Why Is Seismic Activity Low in Antarctica?

Masashi TANI* and Ichiro KAWASAKI*

南極大陸はなぜ地震活動が低いか

谷　祐史*・川崎一朗*

要旨：南極プレート内部，特に南極大陸では地震活動度が低いことが知られている．今回，その原因を世界中の海洋プレート内地震のデータをもとに考察する．海洋プレート内地震の単位面積当たりの発生頻度は，高緯度地域から低緯度地域に向かって増加し，また，海洋プレートの絶対速度と正の相関を示す．また，海洋プレート内地震は震央の海洋底年齢が古くなるにつれ，発生頻度と最大地震の地震モーメントが減少する．これは，海洋リソスフェア中を伝わるうちに，「海嶺押し力」が消散することを示すものと考えられる．このことから南極大陸の低い地震活動度の原因として，次のことが考えられる．

1. 南極大陸は，非常に高緯度に位置している，
2. 南極プレートの絶対速度は小さい，
3. 南極大陸は，海嶺から離れた場所に位置しているため，「海嶺押し力」の影響をあまり受けない．

Abstract: Oceanic intraplate earthquakes which occurred in the oceanic lithosphere show the following features:

1. The level of oceanic intraplate seismicity appears to increase from high latitudes to low latitudes.
2. The level of oceanic intraplate seismicity appears to increase with the absolute velocity of the movement of the oceanic plate.
3. Both the level of oceanic intraplate seismicity and the maximum seismic moment of intraplate earthquakes appear to decrease with age of the ocean floor, which can be regarded as a rough approximate of the distance from an axis of the mid-oceanic ridge. This means that the ridge push force is dissipated while guided through the oceanic lithosphere.

Thus, the potential causes of low seismic activity in Antarctica can be summarized as follows:

1. Antarctica is situated in very high latitudes,
2. The absolute velocity of the movement of the Antarctic plate is small,
3. Because Antarctica is distant from the axes of the mid-oceanic ridge, the continent is almost free from the ridge push force.

1. Introduction

Antarctica is a very aseismic continent (*e.g.*, GUTENBERG and RICHTER, 1954). As the result of seismological observations of the Dry Valley Drilling Project (DVDP), KAMINUMA (1976) reported that the seismic activity around the Dry Valleys in Victoria Land is one micro- or ultra micro-earthquake every two days and the activity around Syowa Station on East Ongul Island is less than one micro-earthquake per month. According to the Earthquake Data File (EDF) of the United States Geological Survey

* 富山大学理学部．Faculty of Science, Toyama University, 3190, Gofuku, Toyama 930.

(USGS), only one earthquake (event ANTA-10 in Table 1) was located in Antarctica and there were only two intraplate earthquakes in the Antarctic plate with magnitudes greater than 6.0 (ANTA-4 and ANTA-12) during a period from 1963 through 1979. These two large earthquakes were located in the Antarctic Sea.

KAMINUMA and ISHIDA (1971) investigated earthquakes occurring from 1966 to 1969 for which the hypocenter determination was not previously made. They used data from "The Antarctic Seismological Bulletin" of the United States Coast and Geodetic Survey (USCGS). Only one event of magnitude 4.3 is located in Antarctica (in the eastern coast side of the Weddell Sea) by them.

These observations show that Antarctica is a very aseismic region and has few large earthquakes. It is a very important problem for solid geophysics in the polar region that the seismic activity is low in the Antarctic plate, particularly Antarctica. The present paper is one of the attempts to explain this problem on the basis of the oceanic intraplate earthquake data.

2. Geographic Latitude, Absolute Velocity of the Movement of the Oceanic-Plate, and Oceanic Intraplate Seismicity

Generally, the structure of oceanic plates is more homogeneous and simpler than that of continental plates. To avoid a systematic bias ascribed to contamination of data of different quality, we restricted our data to oceanic intraplate earthquakes.

TANI and KAWASAKI (in preparation) have compiled 133 oceanic intraplate earthquakes with surface wave magnitudes or body wave magnitudes greater than 5.0, for the period from 1963 through 1979, from EDF of USGS and published papers on oceanic intraplate earthquakes (STEIN, 1978; BERGMAN and SOLOMON, 1980). The epicenters of the 133 oceanic intraplate earthquakes are plotted in Fig. 1.

