Antarctica at the close of a millennium. *Royal Society ofNew Zealand Bulletin* 35: 2002, 479-484
1-877264-06-7

Antarctic seismicity and neotectonics

ANYA M. READING
Department of Geology and Geophysics
University of Edinburgh
West Mains Road
Edinburgh, EH9 3JW, UK*

*Present address: Research School of Earth Sciences,
Australian National University. Canberra, 0200 ACT,
Australia. email: anya@rses.anu.edu.au

Abstract A map of Antarctic intraplale eanhquakes, 1900-99, is presented including records from the Global Seismic Network and recordings made at Antarctic seismic observatories and temporary stations. The results show a Iow but significant level of seismicity through the Transantarctic Mountains and across George V Land to Adelie Land. They also suggest some seismic deformation is taking place in the Antarctic Peninsula, Weddell Sea, East Antarctic coast, and Ross Sea. No globally recorded events have occurred in Marie Byrd Land to date. Local recordings across the continent show that a denser distribution of recording stations is needed before drawing conclusions from areas of apparent Antarctic aseismicity.

This review is one of the first contributions to the SCAR-approved ANTEC initiative, which aims to co-ordinate work on neotectonic deformation across the continent.

Keywords Antarctica; seisrnicity; neotectonics

INTRODUCTION

Antarctica occupies a unique tectonic setting for a major plate since *it* is almost completely surrounded by divergent or conservative margins (Hayes 1991). Active intraplate deformatiun and volcanism both occur in West Antarctica and may be present in the subglacial mountains and basins of East Antarctica (Fig. 1). In addition to tectonic sonrces of stress indicated above, the plate is subject to stress induced by glacial loading and unloading (James & Ivins 1998). The World Stress Map Project (Zoback 1992), which aimed to summarise lithospheric stress worldwide, could not include any constraints on Antarctic neotectonics because data were available at the time. Earthquakes are caused by the inelastic response of rock to strain, so the proportion of seismic and aseismic deformation indicates lithospheric dynamics. Following improvements to the Global Seismic Network (GSN) in 1995, a low, but increased, level of intraplate earthquakes has been recorded. The pattern of seismicity across the continent is now emerging and beginning to provide information on the neotectonics of Antarctica.

Catalogued earthquakes with locations in continental Antarctica have been identified since 1918, but the first reliable hypocentre location for a tectonic (non-volcanic) earthquake was not determined until 1982 (Adams et al. 1985). The installation of more stations in the Southern Hemisphere steadily increased the detection of Antarctic seismic activity (Kaminuma 1994), and the *GEOSCOPE* ex.periment located previously undetected earthquakes (Rouland et al. 1992) around the Antarctic margin including data from D'Urville Station (DRV). Recently, the dramatic increase in the numher of Antarctic earthquakes in global catalogues has come with the inception of the prototype International Data Centre (pIDC) associated with the Comprehensive Test Ban Treaty Organisation (CTBTO). Two Antarctic stations, South Pole (SPA) and Mawson (MAWJ, were upgraded and included in the list of stations comprising the primary network for monitoring the treaty. During this time, there have been other notable stations installed on the Antarctic continent. For example, seismic recording near Neumayer Station was npgraded in 1995 to include three broad-band ,tations (VNA1, VNA2, and VNA3), and a short-period array (Eckstaller et al. 1997).

Surface-wave studies over the whole continent (Roult & Rouland 1994) have placed constraints on crustal and upper-mantle structure with meaningful, sub-continental scale, resolution. More localised studies (e,g., Bannister et al. 2000) have also been successful. At present there are insufficient stations to detennine seismic structure by the tomographic inversion (Lay & Wallace 1995) of body-wave

