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Hypocentral Distribution and Focal Mechanism of Volcanic Earthquakes around Guntur Volcano, West Jawa, Indonesia

Gede SUANTIKA*, Ony Kurnia SUGANDA*, Masato IGUCHI and Kazuhiro ISHIHARA

*Volcanological Survey of Indonesia

Synopsis

Guntur Volcano is an andesitic volcano, located in West Java, Indonesia. A seismic network composed of 4 stations has been installed at Guntur Volcano since October, 1994, in the collaborative study between Sakurajima Volcanological Observatory, DPRI, Kyoto University and Volcanological Survey of Indonesia, DGGMR, Indonesia. Temporary seismic observations were conducted in December 1995-February 1996 and September – December 1996.

Locations of hypocenters were calculated assuming a homogeneous half space of V_p=2.76 km/s. The epicenters seem to be vertically concentrated beneath Guntur summit at depths of 0-5 km, around Kamojang caldera (west of the summit), Gandapura (northwest) and G. Putri (south). The precise determination of hypocenter by temporary observation revealed that the hypocenters are aligned along faults at depth of 5-10 km.

Focal mechanisms of 23 volcanic earthquakes were determined. Mechanisms of most of the events around Kamojang Caldera are generally strike-slip fault with the fault plane direction of NE-SW and NW-SE. Considering the hypocentral distribution and surface geological structure, it is inferred that the earthquakes originate by the slip of the fault to NE and SW. Mechanisms of four events were determined. The mechanisms are normal fault and reverse type. Composite source mechanism in the area did not show consistent character. This suggests that the rocks in hypocentral zones beneath the crater are fractured more in the many directions maybe due to the previous volcanic activities. The smaller magnitude (<0.7) in the summit crater coincides with highly fractured zone.

Keywords: Guntur volcano; volcanic earthquake; hypocenter distribution; focal mechanism

I. Introduction

Guntur Volcano is an andesitic stratovolcano in West Java, Indonesia (longitude : 107° 50.5' E and latitude : 7° 8.87' S) and 35 km southeast from Bandung city (Fig. 1). There are many active volcanoes around Guntur, as Papandayan, Cikuray, Galunggung and so on. The eruption in 1690 was recorded first in historic time. Eruptions frequently occurred until the middle of the 19th century. One of the biggest eruptive events occurred in 1840. Lava extruded from the crater at the summit and reached Cipanas, 3 km southeast of the crater. Rather big eruptions occurred in 1841 and 1843 (Kusumadinata, 1979). No eruption have occurred since 1843 and the crater is covered by forest and minor fumarole has remained. A large fumarolic area is located in the Kamojang caldera, west of the summit of Guntur. The steam emitted from the area is utilized for electric power plant.

