Hypocenters, Spectral Analysis and Source Mechanism of Volcanic Earthquakes at Kuchinoerabujima: High-frequency, Low-frequency and Monochromatic Events

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Synopsis

In 2006, monochromatic events characterized by slowly decaying quasi-sinusoidal coda part increased in August and September, and were followed by the increase of low-frequency (LF) events significantly in October. And then, high-frequency (HF) events increased to 450 events in November. Hypocenters of HF events located at the Shindake crater at depth of 0.0 to 0.6 km beneath the crater. LF and monochromatic events are also distributed inside the crater rim with 0.0 to 0.25 and 0.0 to 0.4 km in deep beneath the crater, respectively. HF events have a wide spectra in frequency range of 6~25Hz, meanwhile LF events dominated by lower frequency around 1~5 Hz. Monochromatic events show two patterns of spectra. First ones have a dominant frequency in range of 1~5 Hz and second ones have higher frequency around 6~15 Hz, and some subdominant peaks also appeared on the spectra. Fault plane solutions of HF events are normal fault type with WNW-ESE extension. Mechanisms of monochromatic events for high-frequency component are similarly normal fault types. LF and low-frequency monochromatic events show non double-couple mechanisms due to polarities at all stations are dilatation.

Keywords: High-frequency events, Low-frequency events, Monochromatic events, Kuchinoerabujima volcano

1. Introduction

Kuchinoerabujima volcano is located at Ryukyu Islands, South off Kyushu. The active crater is Shindake crater and the geothermal area is located at the western part of the crater. Historical records of eruption at Kuchinoerabujima started in 1841. Since then, several eruptions occurred in Shindake crater such as in 1931-1934, 1945 and 1966. The eruptions were dominated by phreatic eruptions. Last eruption was occurred at the fissure, east of the summit crater in 1980. Sometimes, the seismicity increased such as in March-June 1996, February 2004, January 2005 and November 2006. In August-December 1999 the number of volcanic earthquakes increased significantly and from that time to now, the seismicity at Kuchinoerabujima tends to be in the moderate to high level of volcanic activity.

To monitor the seismic activity of Kuchinoerabujima volcano, Sakurajima Volcano Research Center (SVRC) has built a seismic network, which is consisting of three broadband seismometers and three short-period seismometer of 1 Hz around the volcano (Figure 1). The data is telemetered to SVRC by telephone lines. To cover the eastern part of the volcano, since the beginning of September 2006, two temporary seismic stations have been installed at east and southeast part of the volcano (Figure 2). These seismic stations have been equipped with short period (1 Hz) 3 components seismometer. The data has been sampled

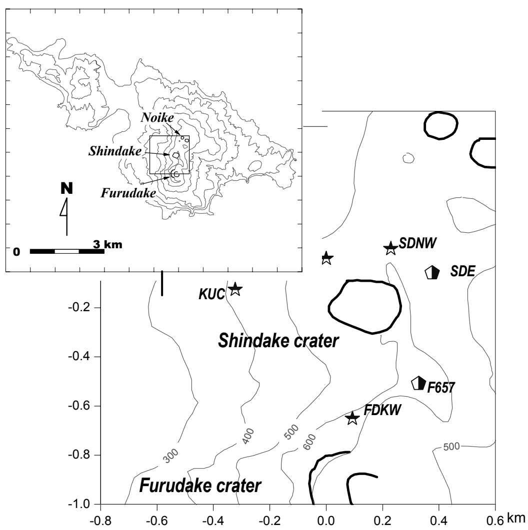

Figure 1 Seismic network at Kuchinoerabujima; stars and pentagons indicate permanent and temporary stations, respectively.

with a frequency of 100 Hz for horizontal components and 200 Hz for vertical component by data loggers (DATAMARK LS-7000XT)

Volcanic earthquakes of Kuchinoerabujima volcano can be classified into (Yamamoto et al., 1997; Iguchi et al., 2001):

1. A-type: P and S-waves can be identified clearly and spectra with dominant frequency 8~10 Hz.
2. High-frequency type (HF): S-wave can not be recognized clearly, has spectra with frequency of 6~30 Hz.
3. Low-frequency type (LF): S-wave can not be recognized clearly, dominated by lower frequency around 2~4 Hz and some subdominant frequency peaks appeared.
4. Monochromatic event: showing slowly decaying quasi-sinusoidal coda part, having 2 patterns of spectra i.e. with low dominant frequency and high dominant frequency, also showing several peaks of subdominant frequency.

