MICROEARTHQUAKE ACTIVITY IN RENDINGAN-ULUBELU-WAYPANAS (RUW) GEOTHERMAL FIELD, LAMPUNG, INDONESIA

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SUMMARY- A local network of nine seismic stations recorded 53 microearthquake events in the Rendingan-Ulubelu-Waypanas (RUW) geothermal area between 13 December 1992 and 24 February 1993. Three main sequences of microearthquake swarm were identified. The hypocenters were determined Using a random analysis technique. There are four areas of microearthquake concentration, only one of them is located outside the geothermal field Most epicenters are aligned either SW-NE or SE-NW, following the two main structural trends of this area. It is possible that some of these microearthquake swarms were caused by magma injections into deep fractures.

1.0 INTRODUCTION

The study area is part of Tanggamus Regency in the Lampung Province, South Sumatra (Fig 1). It is located about 70 km west of the capital Bandar Lampung. The Rendingan-Ulubelu-Waypanas (RUW) field was formerly known as the Ulubelu prospect (Hochstein and Sudarman, 1993). However, further investigations carried out by Pertamina (unpublished reports) indicated that the prospect extends to the north beneath Mt. Rendingan and to the south beyond Mt. Waypanas. Currently, it is still unknown whether these three areas represent a single geothermal system or separate activities.

The geothermal field occurs near the southern end of the chain of the Bukit Barisan volcanoes that are associated with the Sumatra Fault Zone, The prospect area is situated in high terrain, mainly about 700 to 800 m above sea level, and is surrounded by higher volcanic terrain including Mt. Tanggamus, Mt Kabawok, Mt. Kukusan, Mt. Sulah and Mt. Rendingan (Fig 2).

Between 13 December 1992 and 24 February 1993, Pertamina installed a seismic network of 9 stations in the RUW area (Fig 2). We obtained a list of P-wave arrival times recorded by this seismic network, which we used to determine hypocentres of the microearthquake events. Our main objective was to use the microearthquake survey to speculate on some subsurface characteristics of the RUW geothermal system. In addition, we also wanted to determine the background level of seismicity in the RUW area prior to any exploitation of the geothermal prospect.

Since no seismic velocity model was currently available for the RUW area, we used a random analysis technique to localize the hypocentres of the microearthquake events. Only events that were recorded by a minimum of four stations were selected. for analysis. The computations were made on an IBM compatible PC using the MATLAB software.

2.0 RANDOM ANALYSIS OF MICROEARTHQUAKE EVENTS

In this analysis, we assume a seismic event recorded by a network of N stations originated fkom a hypocentre located at coordinates (x_o, y_o, z_o), at time t_o. The seismic P-wave created by the event traveled with a mean velocity V and was recorded at station i (coordinates: x_i, y_i, z_i) at time t_i. Hence, we have the equation:

$$t_i = t_o + S_i/V = t_o + (1/V)[(x_i-x_o)^2 + (y_i-y_o)^2 + (z_i-z_o)^2]^{1/2} \quad (1)$$

where the index i represents the station number for each of the N stations.

For the random analysis, equation (1) is linearised using the Taylor expansion, i.e.

$$t_I^T = F_i(t_o^T, x_o^T, y_o^T, z_o^T) + (\partial F_i/\partial t_o)^T \delta t_o + (\partial F_i/\partial x_o)^T \delta x_o + (\partial F_i/\partial y_o)^T \delta y_o + (\partial F_i/\partial z_o)^T \delta z_o \quad (2)$$

where

$$F_i(t_o^T, x_o^T, y_o^T, z_o^T) = t_o^T + (1/V)[(x - x_o^T)^2 + (y_i-y_o^T)^2 + (z_i-z_o^T)^2]^{1/2}.$$

From the approximate hypocenter parameters (origin time, location coordinates) of t_o^T, x_o^T, y_o^T, z_o^T, and the linear parameter corrections (δt_o, δx_o, δy_o, δz_o), new hypocenter parameters of t_o, x_o, y_o, and z_o can be obtained from the equations:

$$t_o = t_o^T + \delta t_o \;; \quad x_o = x_o^T + \delta x_o \,,$$
$$y_o = y_o^T + \delta y_o \;; \quad z_o = z_o^T + \delta z_o \,. \quad (3)$$

