Korean Journal of Polar Research 10(2): 109-115
© Polar Research Center, KORDI 1999

A Great Earthquake in the Antarctic Plate on March 25, 1998

Reiji Kobayashi, Katsutada Kaminuma, Yoshifumi Nogi, and Masaki Kanao

National Institute of Polar Research, 9-10, Kaga-1, Itabashi, Tokyo 173-8515, Japan

ABSTRACT. A great earthquake with magnitude (Ms) 8.0 struck the Balleny Island region on March 25, 1998.This intraplate earthquake is the largest one in the Antarctic plate and the first felt shock in the Antarctic Continent since the International Geophysical Year (IGY) in 1957-1958.Small amplitude tsunami wave generated by the great earthquake was recognized at some ocean tide stations in the Southern ocean.The aftershock activity of the great earthquake is investigated using the seismicity catalogue of weekly Preliminary Determination of Epicenter (PDE).Sixty seven aftershocks have been located during 273 days after the great earthquake occurred.An induced swarm-like activity is recognized in the aftershock activity.

Key Words: Antarctic earthquake, intraplate earthquake, seismicity, tsunami wave, aftershock

Introduction

It was general seismological knowledge by the International Geophysical Year (IGY) in 1957-1958 that no extreme earthquakes except in the volcanic regions were located in the Antarctic (Gutenberg and Richter 1954). Before the IGY, seismographs have been operated by four earlier expeditions on the Antarctic continent: the Scott expedition (Hut Point Peninsula, McMurdo Sound) in 1902-1903, the Byrd expedition (Rockefeller Mountain) in 1940, the Ronne expedition (Marguerite Bay) in 1947-1948, and the French polar expedition (Adelie Land) in 1951-1952 (Richter 1958). However no permanent seismic station was operating in the south of the Antarctic Circle by IGY. More than ten permanent seismic stations have been established in the Antarctic continent since IGY and are operating as a part of the dense world wide seismological network.

Four earthquakes are listed in the International Seismological Centre (ISC) data base for Antarctica from the early stage of Antarctic research. However Adams *et al.* (1985) concluded that except only one event, no significant earthquakes were located on the Antarctic continent before IGY because neither their exact locations nor their magnitude were determined.

Eleven earthquakes were located by the seismic network on the Antarctic continent and the world wide seismic network from IGY to early of the 1980s (Kaminuma and Ishida 1971; Kaminuma 1991). Four earthquakes out of eleven were located around Deception Island (63°S, 61°W) in the South Shetland Islands, around the Antarctic Peninsula. Deception Island is one of the active volcanoes in the Antarctic. One of the four events occurred on February 8, 1971 has body-wave magnitude (mb) of 6.3. This was the largest earthquake which occurred in the Antarctic since IGY. The other seven earthquakes with magnitude less than 5 seem to be tectonic earthquakes in the Antarctic continent. Very few intraplate earthquakes with magnitude less than 6 were located in the southern ocean by the world wide seismic network.

A great earthquake with surfacewave-magnitude

*corresponding author (reiji@nipr.ac.jp)

(Ms) 8 occurred in the southern ocean on March 25, 1998.The location of the earthquake is about 500km offshore from the Antarctic coast in the Antarctic plate. Even though there are some exceptions such as the Nobi earthquake (M 8.0, 1891) in Japan, the San Fransisco Earthquake (M 7.9, 1906) in USA, some great earthquakes in China etc., it is a general knowledge on seismology that most great earthquakes with magnitude (M) larger than 8 occur in/around the subduction zone areas of the plate boundaries. The great earthquake was the first one located in the Antarctic plate (Tono and Kaminuma 1998; Wines *et al.* 1998). The tectonics in the focal area and aftershock activity of the great earthquake will be discussed in this paper.