Example of waveform of volcanic earthquakes at Kuchinoerabujima, which are analyzed in this study, can be seen in figure 2.

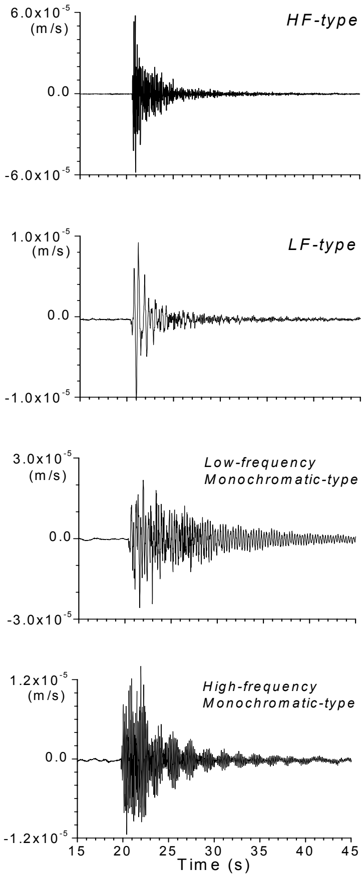

Figure 2. Waveforms of volcanic earthquakes at Kuchinoerabujima.

The seismicity at Kuchinoerabujima is dominated by HF events. Monochromatic event, for the first time was observed in March 1996, following the occurrences of A-type, LF-type and HF-type events in January 1996. During 2006, the seismicity at Kuchinoerabujima kept high level. HF events dominated the seismicity (Figure 3). In August and September, number of monochromatic events reached 115 and 75, respectively. After that, the number of LF events increased significantly in October and about 55 events occurred in several days. And then, in November HF events reached 450 events.

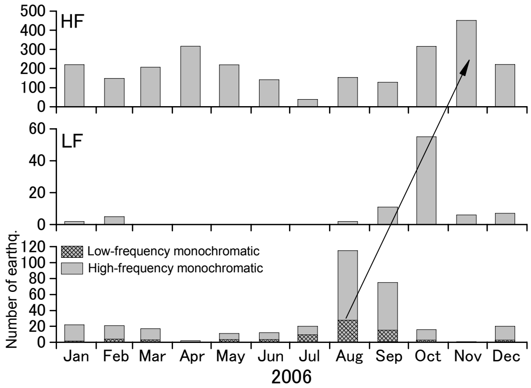

Figure 3. Monthly number of volcanic earthquakes at Kuchinoerabujima volcano in 2006.

Yamamoto et al. (1997) observed the monochromatic events, which were recorded in May-June 1996. They analyzed that the monochromatic events might not be generated by shear faulting mechanism, because polarities of P-wave first motions were dilatational at all the stations. This pattern was similar to LF events. The other study was done by Iguchi et al. (2001) suggested that repetition of HF events, which were generated by normal fault mechanism, was a trigger of monochromatic events that occurred in November 2000 to March 2001. In this study, hypocenter and source mechanism of HF, LF and monochromatic events recorded in 2006 will be analyzed and the results will be compared to the previous studies (Yamamoto et al., 1997; Iguchi et al., 2001).

2. Analysis

2.1. Hypocenter

Hypocenter is calculated by using **WIN** software. For the input is used P-wave arrival time, a reference point, coordinate of seismic stations and assuming a homogeneous half space of V_p is 2.1 km/s (Yamamoto et al., 1997 and Iguchi et al., 2001). In the calculation only t_p is used, due to t_s-t_p is too small ≤ 0.2 s.

Figure 4 shows hypocenter calculation using 4 permanent stations and data from January - August and October – November 2006. Hypocenters of HF events are located at the crater with the depth of 0.0 to 0.6 km below the crater (Figure 4a). LF events are located at the crater with the depth of focus between 0.0-0.25 km below the crater (Figure 4b) and monochromatic events (Figure 4c) is located at depth of 0.0-0.4 km below the crater. Those three types of volcanic earthquakes are located at the same region. These results reveal that hypocenters of volcanic earthquakes in 2006 are shallower than the previous studies which were done by Yamamoto et al. (1997) and Iguchi et al. (2001).

