Seismicity and neotectonics of West Antarctica

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Received 18 June 2003; accepted 10 July 2003; published 19 September 2003.

[1] Newly discovered earthquakes in West Antarctica provide the first documentation of seismicity in the region. The data presented here indicate that the ice sheet does not suppress seismicity as has been previously proposed. However, the observed earthquake pattern suggests the West Antarctic rift system is no longer actively extending. INDEX TERMS: 1645 Global Change: Solid Earth; 7205 Seismology: Continental crust (1242); 7218 Seismology: Lithosphere and upper mantle; 7230 Seismology: Seismicity and seismotectonics; 9310 Information Related to Geographic Region: Antarctica. Citation: Winberry, J. P., and S. Anandakrishnan, Seismicity and neotectonics of West Antarctica, Geophys. Res. Lett., 30(18), 1931, doi:10.1029/2003GL018001, 2003.

1. Introduction

[2] The West Antarctic rift system (WARS) is a region that has experienced diffuse continental extension and is similar in size to the Basin and Range province of the western United States (Figures 1 and 2). However, the thick ice sheet that dominates the WARS largely obscures the tectonic history and structure of the region. Extension between East and West Antarctica that formed WARS is generally agreed to have begun with the initial breakup of Gondwana in the Mesozoic and continued into the Cenozoic [Van der Wateren and Cloetingh, 1999]. Estimates of Cenozoic extension vary from 50 km [Lawver and Gahagan, 1994] to 1000 km [DiVenere et al., 1994; Luyendyk et al., 1996]. However, the regional available geophysical data to date has not been able to conclusively resolve the rift's current activity. Several lines of geophysical evidence [Wannamaker et al., 1996; Clarke et al., 1997; Blankenship et al., 2001] including the lack of seismicity detected by field sensors [Adams and Akoto, 1986] suggest that rifting is no longer active. However, Johnston [1987] proposed that the lack of earthquakes is caused by ice sheet suppression rather than tectonic stability. According to this theory the overburden of the ice sheet counteracts tectonic stresses that would otherwise promote seismic activity. Active volcanism in the region has been hypothesized to indicate an active rift system [Behrendt and Cooper, 1991; Behrendt et al., 1994]. Resolving these differences has been difficult due to the limited exposure of rock available as well as the expense of collecting high-quality geophysical data in the region.

2. Data

[3] To determine the seismicity of the region a broadband seismic network was operated in West Antarctica from November 1998 to November 2001 [Anandakrishnan et al., 2000]. The network was configured to provide the first reliable estimates of local and regional seismicity in the rift's interior and shoulders. Despite the harsh climate and long intervals between visits use of solar panels and wind generators allowed for data collection during approximately half of the deployment. Magnitude estimates were made using the local magnitude scale and locations were optimized using Geiger's method. The network's detection threshold was $M_L \approx 2.5$ for the southern rift boundary, $M_L \approx 2.0$ for the northern rift boundary and less than $M_L \approx 1$ within 75 km of the stations. This study reports on the data collected during the two hundred days in which three or more stations were operational.

3. Discussion

[4] Our data show that earthquakes in West Antarctica are quite common. The network recorded hundreds of earthquakes, most $M_L < 1$, at a rate of up to 20 per day. Earthquakes of $M_L < 1$ were generally recorded at just one station and occasionally at two. In addition to these smaller events a total of twenty earthquakes between $M_L 2$ and $M_L 4$ were recorded during the experiment (Figures 2 and 3). Some of the smaller events, $M_L < 1$, may be the product of icequakes, similar to those that have been previously observed in this region [Anandakrishnan and Bentley, 1993; Anandakrishnan and Alley, 1997]. However, an icequake origin for the $M_L > 2$ is unlikely since they are

Figure 1. Bed elevation map of Antarctica with study area outlined. Data is from the BEDMAP project.
significantly larger than the magnitude 0 icequakes typical of this region [Anandakrishnan and Bentley, 1993]. In this study we analyze the twenty earthquakes recorded by multiple stations of magnitude 2 and larger for which reliable hypocenters were determined (Figure 2). Previous suggestions of aseismicity in the region were due to the limitations of the global seismic network in detecting small events in West Antarctica, not due to ice sheet suppression as suggested by Johnston [1987].

