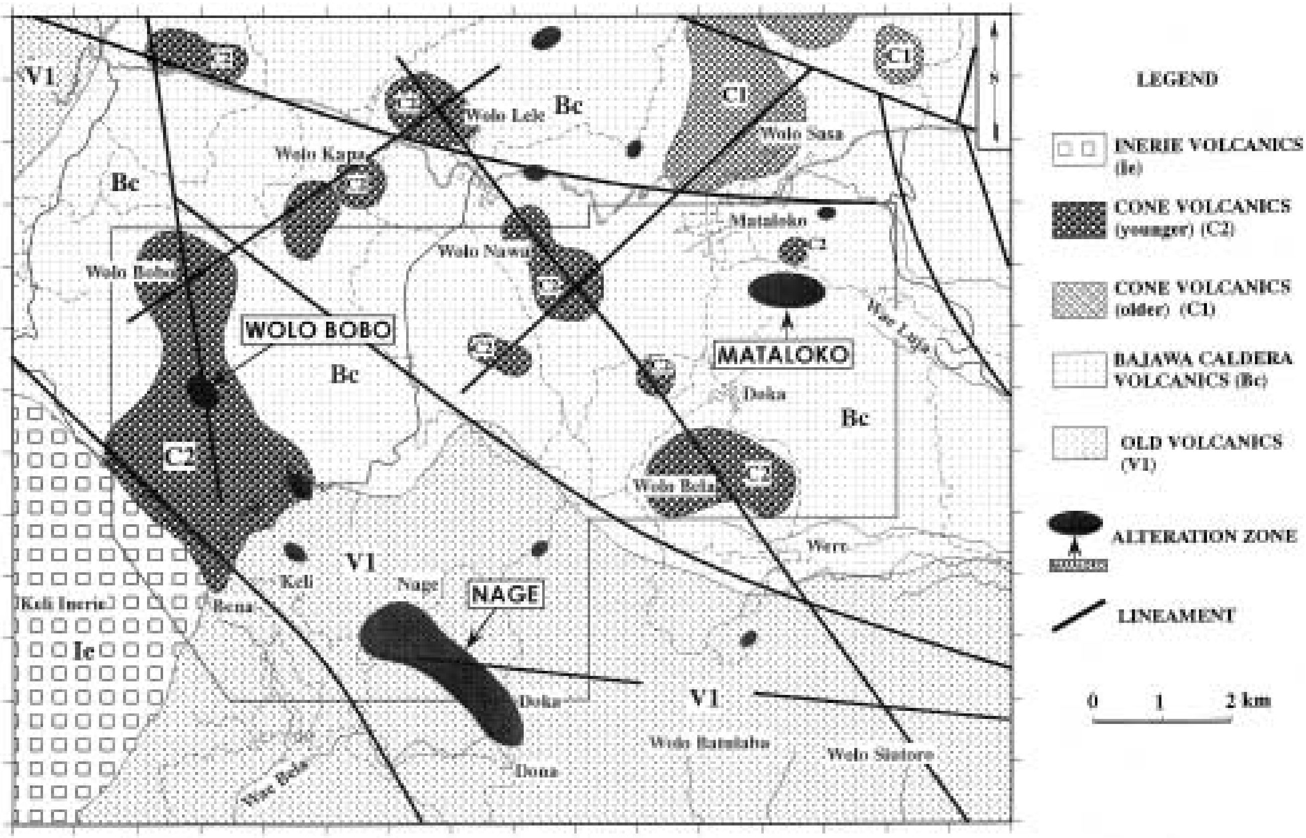


Fig. 6 Geological map of Mataloko area.

