AE and mise-a-la-masse measurements during a 22-day water circulation test at Ogachi ADR site, Japan

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Key words : Induced seismicity, Geophysical methods, HDR. Acoustic emission, Electrical resistivity

ABSTRACT

A 22-day water circulation test,, from a 1,000-m deep injection well through hydraulically fractured zones ut about 720 m and 1,000 m depths tu a production well, was performed at the Ogachi Hot Dry Rock (HDR) site in the fall of 1993. At the beginning of the circulation lest hyporenters of acoustic emission (i.e., microseismic events) were distributed along the lower fracture progression direction which was considered as an main flow path arid apparent electrical resistivity anomaly measured by mise-a-la-masse measurements occurred near the same direction. Unfortunately, water recovery from the production well was small. only 4 % of the injected water during the flow text. According to AE observations, it may be because the production well did not reach to the expected main flow path.

Introduction

The Central Research Institute of Electric Power Industry (CRIEPI) has conducted the Hot Dry Rock (HDR) program at Ogachi, northern Japan, since 1989. An injection well was drilled into pre-Tertiary granitic ruck in 1990. The well reached a depth of 1,000m and a ruck temperature of 228℃.

Two hydraulic fracturings were performed from the injection well. A first (lower) fracture was created in 1991 by injecting a total of 10,163 m^3 of water into a hottom 10-m openhole interval (Kaieda et. al., 1992a). A second (upper) fracture was created in 1992 hy injecting a total of 5,400 m^3 of water into an Interval from 711 to 719 m where the casing of the well was milled as a window (Hori et al., 1994).

A production well was drilled in 1992 directionally to intersect both the fractures. The wellhead is located to the east of the injection well in order tu penetrate the upper fracture and inclined to the north at depth to penetrate the lower fracture (Hori et al.. 1994). The length of the well was measured 1.100 m along the well.

A water circulation lest was performed from the injection well. through ths two fractures, to the production sell. Water was injected for the test from October 17 to November 8 in 1993. At the beginning of the flow test, the water injection flow rate was 400 liter/min at a wellhead pressure of around 20 MPa; later the flow rate increased up to 1,200 liter/min at an almost constant wellhead pressure of 20 MPa. Unfortunately, the maximum flow rate of recovered water from the production well was unly 40 liter/min, but the water temperature at the surface finally increased up to 108℃ (Hori et al., 1995).

This paper describes AE and mise-a la-masse measurement results obtained during the water circulation test and discusses why the water recovery was so small as described above.

AE observation

At the Ogachi HDR site, acoustic mission events were monitored by an 8-station network of three-component geophones installed in 30- to 50-m deep boreholes and by a single-component geophone set at a depth of 480 m in a 946-m deep observation sell. Signals detected by these geophones were band-pass filtered between 10 Hz (or 30Hz) and 1 kHz and digitized by 2 kHz sampling.

Figure 1 shows the time history of the wellhead pressure, the flow rate of the water injection, the frequency of AE events per hour. arid the sum of the squared amplitude of AE events per hour which is considered to be proportional to emitted energy as elastic waves. We divided the time period of AE monitoring into five segments (I ~ V in Figure 1).

The first period (I) is frum Oct.17 to Oct.27 before the flow rate increased to 1,200 liter/min. During this period, the injection flow rate was 400 liter/min at first and gradually increased to 700 liter/min. The frequency of AE events was low with only a few everits per hour and the squared amplitude of AE events was also small. except three days of Oct.18, 23 and 25 in which seismic swarms were observed. It may mean that the injected water flowed with creating a few new fractures at first. The second period (II) is from Oct.27 after the injection flow rate increased to 1,200 liter/min to Oct.29. During this period, many AE events were detected of several tens per hour. This may be caused by increasing the injection flow rate and mean that some new fracture extension occurred. The third (Ⅲ) is from Oct.29 to Nov.2 before the flow rate decreased by a pump failure. In this period, the frequency of AE events and the squared amplitude of AE events were relatively large. This may mean large fracture extension occurred. The forth (Ⅳ) is from Oct.2 to Oct.8 before the pumping stopped. In this period, the frequency of AE gradually decreased, probably because the injection flow rate decreased because of a pump failure. The fifth (Ⅴ) is from Nov.8 after the pumping stopped to Nov.11. Even after the pumping stopped, some AE events were observed.

