Earthquake Activity in Antarctica

Katsutada KAMINUMA* and Mizuho ISHIDA*

南極地域の地震活動

神沼克伊*・石田瑞穂*

要旨：世界の地震観測網が整備され，地球上に起こるマグニチュード5以上の地震は，ほとんど観測されるようになった今日でも，南極大陸およびその周辺に震源の決まった地震はない．

しかし，南極各基地の地震観測の報告をみると，南極の基地だけにしか観測されないような，小さな地震が起こっているらしい．

そこで，USCGSから発行されている "The Antarctic Seismological Bulletin" の資料に基づいて，震源の決定を試みた．少なくとも4点以上の基地で観測されているものにつき，その深さを33kmと仮定し，震央と発震時を求めた．震源決定を試みた地震72個のうち，24個の震央のみを，誤差±100km，O-C residual 3 秒以内で決めることができた．24個の地震のほとんどの震央は，大陸周辺に存在する地震帯の上に決まった．しかし，1個だけではあるが，南極大陸内に震源が決まった地震がある．この震源精度を確かめるために，多くの震源を仮定し，O-C residualの自乗平均値を調べた．その結果，この地震は大陸内20°W，80°S，深さ1kmに起こり，マグニチュード4.3であることが分かった．

現在の地震観測網では，震源を決められない小さな地震が，南極大陸に起こっていることは確実である．

1. Introduction

The geological and the geographical features of the Antarctic Continent are roughly divided into three parts, East and West Antarctica and Ross-Weddell graben(see Fig. 1). East Antarctica has remained an essentially stable continental shield since the older age than the Devonian. The orogenic belts in West Antarctica are composed of Mesozoic and Cenozoic rocks with volcanoes. The Ross-Weddell graben is in the orogenic belt since the middle of Mesozoic and is situated between the two dissimilar tectonic regions of East and West Antarctica.

The first seismological observation in Antarctica using instruments was carried out for several months in 1902–1903, and 136 shocks were recorded. According to Seismicity of the Earth (GUTENBERG and RICHTER, 1954), none of these shocks

* 東京大学地震研究所. Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo.

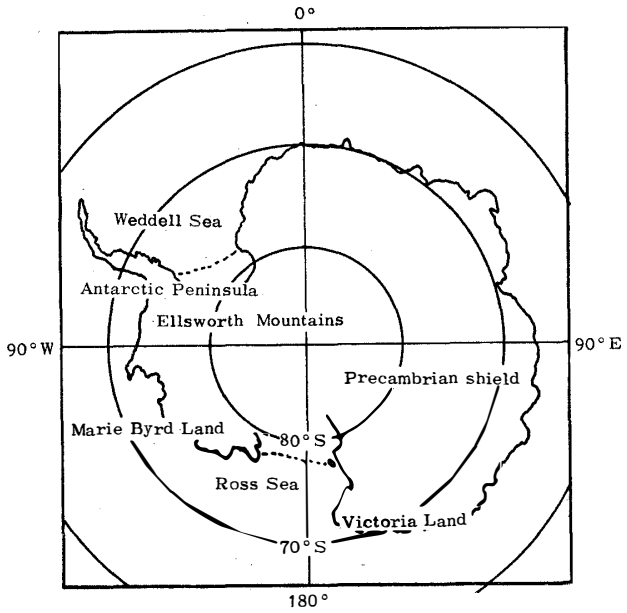

Fig. 1. The geological and geographical features of the Antarctic Continent. East Antarctica; part of the continent, chiefly east of Greenwich that lies south and west of the Ross Sea and south and east of the Weddel Sea. West Antarctica; the Antarctic Peninsula and Marie Byrd Land. Ross-Weddell graben; the Ellsworth Mountains and Victoria Land.

originated from Antarctica. Since then, this region has been studied by many workers (e.g., HATHERTON, 1961; HATHERTON and EVISON, 1962; KOGAN *et al.*, 1965; LAZAREVA and SYTINSKIY, 1965; BROWNE-COOPER *et al.*, 1967; EVISON, 1967; ADAMS, 1969; KAMINUMA, 1971). Some of them have recognized some seismic activity using S-P times observed at Antarctic seismological stations. Others have reported some shocks in the Antarctic region, though these shocks were not confirmed clearly by other investigators. The PDE card of U. S. Coast and Geodetic Survey (US CGS) reports two large volcanic eruptions of Deception Island on December 4, 1967. These two epicenters are believed to be the first instrumentally located in the Antarctic region. In any case, no earthquakes have been located in the Antarctic Continent.