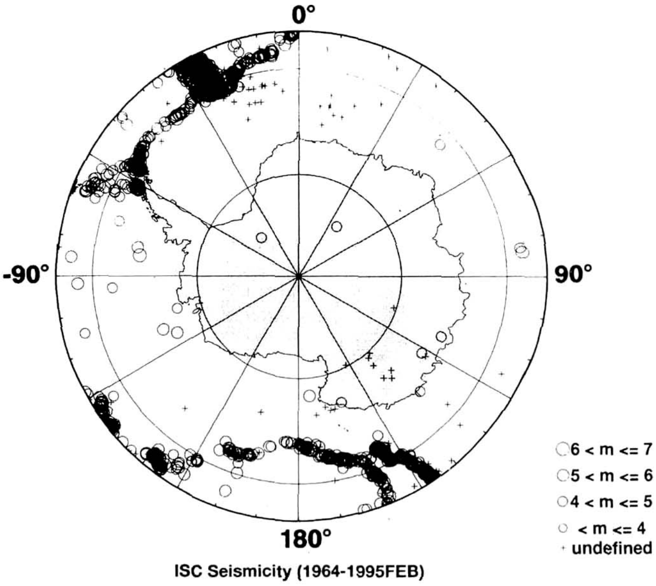

Fig. 1. Earthquake locations in the Antarctic determined by the International Seismological Centre (ISC) from 1964 to 1995.

Background seismicity in the Antarctic

Fig. 1 shows the seismic activities in and around the Antarctic plate in 1964-1995 which was compiled by ISC. Except the high seismic activity along the plate boundaries, the seismic activity in the Antarctic plate is very low. Seismic activities in the Antarctic plate are divided into the following five regions; 1) intraplate low seismic region, 2) high seismic region around the tip of the Antarctic Peninsula, 3) aseismic region of the Antarctic continent, 4) low seismic region of the coastal area at the continental edge and 5) volcanic regions (Kaminuma 1994).

Two earthquakes accompanied with volcanic eruptions of Deception Island on December 4, 1967 were felt by station members on Deception Island. Three stations of Argentine, Chile and UK were operated on Deception Island at that time and all huts were destroyed by eruption ejecta. Magnitude of the first shock was 4.7 and that of the second one was not determined. These two earthquakes were believed to be instrumentally located first time in the Antarctic and the first felt shocks since IGY.

The largest earthquake ever recorded in the Antarctic plate occurred in the South Shetland Islands on February 8, 1971. Its body wave magnitude (mb) and surface wave magnitude (Ms) are determined by National Earthquake Information Center (NEIC) of the US Geological Survey (USGS) to be 6.3 and 7.0, respectively. This earthquake is the only one of which magnitude is larger than 7.0 in the Antarctic.Including these three events, the seismic activity in the tip of the Antarctic peninsula is the highest in the Antarctic.

One earthquake with magnitude 4.3 was located by Kaminuma and Ishida (1971) in the Antarctic Continent using the phase arrival times of five seismic stations in Antarctica. This earthquake was the first earthquake to be located instrumentally in the continent. Since this event occurred in 1968, earthquakes were located by the currently work of the world wide seismic network operation of NEIC and the International Seismological Centre (ISC) in the Antarctic as shown in Fig. 1.

Some local earthquake activities were reported in the coast of the Antarctic continent (e.g. Adams *et al.* 1972, 1982; Akamatsu *et al.* 1990; Kaminuma and Akamatsu 1992). Kaminuma and Akamtsu (1992) estimated that the local earthquakes around Syowa Station in the coast of the Antarctic continent were caused by the crustal uplift after deglaciation. However most of the earthquakes are minor events of which magnitudes are less than 3.

A great earthquake

A great earthquake struck the Balleny Island region on March 25, 1998. The source parameters and magnitudes determined by NEIC are listed in Table 1.This earthquake is the first one of which magnitude is larger than 8 in the Antarctic plate. According to a request for the earthquake information from SyowaStation (SYO: 69°00′S, 39°35′E) of Japan to Dumont d'Urville Station (DRV: 66°40′S, 140°01′E) of France, the station leader informed that all wintering members in the station felt quake and something on the shelf in the building fell down.The epicentral distance at DRV is 624 km. The intensity at the station is estimated to be 3 (8.0~25 Gal) by the Intensity Scale of the Japan Meteorological Agency and V of MSK (Medvedev - Sponheur - Karnik) intensity scale.