The largest magnitude of observed AE was -0.5 which was determined by oscillation (Coda) duration time.

AE event locations were calculated by inversion of P-wave arrival times. Arrival times were picked by hand from digital seismograms. The velocity structure under the Ogachi site was obtained from detonations at the surface while a high-temperature geophone moved from the surface to the bottom of the injection well. The P-wave velocity from the surface to a depth of 100 m was 2.2 km/sec, from 100 m to 300 m, where there was a contact of granodiorite, was 4.0 km/sec and below 300 m was 5.0 km/sec. Station corrections were obtained from a 1 kg detonator shot at a depth of 996 m in the injection well. The estimated uncertainty of event locations was less than 10 m around the injection well.

AE event locations determined for the lower fracture were distributed in the direction N20° E and 1,000 m long (Kaieda et al.,1992a). The upper fracture was estimated to progress in the N110° E direction and was 800 m long (Hori et al., 1994). These AE hypocenter locations are shown in Figure 2.

A total of 1069 AE hypocenters detected during the circulation test were located (see Figure 2). A map view of these events in the time periods described in the previous time history are shown in Figure 4. From this figure, we can see that AE events occurred in a narrow zone extending to the north from the injection well in the first period. This direction is along the lower fracture progression direction. The production well, which was drilled in order to intersect the lower fracture at depth, does not seem to reach to the fracture. In the second period, AE event locations were distributed still along the lower fracture progression direction with some inflation in the east-west direction. However, the production well does not reach the distribution. In the third, AE events were distributed south and west from the injection well and the number of AE events located in the first fracture region decreased. In the forth, AE events were located mostly to the west of the injection well. Finally in the fifth, after the pumping stopped, AE event locations were dispersed to a rim of the entire event distribution. During all of the period, no AE event were located in the upper fracture progression area.

Mise-a-la-masse measurement

For the mise-a-la-masse measurements, the steel casing in the injection well was electrically charged as a line source, and 100 surface electric-potential-measuring stations were distributed around the injection well out to a distance of 400 m. The measurement system is described in our previous paper (Kaieda et al., 1992b).
Apparent resistivity change between the values measured on Oct.18 and that on Oct.22 is shown in Figure 3. In this figure, negative anomalies mean the apparent resistivity of Oct.22 decreased from that of Oct.18.

From this figure, we can see that an apparent resistivity anomaly occurred along the trend similar to the direction of the AE location distribution at the beginning of the flow test, but the trend shifted to the east. This may mean that water flow occurred along the same direction, but that the fracture is inclined.

No resistivity anomaly is occurred in the upper fracture progression direction.

Discussion

During the water circulation test, injection flow rate increased from 400 to 1,200 liter/min. However, production flow rate was as small as of 40 liter/min (Hori et al., 1995). We propose some reasons for this low water recovery. The first is that according to AE hypocenter locations, the production well does not seem to reach to the lower fracture. The second is that the AE event locations distributed in the lower fracture region first then dispersed to the opposite direction from the production well, therefore the injected water flowed into the lower fracture first, and then flowed into new fractures which were created by injecting high pressure water. The third is that, since few AE event were located and no apparent electrical resistivity anomaly occurred in the upper fracture region, little water seemed to flow into the upper fracture.

Considering the reasons mentioned above and operation costs, we thought that it was necessary to conduct a fracturing of the production well to obtain better water recovery.