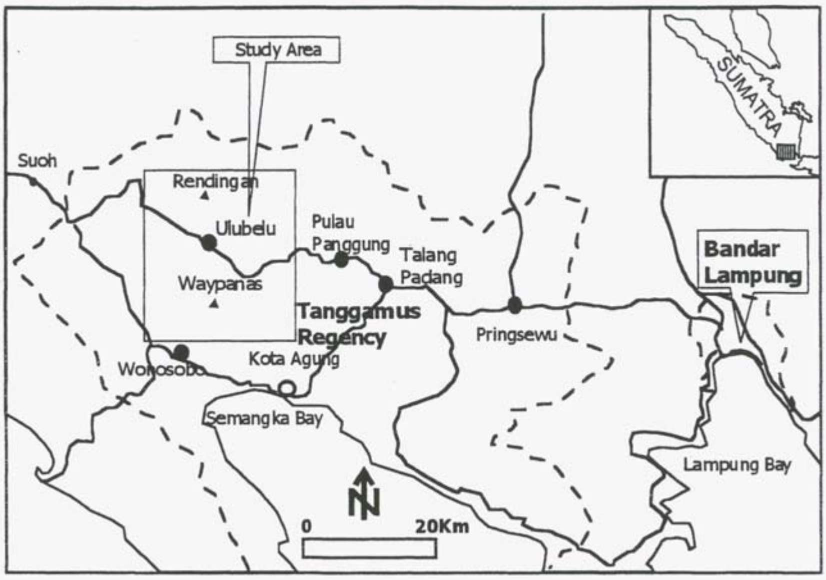

Figure 1. Location map of the *study* area in Tanggamus Regency. Lampung Province, South Sumatra.

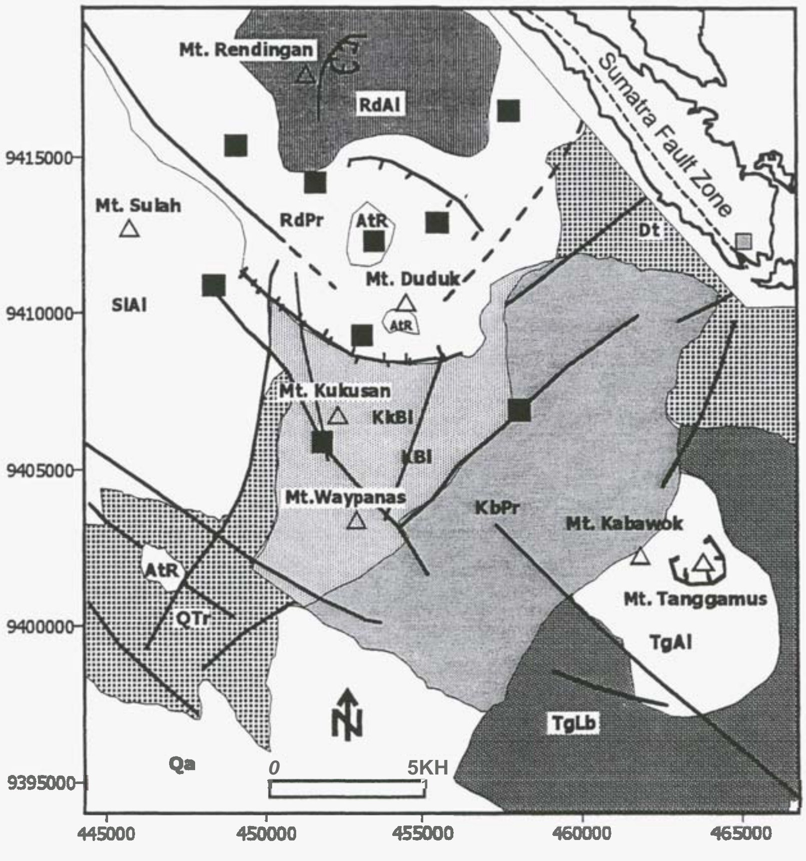

Figure 2. Simplified geological *map* of RUW geothermal prospect. Faults are indicated by solid lines. RdAl: Mt. Rendingan andesitic lavas; RdPr: Mt. Rendingan pyroclastics, SlAl: Mt. Sulah andesitic lavas; KkBl: Mt. Kukusan basaltic-andesitic lavas; KrRl: Mt Kurupan rhyolitic lavas; Dt: Dacite tuff; QTr: Pumice tuff; KbPr: Mt. Kabawok pyroclastics; TgAl: Mt Tanggamus laharic breccia; Atr: hydrothermally altered rocks. The sites of nine microseismic stations operated between 13 December 1992 and 24 February 1993 are shown by solid squares.