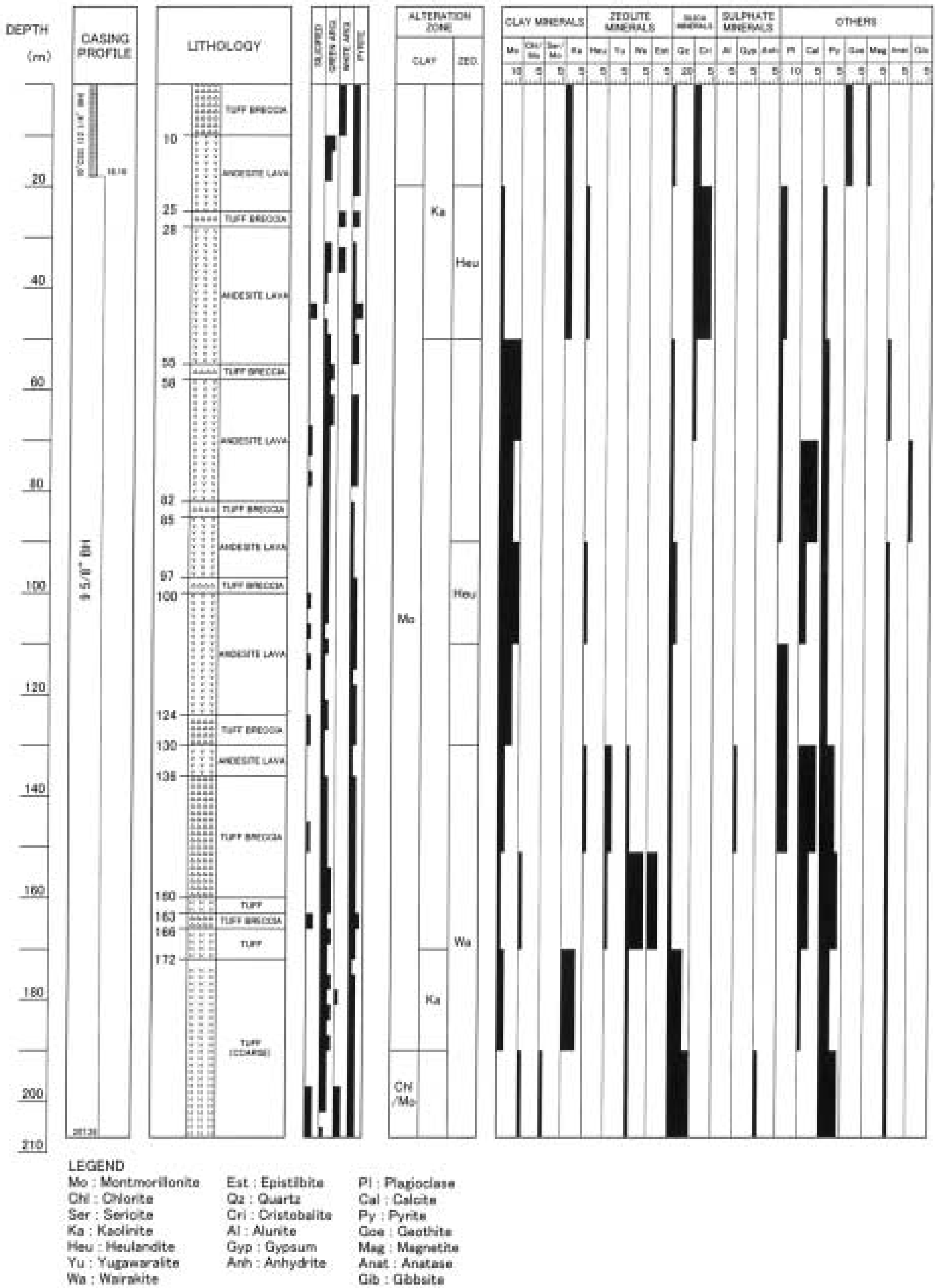


Fig. 7 Geology and distribution of alteration minerals (Well MT-1).

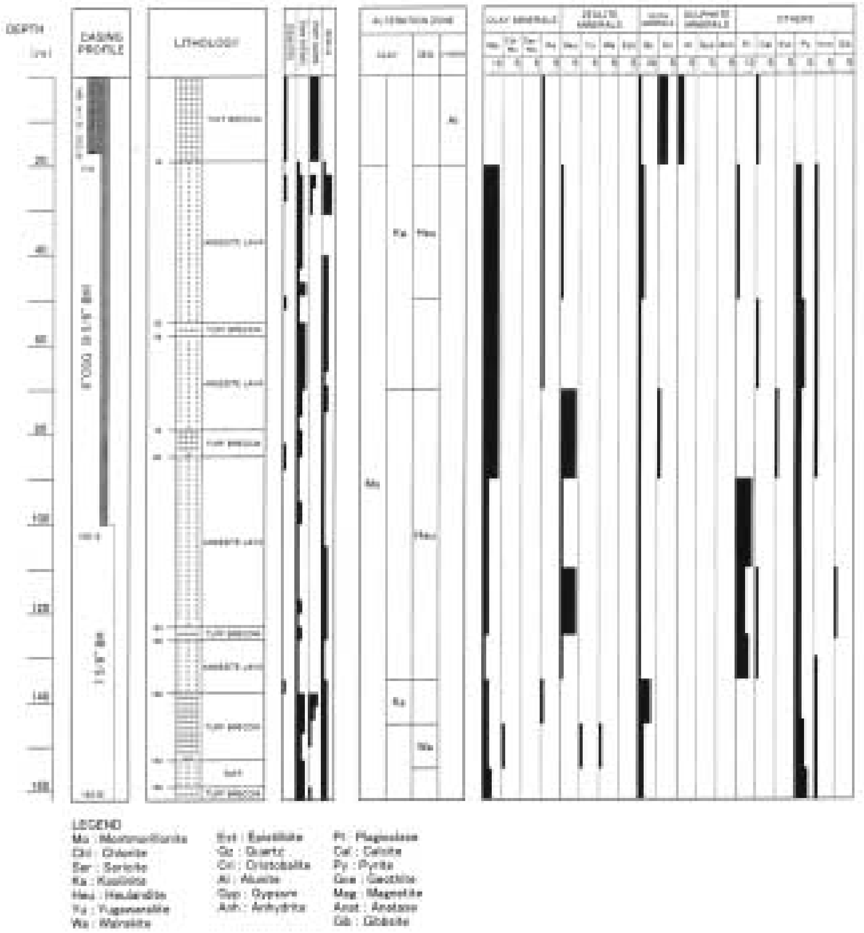


Fig. 8 Geology and distribution of alteration minerals (Well MT-2).

Table 2 Mineral assemblages of the alteration zones.

| ALTERATION ZONE / HYDROTHERMAL MINERALS | CLAY MINERALS | | | ZEOLITE MINERALS | | OTHERS |
|---|---|---|---|---|---|---|
| | Mo | Chl/Mo | Ka | Heu | Wa | Al |
| Montmorillonite | common | | rare | rare | rare | |
| Chl./Mont. | rare | common | | | rare | |
| Kaolinite | rare | | common | rare | rare | common |
| Heulandite | rare | | rare | common | rare | |
| Yugawaralite | rare | | | | rare | |
| Wairakite | rare | common | rare | rare | common | |
| Alunite | | | rare | | | common |
| Quartz | rare | common | common | rare | common | common |
| Cristobalite | rare | | rare | rare | | common |
| Pyrite | common | common | rare | common | common | |

——— common
- - - - - - rare

Mo:montmorillonite zone, Chl/Mo:chl/mo mixed layer zone, Ka:kaolinite zone,

Heu:heulandite zone, Wa:wairakite zone, Al:alunite zone at the surface around the Wae-Luja River and top of well MT-2 and characterized by abundant alunite. The Al zone is considered to have been formed by near surface sulfate-rich acid water. The Heulandite (Heu) zone is present and abundant at each well. The Wairakite (Wa) zone is present and abundant at the deeper part of each well. The argillization develops in the Mo zone and has progressed to form an impermeable layer, which is understood to have become the altered cap rock (Takahashi, 1995). The Wairakite zone is distributed about a 140 m depth at both wells and located below the strongly argillized zone. This zone indicates that geothermal fluids might be high temperature (>200 ℃) and neutral pH fluids.