According to the hypothesis of sea-floor spreading, the Antarctic region is one of the largest blocks on the earth's surface surrounded by marginal seismic belts (LE PICHON, 1968). Other blocks have some seismic activity inside them. The present paper attempts to confirm the existence of earthquakes in Antarctica. The period from 1966 through 1969 is examined.

2. Data

From the third of International Geophysical Year, 1958, the number of the

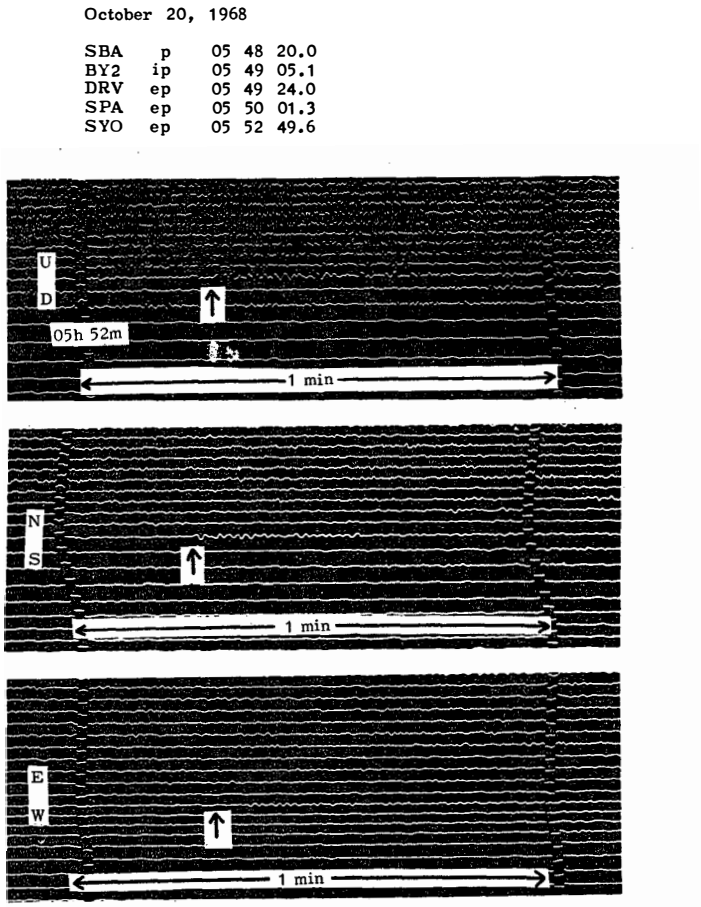

Fig. 2. P arrival times in "The Antarctic Seismological Bulletin" reported from Antarctic seismological stations on October 20, 1968, and the seismograms of a three-component HES seismograph (Tp and Tg; 1.0s) at Japanese Antarctic seismological station Syowa(SYO).

seismological stations in Antarctica increased. The phase readings of these stations have been reported to the USCGS, and contributed to the determination of earthquake locations. The USCGS has published "The Antarctic Seismological Bulletin" on the basis of the phase readings received telegraphically from the Antarctic seismological stations. Some of these readings of P arrival time were not used by the USCGS for the hypocenter determination, probably because no corresponding phase readings were available from other seismological stations outside Antarctica. In this paper, the events for which the phase readings of P arrival time were reported in the bulletin from more than four stations, but for which the hypocenter determination was not made, were used for trial locations. One example is given in Fig. 2. The phase readings reported from the Antarctic seismological stations are shown on the top, and the seismograms of a three-component HES seismograph at the Japanese Antarctic seismological station Syowa(SYO) are shown at the bottom.