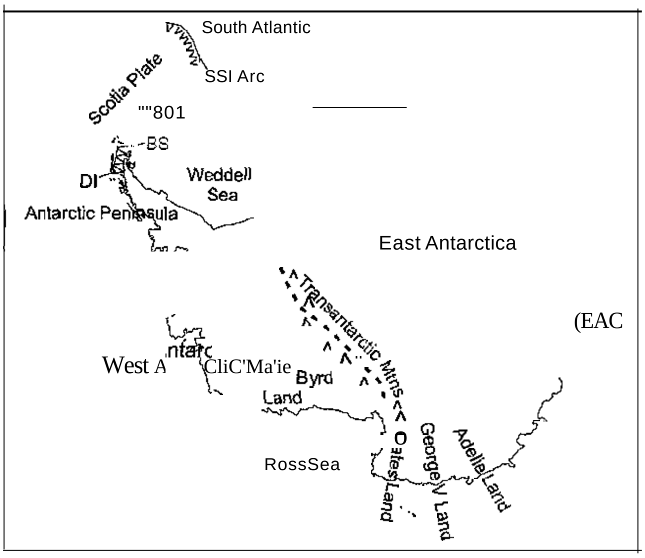

Fig. 1 Sketch outline of Antarctica showing location of geographical areas mentioned in the text. DJ = Deception Island, BS = Bransfield Strait, SOl = South Orkney Islands, Arc = South Sandwich Island EAC = Antarctic Areas of active subduction are indicated by WVV.

