of hornblende, plagioclase, and biotite. Some lamprophyre dikes contain an abundance of crustal xenoliths, including garnet granulites and garnet anorthosites from the deep crust and macrocrysts of diopside, garnet, hornblende, and phlogopite. Further study of these crustal xenoliths should provide valuable information on the late- or post-Ross Orogenic crust in this region.

Both the ultramafic and alkaline lamprophyres have high abundances of compatible elements, with magnesium numbers ≤70 percent: nickel ≤190 parts per million, cobalt ≤63 parts per million, chromium ≤550 parts per million, and scandium ≤31 parts per million. They are also extremely enriched in large-ion-lithophile elements, high-field-strength elements, and light-rare-earth elements, with barium ≤4,200 parts per million, strontium ≤1,800 parts per million, niobium ≤65 parts per million, and cerium ≤195 parts per million. These chemical features imply that these rocks may represent primary melts derived from low-degree partial melting of enriched mantle sources, likely metasomatized peridotites, and have undergone little or no differentiation from crystal fractionation and crustal contamination. The calc-alkaline lamprophyres have a large range of chemical composition with silica equal to 46–57 weight percent and magnesium number equal to 45-72 percent, which, shown by their chemistry and petrology, is probably produced by a combination of crystal fractionation of diopside and hornblende and crustal assimilation. Their most primitive compositions, with magnesium number of ≤72 percent, nickel ≤210 parts per million, cobalt ≤75 parts per million, chromium ≤670 parts per million, and scandium ≤34 parts per million, are likely primary magmas derived from mantle sources. These rocks are also highly enriched in large-ion-lithophile elements and light-rare-earth elements, with rubidium ≤180 parts per million, barium ≤1,500 parts per million, and cerium ≤130 parts per million, but display relatively strong depletion of high-field-strength elements, which is the characteristic of magmas generated above a subduction zone, suggesting involvement of subducted-slab derived components in the generation of calc-alkaline lamprophyric magmas. The chemistry of these lamprophyres strongly suggests the existence of a subduction process and metasomatized mantle below southern Victoria Land during the Ross Orogeny. Other rock types including malchites, microdiorites, porphyrites, and porphyries have a composition range of silica equal to 55–71 weight percent and magnesium number equal to 25–50 percent. Their compositions show continuing trends from calc-alkaline lamprophyres, implying strong genetic relations.

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References

Angino, E.E., M.D. Turner, and E. Zeller. 1962. Reconnaissance geology of lower Taylor Valley, Victoria Land, Antarctica. *Geological Society of America Bulletin*, 73, 1553–1562.

Jones, L.M., and G. Faure. 1967. Age of the Vanda porphyry dikes in Wright Valley, southern Victoria Land, Antarctica. *Earth and Planetary Science Letters*, 3, 321–324.

Seismic investigation of the boundary between East and West Antarctica

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The Transantarctic Mountain front constitutes the boundary between East and West Antarctica. The continental crust of East Antarctica (on which the Transantarctic Mountains are located) is probably thick and tectonically stable (e.g., Stern and ten Brink 1989). The adjacent West Antarctica is, on the other hand, underlain by a thin continental crust resulting from episodic extension (rifting) in the past approximately 70 million years (Cooper, Davey, and Behrendt 1987). Thrusting and folding, which characterize mountain ranges of similar size such as the Andes and the Rocky Mountains, are not observed in the Transantarctic Mountains. The building of the Transantarctic Mountain range was accompanied by extension and a gentle asymmetric tilt of strata toward the polar plateau. Thus, the Transantarctic Mountains are probably the most striking global example of a different category of mountains, the rift-shoulder mountains (e.g., Stern and ten Brink 1989).

Stanford University and the Geology and Geophysics Division of the Department of Scientific and Industrial Research (DSIR) of New Zealand carried out the Seismic Experiment Ross Ice Shelf (SERIS) during austral summer 1990–1991 across the Transantarctic Mountain front at latitudes 82°–83° S. The experiment included a 134-kilometer-long seismic reflection profile and a 96-kilometer-long coincident wide-angle reflection/refraction profile. Gravity and relative elevation (using barometric pressure) were measured along the entire profile. The primary purpose was to image the transition from the rift system to its uplifted shoulder to gain insight into the processes of crustal rifting and rift-shoulder mountain building. Because it was the first large-scale, modern multichannel seismic experiment in the remote interior of Antarctica, SERIS had a second purpose: to test different seismic acquisition techniques and the logistical support that will be involved in future seismic

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exploration of the continent. The geological research of Antarctica heavily depends upon seismic and other remote-sensing techniques because of the paucity of rock exposures.