Figure 5 shows hypocenter calculation using 4 stations and 6 stations (including 2 temporary stations). Recorded data in September and December are used in the calculation. Comparing both results show that the hypocenters are distributed at the crater with depth of hypocenter calculation for 6 stations deeper up to 0.08 km than calculation for 4 stations.

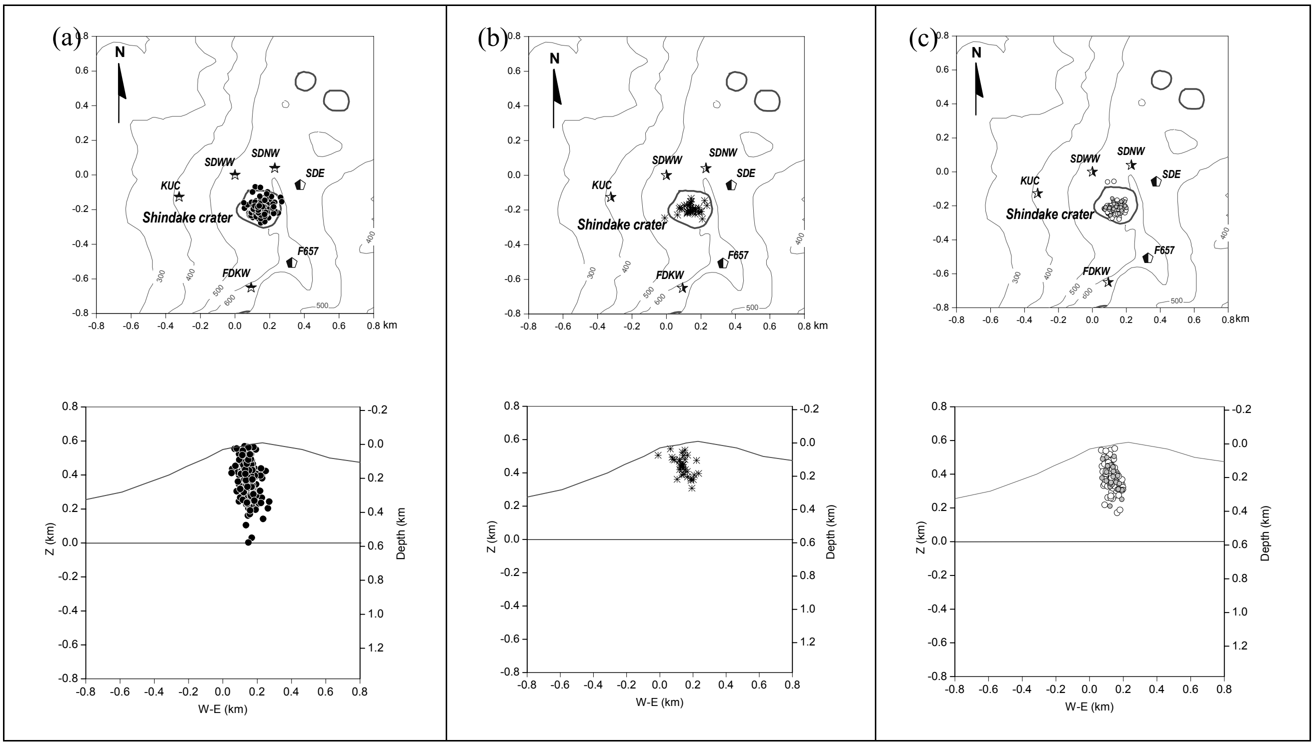

Figure 4. Hypocenter distribution of (a) HF events, (b) LF events and (c) Monochromatic events, grey and open circles indicate low-frequency and high-frequency monochromatic events, respectively.

2.2. Spectra Analysis

Spectral analysis is done by applying FFT algorithm on 10.24 s waveform start from the onset of HF type-, LF-type and monochromatic events. HF events show wide spectra with a dominant frequency around 6~25 Hz. Example of HF event can be seen in figure 6. Spectra of LF events have dominant frequency in range of 1~5 Hz. In figure 7, the dominant peak is about of 1.7 Hz.