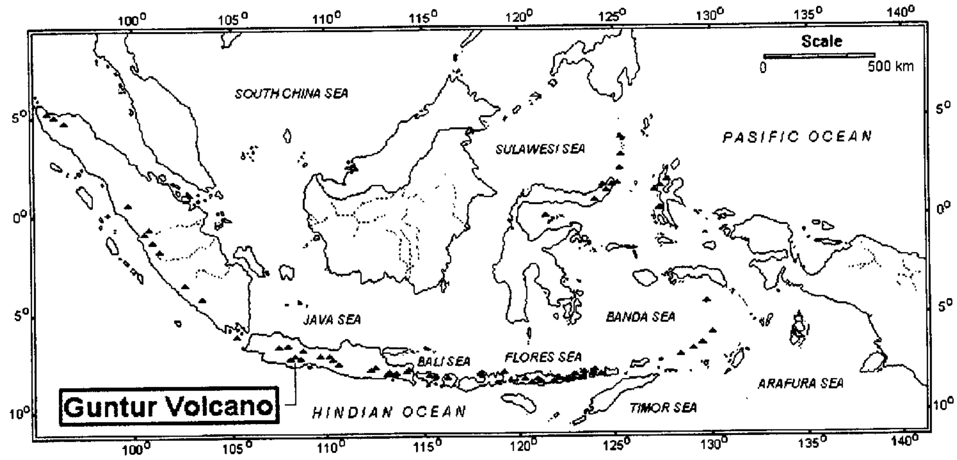

Fig. 1. Location of Guntur volcano

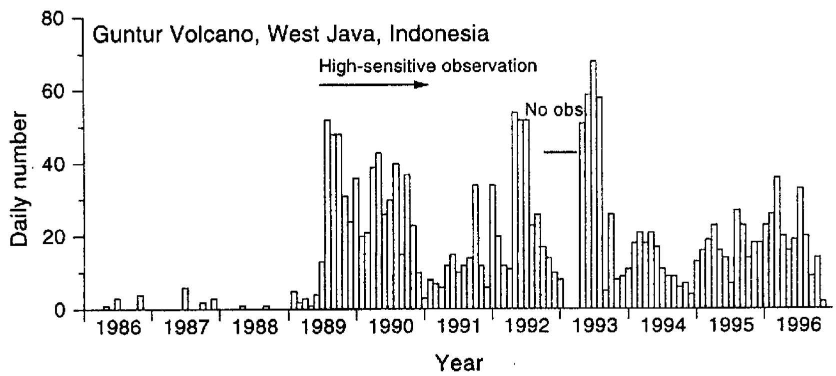

Fig.2 Monthly number of volcanic earthquake during 1986 -1996.

Volcanological Survey of Indonesia (VSI) started seismic observation at an observatory station 6 km apart from the summit crater in order to monitor the activity of the volcano in 1986 by using a low-sensitive seismometer (Hosaka seismograph) with cable system. Very few events were recorded at the station due to distance from the summit crater to the station and low sensitivity of the sensor. Therefore, the monitoring station was moved to Citiis station (CTS) 0.8 km apart from the summit in 1989 and the observation system was replaced by telemeter seismograph (PS-2 Kinemetrics) with higher sensitivity. This observation system revealed that the seismicity around Guntur volcano is not quiet. Average monthly number of volcanic earthquakes is 20 during the period from 1989 to 1996. The monthly numbers of volcanic earthquakes sometimes attained 60 - 70 (Fig.2). VSI has tried to determine hypocenters of volcanic earthquakes by temporal seismic observation at several stations and locations of a few number of volcanic earthquakes were determined (Rasjid *et al.*, 1989; Team Seismik of VSI, 1989; Sitorus, 1991). However, characteristic of hypocenter distribution of the volcano was not made clear due to poor precision of determination and small number of the earthquakes.

Sakurajima Volcanological Observatory (SVO), Disaster Prevention Research Institute began collaboration study on eruption mechanism of volcanoes in West Java with VSI based on the arrangement in 1993. In October 1994, SVO and VSI added installation 3 permanent seismic stations with telemetry and until now Guntur is observed by a permanent seismic network with 4 seismic stations.

Iguchi *et al.* (1996) determined hypocenters of volcanic earthquakes during the period from November 1994 to March 1996. The hypocenters are distributed beneath the summit crater at depths of 0-4 km and around Kamojang caldera at depths <10 km.

In this study, we determine the hypocenters of volcanic earthquakes more precisely by adding the data by the permanent stations after April 1996 and

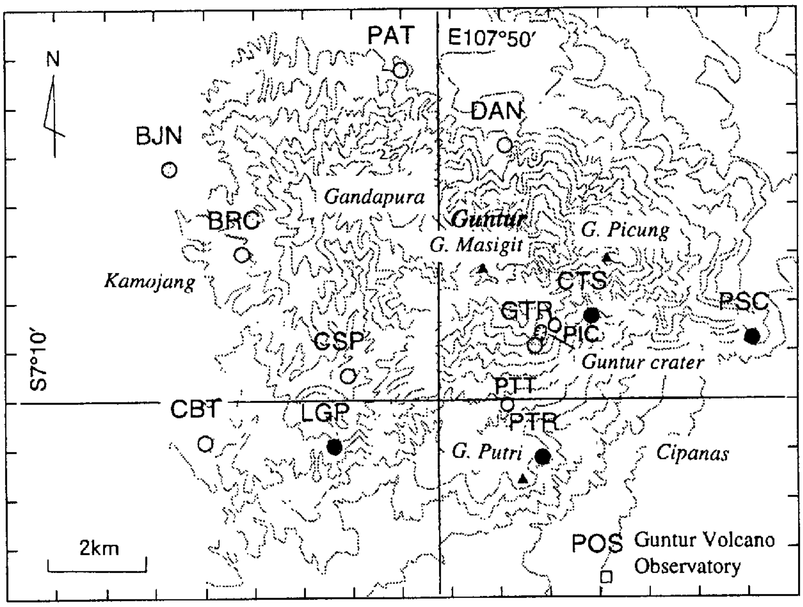

Fig. 3 Seismic network at Guntur volcano. Solid circles indicate permanent stations. Shaded and open circles represent temporary stations during December 1995 – February 1996 and September – December 1996, respectively.

conducting temporary seismic observations during December 1995-February 1996 and September-December 1996 and analysis of focal mechanism. The characteristics of the earthquakes beneath the summit and Kamojang caldera are compared with each other in order to discuss the seismicity with tectonic and geological setting around Guntur volcano.