## 4. Discharge test

In order to evaluate the productivity of well MT-2, a short-term discharge test was carried out from January 22, 2001 to January 27, 2001 immediately after the completion of the drilling works. It was not possible to do the completion tests or bore hole surveys because there was a fear of an unexpected violent steam flow.

### 4.1 Procedure and flow rate measurement method

The wellhead valve was opened two times, on January 18th and January 20th, and it was possible to confirm "only steam" conditions. The flow rate measurements were done using the Lip Pressure method (James, R., 1962). In this method, the total mass flow rate can be calculated using an empirical equation within less than a 3 % error compared to the orifice plate method.

For the discharge tests of well MT-2, the wellhead equipment was set up as shown in Fig. 9. The diameter of the end-pipe of the discharge line was of 77.5 mm (3") or 103.0 mm (4") to establish critical pressure conditions at the end of the pipe. For lip pressure measurements at the end of the pipe, a 3 bar or 10 bar pressure gauge was used. During the discharge tests, the wellhead pressure was varied in approximately three steps by controlling the wellhead valve and changing the discharge end pipe. The wellhead pressure, lip pressure and temperature were recorded every hour in the daytime and every three hours in the nighttime.

### 4.2 Results of discharge test

The wellhead pressure was varied from 0.30 to 0.77 MPag. During the whole period of the tests, the discharge fluid was a single steam phase, but slightly wet steam was observed at a wellhead pressure from 0.7 MPag or higher. This suggests that the discharge steam was close to the saturation condition.

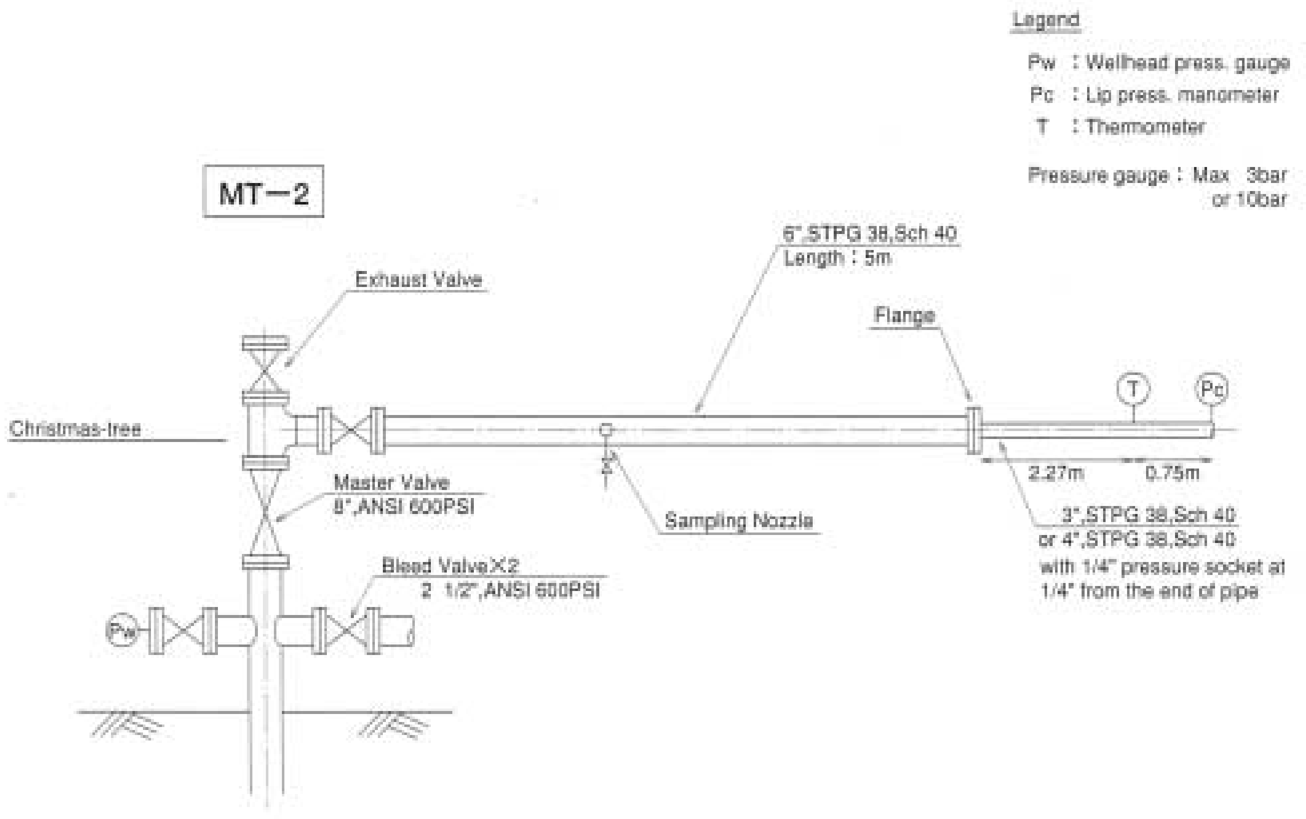


Fig. 9 Wellhead equipment for the discharge test at the well MT-2.