The scientific objective required that the seismic profile cross the Transantarctic Mountain front. Unlike most other antarctic experiments, seismic experiments involve land traverse by large vehicles. Only one glacier along the 1,500-kilometer-long central Transantarctic Mountains, the Skelton, had been previously traversed by heavy vehicles, but the orientation and the location of this glacier were, scientifically, not suitable. After extensive inquiry and two reconnaissance flights, the Robb and Lowery glaciers, two interconnected glaciers 80 kilometers north of the Beardmore Glacier, were selected (figure 1). These glaciers offered moderate topographic slope and were relatively free of crevasses and were sheltered from wind. The profile extended from the Ross Ice Shelf to a distance of 40-50 kilometers into the mountains and terminated against the 4,350-meter-high Markham Plateau where geological markers indicate a 4–6 kilometers of uplift. The experiment sampled two antarctic acquisition environments: grounded glacial ice overlying crystalline basement and floating ice shelf (200–500 meters thick) overlying both water and sediments.

The seismic sources for the reflection experiment were 5- and 7.5-kilogram explosive charges placed at 200-meter intervals at the bottom of 17- to 18-meter-deep holes in the ice. Shot holes were drilled in the ice by a hose ejecting hot (80 °C) water at high pressure. An improved nozzle design saved physical labor. Although the drilling rate, three to five holes per hour, was fast relative to similar operations on soil-covered land, it was, nevertheless, slower than the rate of acquisition. Several test shots of blasting cord were also fired. Using blasting cord as a potential sound source may save fuel and manpower for drilling, eliminate shot preparation, and increase the acquisition rate. Preliminary comparison with down-hole shots indicates, at least, good energy returns from shallow (2–3 seconds) depth.

Two receiving systems were compared during the experiment. A conventional seismic cable with 48 groups of geophone strings at 50-meter intervals was used over 51 kilometers out of the 134-kilometer-long profile, mostly on the glaciers. The remainder of the profile (83 kilometers, on the ice shelf) was recorded using a 1.5-kilometer-long, 60-channel experimental snow streamer borrowed from Norsk-Hydro. Two shots, located 0.2 and 1.8 kilometers ahead of the streamer location, were shot into each streamer location to achieve an effective 3-kilometer-long receiving array of 120 groups of geophone strings at 25-meter group intervals. The streamer was towed by an over-snow vehicle which also housed the seismic recording unit.

Seismic field records from the two systems were found to have similar noise levels despite the fact that the geophones connected to the conventional cable were buried whereas the geophones dragged by the streamer lay on the surface. Some streamer-geophone groups became considerably noisier, however, above wind speeds of 5–6 knots (2.5–3 meters/second). In all other respects, the streamer proved superior to a conventional cable—the rate of acquisition was doubled, manpower was cut by half, and there were considerable savings in vehicles, sleds, and fuel usages.

The wide-angle reflection/refraction experiment consisted of four deployments of a 23–25-kilometer-long receiving array, with 162 channels and a geophone group interval of 100–300 meters. Two of the deployments were situated mostly over glaciers of the Transantarctic Mountains whereas the other two were on the Ross Ice Shelf. Independent recording instruments, cables and geophones all borrowed from Incorporated Research Institutions for Seismology, constituted most of the receiving array.

Shots for each deployment were detonated at each end of the receiving array and farther away from the array with a maximum shot-receiver offset of 90 kilometers on the ice shelf and 51 kilometers on the glacier. Shot sizes ranged (with offset)