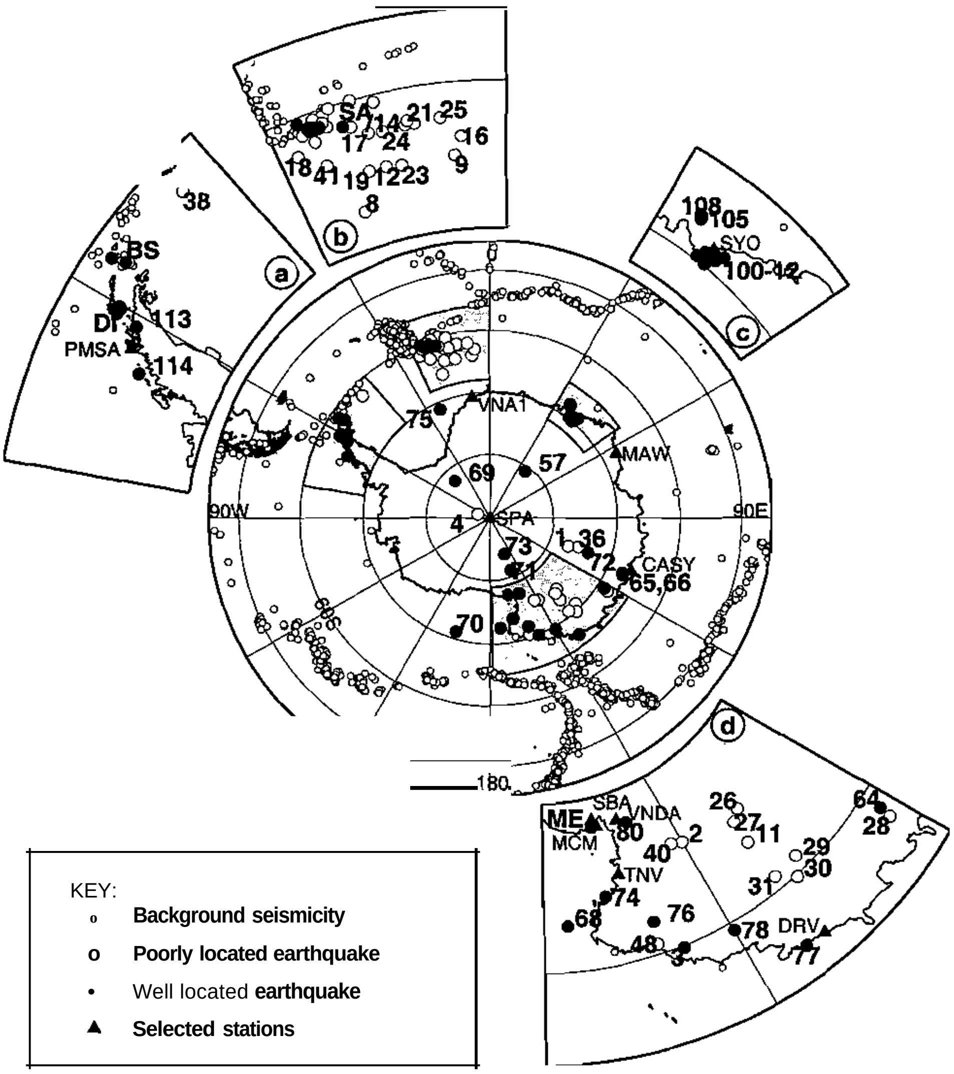

Fig. 2 Distribution of Antarctic earthquakes recorded 1900-99. See text for data sources, and Table 1 to match numbered locations to events. Location of enlarged sections is show by the shaded portions on the main map_ Stations: SYO = Syowa (Japan), **MAW ≈ Mawson (Australia), SPA = South Pole at Amundson-**Scott (USA), CASY = Casey **(Australia), DRV = D'Urville (France), TNV = Terra Nova** (Italy), VNDA = Vanda (New Zealand), SBA = Scott Base (New Zealand), MCM = McMurdo (USA), PMSA = Palmer (USA), **VNAl = Neumayer (Germany). DI = Deception Island, BS = Bransfield Strait, SA = South Atlantic/Antarctic, and ME = Mount Erebus.**

data. Such work would complement the surface-wave studies and improve the resolution of seismic structure. Seismic anisotropy is present in the lithosphere, indicating paleotectonic or neotectonic stress directions, and, in the mantle, indicating flow. Antarctic studies include that of Roult et al. (1994), which indicated the huge potentia! of this approach.

During the 8th International Symposium on Antarctic Earth Sciences (Wellington, July 1999), the ANTEC **initiative was convened to co-ordinate geological and geophysical endeavours in the study of Antarctic neotectonics. This paper represents an early contribution under this initiative and presents data from global catalogues and from individual experiments and observatories. The aim is to summarise what is known about Antarctic continental seismicity and neotectonics, inferred from earthquake data,** to the end of 1999.

DATA COMPILATION

Figure 2 shows known and inferred Antarctic intraplate earthquakes set against the background of interplate seismicity which defines the boundary of the Antarctic plate. **Data sources and a confidence estimate for each earthquake** are listed in Table The two principal sources, the pIDC and the International Seismology Centre (ISC) have different **criteria for including events in their respective catalogues.** The pIDC has a reviewed event bulletin (REB) available **within days of the earthquake occurring and requires at least three stations from its primary or auxiliary network to report the quake. Furthermore, the data must contain an acceptable** number of identified phases beyond the first arrival. The pIDC catalogue begins on I January 1995. The pIDC **magnitude values are systematically lower than those** reported to the ISC before 1995. Tbey are calculated using different algorithms and are not directly comparable. The ISC accepts data from a much wider range of reporting agencies but has catalogued data available 2 years after the **event. The selection criteria are simply that an epicentre** may be determined for the event from ISC location algorithm. Exceptionally, a location may be supplied by **the reporting agency. The ISC catalogue contains events** back to the beginning of the 1900s. Earthquakes which are known to be well located to within a few tens of kilometres) have been indicated with a large filled circle. Those indicated by large open circles may have good

Table I Antarctic earthquakes recorded 1900-99. Event numbers match those in Fig. 2. Note that pIDe and ISC magnitudes are not directly comparable.