Monochromatic events show 2 patterns of spectra, first pattern having a peak dominated by low frequency around 1~5 Hz, and the second pattern has dominant frequency in range of 6~15 Hz. On spectra of monochromatic events, several peaks of subdominant frequency can be identified. Figure 8a shows spectra of monochromatic event that have dominant frequency at 3.6 Hz, and subdominant peaks at 1.4, 6.7 and higher than 10 Hz. Figure 8b shows the dominant frequency at 13.3 Hz and subdominant peaks at 6.3, 12 and 16.4 Hz.

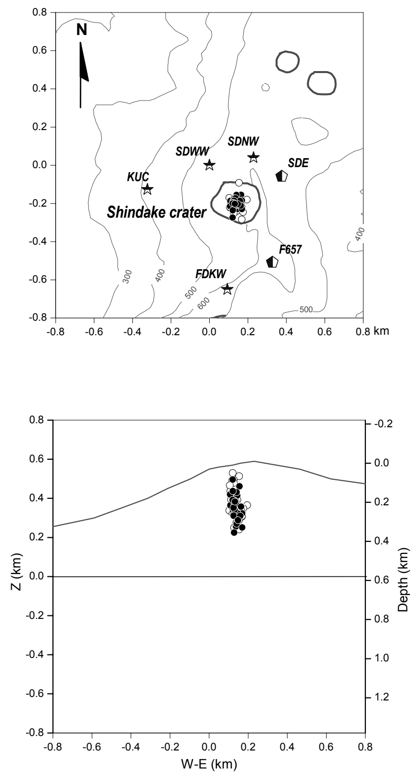

Figure 5. Hypocenter distribution using 4 stations (open circles) and 6 stations (solid circles).

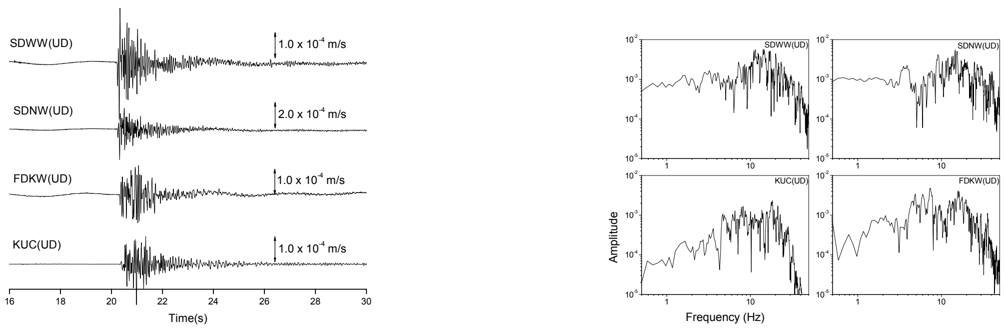

Figure 6. Waveform and spectra of HF event, recorded at 16:35:21, February 27

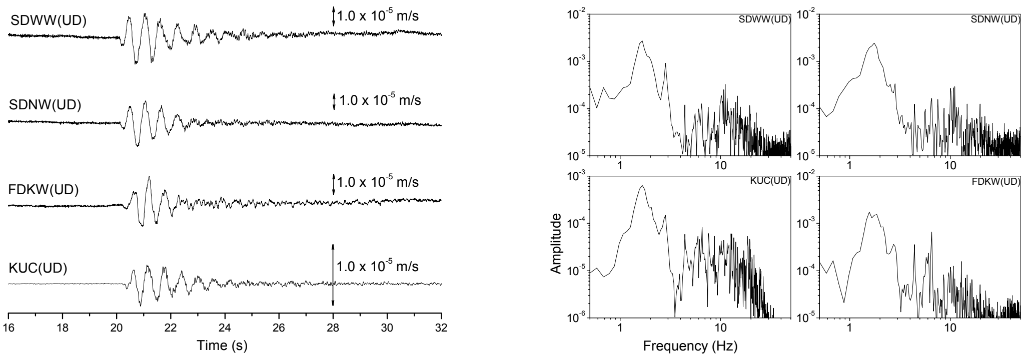

Figure 7. Waveform and spectra of LF event, recorded at 15:20:23, October 9.