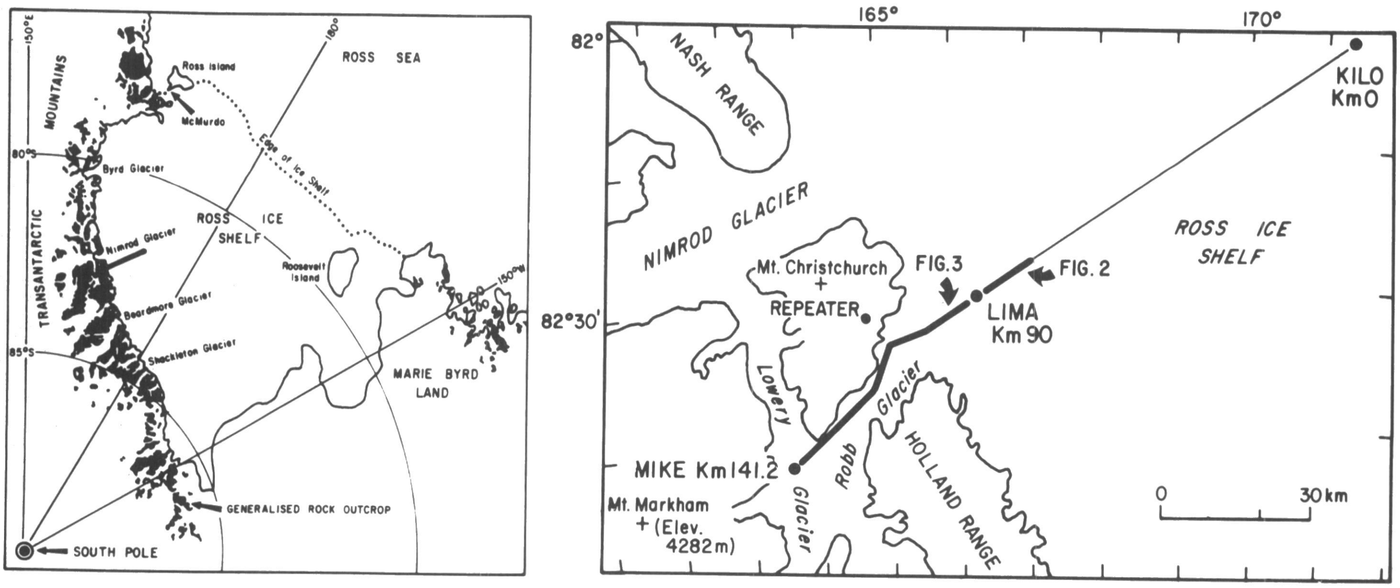

Figure 1. Location of the SERIS profile across the eastern edge of the Transantarctic Mountains and on the Ross Ice Shelf. Three logistical camps, Kilo, Lima, and Mike are marked. (km denotes kilometer.)

between 100 and 400 kilograms and the charges were placed at the bottom of 20-meter-deep holes. Data were recorded on the internal RAM of each unit and were transferred to a portable hard disk immediately following shooting. Preliminary processing was carried out in the field on a workstation.

Preliminary stack section from the ice shelf (see figure 1 for location) shows sub-seafloor sedimentary layers which dip east and away from the mountains (figure 2). Similar east-dipping sedimentary strata are seen in marine seismic sections from the Ross Sea close to the mountain front. The dipping strata in the Ross Sea were interpreted to be the result of the uplift of the mountains (Cooper et al. 1987). Wide-angle reflection data suggests that the Robb and Lowery glaciers are grounded and are directly underlain by crystalline basement (e.g., figure 3). The data further show a band of high reflectivity starting at a travel time of 6.5 seconds under the boundary between the Ross embayment and the Transantarctic Mountains and dipping to a travel time of 10 seconds at the western end of the profile (see figure 1 for location). The zone of high reflectivity is interpreted as the crust-mantle interface. Using an average seismic velocity for crustal rocks of 6 kilometers per second, we determined that the crust-mantle boundary dips from 20 to 30 kilometers under the mountain front. It should be emphasized that these are only partial results. Analysis of the seismic data is currently underway at the U.S. Geological Survey, Stanford University, and the DSIR, New Zealand.

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References

Cooper, A.K., F.J. Davey, and J.C. Behrendt. 1987. Seismic stratigraphy and structure of the Victorialand basin, western Ross Sea, Antarctica. In A.K. Cooper and F.J. Davey (eds.), *The Antarctic continental margin, geology and geophysics of the western Ross Sea*. Earth Science Series (vol. 5B). Houston: Circum-Pacific Council for Energy and Mineral Resources.

Stern, T.A., and U.S. ten Brink. 1989. Flexural uplift of the Transantarctic Mountains. *Journal of Geophysical Research*, 94, 10,315–10,330.