Conclusions

A 22-day water circulation test was conducted. During the flow test recovered water volume was low. At the beginning of the flow test AE event locations were distributed in the lower fracture progression region. This distribution agreed with the apparent electrical-resistivity change obtained by mise-a-In-masse measurements. However, the production well did not seem to reach to the main flow path of the lower fracture. No AE events and no apparent resistivity change were observed in the upper fracture zone. Therefore we will conduct fracturing in the production well to get better water recovery.

Acknowledgement

We wish to thank the prefectural government of Akita and the town office of Ogachi-machi for their understanding and helping our experiment.

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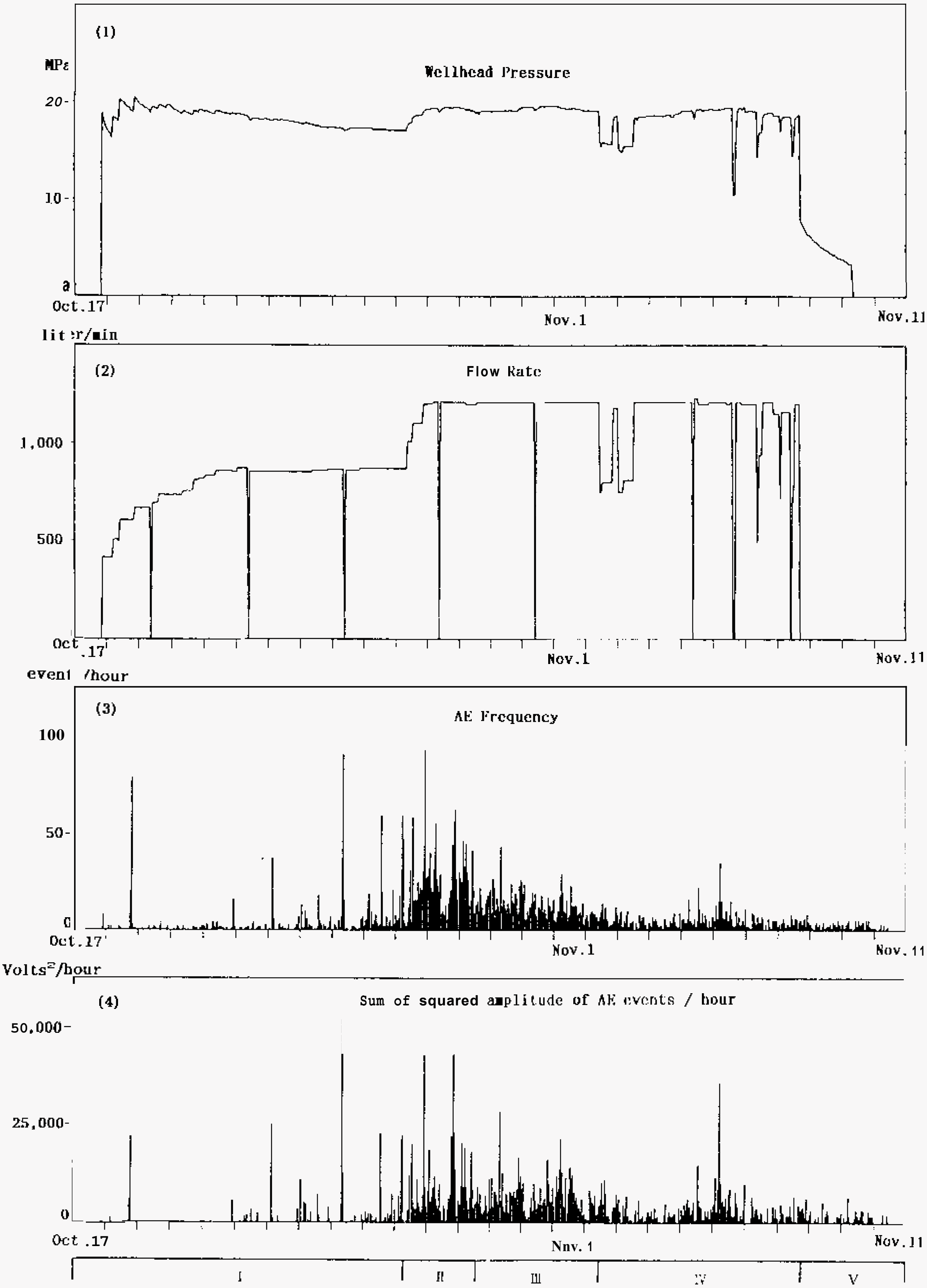
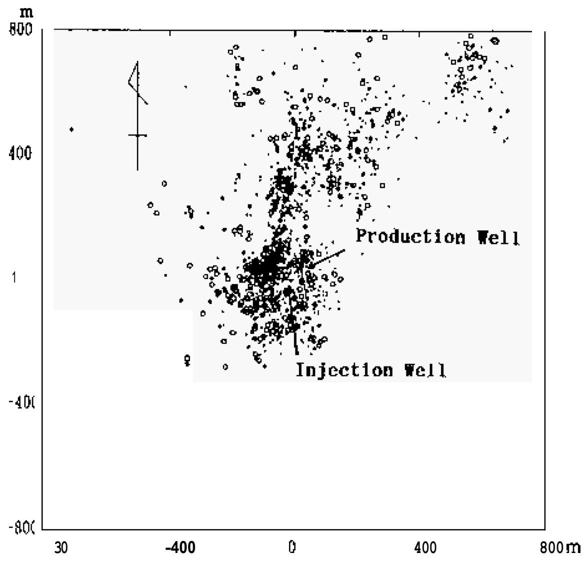
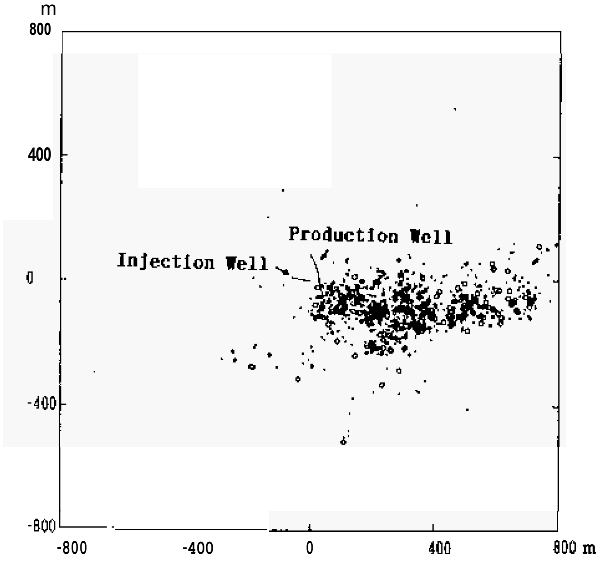