Defining $\delta t_i = t_i^T - t_i$, we can obtain from equation (2):

$$\delta t_i = (\partial F_i/\partial t_o)^T \delta t_o + (\partial F_i/\partial x_o)^T \delta x_o + (\partial F_i/\partial y_o)^T \delta y_o + (\partial F_i/\partial z_o)^T \delta z_o + (\partial F_i/\partial v_o)^T \delta v_o . \quad (4)$$

The matrix expression of equation (4) is:

$$\delta t_i = G_{ij}\ \delta m_j \quad (5)$$

where $G_{i1} = \partial F_i/\partial t_o$; $\delta m_1 = \delta t_o$

$G_{i2} = \partial F_i/\partial x_o$; $\delta m_2 = \delta x_o$

$G_{i3} = \partial F_i/\partial y_o$; $\delta m_3 = \delta y_o$

$G_{i4} = \partial F_i/\partial z_o$; $\delta m_4 = \delta z_o$

$G_{i5} = \partial F_i/\partial v_o$; $\delta m_4 = \delta v_o$

with $F_i = F_i\ (t_o^T, x_o^T, y_o^T, z_o^T, v_o^T)$ represents the first approximation of origin time, hypocentre coordinates and mean seismic velocity.

The first order differential factor δm_j is a correction parameter consisting of (δt_o, δx_o, δy_o, δz_o, δv_o) and can be determined fiom the matrix equation:

$$G_{ji} . \delta\ t_i = (G_{ji} . G_{ij}) . \delta m_j ,$$

i.e.

$$\delta m_j = [G_j . G_{ij}]^{-1} . G_{ji} . \delta t_I . \quad (6)$$

The parameter δm_j is used to reduce the error of the theoretical calculation of the first arrival time (t_i^T) with respect to the measured first arrival time data (t_i). Iteration process is carried out to minimize the travel time error expressed by

$$\epsilon^2 = (t_i - t_i^T)^2 . \quad (7)$$

3.0 RESULTS

A total of 53 events ranging in magnitude from 0.5 to 2.7 were identified from the survey between 13 December 1992 and 24 February 1993. This result shows that microearthquake activity is common in the RUW area. During the period of recording, the activity varied considerably (Fig. 2). There were many quiet days without any events. The maximum number of events per day was 20 which occurred on the last day of recording (24 Feb. 1993).

Out of the 53 events shown in Fig 2, we can only determine the hypocentres of 38 events. The mean seismic P-wave velocity obtained fkom the random analysis solution for each of these 38 events ranges from about 5 to 6 km/s. The final sums of travel time errors given by the solution are mostly between 0.01 and 0.09 seconds, suggesting that most of the hypocentre locations are accurate to at least within 500 m horizontal radius.

The epicentres of the microearthquake events are plotted in Fig 4. Four areas of microearthquake concentration can be recognized, namely Area I (Sulah), Area II (Rendingan), Area 111 (Ulubelu), and Area IV (Waypanas). Areas II, III and IV are inside the RUW field; Area I is outside.

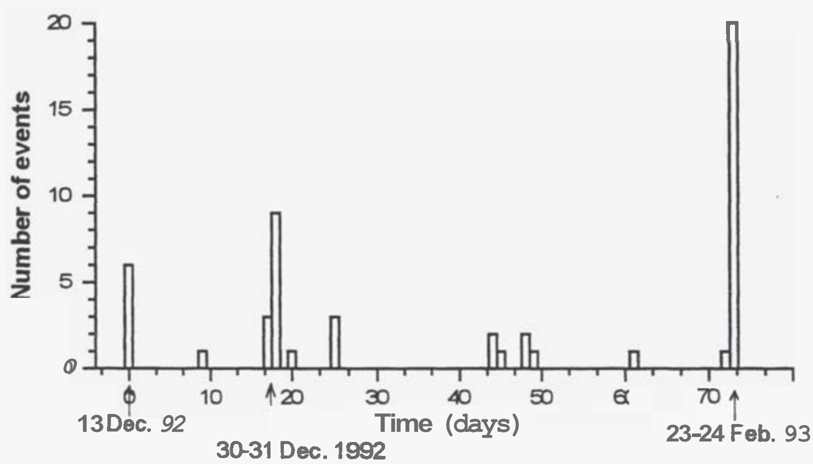

Figure 3. Microearthquake activity in the RUW area between 13 December 1992 and 24 February 1993.