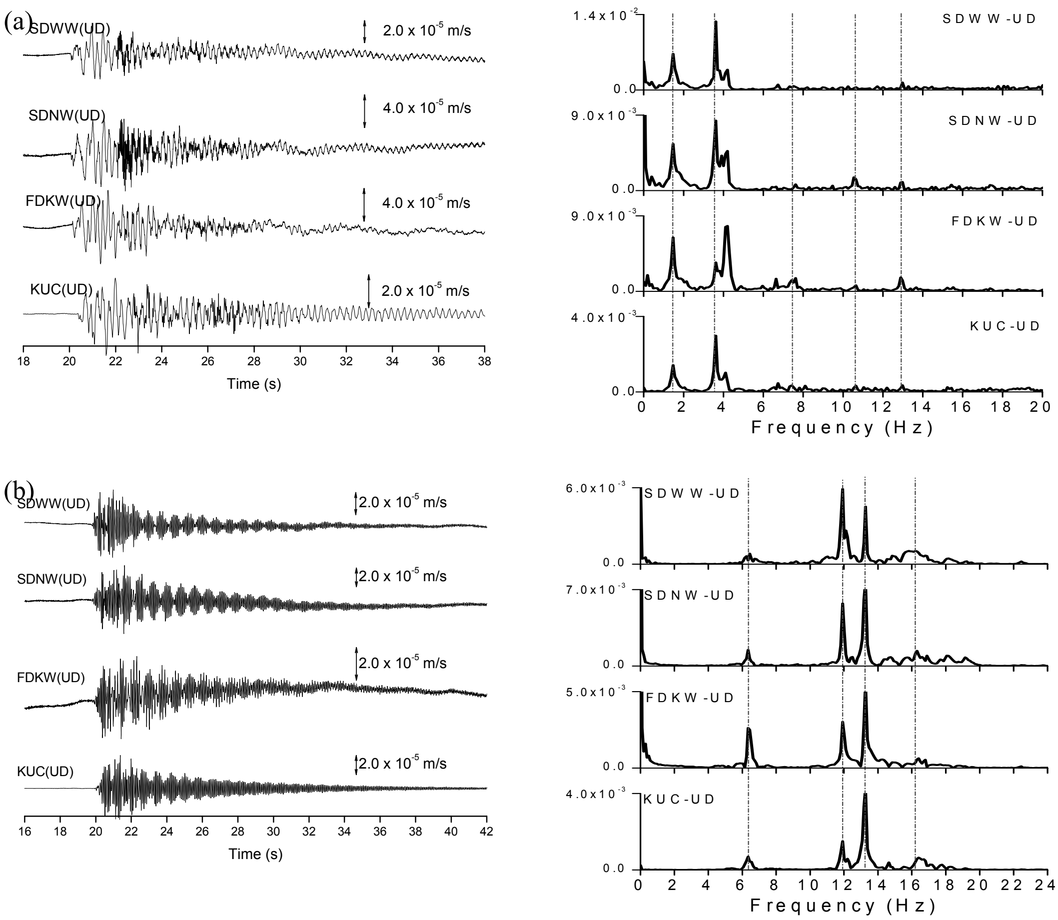

Figure 8. Waveform and spectra of monochromatic events, recorded (a) at 02:47:05, February 24 and (b) at 03:48:22, June 11.

2.3. Source Mechanism

In this section, fault plane solution will be obtained by assuming double-couple (DC) mechanism due to polarity of dilatational and compressional of P-wave first motions are mixed. Fault plane solutions of HF events are dominated by normal fault types with T-axis toward to WNW-ESE direction and P-axis nearly vertical (Figure 9). These results are similar to a previous study done by Iguchi et al. (2001). HF events occurred in November 2000 – March 2001 were also generated by normal fault type with east-west extension.

Due to only 4-6 stations used in this study, focal mechanism of HF events during period 2006 is compared to the HF events recorded during the research of subsurface seismic structure of Kuchinoerabujima volcano in November 2004. In the 2004`s research, 79 temporary stations were deployed on Kuchinoerabujima Island. Polarity distribution of P-wave first motion which can be identified is shown in figure 10. Those HF events in November 2004 were generated by normal fault type with T-axis tend to WNW-ESE direction and P-axis nearly vertical. In figure 10, two HF events recorded in November 11, 2004 were located at southern part of the crater with a depth about of 0.11-0.14 km below sea level deeper than HF events which occurred in 2006. In the hypocenter and focal mechanism determination, velocity structure resulting from active seismic survey at Kuchinoerabujima (Yamamoto et al., 2005) was used.