Event (Fig. 2)	Year	Agency	Loc. good?	Magnitude (mb)	Comment
1	1918	ISS	N	-	intraplate, main map
2	1920	ISS	N	-	intraplate, inset (d)
3	1952	ISS	Y		coastal, inset (d)
4	1960	BelS	N	-	intraplate, main map
5	1964	Ise	N	5.3	SA group, inset (b)
6, 7	1965	Ise	N	-	SA group. inset (b)
8, 9	1966	Ise	N	-,6.2	inset (b)
10	1967	Ise	N	-	SA group, inset (b)
11	1967	Ise	N	-	intraplate, inset (d)
12	1967	Ise	N	-	inset (b)
13	1967	Ise	N		SA group, inset (b)
14	1967	Ise	N	-	inset (b)
15	1967	Ise	y	4.4	DJ group, inset (a)
16	1967	Ise	N		inset (b)
17-19	1968	Ise	N		inset (b)
20	1968	Ise	N	-	SA group, inset (b)
21	1968	Ise	N		inset (b)
22	1968	Ise	N		SA group, inset (b)
23-25	1968	ISe	N	-	inset (b)
26-31	1968	ISe	N	-, #30 = 4.9	intraplate, inset (d)
32	1968	ISe	N		SA group, inset (b)
33	1968	ISe	N	4.7	01 group, inset (a)
34	1968	ISe	N	4.8	SA group, inset (b)
35	1969	ISe	N	-	SA group, inset (b)
36	1969	ISe	N		intraplate, main map
37	1969	lse	N	5.6	SA group, inset (b)
38	1969	[Se	N	-	intraplate, inset (a)
39	1970	ISe	N	-	SA group, inset (b)
40	1970	Ise	N		intraplate, inset (d)
41	1970	lse	N		inset (b)
42	1970	ISe	N	4.7	DI group, inset (a)
43	1971	ISe	N	4.8	SA group. inset (b)
44	1972	ISe	N	5.1	SA group, inset (b)
45-46	1973	ISe	N	6.2,4.7	SA group, inset (b)
47	1974	lse	N	5.4	SA group, inset (b)
48	1974	ISe	N	4.7	coastal, inset (d)
49	1975	ISe	N	4.7	BS group, inset (a)
50	1975	ISe	N	5.1	SA group, inset (b)
51-54	1981	ISe	N	4.7,5.2,4.6,5.0	SA group. inset (b)
55	1982	lse	N	4.8,	BS group, inset (a)
56	1982	ISe	N	6.0	SA group, inset (b)
57	1982	ISe	y	4.5	intraplate, main map
58	1982	ISe	N	4.8	SA group, inset (b)
59-62	1982	ISe	y	4.8,5.2,5.0,5.7	DI group, inset (a)
63	1983	[Se	y	4.9	SA group, inset (a)
64	1983	lse	y	4.4	intraplate, inset (d)
65-66	1984	ISe	y	4.9,4.5	coastal, main map
67	1990	ISe	y	5.1	BS group, inset (a)
68	1993	ISe	y	5.3	coastal, inset (d)
69	1995	pIDe	y	3.9	intraplate, main map
70	1995	pIDe	y	3.5	offshore, main map
71-73	1996	pIDe	y	3.6,3.8, -	intraplate, main map
74	1997	pIDe	y	4.0	coastal, inset (d)
75	1997	pIDe	y	3.9	offshore, main map
76-79	1998	pIDe	y	4.2,3.3,3.4,3.9	intraplate
80	1999	pIDe	y	3.5	intraplate
100-103	1987	NIPRJ	Y	2.6 and less	coastal, inset (c)
104-108	1988	NIPRJ	Y	2.3 and less	coastal, inset (c)
109	1993	NIPRJ	y	<2.0	coastal, inset (c)
110	1994	NIPRJ	Y	<2.0	coastal, inset (c)
III	1995	NlPRJ	Y	<2.0	coastal, inset (c)
112	1996	NIPRJ	Y	<2.0	coastal, inset (c)
113	1998	WUSL	y		intraplate, inset (a)
114	1998	AWl	Y	-	intraplate, inset (a)

locations but no assessment of the event has been possible.

The earthquake locations shown as the background seismicity in Fig. 2 are distributed by the United States Geological Survey (USGS), as catalogued by the International Research Institution for Seismology (IRIS) Data Management Centre (DMC). Earthquakes are well located but the catalogue does not include some of the smaller quakes that are reported to the pIDC and ISC.