Table 3 Results of discharge test and calculation of flow rate for well MT-2.

| Date/Time | Total Time | $WHV$[1] | $WHP$[2] | $d_c$[3] | $p_c$[4] | $T_c$[5] | $H_{sat}$[6] | $FR_{sat}$[7] |
|---|---|---|---|---|---|---|---|---|
| | hour | % | MPag | mm | MPaa | ℃ | kJ/kg | kg/s |
| 2001/1/22 16:30 | 0.00 | 100 | 0.30 | 77.5 | 0.169 | 120 | 2698.6 | 2.42 |
| 2001/1/22 18:00 | 1.50 | 100 | 0.31 | 77.5 | 0.175 | 120 | 2700.2 | 2.50 |
| 2001/1/22 20:00 | 3.50 | 100 | 0.32 | 77.5 | 0.181 | 120 | 2701.9 | 2.59 |
| 2001/1/22 22:00 | 5.50 | 100 | 0.37 | 77.5 | 0.189 | 120 | 2703.6 | 2.69 |
| 2001/1/23 0:00 | 7.50 | 100 | 0.38 | 77.5 | 0.191 | 120 | 2704.3 | 2.72 |
| 2001/1/23 2:00 | 9.50 | 100 | 0.38 | 77.5 | 0.196 | 123 | 2705.9 | 2.81 |
| 2001/1/23 4:00 | 11.50 | 100 | 0.39 | 77.5 | 0.204 | 125 | 2707.2 | 2.88 |
| 2001/1/23 6:00 | 13.50 | 100 | 0.41 | 77.5 | 0.206 | 125 | 2707.6 | 2.92 |
| 2001/1/23 8:00 | 15.50 | 100 | 0.41 | 77.5 | 0.208 | 125 | 2708.0 | 2.94 |
| 2001/1/23 9:10 | 16.67 | 100 | 0.41 | 77.5 | 0.208 | 125 | 2708.0 | 2.94 |
| 2001/1/23 10:00 | 17.50 | 100 | 0.41 | 77.5 | 0.209 | 125 | 2708.3 | 2.96 |
| 2001/1/23 11:00 | 18.50 | 100 | 0.42 | 77.5 | 0.212 | 125 | 2708.9 | 2.99 |
| 2001/1/23 12:00 | 19.50 | 100 | 0.42 | 77.5 | 0.215 | 125 | 2709.5 | 3.03 |
| 2001/1/23 13:00 | 20.50 | 100 | 0.42 | 77.5 | 0.217 | 125 | 2709.9 | 3.06 |
| 2001/1/23 14:00 | 21.50 | 25 | 0.42 | 77.5 | 0.218 | 125 | 2710.1 | 3.07 |
| 2001/1/23 14:07 | 21.62 | 25 | 0.49 | 77.5 | 0.198 | 122 | 2705.9 | 2.81 |
| 2001/1/23 15:00 | 22.50 | 25 | 0.54 | 77.5 | 0.193 | 120 | 2704.7 | 2.75 |
| 2001/1/23 18:00 | 25.50 | 25 | 0.54 | 77.5 | 0.195 | 125 | 2705.2 | 2.77 |
| 2001/1/23 21:00 | 28.50 | 25 | 0.54 | 77.5 | 0.197 | 122 | 2705.6 | 2.80 |
| 2001/1/24 0:00 | 31.50 | 25 | 0.57 | 77.5 | 0.199 | 122 | 2706.1 | 2.82 |
| 2001/1/24 3:00 | 34.50 | 25 | 0.57 | 77.5 | 0.205 | 125 | 2707.4 | 2.90 |
| 2001/1/24 6:00 | 37.50 | 25 | 0.57 | 77.5 | 0.206 | 125 | 2707.6 | 2.92 |
| 2001/1/24 9:00 | 40.50 | 25 | 0.58 | 77.5 | 0.203 | 125 | 2707.0 | 2.88 |
| 2001/1/24 10:00 | 41.50 | 25 | 0.58 | 77.5 | 0.205 | 125 | 2707.4 | 2.90 |
| 2001/1/24 11:00 | 42.50 | 25 | 0.58 | 77.5 | 0.206 | 125 | 2707.6 | 2.92 |
| 2001/1/24 11:55 | 43.42 | 25 | 0.58 | 77.5 | 0.208 | 125 | 2708.0 | 2.94 |
| 2001/1/24 12:00 | 43.50 | 20 | 0.69 | 77.5 | 0.173 | 120 | 2699.6 | 2.47 |
| 2001/1/24 12:12 | 43.70 | 20 | 0.74 | 77.5 | 0.160 | 116 | 2696.2 | 2.30 |
| 2001/1/24 15:00 | 46.50 | 100 | 0.30 | 103.0 | 0.158 | 128 | 2695.7 | 4.01 |