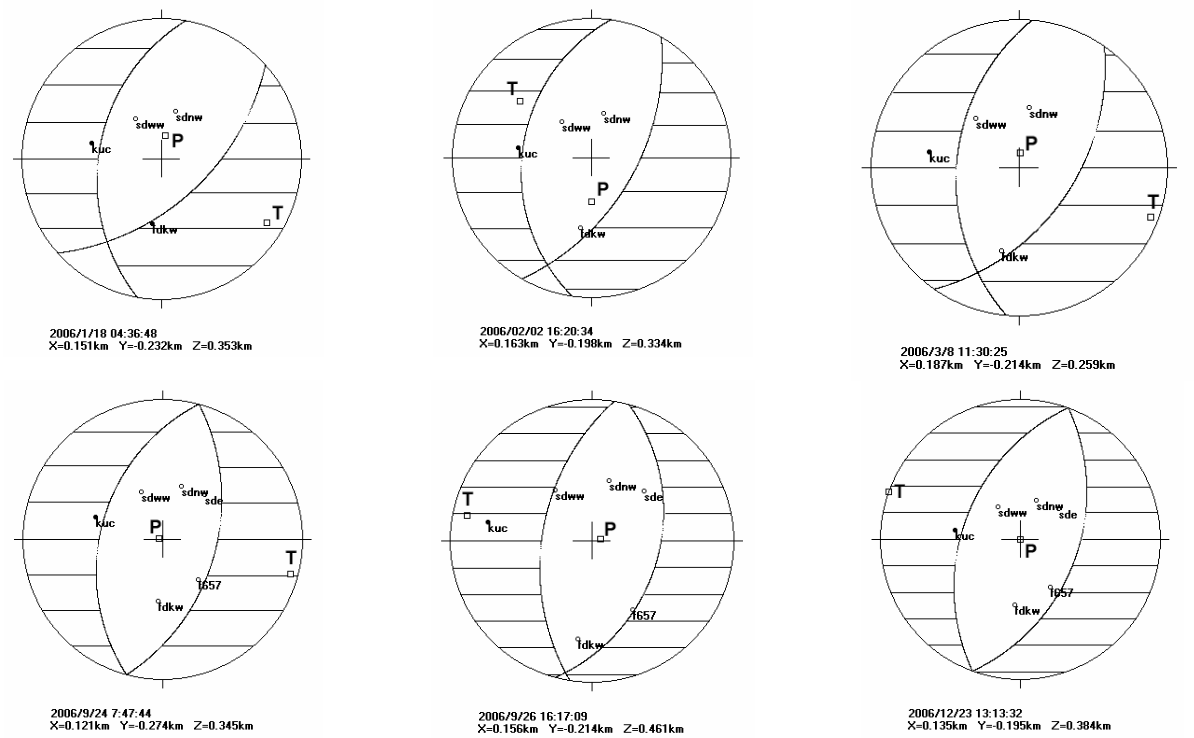

Figure 9. Focal mechanism of HF event in period year 2006 using 4 stations (above) and 6 stations (below)