RESULTS

Antarctic Peninsula

Earthquakes in the Peninsula region include those due to volcanic activity at Deception Island (Fig. 2, DJ) and those associated with subduction in the Bransfield Strait (Fig. 2, BS, see also Robertson et al. this volume). Event 38 has an interesting hypocentre location within the continental fragment of the South Orkney Islands. It is, however, possible that the event has been mislocated from the nearby boundary with the Scotia plate. Events 113 and 114, recently recorded with well-known location errors (Stacey Robertson and Christian Müller pers. comm.), are evidence of continuing seismic activity on the west Peninsula margin.

South Atlantic/Weddell Sea

Earthquakes close to the South Sandwich/Scotia/South Atlantic triple junction (Livermore et al. 1994) are likely to be mislocated plate boundary events (Fig. 2, SA). The two distinct lines of events 18-23 and 17-25 correspond to lineations visible on the seafloor topography map of Smith & Sandwell (1997), but the better constrained locations of more recent events are closer to the South Sandwich Island Arc. Given the relatively high seismicity, it is likely that the events in Fig. 2(b) are caused directly by interactions at the plate boundary. 75 (Fig.2, central map) is a recent, well-located event and provides good evidence for active seismic deformation in the Weddell Sea. It was recorded by the array VNA1 operated from Neumayer Station (Eckstaller 1997). Improving the location and focal mechanism is the subject of present work at the Alfred Wegener Institute (Christian Müller pers. comm.).

East coast

Events 100-112 represent microseismicity close to Syowa Station (SYO) recorded on a network of three stations. Karninuma & Akamatsu (1992) interpreted the earthquakes in terms of the crustal uplift of the coast after deglaciation. Local seismicity is also reported at Mawson Station (MAW).

Transantarctic Mountains

A distinct band of seismicity through the Transantarctic Mountains is emerging including not only a very early event (4), but also several well-located events recorded on the global network (69, 73, 71, 80 and 76). The seismicity is clearly associated with the boundary zone between East and West Antarctica and forms the backbone of seismic deformation within the Antarctic plate. A field experiment which recorded micro-earthquakes in the Transantarctic Mountains took place during the austral summer of 1999/2000 (Stephen Bannister pers. comm.). Events associated with volcanic activity at Mount Erebus (Fig. 2, ME) are well recorded but not supplied to the ISC since the source mechanism is clearly non-tectonic (Rowe et al. 1998). They are, therefore, not included in this compilation.

Oates Land to Adelie Land

The considerable number of intraplate earthquakes in the 90-180° E quadrant not associated with the Transantarctic Mountains are notable in that they are occurring under an ice-covered area of considerable extent. Events 26, 27, 11, 29, 30 and 31 are poorly located and may result from mis-associations in the catalogue process. Events 74, 3 and 77 are well located and may result from crustal uplift of the coast. Those occurring under the ice, 78 and 64. are rare but may hold vital clues to the balance of forces on the crust under the ice sheet.

Ross Sea and Marie Byrd Land

Events 68 and 70 are well located and represent seismic deformation in the Ross Sea. Tectonic quakes recorded on seismic stations near to Mount Erebus-McMurdo Sound' (MCM), Scott Base (SBA), and Vanda (VNDA)-may have been mis-identified as volcanic. A vast area including Marie Byrd Land is aseismic at current global recording thresholds. Some local seismicity was, however, observed in initial data from the *ANUBIS* experiment that continued until at the end of the 1999/2000 austral summer. Local and regional seismicity recorded as part of this experiment will be addressed in future work at Alabama University (Sridhar Anandakrishnan pers. comm.).