Figure 1. The history of injection pressure (1), flow rate (2), frequency of AE events (3) and sum of squared amplitude of AE events / hour (4) during a *22-day* water circulation test. The time period was divided into five segments (I ~ V) shown at the bottom of this figure.





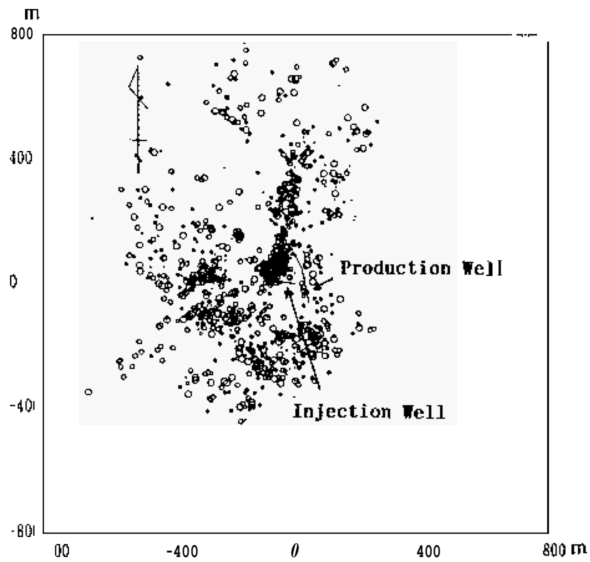


Figure 2 AE hypocenter location map. The top left frame is a map view