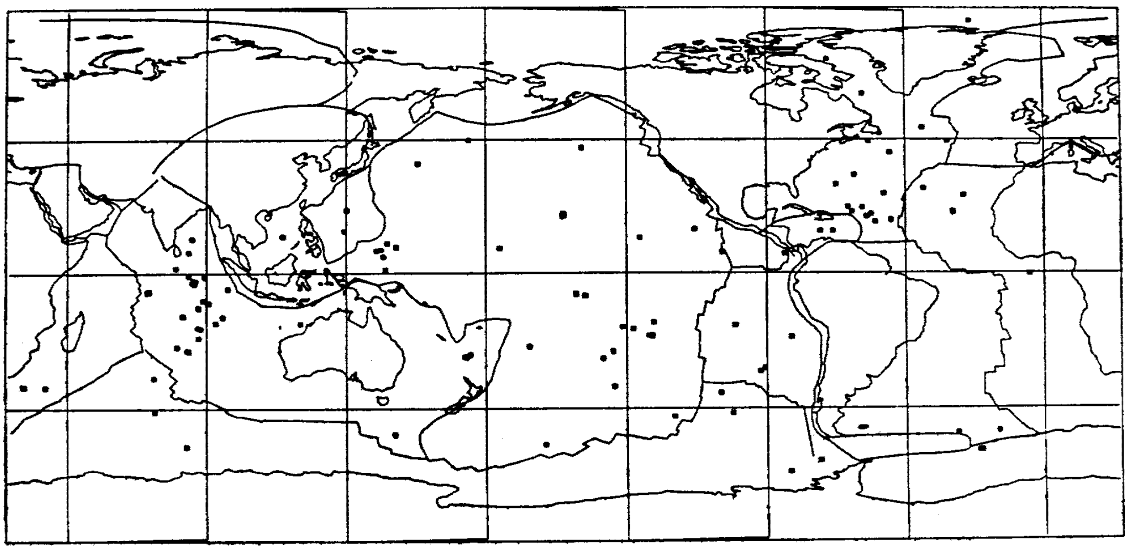

Fig. 1. Plate boundaries and global distribution of epicenters of oceanic intraplate earthquakes with magnitudes greater than 5.0 for the period from 1963 to 1979.

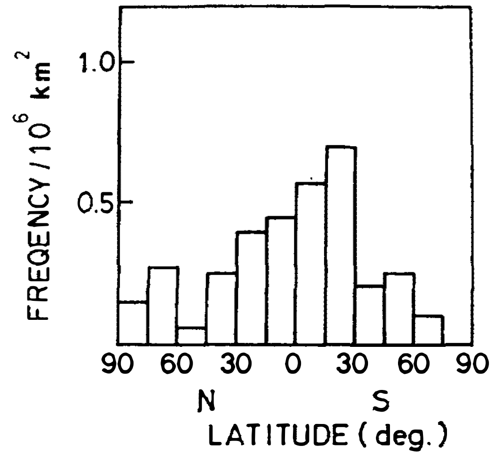

Fig. 2. Seismicity per unit area versus geographic latitude.

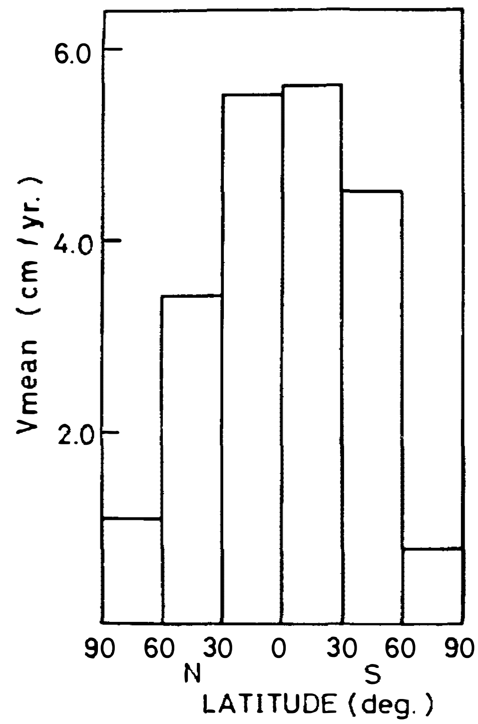

Fig. 3. Average absolute velocity of oceanic plate (V_{mean}) calculated by AM1-2 of MINSTER and JORDAN (1978) versus geographic latitude.