| 2001/1/24 18:00 | 49.50 | 100 | 0.30 | 103.0 | 0.160 | 130 | 2696.2 | 4.06 |
| 2001/1/24 21:00 | 52.50 | 100 | 0.31 | 103.0 | 0.162 | 130 | 2696.8 | 4.10 |
| 2001/1/25 0:00 | 55.50 | 100 | 0.31 | 103.0 | 0.165 | 132 | 2697.6 | 4.18 |
| 2001/1/25 3:00 | 58.50 | 100 | 0.31 | 103.0 | 0.165 | 132 | 2697.6 | 4.18 |
| 2001/1/25 6:00 | 61.50 | 100 | 0.31 | 103.0 | 0.168 | 131 | 2698.4 | 4.25 |
| 2001/1/25 9:00 | 64.50 | 100 | 0.32 | 103.0 | 0.165 | 133 | 2697.6 | 4.18 |
| 2001/1/25 10:00 | 65.50 | 100 | 0.32 | 103.0 | 0.166 | 131 | 2697.8 | 4.20 |
| 2001/1/25 11:00 | 66.50 | 100 | 0.32 | 103.0 | 0.169 | 132 | 2698.6 | 4.27 |
| 2001/1/25 11:38 | 67.13 | | 0.57 | 103.0 | 0.133 | 123 | 2688.1 | 3.42 |
| 2001/1/25 12:00 | 67.50 | | 0.52 | 103.0 | 0.235 | 137 | 2713.7 | 5.84 |
| 2001/1/25 13:00 | 68.50 | | 0.34 | 103.0 | 0.175 | 133 | 2700.2 | 4.41 |
| 2001/1/25 13:20 | 68.83 | | 0.34 | 103.0 | 0.176 | 132 | 2700.4 | 4.43 |
| 2001/1/25 15:00 | 70.50 | | 0.35 | 103.0 | 0.176 | 132 | 2700.4 | 4.43 |
| 2001/1/25 18:00 | 73.50 | | 0.37 | 103.0 | 0.176 | 132 | 2700.4 | 4.43 |
| 2001/1/25 21:00 | 76.50 | | 0.38 | 103.0 | 0.178 | 132 | 2701.2 | 4.50 |
| 2001/1/26 0:00 | 79.50 | | 0.38 | 103.0 | 0.178 | 132 | 2701.2 | 4.50 |
| 2001/1/26 3:00 | 82.50 | | 0.38 | 103.0 | 0.178 | 132 | 2701.2 | 4.50 |
| 2001/1/26 6:00 | 85.50 | | 0.36 | 103.0 | 0.181 | 133 | 2701.9 | 4.57 |
| 2001/1/26 9:00 | 88.50 | | 0.36 | 103.0 | 0.178 | 133 | 2701.2 | 4.50 |
| 2001/1/26 10:00 | 89.50 | | 0.36 | 103.0 | 0.178 | 133 | 2701.2 | 4.50 |
| 2001/1/26 11:37 | 91.12 | | 0.60 | 77.5 | | 142 | | |
| 2001/1/26 12:00 | 91.50 | | 0.59 | 77.5 | 0.291 | 140 | 2723.3 | 4.04 |
| 2001/1/26 14:00 | 93.50 | | 0.77 | 77.5 | 0.216 | 126 | 2709.7 | 3.05 |
| 2001/1/26 15:00 | 94.50 | | 0.77 | 77.5 | 0.216 | 126 | 2709.7 | 3.05 |
| 2001/1/26 18:00 | 97.50 | | 0.77 | 77.5 | 0.216 | 126 | 2709.7 | 3.05 |
| 2001/1/26 21:00 | 100.50 | | 0.77 | 77.5 | 0.217 | 126 | 2709.9 | 3.06 |
| 2001/1/27 0:00 | 103.50 | | 0.77 | 77.5 | 0.217 | 126 | 2709.9 | 3.06 |
| 2001/1/27 3:00 | 106.50 | | 0.77 | 77.5 | 0.217 | 126 | 2709.9 | 3.06 |
| 2001/1/27 6:00 | 109.50 | | 0.77 | 77.5 | 0.217 | 126 | 2709.9 | 3.06 |
| 2001/1/27 9:00 | 112.50 | | 0.77 | 77.5 | 0.217 | 128 | 2709.9 | 3.06 |
| 2001/1/27 10:00 | 113.50 | | 0.77 | 77.5 | 0.215 | 128 | 2709.5 | 3.03 |
| 2001/1/27 11:00 | 114.50 | | 0.60 | 77.5 | 0.296 | 140 | 2724.1 | 4.11 |
| 2001/1/27 12:00 | 115.50 | | 0.58 | 77.5 | 0.292 | 135 | 2723.5 | 4.05 |
| 2001/1/27 13:00 | 116.50 | | 0.58 | 77.5 | 0.292 | 135 | 2723.5 | 4.05 |