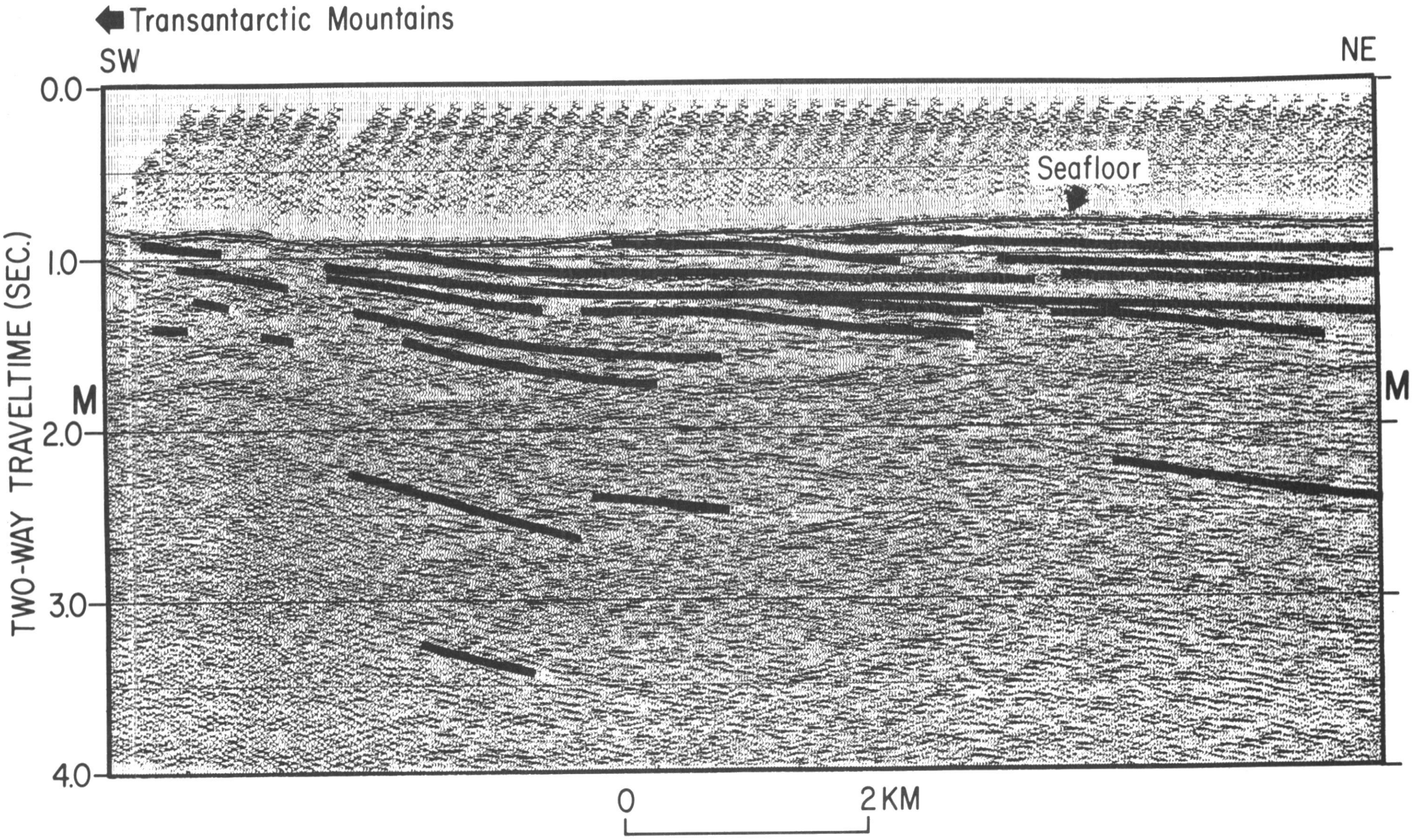

Figure 2. Preliminary stack section (7–8 fold, 12.5 meters thrace interval) over the ice shelf of the seismic reflection data collected with the snow streamer (120 geophone groups). See figure 1 for location. The section shows reflectors dipping away from the Transantarctic Mountains. The processing sequence included filtering in the frequency-wave number domain to remove ground roll and spiking deconvolution before stack. (M denotes multiple reflection from the sea floor. KM denotes kilometer.)