At least three felt shocks were recorded in the Antarctic since IGY. As described in the previous section,the first one was the M 4.7 earthquake accompanied with volcanic eruption of Deception Island on December 4, 1967. The huts of the stations on Deception Island were destroyed by the eruptions, but all members in the stations evacuated safely after the eruptions. The Ms 7.0 earthquake occurred near Deception Island on February 8, 1971, and was felt at Farady Station (65°14.8′S, 64°15.5′W) of UK. This earthquake is the second felt shock in the Antarctic. The eruptions of Mount Erebus occurred on October 13, 1984 and people in McMurdo Station (77°51′S, 166°40′E) of US felt quake. This is the third felt shock in the Antarctic. However all these events are volcanic ones (Kaminuma 1994). The earthquake on March 25, 1998 is the first felt tectonic earthquake in the Antarctic except volcanic earthquakes since IGY.

According to the report by the US National Ice Center (US-NIC), sea ice edge was located along 65~66°S line in latitude, 200~400 km offshore from the Antarctic coastal line in the end of March, 1998 as shown in Fig. 2. Even if tsunami generated by the earthquake, the amplitude of the tsunami wave should be decreased by sea ice covered around the Antarctic Continent. Considering the sea ice condition, no clear tsunami was recorded by the tide guage at Syowa Station. It was also estimated from the fault plane solution determined by NEIC, large tsunami was not generated by the great earthquake. The National Tide Facility in the Flinders University of South Australia reported that small tsunami can be clearly seen in the records of tide gauges at Portland of Australia and Jackson Bay of New Zealand in the southern ocean.

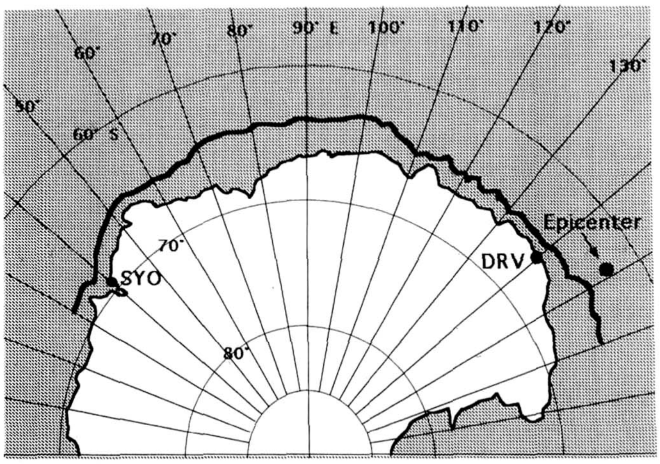

Fig. 2. Sea ice edge in the Antarctic ocean in the end of March 1998 obtained by the US National Ice Center. DRV and SYO show the abbreviations for Dumont d'Urville and Syowa Stations respectively.

Aftershocks

Kaminuma *et al.* (1999) already discussed about the aftershock activity of the great earthquake. According to the Weekly Preliminary Determination of Epicenter of NEIC, sixty seven aftershocks occurred during 273 days from March 25 to December 23, 1998. The epicentral distribution of the main shock and aftershocks are shown in Fig. 3. Nine hours after the main shock, the largest aftershock with Ms 6.1 occurred about 120 km southwest from the main-shock epicenter. Seven aftershocks with magnitude larger than 5.0 occurred nine minutes, about nine and ten hours, one day, four days, six days and 142 days each after the main shock occurred.