Figure 2 is a histogram showing the number of oceanic intraplate earthquakes per unit area versus geographic latitude. Oceanic intraplate seismicity decreases from low latitudes to high latitudes. The major oceanic plates at low latitudes are the Pacific plate and the Indian plate. The absolute velocities of these two plates are large. On the other hand, the major oceanic plates at high latitudes such as the Antarctic plate or the Eurasian plate have small absolute velocities.

Figure 3 is another histogram showing the average absolute velocity (V_{mean}) of the movement of the oceanic plate, calculated by AM1-2 of MINSTER and JORDAN (1978), versus the geographic latitude. The value of the V_{mean} decreases from low latitudes to high latitudes. This is analogous to the change in geographic latitude and particle velocity (V_r) at the earth's surface due to the rotation of the earth. As the earth is a sphere, V_r can be represented as

$$V_r(\mathrm{km/h}) = 2\pi R\cos\varphi/24,$$

where R is a radius of the earth (6369 km), and φ is the geographic latitude. Figure 4 shows the geographic latitude versus the V_r. The V_r is decreasing from low latitudes to high latitudes. On the other hand, there are other physical quantities of function of geographic latitude, such as the tidal force or centrifugal force. These physical quantities seem to be responsible for intraplate earthquakes.

Physical quantities used as the ordinates of Figs. 2, 3 and 4 decrease from low latitudes to high latitudes. Therefore, these three physical quantities, namely, the number of oceanic intraplate earthquakes per unit area, the V_{mean} and the V_r have a normal correlation with each other. We cannot, however, explain the physical relation among these three physical quantities.

We have examined the correlation between the average absolute velocity of the oceanic plate and the number of oceanic intraplate earthquakes per unit area. Figure 5 shows the average absolute velocity (V_{plate}) of each oceanic plate, calculated by AM1-2 of MINSTER and JORDAN (1978), versus the number of oceanic intraplate earthquakes per unit area. We have used the same abbreviations for plate names as MINSTER and JORDAN (1978). The Cocos and Caribbean plates are excluded in this figure because the area of these two plates is very small compared with the other oceanic plates. Oceanic intraplate seismicity seems to have a normal correlation with the average absolute velocity, therefore, the seismicity of the slow plates, like the Antarctic plate, is low.

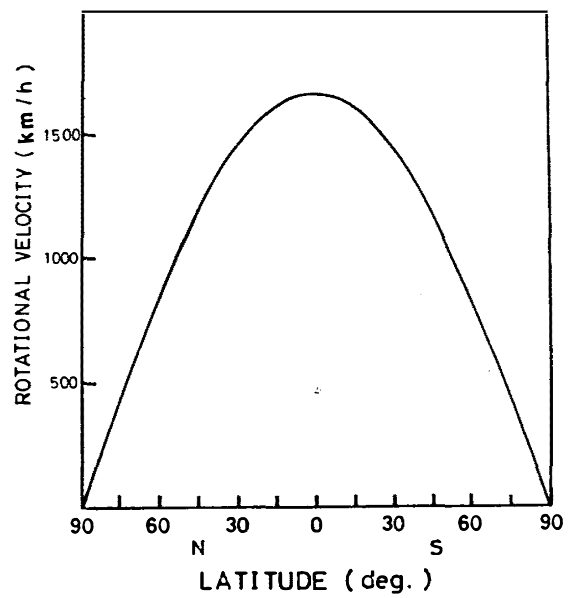

Fig. 4. Particle velocity at the earth's surface (V_r) versus geographic latitude.

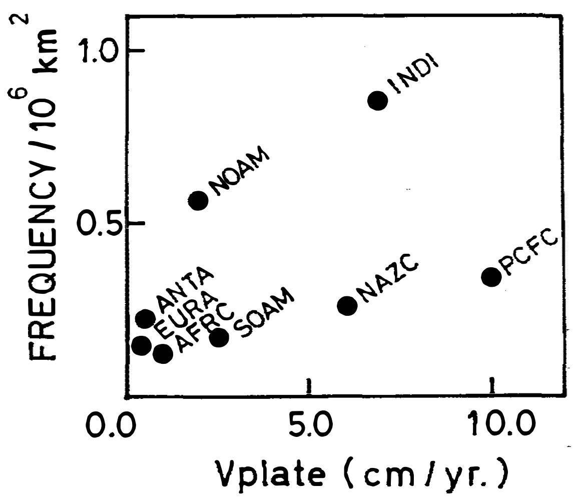

Fig. 5. Seismicity per unit area as a function of average absolute velocity of oceanic plate (V_{plate}) calculated by AM1-2 of MINSTER and JORDAN (1978).