of the first (lower) fracturing. the top right frame is a rap view of the second (upper) fracturing and the bottom left frame is a map view of the rater circulation test. Size of circles at events location depends on their magnitude (M) as follows.

- ·: -2 > M
- •: -2 < M < -1.5
- o: -1.5 < M < -1
- O: -1 < M

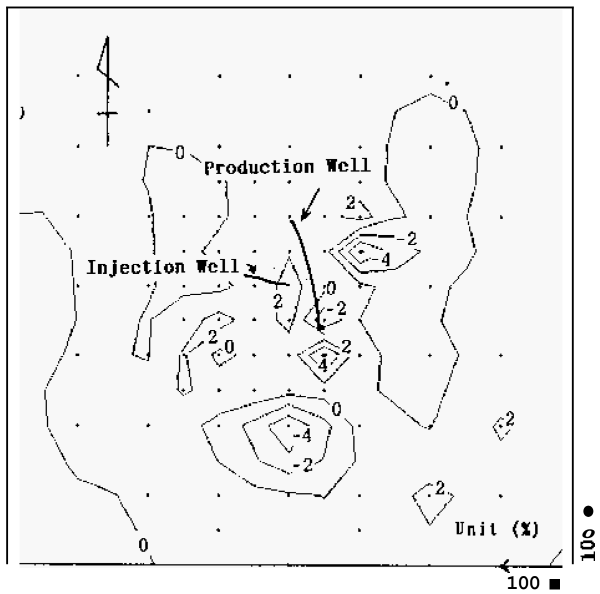
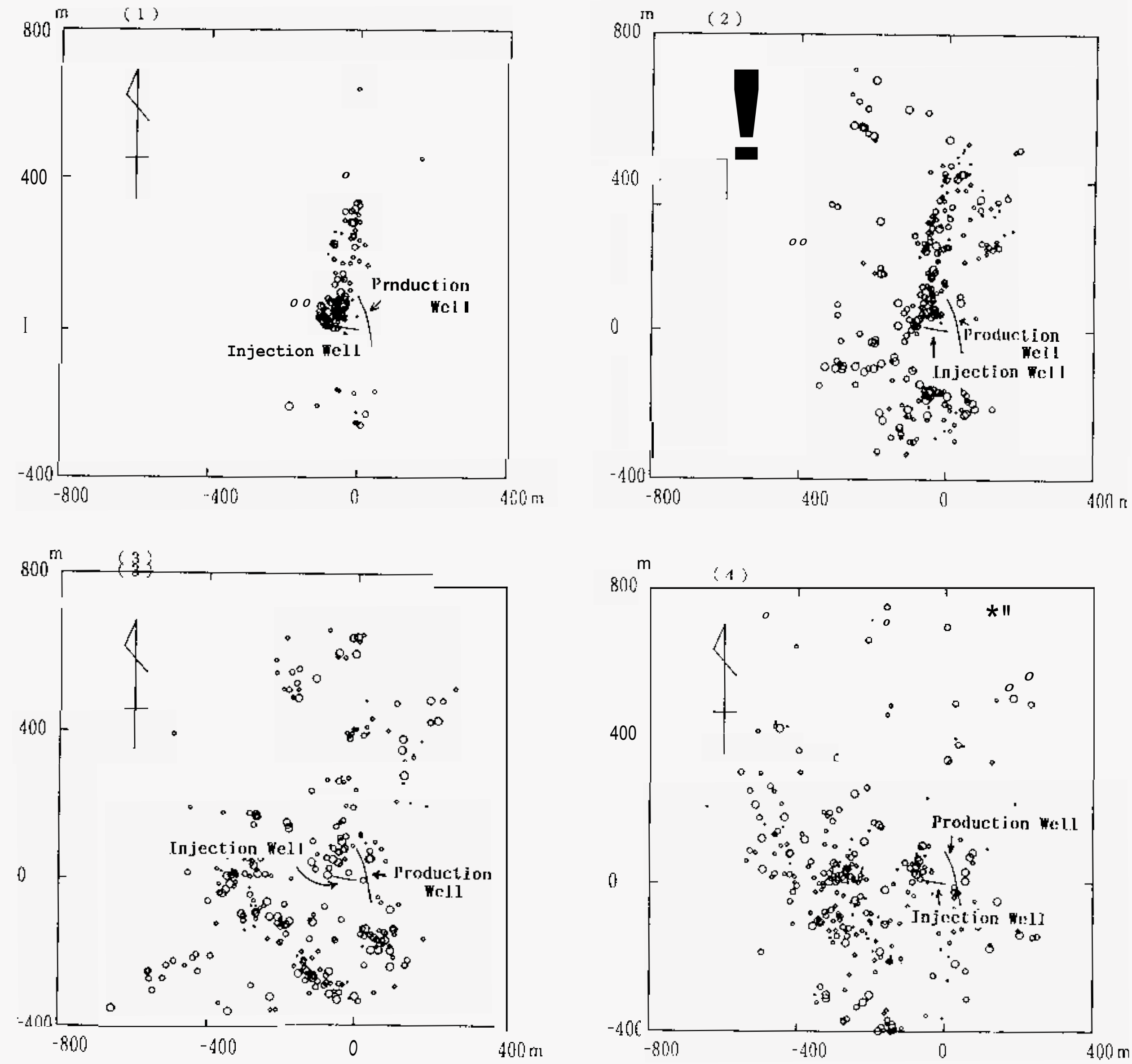