DISCUSSION

Antarctic intraplate seismicity is characterised by a total absence of earthquakes over $m_b = 5.0$. Those listed in Table 1 with magnitudes above this value occur either at the boundary with the southern Atlantic plate (SA) or in association with volcanic activity at Deception Island (DJ). Seismicity is low even in comparison with other intraplate regions. As proposed by Stein et al. (1989), deep ice-cover creates a mechanical force that rotates the principal stress direction in the underlying rock. Such stress changes can either inhibit earthquakes by moving the stress state of the lithosphere away from brittle failure, or encourage earthquakes by moving the stress state closer to brittle failure. The distribution shown in Fig. 2 implies that tectonic earthquakes are being suppressed in Antarctica, with only the Transantarctic Mountains being active enough to overcome the ice-loading and cause detectable earthquakes. The two major influences on lithospheric stress-tectonic forces and ice-loading-are apparently working in opposition. If ice-loading inhibits earthquakes, the converse is also true: ice-unloading predisposes the crust to earthquakes. This has been observed in several recently deglaciated areas in the Northern Hemisphere (e.g., Muir Wood 1989; Main et al. 1999). At the ice margins, loading is decreasing and the crust is more likely to fail. This is consistent with the events shown in Fig. 2 (but see below regarding the optimal siting of new stations). A full consideration of the forces in the lithosphere must include also mantle viscosity (Lambeck & Johnston 1998).

It is clear (Table I) that an increase in recorded seismicity during the 1990s has taken place, due to improvements in both global and local coverage of Antarctica. In such an area of low seismicity, it is important that the catalogue be as complete as possible and lower detection thresholds for various Antarctic regions be established in order to draw meaningful conclusions about, for example, the aseismicity of Marie Byrd Land. Adams et al. (1985) reported the successful recording of event 57 at $m_b = 4.5$. One cannot, however, assume that events of similar magnitude would normally be detected. The lower detection threshold for Antarctic quakes has been very irregular before the 1990s and remains uneven. Poor weather at a particular recording station (Palmer Station, PMSA, is an example) often leads to low signal-to-noise response and consequently insufficient station records for an earthquake to be located. Such events would not be included in the global catalogues. Although there have been Antarctic seismic observatories in place, well distributed across the continent, the station coverage is still not dense enough to achieve catalogue completeness at the magnitude of even the larger Antarctic intraplate earthquakes. The completeness threshold for Antarctic quakes during the 1990s would have been similar to the GSN threshold, c. $m_b = 5.5$. The problem of the small number of earthquakes and the time taken to establish a representative seismicity distribution also remains. Once a denser Antarctic recording network is established, it will be some years before patterns emerge. There would, of course, be immediate worldwide benefit to the GSN and pIDC from any new stations installed in Antarctica recording teleseismic earthquakes from other plates (Pearce 1996).

Ice-quake/earthquake discrimination presents a continued challenge (Sinadinovski et al. 1999 and references therein). Discussion with many workers concerned with Antarctic seismic observatories suggests that locally recorded events are being dismissed as ice-quakes without full investigation. Rather than Antarctic seismicity being overestimated as a result of the erroneous inclusion of ice-quakes, it seems that the converse is more likely, with lower magnitude earthquakes being ignored. This is especially important at the ice margins of the continent, where deglaciation may be causing the level of seismicity to rise. While more coastal stations are desirable to monitor this effect, they should be complemented by stations in the interior to avoid biasing the recorded distribution. The lack of permanent stations in the East Antarctic interior and in Marie Byrd Land, coupled with noise problems at SPA, may be contributing to the apparent lack of earthquakes. Good results from stations on ice are possible provided the sensor is placed deep enough to couple with hard ice and the rock/ice interface is accounted for (Shridhar Anandakrishnan and others pers. comm.).

The GSN is optimised for the determination of whole-earth structure. In improving the coverage of seismic recording in the Antarctic, array stations (Douglas 1998) with a supplementary broad-band 3-component instrument rather than standard GSN instrumentation would provide the kind of data most suited to investigating Antarctic earthquakes. These data enable well-constrained focal mechanisms to be determined from a small number of stations (Pearce & Rogers 1989). Importantly, high signal-to-noise recording from Antarctic array stations would lower the detection threshold of earthquakes across the continent. Low-power recording technology and low-earth orbiting satellite communication will soon provide a practical solution to the problem of year-round remote recording. Therein lies the means of deploying a sufficiently dense Antarctic network to ensure catalogue completeness.