3. Ridge Push Force and Oceanic Intraplate Earthquakes

Figure 6 shows the correlation between the ocean floor age of the epicentral regions of the intraplate earthquakes and the number of earthquakes per unit area. Oceanic intraplate seismicity decreases from the young ocean floor to the old ocean floor. A similar result was obtained by WIENS and STEIN (1983).

TANI and KAWASAKI (in preparation) determined the seismic moments of some large oceanic intraplate earthquakes. The seismic moments were obtained by the moment tensor inversion method for P wave first motions (FITCH *et al.*, 1980).

Figure 7, reproduced from TANI and KAWASAKI, shows the seismic moments of the intraplate earthquakes versus the ocean floor age of the epicentral regions. The trend of the maximum seismic moments indicates a decrease with age of the ocean floor. They concluded that the ridge push force is responsible for oceanic intraplate earth-

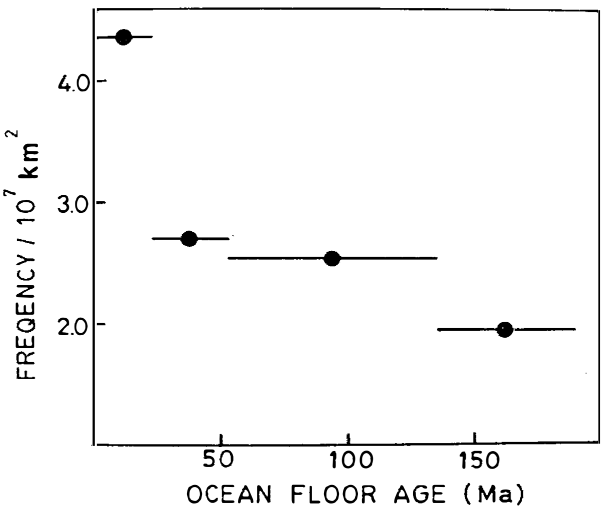

Fig. 6. Seismicity per unit area as a function of ocean floor age reproduced from PITMAN et al. (1974), KANAMORI and FUJITA (1979) and Plate-Tectonic Map of the Circum-Pacific Region of ADDICOTT and RICHARDS (1981) (after TANI and KAWASAKI, in preparation).

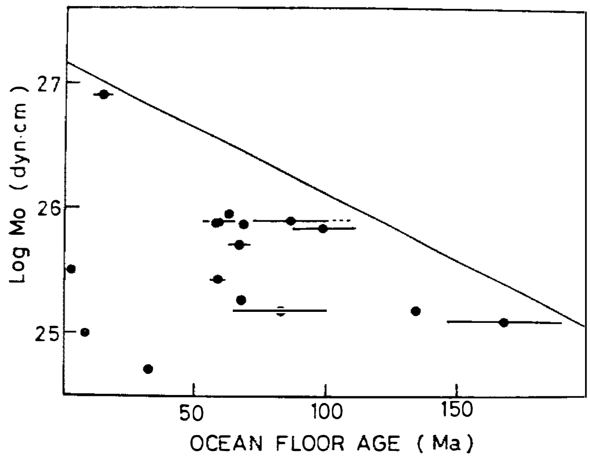

Fig. 7. Seismic moments of world oceanic intraplate earthquakes as a function of ocean floor age (after TANI and KAWASAKI, in preparation).

quakes, and the ridge push force is dissipated while guided through the oceanic lithosphere.

4. Seismicity of the Antarctic Plate

The Antarctic plate is surrounded by mid-oceanic ridges. Therefore, this plate is a good field appropriate to investigation the dissipation of the ridge push force guided through the oceanic lithosphere. If the ridge push force dissipated while guided through the oceanic lithosphere, the intraplate seismicity and the maximum seismic moments of the intraplate events in the Antarctic plate should decrease from the ridge to the central part.