2. Observation

Guntur is a volcano complex, composed of Gunung Gajah (2123m), G. Masigit (2249m), G. Agung (2170m), G. Picung (1910m), G. Guntur (1956m), G. Putri (1350m). The permanent seismic stations are located at south and east flank of these volcanoes to transmit the seismic signals to the main observatory (POS) as shown in Fig. 3. The seismic station (CTS) is equipped with one vertical component seismometer (T_o=1.0s, h=0.7) and three new permanent stations PSC, PTR, and LGP have short period 3-component seismometer (T_o=1.0s, h=0.7). The seismic signal from the seismometers are transmitted to the main observatory by radio telemeters. The seismic signals are stored in data logging device (DATAMARK LS8000-SH, Morita and Hamaguchi, 1996) with sampling interval of 0.01 second. The recording initiated by the trigger with a STA/LTA (ratio of short-term average to long-term average) algorithm. The internal clock in the data logging device is calibrated by GPS every 3 hours. The data logger has a memory of 20 Mbytes and can record 1000 events. The data stored in the data logging devices are transferred to a PC with a PCMCIA interfaces and finally recorded in magneto optical disks (Iguchi *et al.*, 1996).

Temporary seismic observations were conducted twice. First observation was done in the period from December 1995 to February 1996. The permanent stations are deviated in eastern and southern part of the flank of Guntur volcano. We installed 7 seismic stations at western and northern part of the volcano to surround the crater. Distribution of the stations are shown in Fig.3. Second temporary observation has been conducted since September 1996 adding three stations near the Guntur summit. In two observations, seismometers with a vertical component (T_o=0.5s, h=0.7) was installed at stations and seismic signals were recorded in the data logging devices with the same triggering algorithm. Time was calibrated by GPS every 3 hours and the time base at all the stations including permanent stations has the accuracy of 0.01 second.

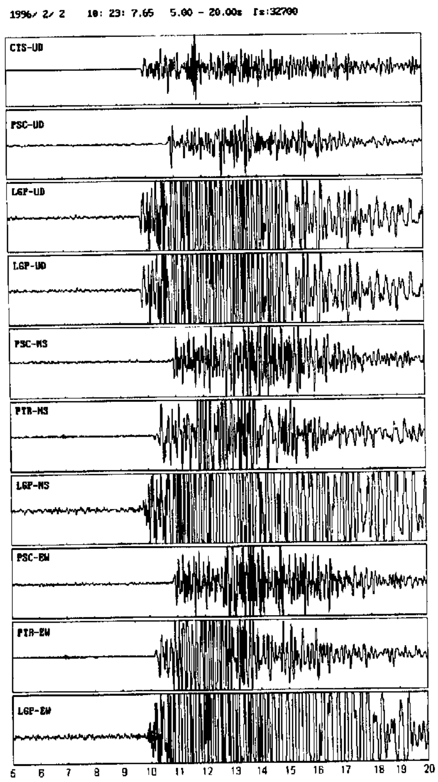

Fig. 4. Typical 3-component seismogram of Guntur volcanic earthquake recorded at four permanent stations.

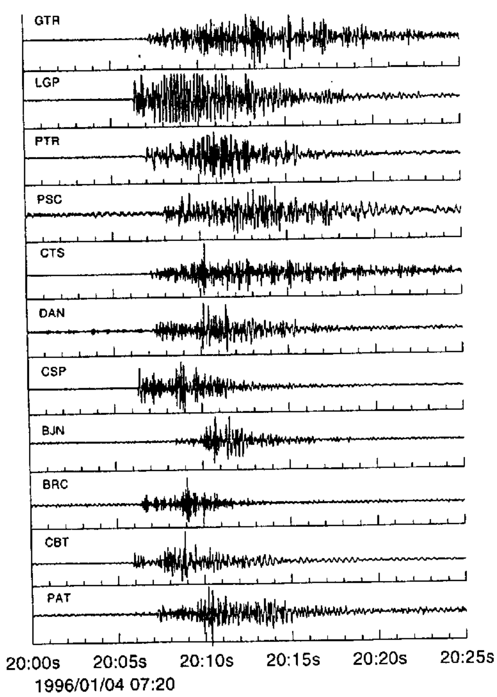

Fig. 5. An example of vertical component seismogram of Guntur volcanic earthquake recorded at temporary seismic stations.