3. Earthquake Location

The events in the bulletin for 1966 to 1969 were located as earthquakes. For the hypocenter determination of the earthquakes, the standard method which employs the non-linear least-squares method and the JEFFREYS-BULLEN travel-time table was used. The effect of the earth's ellipticity and the station's height were included (BULLEN, 1963). The epicenter coordinates and the origin time of events were determined by using more than four stations in Antarctica. The focal depth was assumed as normal (33km). This assumption is reasonable, because presumably no deep seismic activity exists in and around the Antarctic Continent. The computation converged within five iterations.

Table 1. Located hypocenters in and around Antarctica. Depths are restrained at normal depth (33km). S.D.=standard errors in latitude and longitude. RMS. of RES.=root mean square of the O-C residuals.

Date	Origin time	Latitude	S.D. (km)	Longitude	S.D. (km)	Depth	S D. (km)	RMS. of RES.	Station used
	h m s								
1966. 9.29	08 32 20.6	37.6°S	95.3	78.2°E	85.3	33	(R)	0.56	4
1967. 5.15	00 33 33.1	63.5°S	57.8	164.8°W	27.1	33	(R)	0.52	4
9.10	01 59 29.1	62.6°S	65.5	165.5°E	24.5	33	(R)	1.09	4
10.17	11 23 40.4	65.6°S	26.9	176.5°E	13.6	33	(R)	0.58	4
1968. 5.28	01 22 27.2	58.0°S	86.2	178.1°W	14.1	33	(R)	0.22	4
6.26	18 20 56.1	79.5°S	17.4	20.5°W	20.2	33	(R)	1.41	5
7.12	20 18 18.4	28.3°S	53.3	165.0°E	19.4	33	(R)	0.12	4
7.15	12 05 03.9	63.9°S	3.5	169.5°E	1 4	33	(R)	0.07	4
7.25	20 32 30.7	58.3°S	20.2	9.5°W	3.3	33	(R)	0.08	4
8.21	22 25 27.7	56.3°S	54.1	179.8°E	15.1	33	(R)	0.18	4
8.22	06 40 03.6	29.8°S	17.2	177.0°W	5.3	33	(R)	0.09	4
8.22	14 06 32.7	49.4°S	21.4	123.1°E	3.6	33	(R)	0.07	4
9.04	05 49 18.8	64.9°S	35.0	179.3°E	9.6	33	(R)	0.18	4
9.17	09 51 02.4	53.5°S	36.5	144.2°E	6.5	33	(R)	0.11	4
10.15	21 33 11.0	55.5°S	25.9	26.4°W	10.6	33	(R)	0.13	4
10.17	02 14 20.4	69.9°S	20.2	174.1°E	12.7	33	(R)	0.77	5
10.18	03 19 26.5	64.1°S	58.5	165.8°W	26.9	33	(R)	1.41	5
10.20	05 44 20.7	63.1°S	17.3	164.7°W	9.4	33	(R)	0.42	5
10.30	16 44 42.5	63.1°S	34.2	165.3°E	12.8	33	(R)	0.84	5
11.01	20 02 01.7	27.7°S	94.0	177.9°W	39.5	33	(R)	0.41	4
1969. 7.24	12 25 58.1	64.1°S	25.7	171.2°E	16.4	33	(R)	0.42	4
8.29	21 46 18.1	64.3°S	26.7	154.4°E	12.8	33	(R)	0.35	4
10.04	12 02 18.9	63.5°S	37.0	60.2°W	18.4	33	(R)	0.58	4
11.14	19 44 59.5	49.4°S	80.6	125.8°E	15.2	33	(R)	0.38	4