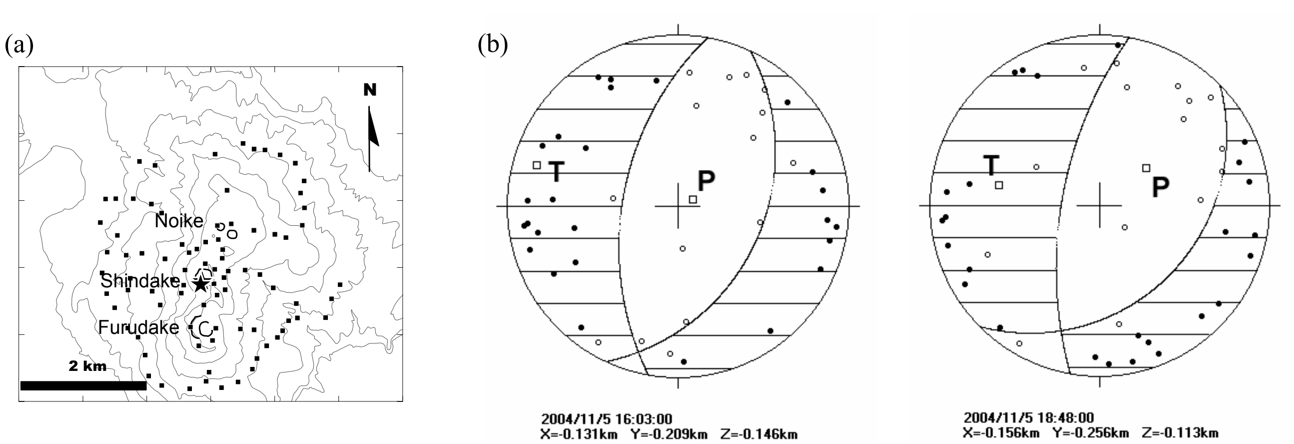

Figure 10. (a) Location of seismic stations (solid square) and hypocenters (solid stars). (b) Focal mechanisms of two HF events on November 11, 2004, plotted on the upper hemisphere of focal sphere. Solid and open circles indicate compressional and dilatational components, respectively.

Since all polarities of LF events are dilatational components, the fault plane solution could not be obtained (Figure 11). The other method, such as moment tensor analysis could be used to determine the mechanism of LF events.

Monochromatic events at Kuchinoerabujima reveal some mechanisms. Solution for monochromatic events, which have low frequency component, could not be determined since all of the polarities are dilatational components and those are similar to LF events mechanisms (Figure 12a and b). These results are similar to the previous study which was done by Yamamoto et al. (1997) that showed both LF and low-frequency monochromatic events may not be generated by double-couple mechanisms due to all the polarities are dilatation at all the stations. These results are similar to study by Yamamoto et al. (1997) that inferred LF and low-frequency monochromatic events may not be generated by double-couple mechanisms. Otherwise, fault plane solutions for the monochromatic events that have high-frequency component could be obtained. The solutions of such events are similar to HF event mechanisms that can be seen in figure 12c and d. Those high-frequency monochromatic events are generated by normal fault type mechanism with T-axes tend to WNW-ESE direction and P axes nearly vertical. Iguchi et al. (2001) suggested the initial part of monochromatic events which have high-frequency component were reflected by repetition of high-frequency events which were generated by normal fault mechanism.

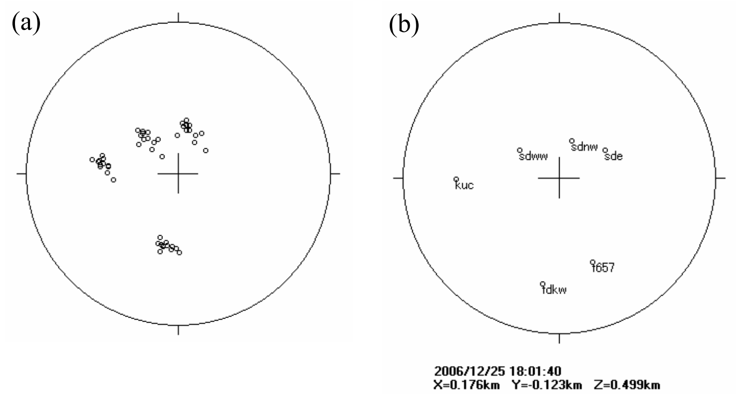

Figure 11. (a) Composite polarities of 12 LF events for 4 stations and (b) Polarities of LF events for 6 stations, recorded at 18:01:40 on December 25.