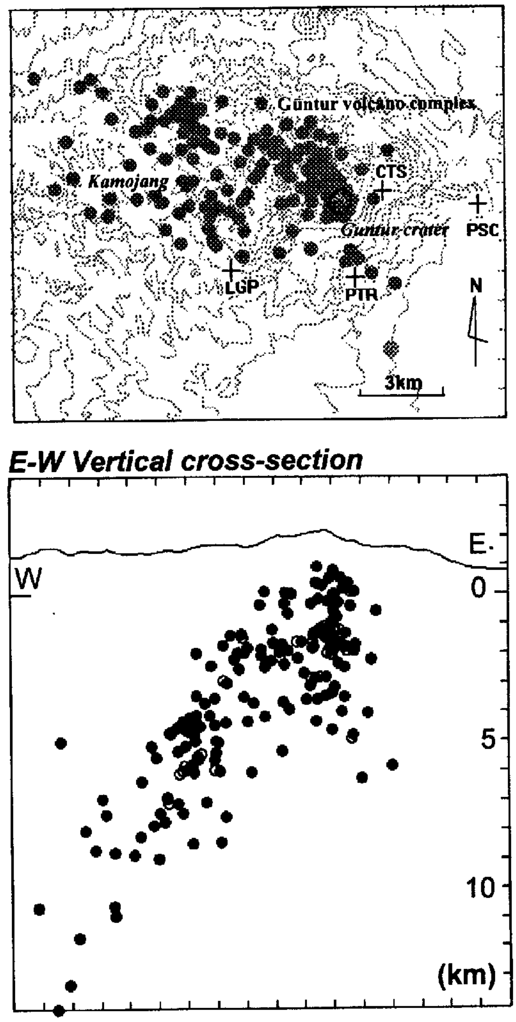

Fig.6 Hypocenter distribution around Guntur volcano in November 1994 - December 1996. Upper: epicenter, Lower: vertical cross-section of east-west direction. Crosses indicate stations.

3. Hypocentral Distribution

Examples of seismograms of typical volcanic earthquakes at Guntur are shown in Figs. 4 and 5. The 3 components seismogram at permanent stations shows the earthquake is a typical A-type earthquake with clear P and S-waves. The seismograms recorded by different data logging devices are aligned in the same time scale in Fig. 5.

Hypocenters are determined by using 4 P-wave onset times at permanent stations assuming homogeneous half space of V_p=2.76 km/s (Rasijd *et al.*, 1989). The data by permanent stations in March to December, 1996 are added. The hypocentral distribution is shown in Fig. 6. The pattern of the distribution is almost the same as the previous study (Iguchi *et al.*, 1996). Epicenters are concentrated