Utsu (1965) applied the maximam likelihood pro-

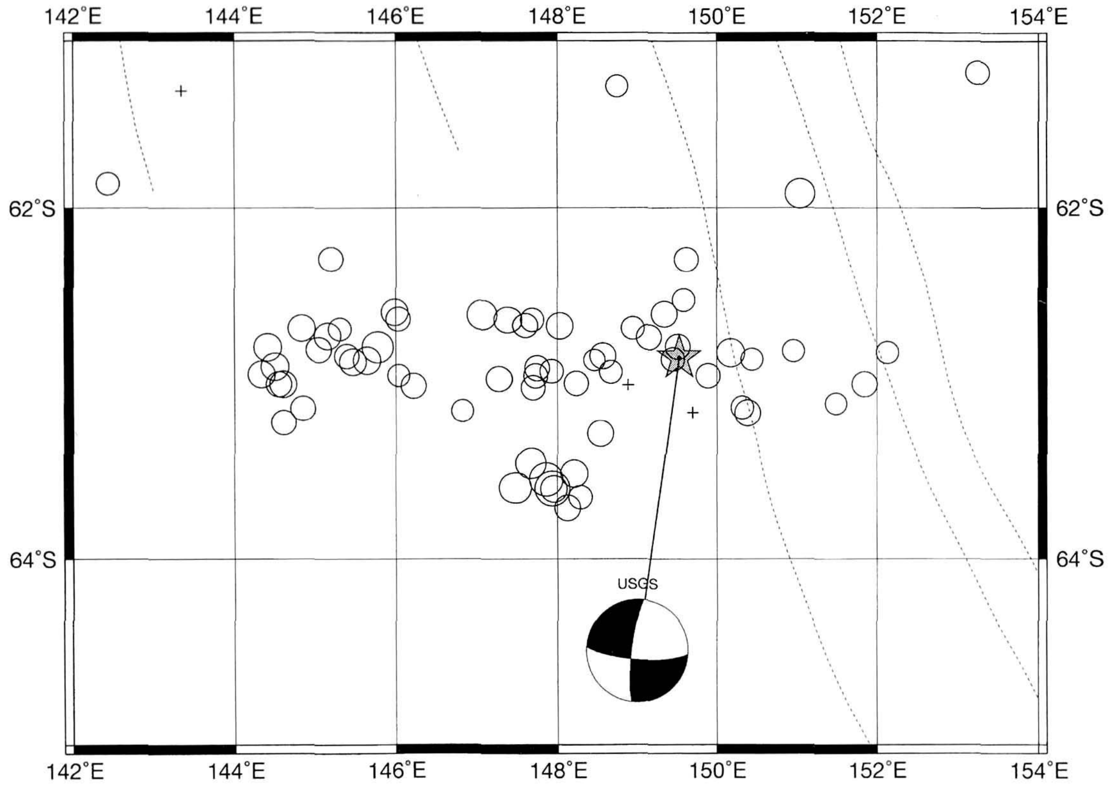

Fig. 3. Epicenter locations of the main shock (star) with surface magnitude 8.0 on March 25, 1998 and aftershocks (circles). The dashed lines show fracture zones.

cedure to obtain the "b" value of the Gutenberg-Richter's magnitude-frequency relation for earthquake (1944), which is one of the important statistical laws in seismology. The relation is as follows.

$$\log n(M) = a - bM,$$

where n denotes the number of earthquakes as a function of magnitude M, and a and b are constants depending on the group of earthquakes discussed. The b value for aftershocks with M 4.3 to 6.1 determined using the Utsu's method is 1.05 as shown in Fig. 4. As it is clear in Fig. 4, the Gutenberg-Richter's relation does not fit the aftershocks with magnitude less than 4.3. This might suggest that the NEIC data can mostly detect earthquakes with magnitude larger than 4.3 in the focal region.

The frequency of aftershocks with magnitude larger than a fixed level decreases with increasing time as given by the following equation.

$$n(t)dt = \frac{K}{(t + c)^p} + B,$$

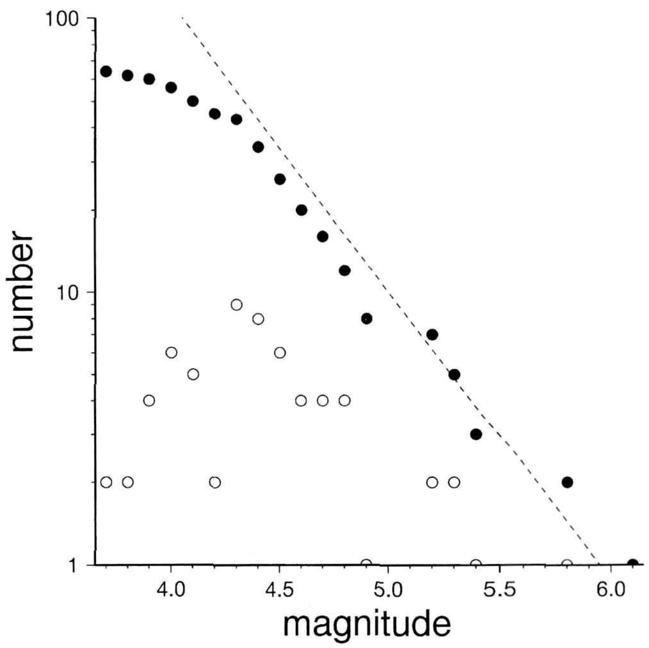

Fig. 4. Number of aftershocks as a function of magnitude (open circles). Solid circles represents the total number of aftershocks with magnitude more than M. The regression is represented by log n(M) = 6.259-1.05 M.

where n(t) dt denotes the frequency of aftershocks occurring between time t and t + dt, B denotes back-

Table 1. Source parameters of the main shock and largest aftershock.

