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Lithospheric Structure of Antarctica and Implications for Geological and Cryospheric Evolution

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Recent broadband seismic deployments, including the AGAP/GAMSEIS array of 24 broadband seismographs over the Gamburtsev Subglacial Mountains (GSM) in East Antarctica and the POLENET/ANET deployment of 33 seismographs across much of West Antarctica, reveal the detailed crust and upper mantle structure of Antarctica for the first time. The seismographs operate year-around even in the coldest parts of Antarctica, due to novel insulated boxes, power systems, and modified instrumentation developed in collaboration with the IRIS PASSCAL Instrument Center. We analyze the data using several different techniques to develop high-resolution models of Antarctic seismic structure. We use Rayleigh wave phase velocities at periods of 20-180 s determined using a modified two-plane wave decomposition of teleseismic Rayleigh waves to invert for the three dimensional shear velocity structure. In addition, Rayleigh wave group and phase velocities obtained by ambient seismic noise correlation methods provide constraints at shorter periods and shallower depths. Receiver functions provide precise estimates of crustal structure beneath the stations, and P and S wave tomography provides models of upper mantle structure down to $\sim$ 500 km depth along transects of greater seismic station density.

The new seismic results show that the high elevations of the GSM are supported by thick crust ($\sim$ 55 km), and are underlain by thick Precambrian continental lithosphere that initially formed during Archean to mid-Proterozoic times. The absence of lithospheric thermal anomalies suggests that the mountains were formed by a compressional orogeny during the Paleozoic, thus providing a locus for ice sheet nucleation throughout a long period of geological time. Within West Antarctica, the crust and lithosphere are extremely thin near the Transantarctic Mountain Front and topographic lows such as the Bentley Trench and Byrd Basin, which represent currently inactive Cenozoic rift systems. Slow seismic velocities beneath Marie Byrd Land at asthenospheric depths suggest a major thermal anomaly, possibly due to a mantle plume. Volcanic earthquakes detected in this region indicate the presence of currently active magma systems. The results suggest large lateral changes in parameters needed for glaciological models, including lithospheric thickness, mantle viscosity, and heat flow. Extremely high heat flow is predicted for much of West Antarctica, consistent with recent results from the WAIS ice drilling. Using the seismic results to estimate mantle viscosity, we find several orders of magnitude difference in viscosity between East and West Antarctica, with lowest viscosities found beneath Marie Byrd Land and the West Antarctic Rift System. Realistic glacial isostatic adjustment models must take these large lateral variations into account.