[1] well head valve openning ratio
[2] well head pressure
[3] diameter of discharge pipe
[4] lip pressure (pressure at the end of discharge pipe)
[5] temperature at the middle of discharge pipe
[6] saturated fluid enthalpy at the lip pressure
[7] discharge flow rate assuming saturation state

The measured parameters and calculated steam flow rates are presented in Table 3. The flow rate was calculated assuming the discharge steam was entirely in the saturation state. Specific enthalpy of the discharge fluid was read from the steam tables based on the measured lip pressure. The calculated flow rates range from 2.30 to 5.84 kg/s (8.27-21.0 tons/hr). However, the highest flow rate was observed instantaneously with the re-opening of the wellhead valve after a temporary shut-in to change the discharge pipe. The observed lip pressure was likely to be affected by the discharge of condensed water in the borehole accumulated during the shut-in. Not taking into account these data, the highest

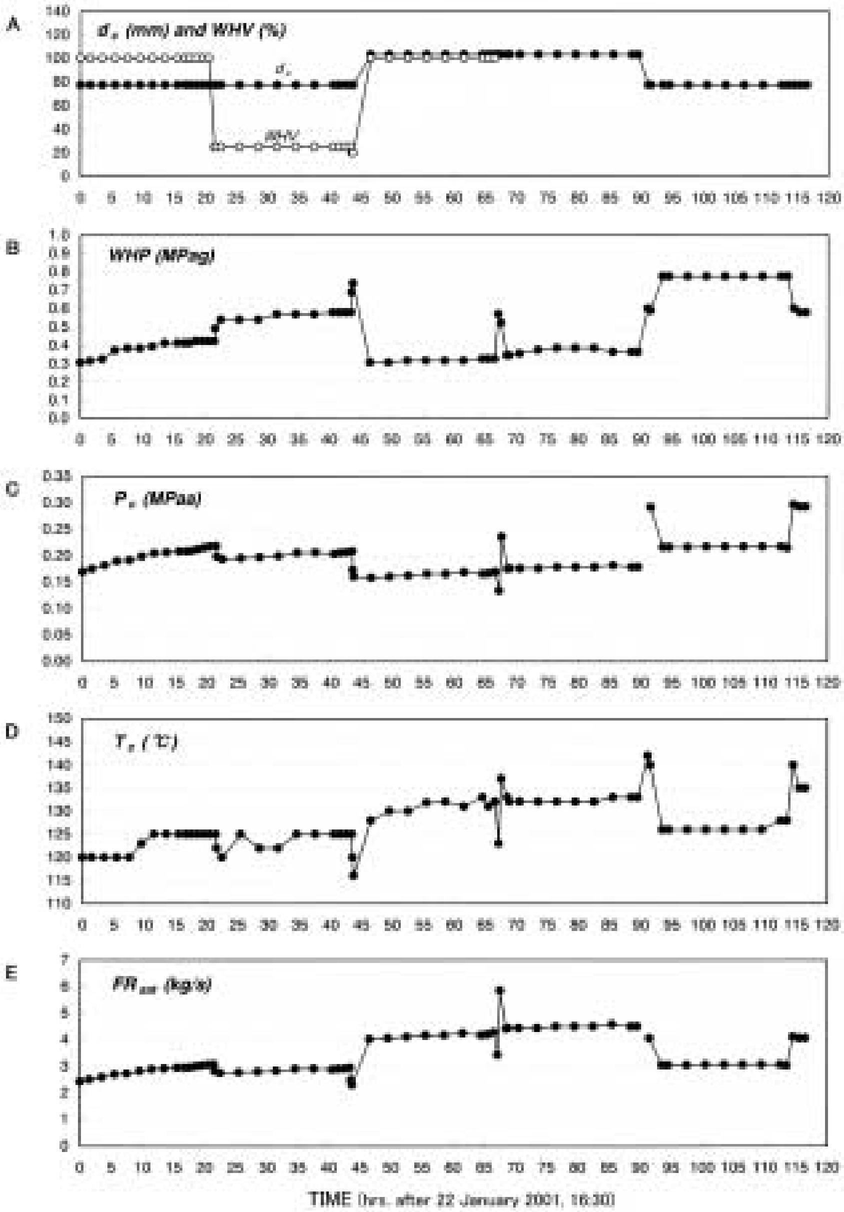

Fig. 10 Trend diagram of measured parameters and calculated steam flow rate for the discharge test of the well MT-2. The definitions for the parameters in diagram are mentioned in Table 3.

flow rate was calculated as 4.57 kg/s (16.5 tons/hr) for a wellhead pressure of 0.36 MPag, 85.5 hours after the initial well opening.

The measured parameters during the tests and calculated steam flow rate are shown in Fig. 10. Wellhead pressure, lip pressure and flow rate rose gradually with time until the total discharge time about 43 hours. After the measurement at the discharge time of 43.42 hours from initial discharge, it was tried to increase the wellhead pressure to about 8 MPag at wellhead. However, after throttling the valve (20 % open) and at a wellhead pressure over 7 MPag, the discharge conditions turned drastically unstable. The wellhead valve was temporary shut-in and the 77.5 mm (3") diameter discharge pipe was replaced by a 103.0 mm (4") diameter pipe. During discharge times from 46.50 hours to 66.50 hours, the discharge conditions were comparatively stable at a wellhead pressure around 0.3 MPag, with a slight increase of wellhead pressure, lip pressure and flow rate. From the discharge time of 67.13 hours to the end of the test, wellhead pressure, lip pressure and flow rate was almost stable, excluding times when the wellhead valve was throttled or closed to replace the discharge pipe.

### 4.3 Data analyses and discussion

Figure 11 shows the mass flow rate against wellhead pressure calculated assuming the steam saturation state. The data collected at discharge