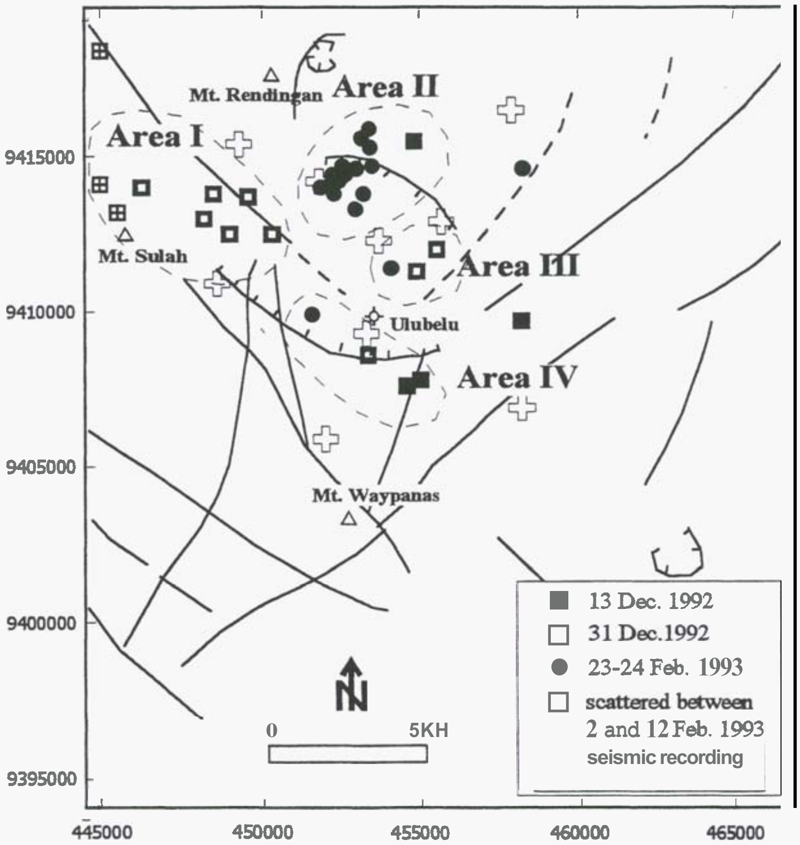

Figure 4. Epicentres of microearthquake events in the RUW field between 13 December 1993 and 24 February 1994. Four areas of microearthquake concentration are indicated: Area I (Sulah), Area II (Rendingan), Area III (Ulubelu) and Area IV (Waypanas).

4.0 DISCUSSION

There was no recognizable 'main shock' associated with the microearthquake activity shown in Fig 3. Hence, these events can be classified as earthquake swarms (Hochstein et al., 1995). Three main sequences are identified, i.e. 13 Dec. 92 (6 events), 30-31 Dec. 92 (12 events) and 23-24 Feb. 93 (21 events). Most of the events on the 23-24 Feb. fit an additional, less common, characteristic for swarm activity stated by Hochstein et al. (1995); namely, most of their epicentres are bunched together, see Fig. 4.

Swarm-type microearthquake activity is common in many other high temperature geothermal systems (Ward and Bjornsson, 1971; Hamilton and Muffler, 1972; Combs and Rotstein, 1976; Combs and Hadley, 1977; Tosha et. al., 1993; Hochstein et al., 1995). Two possible sources of microearthquake swarms associated with geothermal areas are shallow magmatic activity and hydrothermal processes that trigger tectonic release (Combs and Rotstein, 1976).

Fig. 4 shows the epicenters in Areas I and IV are aligned SE-NW, whereas those in Areas II and 111 are aligned SW-NE. These two directions are also the main faulting trends in this area, suggesting a relationship between the microearthquake swarms and geological structures. A possible mechanism that could account for the RUW microearthquake swarms is magma injections into deep fractures. Such a mechanism has been suggested by Hochstein et al. (1995) to explain four microearthquake swarms recorded between April 1986 and January 87 in the Tokaanu-Waihi geothermal prospect in NZ. The Tokaanu-Waihi swarms also showed epicentres that are aligned along the main structural trend of the area; two large swarms had epicentres that are bunched together.

Hochstein et al. (1995) suggested two types of test for the magma injection model of earthquake swarms, a first motion analysis of records from densely-spaced network, together with a monitoring of non-reactive gases discharged by fumaroles during the period of recording The set of data currently available to us is not sufficient for such tests.

5.0 CONCLUSIONS

1. Microearthquake activity is common in the RUW area Four areas of microearthquake concentration were identified by a survey conducted between 13 Dec. 92 and 24 Feb. 93, only one of them (Area I near Mt. Sulah) is located outside the iderred geothermal field

2. The 53 microearthquake events recorded during the survey occurred as swarm-type sequences. The epicentres of the largest swarm on 23-24 Feb. 93 are mostly clustered inside Area II to the SE of Mt. Rendingan. Most epicenters are aligned either SW-NE or SE-NW, following the two main *structural* trends of the RUW area.

3. A possible mechanism suggested for the RUW microearthquake swarms is magma injections into deep fractures.

6.0 ACKNOWLEDGEMENTS

The authors would like to thank the Management Team, Pertamina, for their permission to publish this paper.

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