Key objectives are to:

(1) install new stations, including some array stations, at optimum locations for recording earthquakes on both the ice margin and the continental interior;

(2) complete the seismicity catalogue down to $m_b = 3.8$ (pIDC magnitude) and record waveform data to determine focal mechanisms for Antarctic earthquakes.

Once these are achieved, the full range of modern seismological methods (Lay & Wallace 1995) may be applied to Antarctica. It is particularly important that the crustal stress modifications due to ice-loading are determined in order to address the tectonic processes acting on the plate. It may take a decade or more to acquire the necessary data for some basic but essential projects, for example, the determination of body-wave structure to a regional scale. Other top priority projects include investigating mantle structure and flow beneath Antarctica, which controls lithosphere dynamics and may hence influence ice-sheet stability. The Antarctic community should have the vision to "play the long game" and undertake this fundamental work. It is important that the data review, archiving, and dissemination of earthquake records from any new, remote stations be carried out effectively. The ANTEC group will play a key role in co-ordinating these activities.

CONCLUSIONS

1. A low, but significant, level of seismic deformation is occurring in the Transantarctic Mountains.
2. Antarctic earthquakes are being suppressed by ice cover but may be enhanced as deglaciation occurs around the land margins.
3. Fundamental advances in Antarctic neotectonics could be made by installing remote recording stations in the continental interior.

ACKNOWLEDGMENTS

Shridar Anandakrishnan of the University of Alabama, Tuscaloosa, USA, Katsutada Kaminuma of the National Institute for Polar Research, Tokyo, Japan, Kevin McCue of the Australian Geological Survey Organisation, Christian Müller of the Alfred Wegener Institute, Bremerhaven, Germany, and Stacey Robertson and Doug Wiens of Washington University, St Louis, USA, are thanked for contributing observations and data to this compilation. Robin Adams and Bob Pearce are thanked for helpful discussion, and referee's comments from Martha Savage have significantly improved the manuscript. The work was made possible by a grant from the Moray Endowment Fund, University of Edinburgh.

REFERENCES

Adams, R. D.; Hughes, A. A.; Zhang, B. M. 1985; A confirmed earthquake in continental Antarctica. *Geophysical Journal of the Royal Astronomical Society* 81; 489-492.

Bannister, S.; Snieder, R. K.; Passier, M. L. 2000: Shear-wave velocities under the Transantarctic Mountains and Terror Rift from surface wave inversion. *Geophysical Research Letters* 27;

Douglas-, A. 1998: Making the most of recordings from short-period seismometer arrays. *Bulletin ofthe Seismological Society ofAmerica* 8: 70.

Eckstaller, A.; Schmidt, T.; Gaw, V.; Muller, C.; Rogenhagen, J. 1997: The geophysical observatory at Neumayer Station, Antarctica: geomagnetic and seismological observations in 1995 and 1996. *Berichte ziir Polarforschung* 244: 3-14.

Hayes, D. E. 1991: Tectonics and age of the oceanic crust: circum-Antarctic to 30°S. *In:* Hayes, D. E. *ed.* Marine geological and geophysical atlas of the circum-Antarctic to 30°S. Washington, D.e., American Geophysical Union. Pp. 47-56.

lames, T. S.; Ivins, E. R. 1998: Predictions of Antarctic crustal motions driven by present-day ice sheet evolution and by isostatic memory of the Last Glacial Maximum. *Journal of Geophysical Research 103: 4993-5017.*

Kaminuma, K. 1994: Seismic activity in and around the Antarctic Continent. *Terra Antartica Special Issue* 1:

Kaminuma, K.; Akamatsu, J. 1992: Intermittent micro-seismic activity in the vicinity of Syowa station, East Antarctica. *In:* Yoshida, Y. et al. *ed.* Recent progress in earth science. Tokyo, TERRAPUB. Pp. 493-497.

