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GEOGRAPHY

# Geophysical Investigations of the Subglacial Lake Vostok in Eastern Antarctica

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The assessment of the results of the Soviet seismic (1959–1964) [3] and British airborne radar sounding (1971 and 1974/1975) [13] of the subglacial relief of central Antarctica, as well as materials on the altimetry of the ice sheet surface, which were obtained with the help of the Earth Resources Satellite-1 (ERS-1), suggested the existence of a large subglacial lake north of the Russian Antarctic Station Vostok [11]. The lake has the same name.

Tens of subglacial lakes have recently been revealed in central Antarctica, the largest one being Lake Vostok [2, 15]. The lake is more than 280 km long and 50 km wide, the water table area makes up about 10 000 km$^2$ and is comparable with renowned lakes, such as Onega (Europe), Chad and Rudolf (Africa), Nicaragua (Central America), and Titicaca (South America) [5, 12, 14]. The position of the subglacial lake shoreline was determined by its manifestation as an even sector of the ice sheet surface. Based on satellite altimetry data, the Vostok Station is located beyond that boundary, although results of radar and seismic sounding confirmed the presence of a water layer beneath the station. Hence, the study of the compliance of the lake's actual shoreline position with its manifestation in topography becomes an important issue.

The ice sheet in the lake region is 3700-4200 m thick. It moves eastward at the rate of about 3 m/yr. The Russian glaciologist Kotlyakov believes the ice sheet to be a peculiar shelf glacier [4]. Ice has reliably been isolating the lake water mass from contacts with the atmosphere for a million years. The upper layer of the watermass is saturated with air released during the thawing of the lower surface of the glacier, which may contain old bacteria. Hence, along with the study of geological, geochemical, biochemical, and glaciological processes of the formation of the ice sheet, the problems of the origin and evolution of live organisms, which are likely to exist in it, are of great interest. Moreover, space specialists show great interest in this natural phenomenon. They consider Lake Vostok as a good scientific site for testing space technologies and engineering designs in studying one of the Jupiter's satellite (Europe), where, in their opinion, microorganism of extraterrestrial origin may exist under similar conditions (thickness of the ice sheet, the presence of a water layer beneath it, and the temperature of the planet's surface) [10].

This situation allowed the international scientific community to consider investigations of the Vostok subglacial lake as one of the principal lines in studying Antarctica at the turn of the 21st century. The solution of the above-mentioned problems naturally requires special geological, geophysical, glaciological, and microbiologcal investigations. We should also study the technological and engineering problems of ecologically safe penetration into the lake. Nevertheless, all investigations should be preceded by comprehensive studies of lake parameters, such as the position of the shoreline; the thickness of bottom sediments, watermass, and ice sheet above it, and others. Remote methods including seismic and radar sounding are the most effective for achieving the objectives posed. Starting in 1995, the methods were used during annual specialized geophysical studies of the subglacial lake by researchers of the Polar Marine Geological Research Expedition (PMGRE) of the Ministry of Natural Resources of the Russian Federation (MNR RF) within the framework of the Russian Antarctic Expedition (RAE).

Until 1995, only one seismic sounding was carried out in the lake region, and the obtained data became the cornerstone of the issue related to priority in the discovery of the Vostok subglacial lake. Mass seismic data acquisition in central Antarctica by common techniques (the deepening of the wave excitation source or detector) at a considerable thickness (up to tens of meters) of the snow–firn pile presented difficulties since that required preliminary drilling of the ice surface in each point of sounding. Therefore, the first stage of seismic investigations commenced by the RAE in 1995 included special methodological studies that helped to reduce the preparation period for sounding and, hence,

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to increase the efficiency of the method. At the same time, the use of a borehole, which was drilled earlier through the ice sheet in the Vostok Station according to the program for studying climatic variations in the Antarctic region, allowed researchers to study the vertical distribution of seismic wave velocities in the ice sheet and to determine the remaining distance from the borehole bottom to the lower edge of the glacier. The latter was of great importance for establishing the depth of safe drilling in ice until the ecologically safe procedure of penetrating into the lake watermass is elaborated. As the result of the vertical seismic profiling (VSP) carried out at the 61-m horizon throughout the whole length of borehole 5G-1, the layer-by-layer distribution of average velocities of seismic waves in the ice sheet was studied for the first time for central Antarctica. It was also established that the lake watermass is separated from the borehole bottom by a 130-m-thick ice layer (Fig. 1) [6, 12].