	Main shock	Largest aftershock
Origin time (UTC)	1998/03/25 03:12:24.7	1998/03/25 12:17:22.7
Location	62.876°S, 149.712°E	63.578°S, 147.876°E
Depth	10 km	10 km
Magnitude	m_b 6.6, M_S 8.0, M_W 7.7	m_b 5.8, M_S 6.1, M_W 6.5
Best double-couple	(94°, 76°, –9°),	(277°, 67°, 21°),
(strike, dip, slip)	(187°, 81°, –165°)	(179°, 71°, 156°)

ground seismicity, and K, c and p are positive constants. This equation is called "modified Omori formula". The value of p is an index of the rapidness of attenuation in frequency. In this paper,B can be ignored because of no seismicity in the focal region before the great earthquake occurred, t is number of day, and each parameter is obtained by Ogata's method (1983) as follows. K = 6.76,c = 0.1andp = 1.14.

Table 2. *b*- and *p*-values of aftershocks of great earthquakes in Japan

Location	Year	M	*b*	*p*	Remarks
Kanto	1923	7.9		1.3	
Sanriku	1933	8.1	1.1	1.5	U1
To-nankai	1944	7.9	0.7	1.1	U2
Nankai	1946	8.0	0.7	1.0	U2
Tokachi-oki	1952	8.2	0.8	1.1	U1
Tokachi-oki	1968	7.9	0.9	1.0	U2
Antarctica	1998	8.0	1.05	1.14	

Discussion

Two nodal lines of the best double copule are obtained for the main shock and the largest aftershock on March 25 as shown in Table 1. The earthquakes are strike slip ones and both double couples have nearly the same directions of strike as north-south and east-west.

There are some fracture zones located in the focal region for the NNW-SSE direction which is a perpendicular to the plate boundary. However the epicenter itself is not located on the fracture zone. No tectonic lineation trending east-west in the focal region has been detected on the maps of bathymetry and gravity anomaly, and the stress field inferred from the fracture zone trending NNW-SSE can not interpret the mechanism of the main shock indication NE-SW compression.

The fault plane was taken as the east-west direction estimating from aftershock distribution. The size of the fault plane estimated by aftershocks is 300 km long. The depth of most of aftershocks is 10 km.

Table 2 lists the p and b values of aftershocks of six great shallow earthquakes in Japan obtained by Utsu (1961, 1969). U1 and U2 in Remarks of Table 2 denote Utsu (1961) and Utsu (1969) respectively.

The coefficient b is considered to be related to some tectonic condition or physical properties of crustal rock in the focal area. The b values of great earthquakes ordinary range between 1.1 and 0.7 as shown in Table 2. The b value of 1.05 means that the number of smaller magnitude aftershocks occur more than those of the other great earthquakes. Large b value means that the structure of the focal area is largely inhomogeneous to compare with other great shock areas.

The p value as 1.14 of the earthquake is relatively small among those of great earthquakes in Table 2. This means that the aftershock activity of the great earthquake continued for a long time.

The largest aftershock locates about 120 km southwest from the main shock and 60 km south of the fault plane with concentrating some aftershocks. The largest aftershock seems to be an induced activity with one foreshock and some aftershocks, because the epicenters of these shocks concentrated about 60~70 km south from the fault plane. Considering four earthquakes with magnitude larger than 6 occurred in the concentrated region, the activity also seems to be an induced swarm activity. This is very interesting phenomenon considering the seismo tectonics in this earthquake field.

Conclusion

The results of this paper are summarized as follows:

1. The earthquake with Ms 8.0 on March 25, 1998 is the first felt earthquake in the Antarctic except volcanic earthquakes since IGY.

2. The fault plane of the main shock determined by aftershock distribution trends E-W and 300 km long. Most of the aftershocks is about 10 km in depth.