[5] Seismicity of magnitude greater than 2 is predominantly concentrated in two geographic clusters (Figure 2), one near the northern border of WARS (Cluster II) and one within the interior of WARS (Cluster I). Only two located earthquakes occur outside these clusters (Figure 2), both of which were near the network detection limit for earthquakes of their size. We were unable to determine if these were isolated events or were associated with other small earthquakes.

The spatial distribution and magnitude of seismicity in the region suggest that at present WARS is extensionally dormant. Actively extending regions tend to have diffuse zones of seismic activity associated with their boundaries, such as the intermountain seismic belt (ISB) of the Basin and Range province [Parsons, 1995]. During a typical two hundred day period the ISB experiences ten or more earthquakes of magnitude greater than 3 (National Earthquake Information Center). However, along the southern boundary of WARS no earthquakes of magnitude greater than 3 were detected. Given the absence of any activity it appears that the southern boundary is extensionally inactive. While no large events were located near the southern boundary we cannot rule the occurrence of small events below the networks detection threshold, similar to those recorded by Bannister and Kennett [2002] north of our study area. The northern boundary exhibits limited seismicity associated with Cluster II. Seismotectonic evidence for active rifting is also sparse within the interior of WARS where larger earthquakes occur only in cluster I. This set of earthquakes is located near a proposed graben boundary interpreted from airborne gravity data [Studinger et al., 2002] suggesting the possibility these earthquakes may be related to motion on this fault. Overall, the seismic evidence for active extension in the region is minimal. This interpretation is consistent with recent results of GPS studies that indicate an inactive rift [Donelan and Luyendyk, 2002].

[6] Abundant late Cenozoic volcanic activity has been observed in West Antarctica [Hole and Lemausier, 1994]. This activity provides another possible mechanism for the observed pattern of seismicity. The earthquakes observed in this study do not exhibit a clear foreshock-aftershock sequence and are tightly clustered in time and space (Figures 2 and 3), typical of small magmatic intrusions into the seismogenic portion of the crust [Lay and Wallace, 1995]. Cluster I is located in a region that has been associated with subglacial volcanic activity based on high-resolution airborne magnetic data [Blankenship et al., 1993; Behrendt et al., 1994]. Cluster II resides near exposures of the late Cenozoic volcanic rocks. Magmatic driven seismicity would be consistent with previous inferences of subglac-

Figure 2. Bed elevation map for the West Antarctic Rift System with the inferred boundaries of WARS indicated by hachured lines, earthquake locations by red dots, and seismic stations indicated by triangles.

Figure 3. Plot of earthquakes as a function of time. Time-axis is discontinuous and is zoomed in around the temporal clustering of events. Each marker represents one earthquake with the vertical axis representing magnitude.
cial volcanism [Blankenship et al., 1993; Behrendt et al., 1994] and observations of subaerial volcanism [Hole and Lemasuier, 1994] in WARS.

4. Conclusions

The data in this paper provide the first documentation of seismicity within the West Antarctica rift system. This argues against an ice-sheet suppression of seismicity in the region. The characteristics of observed seismicity favor the interpretation of a largely dormant rift system. If this is the case the present seismicity may be driven by localized tectonic activity or by igneous processes responsible for the late Cenozoic volcanic exposures documented throughout the region.

Acknowledgments. Support was provided by NSF OPP grants 9615147 and 0296200. J.P.W. was supported by the NSF OPP and PSU ARL. We thank Kenn Borek Air, The N.Y. Air National Guard, Don Voigt, Bruce Long, Peter Burkett, Rick Henry, and Jerry Bowling for Field Assistance. We thank the IRIS/PASSCAL Instrument center for equipment and technical support. Helpful comments by Richard Alley and Audrey Huerta improved the manuscript.

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