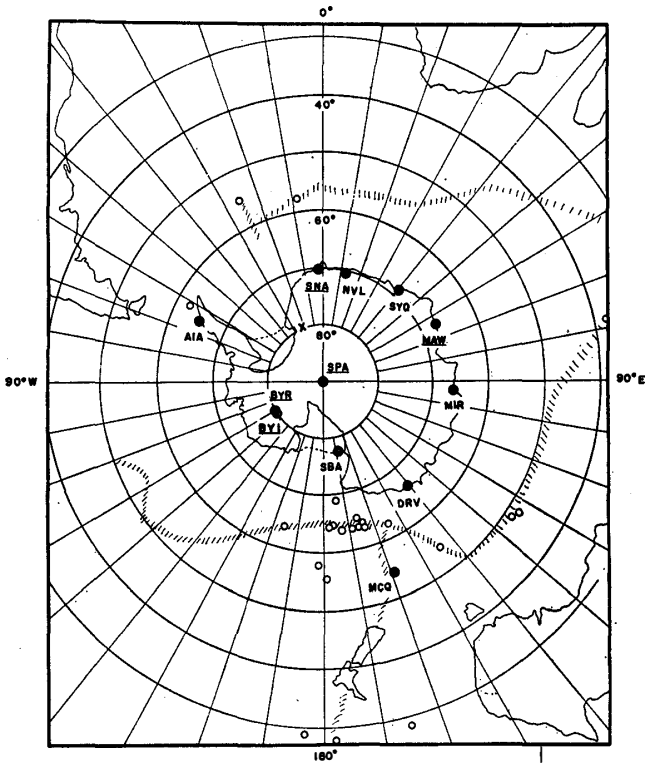

Fig. 3. Earthquakes located in and around Antarctica for the period 1966 through 1969. Open circles indicate the epicenters. Solid circles indicate seismological stations. The hatched areas indicate the seismic belt, and the underlined stations are used for the location of the event which is shown by a cross (June 26, 1968).

Only 24 events out of 72 events which were subjected to the determination could be located as shown in Table 1. The standard error is within 100km in the epicenter coordinates and the O-C residual (the observed minus the computed travel-time) is less than 3 seconds. The epicenters of most of these events are located in and near the existing seismic belts as shown in Fig. 3. This result implies that the hypocenter determination in this study is considerably reliable.

4. An Earthquake in Antarctica

One event which occurred on June 26, 1968, was located in the Antarctic Continent, near 20°W and 80°S. The stations used for the hypocenter determination are SANAE(SNA), South Pole(SPA), Byrd(BYR), one of the branch stations of Stanford seismological network at Byrd (BY1) and Mawson (MAW).

For the purpose of examining the location accuracy of this event, the epicenter is assumed at various places and the root mean square of the O-C residuals at each station used in the determination is calculated. The latitude of the assumed epicenter is varied with the interval of 2° from 60°S to 90°S and the longitude, with the interval of 10° from 0° to 350°. The depth is assumed at 1, 5, 10 and

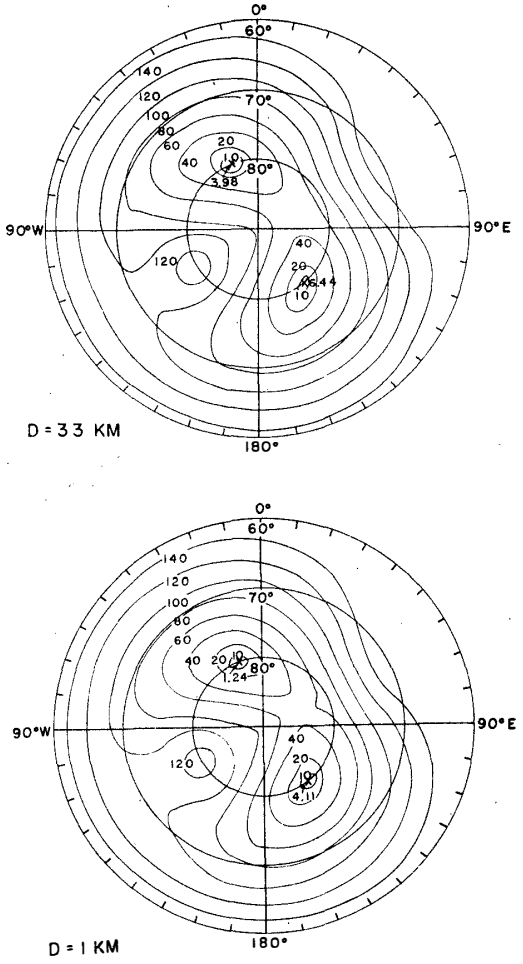

Fig. 4. The contour lines showing the value of root mean square of O-C residuals. The event occurred on June 26, 1968.