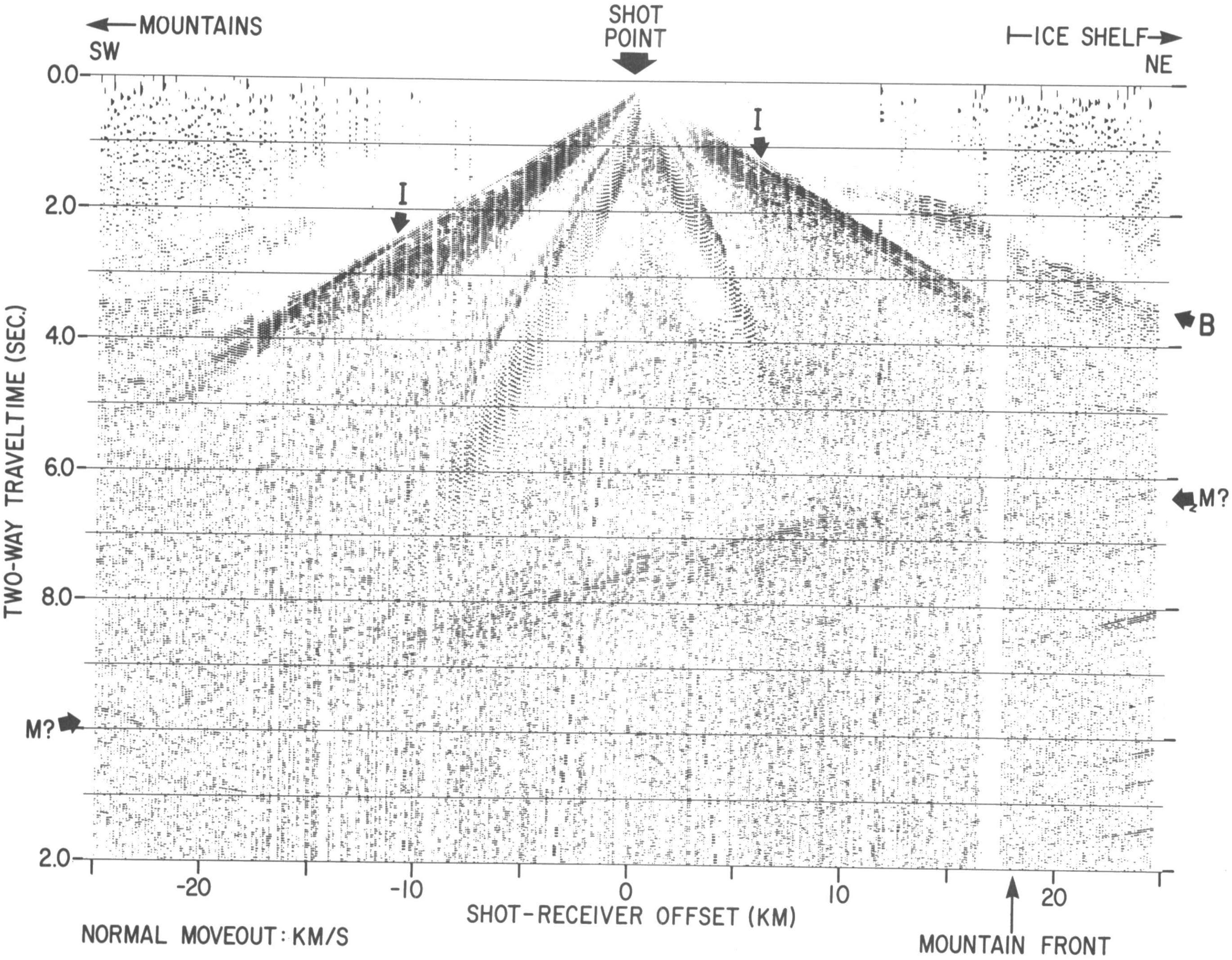

Figure 3. Wide-angle reflection shot gather on Robb Glacier in the Transantarctic Mountain front. See figure 1 for location. Horizontal scale represents shot-receiver offset. The wide-angle shot gather was recorded by two arrays of 25 independent recording instruments at 100-300-meter-group interval using 100 kilograms of ammonium-nitrate as a sound source. The section was plotted with a normal moveout of 6 kilometers per second (KM/S) to correct for the increasing travel time with shot-receiver offset. (I denotes direct wave within the ice layer. B denotes diving wave from the crystalline basement. M denotes reflections from the crust/mantle interface (?).)