More than 160 seismic soundings were carried out to study the morphology of lake depression slopes, the geological structure of the lake bottom, and the watermass thickness. The majority of soundings were made in the region of the Vostok Station where several reference profiles were laid (*AB* and others, Fig. 2) which crossed borehole 5G-1 in various directions that allowed the researchers to obtain a continuous distribution of the wavefield parameters in the region. North of the station, the measurements were less detailed and focused on sublatitudinal (*KM*) and submeridional (*NQP*) reference profiles (Fig. 2) and extended beyond the lake.

In the 1960s–1970s, the Soviet Antarctic Expedition successfully measured the 3500-m-thick ice sheet by ground-based radar sounding [1, 9]. On the basis of experimental results, a new digital software and hardware complex was elaborated to study the phenomenon of Lake Vostok. The complex includes an ice radar, a satellite navigation system, and peripheral devices of digital recording [5, 7, 12]. This allowed continuous radar profiling to be made from a moving vehicle. Results of the studies made it possible to determine the shoreline configuration of the studied lake sector. They also considerably improved the accuracy of the topographical control and measurement of ice sheet thickness [5]. Moreover, the maximal thickness (more than 4000 m) of the ice sheet was reliably measured and the efficiency of the method was upgraded to 100% [12]. It should be pointed out that ground-based radar sounding is a more precise technique compared to its airborne analogs due to small velocities of the carrier. The technique allows a more detailed study of the original topography and subsequent geomorphological interpretation. Yet another important advantage of ground investigations is the possibility of making an instantaneous decision when observing changes in the position of measurement profiles that improves the quality of work during the determination of a complicated shoreline configuration.

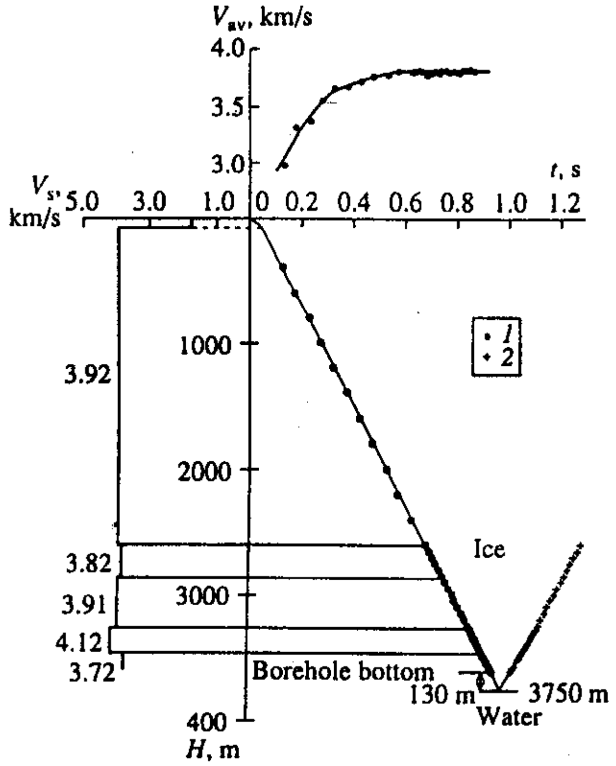


**Fig. 1.** Vertical traveltime curve, plots of average ($V_{av}$) and stratal ($V_s$) velocities based on the VSP data of BH 5G-1. (*1*) Time of direct arrival; (*2*) arrival time of a wave reflected from the glacier bottom.