Figure 3. Apparent electrical-resistivity change (%) calculated as a ratio of the values *obtained* on Oct.22 to that on Oct.18.



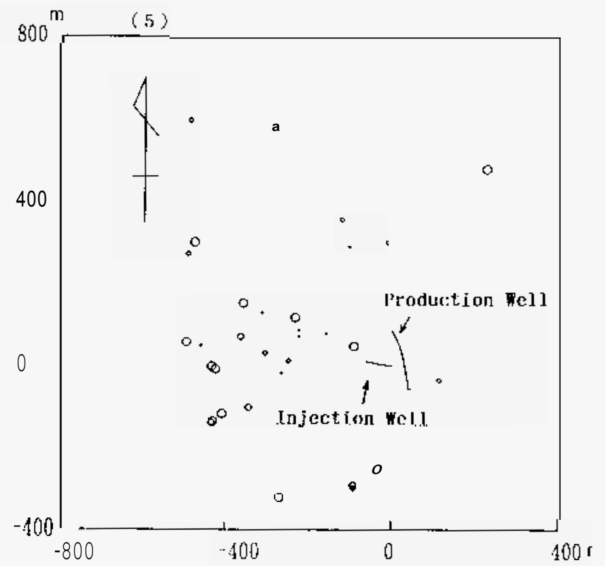


Figure 4. AE hypocenter location map. (1) AE events detected in the first period (I), (2) AE events detected in the second (II), (3) AE events detected in the third (III), (4) AE events detected in the forth (IV) and (5) events detected In the fifth (V). These periods are described in text and Figure 1. Size of circles at events location depends on their magnitude (M) as follows.

- · : 2 > M
- ▸ : 2 < M < -1.5
- ○ : -1.5 < M < -1
- O : -1 < M