We compiled 13 intraplate earthquakes in the Antarctic plate from EDF of USGS and KAMINUMA and ISHIDA (1971) with surface wave magnitudes or body wave magnitudes greater than 4.0 for the period from 1963 through 1979. These 13 events are listed in Table 1 and are plotted in Fig. 8. Eleven events among the 13 events occurred in the oceanic area, and two events (event ANTA-2 and ANTA-10 in Table 1) are located in the continent area. There were only two large intraplate events (ANTA-4 and ANTA-12 in Table 1) in the Antarctic plate, whose magnitudes were greater than 6.0. The forcal mechanisms of these two earthquakes were presented by FORSYTH (1973) and OKAL (1980). Direction of maximum horizontal compressive stress (P axes) of these two earthquakes is illustrated in Fig. 8. The P axes are approximately perpendicular to the Pacific-Antarctic Ridge. FORSYTH (1973) considered that this P axis can be explained most simply by the failure at a weak point of the lithosphere under horizontal compressive stress caused by the ridge push force.

The features of the Antarctic plate seismicity are summarized from Fig. 8 as follows:

Table 1. Intraplate earthquakes in the Antarctic plate from 1963 to 1979, compiled from EDF of USGS and KAMINUMA and ISHIDA (1971). The seismic moments are determined by TANI and KAWASAKI (in preparation).

Event No.	Date	Origin time (UT)	Magnitude (mb)	(Ms)	Lat.	Long.	Depth (km)	Seismic moment (10^{25}dyn•cm)
ANTA- 1	1965 12 19	$15^h59^m17.6^s$	5.4		34.80°S	73.00°E	33	
ANTA- 2	1968 6 26	18 20 52.8	4.3		79.56°S	20.33°W	1	
ANTA- 3	1970 6 6	06 14 13.3	4.8		62.76°S	93.50°W	33	
ANTA- 4	1971 5 9	08 25 01.7	6.2	6.0	39.78°S	104.84°W	33	1.0
ANTA- 5	1971 5 9	08 53 25.9	5.2		39.74°S	104.93°W	33	
ANTA- 6	1971 5 9	18 00 59.9	5.4		39.84°S	104.89°W	33	
ANTA- 7	1971 5 9	18 35 09.8	5.4	5.4	39.72°S	104.98°W	33	
ANTA- 8	1973 3 20	18 13 24.8	5.4		57.92°S	83.57°E	33	
ANTA- 9	1973 5 3	23 11 05.7	5.5	5.5	46.10°S	73.20°E	33	
ANTA-10	1974 10 15	07 31 42.0	4.9		70.52°S	161.53°E	33	
ANTA-11	1976 1 11	23 22 40.5	5.6	5.0	46.48°S	101.07°W	33	
ANTA-12	1977 2 5	03 29 18.9	6.2	6.2	66.45°S	82.58°W	33	2.6
ANTA-13	1979 11 7	11 31 49.6	5.1		62.58°S	72.91°W	10	

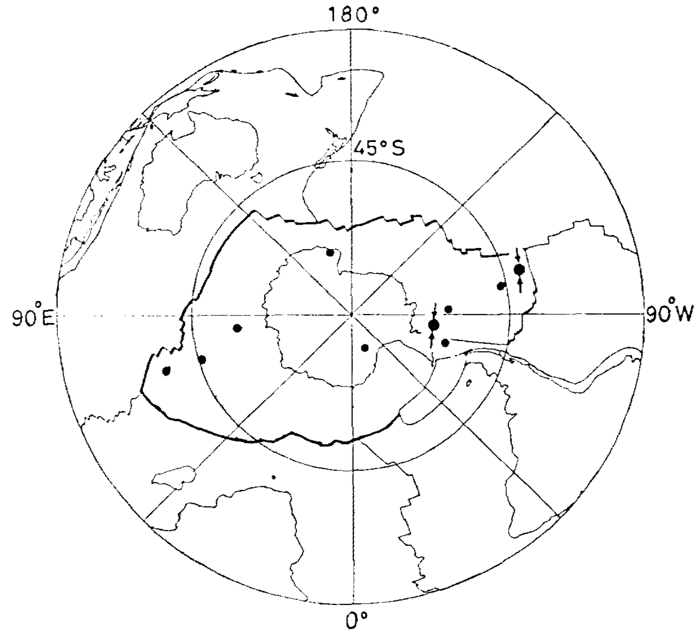

*Fig. 8. Spatial distribution of earthquakes in the Antarctic plate, as listed in Table 1. The large solid circles are epicenters of earthquakes with magnitude greater than 6.0. Arrows show distribution of the maximum holizontal compressive stress (*FORSYTH*, 1973;* OKAL*, 1980).*

1. The level of seismicity is relatively high in the oceanic area (the marginal part of the plate), and is low in the continental area (the central part of the plate).