To increase the accuracy of measurements of glacier thickness by the radar sounding, the velocity of electromagnetic wave propagation in the glacier was measured by inclined sounding. The velocity was equal to 168.4 ± 0.5 m/s [8, 12], which differs somewhat from the value used by other researchers for the region. The consideration of this velocity allowed us to refine the ice sheet thickness in the Vostok Station region. This is confirmed by good agreement with seismic sounding data.

To map the shoreline of the subglacial Lake Vostok, the radar profiling was carried out in 1998–2001 along 75 traverses with a total length of 1260 km, and the shoreline position was established in 56 points (Fig. 3).

According to data of combined geophysical investigations carried out within the framework of the Russian Antarctic Expedition from 1995 to 2001, the thickness of the glacier above the lake varies from 3700 m in the southern part to 4350 m in the western part. The latter value is the largest one ever measured by Russian (Soviet) specialists in Antarctica (Fig. 3). The glacier thickness increases, in general, to the north and east. The glacier bottom is located above the lake at the height ranging from –700 to –200 m bsl (Fig. 3).

The western shore of the lake is very irregular and more gentle compared to the eastern one (Fig. 3). A rounded bay is located 60 km northwest of the Vostok

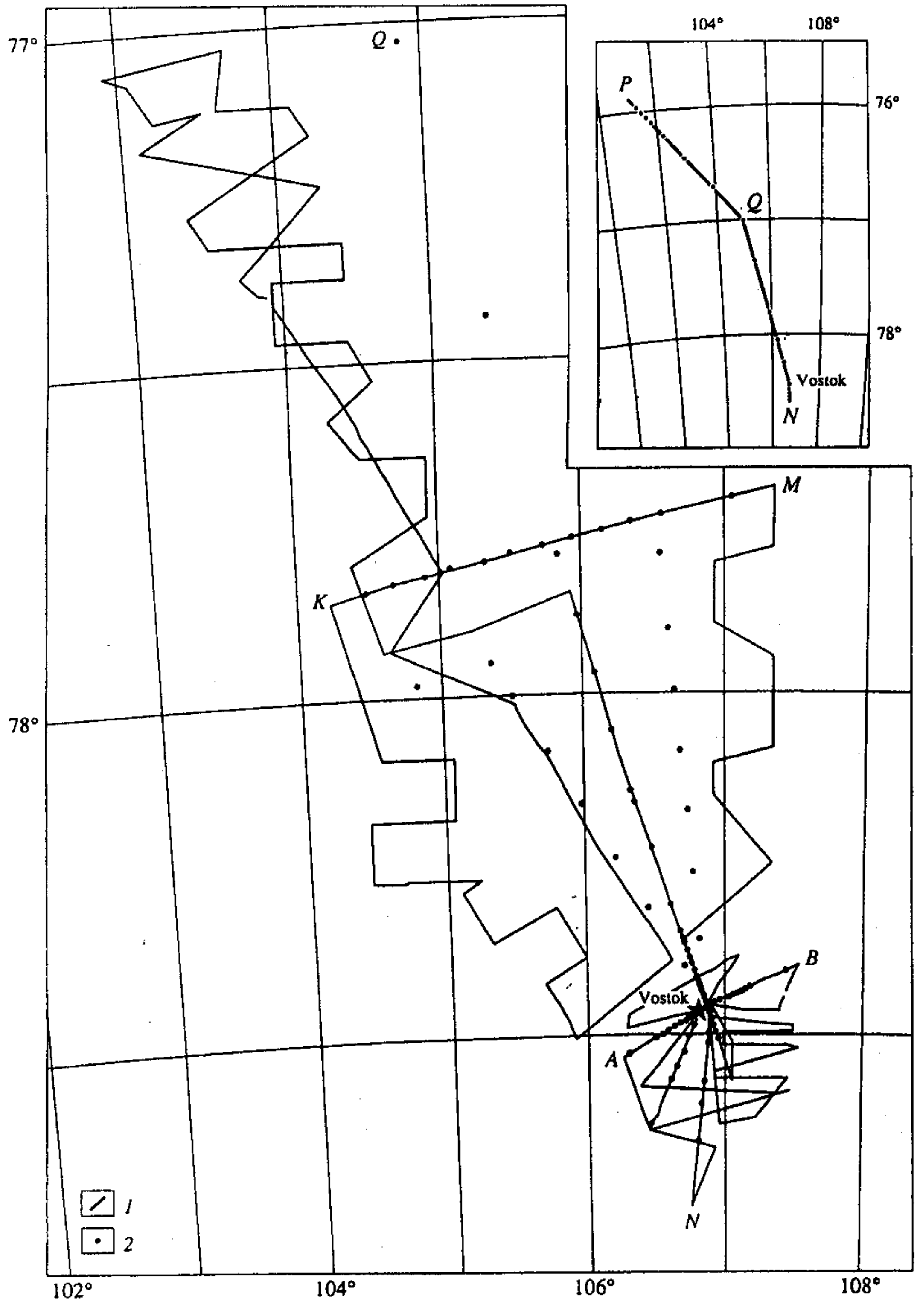


**Fig. 2.** Layout of radar sounding profiles and points of seismic sounding. (*1*) Location of radar sounding profiles; (*2*) location of seismic sounding points.