33km.

The contour lines of the value of root mean square at depths of 1 and 33 km are shown in Fig. 4. Two minima are found. One is located around the point of 20°W and 80°S and the other around the point of 140°E and 80°S for the two cases with different depths. This tendency is the same in the other two cases where the depth is assumed at 5 and 10 km. The former point agrees with the result of determination by the least-squares method as described in the previous section. The value for the two minima at depth of 1 km is smallest among the four cases. Thus the depth of the event seems very shallow. The hypocenter of the event is redetermined taking the above two points as the initial value for the hypocenter. The depth is restrained at 1 km. In both cases, the hypocenter coordinates converge at the same point. The location of the event is redetermined as follows;

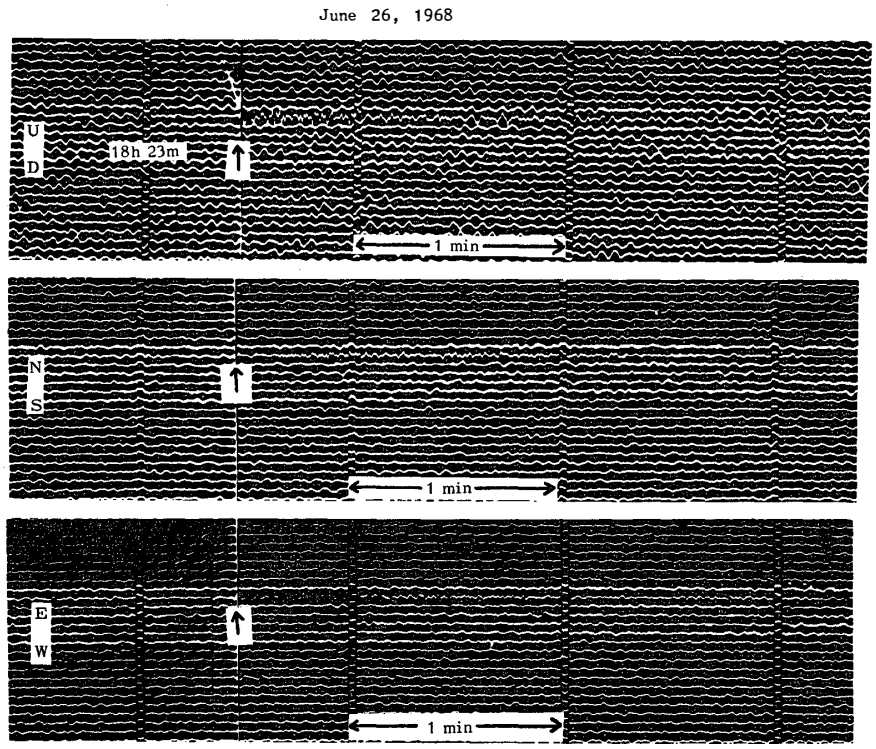

Fig. 5. The seismograms of a three-component Benioff short period seismograph at SPA. The shock is marked with an arrow.

Origin time	$18^h\ 20^m\ 52.8^s$
Latitude	79.56° S
Longitude	20.33°W
Depth	1 km (under sea level)

The epicenter of the event is located in Coats Land in Queen Maund Land (the eastern coast side of Weddell Sea), as shown in Fig. 3. We feel that this finding is fairly reliable.

The seismograms of this event recorded by a three-component Benioff short-period seismograph at SPA are shown in Fig. 5. The epicentral distance of SPA is 10.5 degrees. Using the maximum amplitude of P wave on the vertical component and the method employed by the U. S. Department of Commerce (1966), the magnitude is determined as 4.3.

5. Conclusion

No seismological activity has so far been reported in Antarctica. In this study, one earthquake (magnitude ~4.3) is located near 20°W and 80°S using the P arrival times in "The Antarctic Seismological Bulletin." This may be the first evidence of an earthquake occurrence in Antarctica. It is concluded that a minor earth-

quake activity exists in Antarctica though it is not detectable by the insufficient seismological network presently available.

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