2. The large earthquakes with magnitudes greater than 6.0 occurred in the oceanic area (the marginal part of the plate), with P axes approximately perpendicular to the oceanic ridge enclosing the Antarctic plate.

These features explain that the ridge push force is responsible for the intraplate seismicity, and the ridge push force is dissipated while guided through the lithosphere of the Antarctic plate.

We consider that the low seismic activity in Antarctica is principally attributed to a lack of tectonic stress due to the active tectonic zone. Excluding the effects of loading and cooling by the ice sheet (KAMINUMA, personal communication), the stress due to the ridge's pushing should be most important tectonic stress in Antarctica. At the present, we see no clear relation between the seismicity and the effect by ice sheet. Therefore, we think that the dissipation of the ridge push force is principally responsible for the low seismic activity of Antarctica.

5. Conclusion

Oceanic intraplate earthquakes show the following features:

1. The level of oceanic intraplate seismicity appears to increase from high latitudes to low latitudes.

2. The level of oceanic intraplate seismicity appears to increase with the absolute velocity of the movement of the oceanic plate.

3. Both the level of oceanic intraplate seismicity and the maximum seismic mo-

ment appear to decrease with age of the ocean floor, which can be regarded as a rough approximate of the distance from the axis of the mid-oceanic ridge. This means that the ridge push force is dissipated while guided through the oceanic lithosphere.

These features of oceanic intraplate earthquakes seem to explain the low seismic activity in the Antarctic plate. The features 1 and 2 coincide with the features of the Antarctic plate which is situated at very high latitudes, so that the particle velocity at the surface, and the absolute velocity of this plate is small. The level of seismicity in the Antarctic plate is higher in the oceanic area than in the continental area, and the large earthquakes with magnitudes greater than 6.0 occur in the oceanic area. The difference in seismicity between the oceanic area (the marginal part of the plate) and the continental area (the central part of the plate) is explained by feature 3.

The low seismic activity in Antarctica can be accounted for by the following:

a. Antarctica is situated in very high latitudes,

b. The absolute velocity of the Antarctic plate is small,

c. Because Antarctica is distant from the mid-oceanic ridges, this continent is barely influenced by the ridge push force.

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References

ADDICOTT, W. O. and RICHARDS, P. W. (1981): Plate-Tectonic Map of The Circum-Pacific Region. Oklahoma, The American Association of Petroleum Geologists.

BERGMAN, E. A. and SOLOMON, S. C. (1980): Oceanic intraplate earthquakes: Implications for local and regional intraplate stress. J. Geophys. Res., **85**, 5389–5410.

FITCH, T. J., MCCOWAN, D. W. and SHIELDS, M. W. (1980): Estimation of the seismic moment tensor from teleseismic body wave data with applications to intraplate and mantle earthquakes. J. Geophys. Res., **85**, 3817–3828.

FORSYTH, D. (1973): Compressive stress between two mid-ocean ridges. Nature, **243**, 78–79.

GUTENBERG, B. and RICHTER, C. F. (1954): Seismicity of the Earth. 2nd ed. Princeton, Princeton Univ. Press, 310 p.

KAMINUMA, K. (1976): Seismicity in Antarctica. J. Phys. Earth, **24**, 381–395.

KAMINUMA, K. and ISHIDA, M. (1971): Earthquake activity in Antarctica. Nankyoku Shiryô (Antarct. Rec.), **42**, 53–60.

KANAMORI, H. and FUJITA, K. (1979): A large intraplate event near the Scotia Arc. EOS, **60**, 894.

MINSTER, J. B. and JORDAN, T. H. (1978): Present-day plate motions. J. Geophys. Res., **83**, 5331–5354.

OKAL, E. A. (1980): The Belling Sea earthquakes of February 5, 1977: Evidence for ridge generated compression in the Antarctic plate. Earth Planet. Sci. Lett., **46**, 306–310.

PITMAN, W. C., III, LARSON, R. L. and HERRON, E. M. (1974): Isochron Map and Age Map of Ocean Basins. Boulder, Geol. Soc. Am.

STEIN, S. (1978): An earthquake swarm on the Chagos-Laccadive Ridge and its tectonic implications. Geophys. J. R. Astron. Soc., **55**, 577–588.

WIENS, D. A. and STEIN, S. (1983): Age dependence of oceanic intraplate seismicity and implications for lithospheric evolution. J. Geophys. Res., **88**, 6455–6468.

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