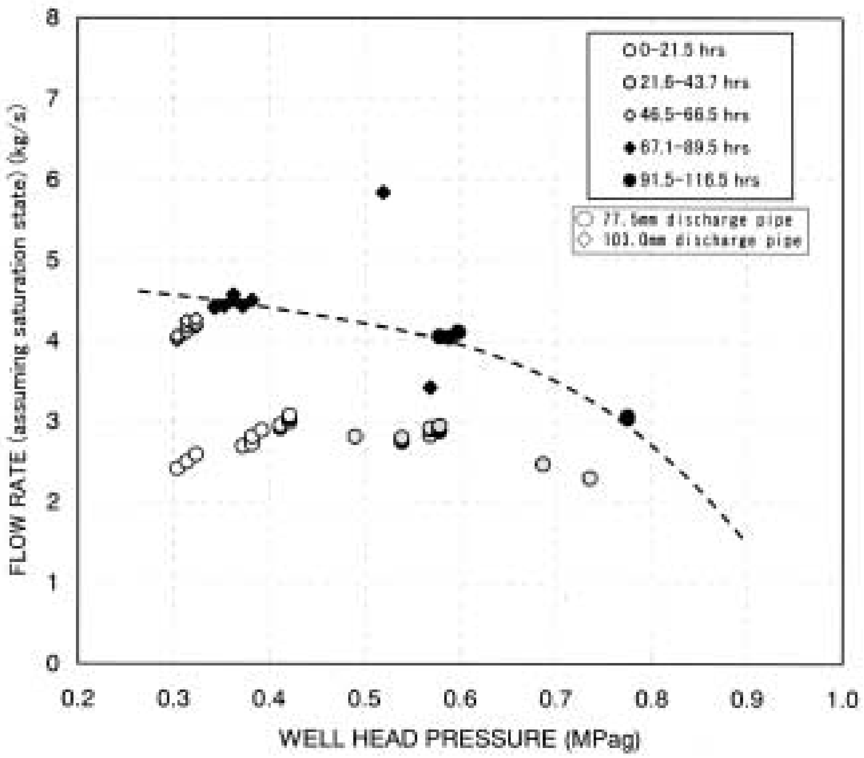


Fig. 11 Flow rate vs. wellhead pressure plot for well MT-2.

times from 0 to 66.5 hours shows relatively lower flow rates. This is thought to be affected by the drilling mud in the formations. Thus the discharge characteristic curve was constructed using data collected in the later period of the discharge test (from 67.1 to 116.5 hours). The shape of the discharge characteristic curve is a typical curve showing a decline of flow rate as wellhead pressure increases. Because there are no irregularities observed in this curve, it is suggested that there are no multiple feed points of different P-T conditions in the borehole. This is supported by no recordings of circulation losses during drilling. A single feed point may exist near the bottom of the hole, probably from 162.35 m to 155 m where the returned mud temperature started to rise during the drilling.

Since injection test and bore hole surveys were not been carried out, the temperature, pressure and permeability of the geothermal reservoir were estimated through well bore simulation using the data collected during the discharge tests. Table 4 shows the input data and Fig. 12 shows the result of matching well discharge characteristic. The following parameters were input as constant values:

- Reservoir pressure: 1.47 MPaa; based on the maximum shut-in wellhead pressure observed prior to the discharge test
- Reservoir temperature: 197.37 ℃; saturation temperature at 1.47 MPaa
- Production casing: 101.12 m in depth and 0.20 m diameter; actual values
- Open hole: 0.194 m diameter; drilling bit diameter

Table 4 Input and output parameters for matching analysis of the well discharge characteristic for well MT-2.

*INPUT DATA*

| | |
|---|---|
| RESERVOIR PRESSURE: | 1.47 MPaa |
| RESERVOIR TEMPERATURE: | 197.37℃ |
| TRNSMISSIVITY (kh): | 3.50 darcy-m |
| PRODUCTION CASING: | 101.12m-depth |
| PRODUCTION CASING: | 0.200m-diameter |
| OPEN HOLE: | 0.194m-diameter |
| FEED POINT: | 162.35m-depth |
| SKIN FACTOR: | 0 |
| FLASH POINT: | 500m away from the well |

*OUTPUT DATA*

| WHP (MPag) | Flow Rate (kg/s) | Enthalpy (kJ/kg) | Feed Point P. (MPaa) | Feed Point T. (℃) |
|---|---|---|---|---|
| 1.12 | 1.39 | 2791.5 | 1.22 | 188.8 |
| 1.07 | 1.67 | 2791.5 | 1.17 | 187.0 |
| 1.01 | 1.94 | 2791.5 | 1.12 | 184.8 |
| 0.96 | 2.22 | 2791.5 | 1.06 | 182.5 |
| 0.90 | 2.50 | 2791.5 | 1.01 | 180.2 |
| 0.84 | 2.78 | 2791.5 | 0.95 | 177.8 |
| 0.78 | 3.06 | 2791.5 | 0.89 | 175.1 |
| 0.72 | 3.33 | 2791.5 | 0.83 | 172.2 |
| 0.66 | 3.61 | 2791.5 | 0.78 | 169.3 |
| 0.58 | 3.89 | 2791.5 | 0.71 | 165.3 |
| 0.51 | 4.17 | 2791.5 | 0.64 | 161.2 |
| 0.42 | 4.44 | 2791.5 | 0.56 | 156.5 |
| 0.34 | 4.72 | 2791.5 | 0.50 | 151.5 |
| 0.22 | 5.00 | 2791.5 | 0.40 | 143.9 |