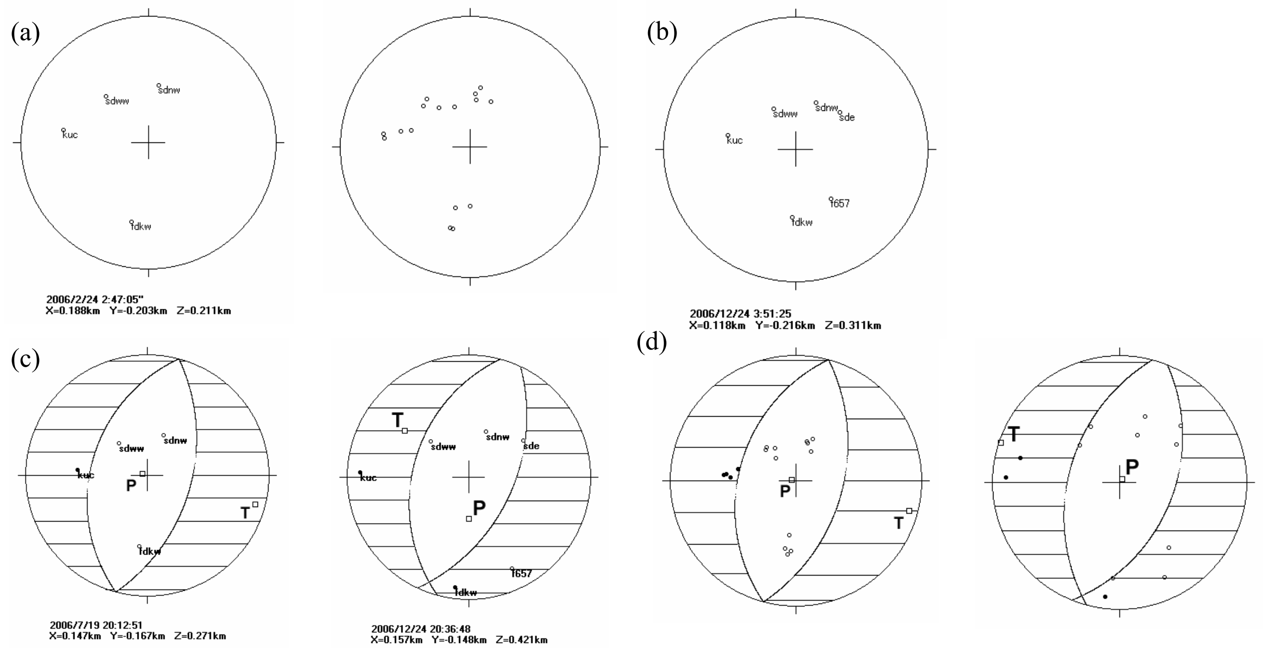

Figure 12. (a) Polarities and composite of low-frequency monochromatic events for 4 stations (b) Polarities of low-frequency monochromatic events for 6 stations. (c) Focal mechanism and (d) Composite of high-frequency monochromatic events for 4 and 6 stations.

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口永良部島火山における
火山性地震の震源分布，スペクトルおよび震源メカニズムについて
—高周波地震，低周波地震，モノクロマティック地震—

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要旨

口永良部島火山では2006年8月ごろからモノクロマティック地震と呼ばれる正弦波的な振動からなる長いコーダ部分をもつ地震が頻繁に現われるようになった．この活動は9月ごろまで続いた，引き続き10月には低周波地震が発生するようになった．更に11月には高周波地震が頻発し，450回を記録した．京都大学防災研究所では新岳周辺の常設の4観測点加え，臨時観測点を火口の東側に増設することにより，周辺の震源位置，スペクトル，震源メカニズムを調べたところ次の知見が得られた．(1)これら3種類の地震の震央はいずれも新岳の火口内にあり，深さは600m以下と浅い．特に，低周波地震の震源の深さは200m以下と極めて浅い場所に求まった．(2)高周波地震は6-25Hzの高周波側の広い周波数帯域を示す．一方，低周波地震のスペクトルでは1-5Hzの間に卓越したピークがみられ，副次的なピークも検出できた．モノクロマティック地震では3個以上のピークが見られる．ピークの周波数範囲から2種類に分類できる．低周波型モノクロマティック地震ではピーク周波数は1-5Hzの範囲にあるが，高周波型モノクロマティック地震では6-15Hzの高周波側にピークがみられる．(3)高周波地震および高周波型モノクロマティック地震では初動は押しであるものと引きであるものが混在するため，4象限型の押し引き分布をもつダブルカップルのメカニズムを仮定するのが妥当である．これらのタイプではすべて西北西－東南東に伸張軸をもつ正断層型のメカニズムが得られた．一方，低周波地震および低周波型モノクロマティック地震では初動がすべて引きであり，4象限型の節線を引くことが困難である．収縮震源によって励起されていると考えられる．