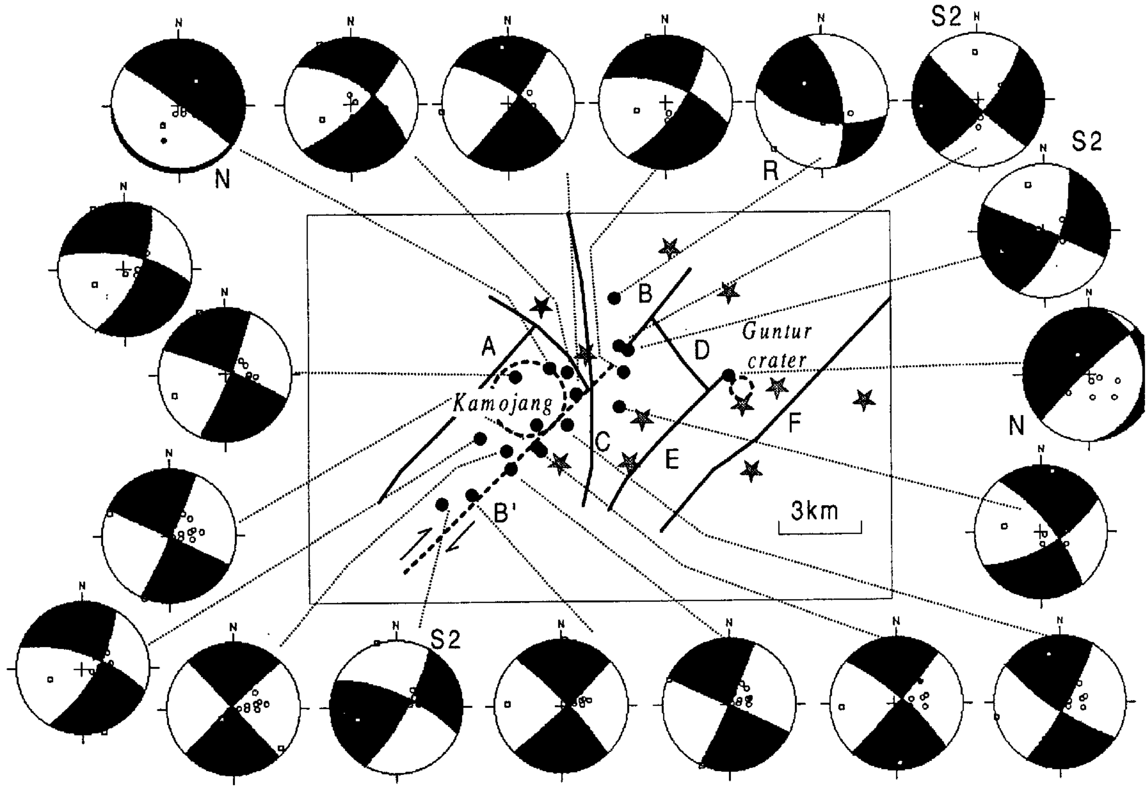

Fig.7. Source mechanisms of volcanic earthquake around Kamojang Caldera. Slid circles and stars represent epicenters and stations, respectively. Solid line indicate geological fault (Alzwar *et al.*, 1992) as shown by A-F. Focal mechanism diagrams are equal-area projection of the upper-hemisphere of the focal sphere.

beneath the summit crater, and some of them are located near Gandapura caldera and northeastern and eastern part of Kamojang caldera. Hypocenters are located shallower than 5 km below sea level beneath the summit crater. On the other hand, the hypocenters are rather deep around Kamojang caldera up to about 10 km.

In this study, small number of earthquakes are found beneath Gunung Putri, south of the summit crater at a depth of 8 km. The earthquakes occurred in May 1996. This shows earthquakes occur in wide area around Guntur volcano.

The hypocenters were determined by using more than 7 onset times of P-wave obtained in the temporary observation from December 1995 to February 1996. The results are shown in Fig.7 with the location of faults on geological map (Alzwar, 1992). The most of the events are located in Kamojang area. The epicenters are aligned in the NE-SW direction from the southwest edge of the Fault B.

4. Focal Mechanism

4.1 Kamojang Area

We try to determine focal mechanisms of 19 volcanic earthquakes observed at more than 7 seismic stations in temporary observation December 1995 - February 1996 (Fig.7). Focal mechanisms of the earthquakes were determined using more than 7 P-wave first motions assuming quadrantal pattern of P-wave push-pull by the method of try-and-error. The typical mechanisms are shown in Fig. 7. The P-wave first motions are projected on the upper hemisphere of the focal sphere. All plots are equal-area projection. The source mechanisms of most of the earthquakes are strike-slip type whose directions of nodal planes are NE-SW and NW-SE. The compression and tension axes were oriented to east-west and north-west, respectively. Considering directions of alignment of hypocenters and the dominant directions of faults from NE to SW in this area, the plane of NE-SW direction may be slipped as shown in Fig. 7. Considering a geological map (Alzwar, 1992) and focal mechanism in this study, this area may be effected by tectonic stress, extension in north-south and compression in east-west.

The source mechanism of earthquakes at the northeastern and southeastern of this cluster (represented by S2 in Fig.7) are strike-slip type, too. But the mechanism shows north-south compression and east-west extension. These three earthquakes may be generated by the slip of the other faults. An earthquake in Kamojang caldera has the mechanism of normal fault (N).

4.2 Mechanism at Guntur Summit

We try to determine the source mechanism of volcanic earthquakes beneath summit by using the data by temporary observation from September to December 1996, adding three stations (one station failed to record events) around Guntur crater. Examples of mechanisms are shown in Fig. 8. The earthquakes near the summit crater is smaller than those in Kamojang area. Only 6 stations are useful to determine focal mechanism and it is difficult to obtain unique solution for these earthquakes. Two of them may be normal-fault and the other reverse fault type. It is difficult to draw nodal lines for strike-slip fault as found along the fault near Kamojang. Composite focal mechanism were obtained by the polarity data of P-wave onset time at 4 permanent stations. However, no consistent source mechanisms were found.