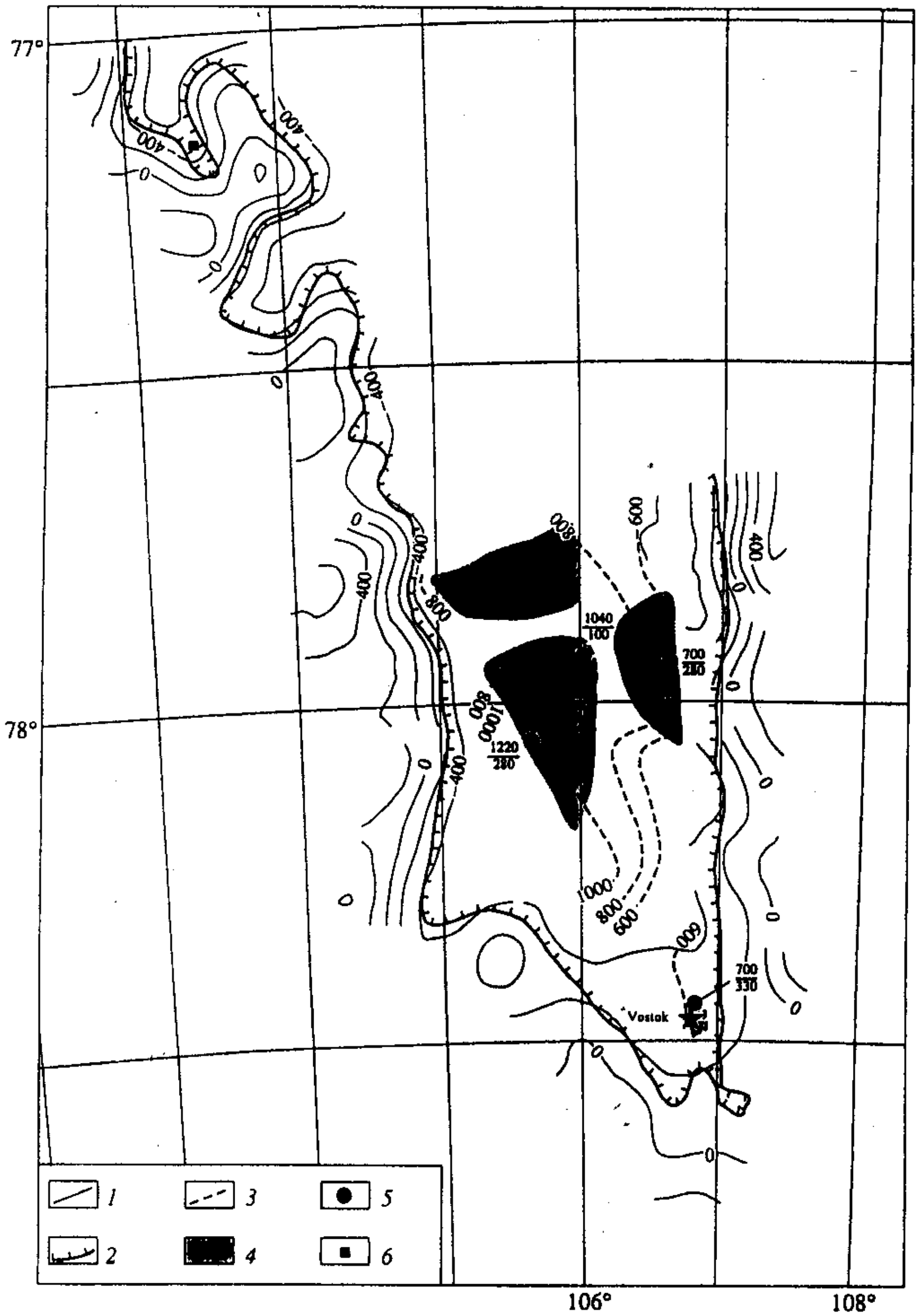


**Fig. 3.** Ice base map. (*1*) Ice base contours (200-m isohypses); (2) boundary of the Vostok glacier lake; (*3*) contours of the water layer thickness; (*4*) areas dominated by more than 100-m-thick sediments; (*5*) points of seismic sounding and the thickness of the water layer (numerator) and sediments (denominator); (*6*) maximal registered glacier thickness (4350 m).

Station, which runs deep and inland for nearly 10 km. A series of bays and capes is registered at a distance of 170 km from the station. The