3. The "b" value of Gutenberg- Richter's relation for earthquakes is obtained to be 1.05. This means that small earthquakes occurred frequently, and the structure of the focal area might be inhomogeneous.

4. The "p" value of so called modified Ohmori's formula is obtained to be 1.14. This means that the aftershock activity continuous longer than those of other great earthquakes.

5. An induced earthquake swarm activity is recognized in the aftershock activity. The induced earthquakes locate about 60~70 km south from the fault plane.

Acknowledgments

The aftershock data are taken from the IRIS Data Management Center. Prof. K. Shibuya, the leader of the 39th Japanese Antarctic Research Expedition, send us many information about the earthquake from Syowa Station. The authors express their sincerely thanks to them.

The manuscripts of this paper is prepared by Ms. Minegishi of National Institute of Polar Research.

The authors thanks extend to two anonymous reviewers for their critical reading of the manuscript.

References

Adams R.D. 1972. Local Earthquakes in Victoria Land,In: R.J. Adie (ed.), Antarctic Geology and Geophysics, Universitetsforlaget, Oslo, pp495-499.

Adams R.D. 1982. Source properties of the Oates Land Earthquake, In: C. Craddock (ed.), Antarctic Geoscience, Univ. Wisconsin Press, Wisconsin, pp. 955-958.

Adams R.D., Hughes A.A., and Zhang B.M. 1985. A Confirmed Earthquake in Continental Antarctica, Geophys. *J.R. Astr. Soc.* **81:** 489-492.

Akamatsu J., Ichikawa N., and Kaminuma K. 1990. Seismic observation with local telemetry network around Syowa Station, East Antarctica (2), *Proc. NIPR Symp. Antarct. Geosci.* **4:** 90-99.

Gutenberg B. and Richter C.F. 1954. Seismicity of the Earth and associated Phenomena, Princeton Univ. Press, Princeton, p. 93.

Gutenberg B. and Richter C.F. 1944. Frequency of earthquakes in California, *Bull. Seismol. Soc. Am.* **34:** 185-188.

Kaminuma K. and Ishida M. 1971. Earthquake activity in Antarctica, AntarcticRec., No. **42:** 53-60.

Kaminuma K. 1991. Seismicity in Antarctica and Local Earthquake Activities around Syowa Station, EastAntarctica. Korean Journal of Polar Research, Vol. 2, No. 1 (Spec. Issue): 87-96.

Kaminuma K. and Akamatsu J. 1992. Intermittent micro-seismic activity in the vicinity of Syowa Station, East Antarctica, In: Y. Yoshida, K. Kaminuma and K. shiraisi (eds) Progress in antarvitv Earth science, TERRAPUB, Tokyo, pp. 493-497.

Kaminuma K. 1994. Seismic Activity in and around Antarctic Continent. Terra Antarct, **1(2):** 423-426.

Kaminuma K., Kobayashi, R., Nogi Y., and Kanao M. 1999. Aftershock activity of the great 1998 earthquake in the Antarctic plate, Polar Geosci., in press.

Ogata Y. 1983. Estimation of the parameters in the modified Omori formula for aftershock frequencies by the maximum likelihood procedure., *J. Phys. Earth*, **31:** 115-124.

Tono Y. and Kaminuma K. 1998. A great earthquake in the Antarctic Plate on 25 March 1998 (in Japanese with English abstract), *Antarctic Rec.* **42:** 190-195.

Richter C.F. 1958. Elementary seismology, W.H. Freeman and Company, San Francisco, pp. 334-335.

Utsu T. 1961. AStatistical study on the occurrence of aftershocks, *Geophys. Mag.* **30:** 521-605.

Utsu T. 1965. A method for determining the value b in a formulalon n = a-bM sowing the magunitude frequency relation for earthquakes, Geophys. *Bull. Hokkaido Univ.***13:** 99-103 (in Japanese with English abstract).

Utsu T. 1969. Aftershocks and earthquake statistics (I), J. Fac. Sci., HokkaidoUniv., Ser VIII, **3:** 129-195.

Wiens D.A., Wysession M.E., and Lawver L. 1998. Recent oceanic intraplate earthquake in Balleny Sea waslargest ever detected., Eos, Trans., *Am. Geophys. Union*, **79:** 353-354.

Received 5 July 1999
Accepted 7 October 1999