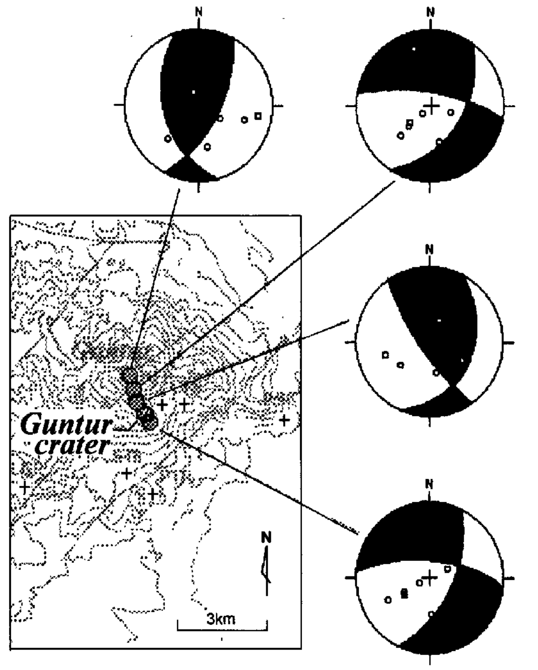

Fig.8. Source mechanisms of volcanic earthquake around the summit crater.

5. Discussion and Conclusion

From determination of hypocenter and focal mechanism, difference in feature of earthquakes in summit area and Kamojang area was made clear.

[1] The hypocenters are vertically elongated beneath the summit crater. In Kamojang area, hypocenters are aligned along the fault. The depths are rather deep up to 10 km.

[2] The strike-slip fault with the direction of NE-SW are dominant in Kamojang area. In contrast, no consistent source mechanism is found in summit area. In this analysis, normal and reverse fault types were found.

From these facts, the earthquakes in Kamojang area are generated by the slip of fault in the direction of northeast-southwest. The earth-quakes beneath the summit crater may be generated by small-size fracture in the rock of the conduit which may be created by previous eruptions. The upper limit of the magnitude of the earthquake beneath the summit is 0.7 (Iguchi *et al.*, 1996). This fact coincides with highly fractured zone. The vertically elongated pattern of distribution in the summit area is similar to those at Sakurajima (Ishihara, 1990; Iguchi, 1994), Asama (Sawada, 1995) and other volcanoes. It is reported that no consistency of source mechanism is found beneath the shallower part of summit of Sakurajima (Nishi, 1987). Andesitic volcanoes where summit eruptions occur may have the similar structure of the conduit.

In this study, stress field around Guntur volcano are analyzed by means of seismological method. It is necessary to confirm this model by deformation study.

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要　旨

京都大学防災研究所火山活動研究センターはインドネシア火山調査所と共同して，ジャワ島西部にあるグントール火山に4観測点からなる定常地震観測網を設置し，1994年11月から観測を続けている。また，1995年12月から1996年2月，1996年9月から12月にかけて臨時地震観測を行った。その結果，次のことが明らかになった。(1)火山性地震は，山頂の火口直下の海面下深さ0～5 kmに円筒状に分布する。また，北西部のガンダプラカルデラ，西部のカモジャンカルデラ周辺，南部のプツリ山直下にも分布している。特に，臨時多点観測による精密震源決定では，カモジャンカルデラ周辺の地震は深さ10kmまでに地表に現れた断層の延長線上に直線的に分布することが明らかになった。(2)カモジャンカルデラの周辺の地震の多くは，節線が北東－南西，南東－北西を向く横ずれ断層のメカニズムをもつ。一方，山頂火口周辺では正断層および逆断層となる解が得られたが，系統的なメカニズム解は得られなかった。(3) カモジャンカルデラ周辺の地震は，この地域に特徴的な北東－南西方向の断層の右横ずれ運動によって発生したものと考えられる。一方，山頂火口周辺の地震は，過去の噴火によって形成された火道周辺の岩石の様々な方向への微少破壊によるものと思われる。火口周辺の地震のマグニチュードの上限が0.7であることは，このことと調和的である。

キーワード：グントール火山，火山性地震，震源分布，発震機構