Lambeck, K.; Johnston, P. 1998: The viscosity of the mantle: evidence from analyses of glacial-rebound phenomena. *In:* Jackson, 1. *ed.* The Earth's mantle. composition, structure and evolution. Cambridge, Cambridge University Press. Pp. 461-502.

Lay, T.; Wallace, T. C. 1995: Modern global seismology. San Diego, Academic Press. Pp. 243-249.

Livermore, R; McAdoo, D.; Marks, K. 1994: Scotia Sea tectonics from high-resolution satellite gravity. *Earth and Planetary Science Letters* 123: 255-269.

Main, I.; Irving, D.; Musson, R; Reading, A. 1999: Constraints on the frequency-magnitude relation and maximum magnitudes in the UK from observed seismicity and glacio-iostatic recovery rates. *Geophysical Journal Intenlational* 137: 535–550.

Muir Wood, R. 1989: Extraordinary deglaciation reverse faulting in northern Fennoscandia. *In:* Gregerson, S.; Basham, P. W. *ed.* Earthquakes at North Atlantic passive margins: neotectonics and post placial isostatic rebound. Netherlands, Kluwer Academic Publishers. Pp. 141-173.

Pearce, R G. 1996: Seismic source discrimination at teleseismic distances-can we do better? *In:* Husebye, E. S.; Dainty, A. M. *ed.* Monitoring a comprehensive test ban treaty. Netherlands, Kluwer Academic Publishers. Pp. 805-832.

Pearce, R. G.; Rogers, R. M. 1989: Determination of earthquake moment tensors from teleseismic relative amplitude observations. *Journal of Geophysical Research 98:* 775-786

Robertson, S. D.; Wiens, D. A.; Shore, P. J.; Smith, G. P.; Vera, E. this volume: Seismicity and tectonics of the South Shetland Islands and Bransfield Strait from the SEPA broadband seismograph deployment. *In:* Gamble, J. A.; Skinner, D. N. B.; Henrys, S. *ed.* Antarctica at the close of a millennium. Proceedings of the 8th International Symposium on Antarctic Earth Sciences. *Royal Society of New Zealand Bulletin* 35: 549-553.

Rouland, D.; Condis, C.; Parmentier, C.; Souriau, A. Previously undetected earthquakes in the southern hemisphere located using long-period geoscope data. *Bulletin of the Seismological Society of America 82:* 2448-2463.

Roult. G.; Rouland, D. 1994: Antarctica I: Deep structure investigations inferred from seismology; a review. *Physics of the Earth and Planetary Interiors* 84: 15–32.

Roult, G.; Rouland, D.; Montagner, 1. P. 1994: Antarctica II: Upper-mantle structure from velocities and anisotropy. *Physics of the Earth and Planetary Interiors* 84: 33-57.

Rowe. C.; Aster, R.: Kyle, P.; Schlue, J.; Dihhle. R. 1998: Broad-band recording of Strombolian explosions and associated very-long period seismic signals on Mount Erebus Volcano, Ross Island, Antarctica. *Geophysical Research Letters 25:* 2297-2300.

Sinadinovski, C.; Muirhead, K.; Leonard, M.; Spiliopoulos, S.; Jepsen, D. Effective discrimination of icequakes on seismic records from Mawson station. *Physics afthe Earth and Planetary Interiors* 113: 203-2ll.

Smith, W.; Sandwell, D. 1997: Measured and estimated sea-floor topography (version 4.2), World Data Center A for Marine Geology and Geophysics research publication RP-1, poster.

Stein, S.: Cloethiogh, S.; Sleep, N. H.: Wortel, R. 1989: Passive margin earthquakes, stresses and rheology. *In:* Gregerson, S.; Basham, P. W. *ed.* Earthquakes at North Atlantic passive margins: neotectonics and post glacial isostatic rebound. Netherlands, Kluwer Academic Publishers. Pp. 231-259.

Zoback, M. L. First and second-order patterns of stress in the lithosphere: the World Stress Map Project. *Journal of Research* 97: 11703-11728.