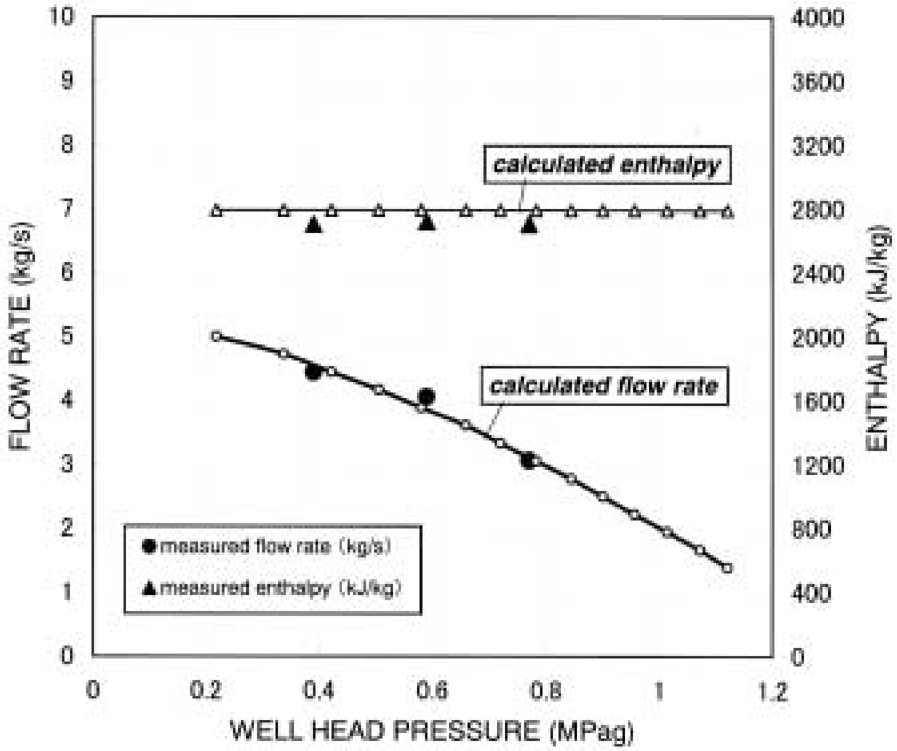


Fig. 12 Result of matching analysis of well discharge characteristic for well MT-2.

| | |
|---|---|
| -Feed point | 162.35 m; bottom of the hole |
| -Skin factor | 0 |
| -Flash point | 500 m away from the well; assuming reservoir fluid of a single vapor phase in a dynamic condition |

Transmissivity was used as a varying parameter in a trial-and-error calculation for the curve matching. The resulting value of transmissivity was 3.50 darcy-m, which is an appropriate value for a typical production well. The successful result of the matching analysis indicates that the assumed constant values, reservoir pressure of 1.47 MPaa and reservoir temperature of 197.37 ℃, and assumed reservoir fluid of a single vapor phase in a dynamic condition are also appropriate as properties of the geothermal reservoir.

## 5. Conclusions

The following is concluded from the results of drilling and testing of the exploratory wells MT-1 and MT-2.

(1) Based on the drilling results of the wells MT-1 and MT-2, steam zones exist at around both wells below the 155m depth.

(2) Existence of a wairakite zone in both wells and results of this discharge test of well MT-2 strongly indicate that the temperature of the geothermal fluids might be higher than 200 ℃ and neutral pH.

(3) According to the results of the Lip Pressure method, the flow rate from well MT-2 was calculated as 2.30 to 4.57 kg/s (8.27-16.5 tons/hr) of steam assuming a steam saturation condition.

(4) The discharge characteristic of the well MT-2 in conjunction with the drilling results suggests a single feed point near the bottom of the hole, possibly from 155 m to 162.35 m in depth.

(5) The result of the matching analysis using a well-bore simulation program indicates a reservoir pressure of 1.47 MPaa, reservoir temperature of 197.37 ℃, transmissivity of 3.50 darcy-m and reservoir fluid of a single vapor phase in a dynamic condition for well MT-2.

**Acknowledgements**: This project is an international cooperation research project between Japan and Indonesia and was entrusted by NEDO to WJEC and MRC for its execution. We would like to express our sincere appreciation to NEDO and related authorities for their permission to prepare this paper. We also would like to express our deep thanks to the members of Directorate of Mineral Resources Inventory of Indonesia especially for their great cooperation in the field operations.

## References

James, R. (1962) Steam-water critical flow through pipes, *Proceedings, Inst. Mech. Engrs.*, **176**, 741-748.

Koseki T., Tanaka K., Tagomori K., Futagoishi M. and Dwipa S. (2000) Geothermal system of the Mataloko area, Central Flores, Nusa Tenggara Timor, Indonesia. *Proceeding, Asia Geothermal Symposium 2000*, 118-120.

Takahashi H. (1995) Alteration cap rock formation method - A case study Hosokura ore deposit in Northeastern Japan. *Jour. Geotherm. Soc. Japan,* **17,** 271-284 (in Japanese with English abstract).

Received September 25, 2001
Accepted February 21, 2002

## インドネシア・フローレス島・マタロコ地熱地帯における調査井 MT-1 と MT-2 の掘削および噴出試験

末吉喜和・松田鉱二・下池忠彦・小関武宏・高橋　洋・二子石正雄・
Kastiman SITORUS・Janes SIMANJUNTAK

### 要　旨

地熱エネルギーが広く賦存すると考えられているフローレス島のマタロコ地熱地帯において，2本の調査井を掘削した．坑井 MT-1 は，ワエ・ルジャ川北側において掘削深度 1,000 m で計画したが，深度 207.26 m 付近で蒸気層に遭遇し，蒸気が噴出した．ただちに坑口弁を閉じたが，同時に坑井周辺の地表部から蒸気が噴出し，坑井周りの地獄化が懸念されたため，MT-1 坑口周辺のセメントグラウト作業を実施した．グラウト完了後，清水注入により噴出を停止させ，坑井をセメントで埋め戻した．2本目の坑井 MT-2 は，MT-1 と同一基地から掘削深度 230 m で計画したが，深度 162.35 m 付近で蒸気層に遭遇した．同深度で仮噴出試験を実施し，噴出に成功したため，掘り止めを決定した．MT-2では，本格的な噴出試験をリップ・プレッシャー法により実施し，坑口圧力・蒸気流量の測定，同時に化学同位体分析のために，噴出流体のサンプリングを行った．噴出量測定から，本坑井の最大蒸気量は 4.57 kg/sec. (16.5 ton/hr) であることが確認された．