southernmost 10-km-wide cape extends along longitude 104°20′ E into the lake for 15 km. A rounded bay running inland for about 20 km is registered on the northern side. Further northward, a L-shaped peninsula, approximately 30 × 15 km in size, is located. Two small bays and a cape jutting out into the lake for 6 km are located on the southern shore. The shoreline configuration based on data of radar

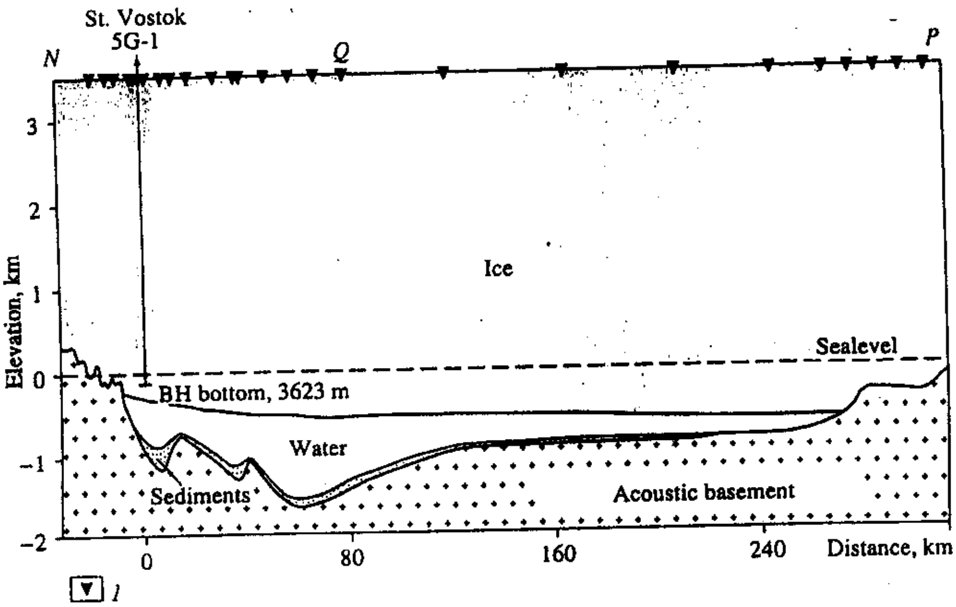


**Fig. 4.** Composite geophysical section along the long axis of the Lake Vostok. (1) Points of sounding.

sounding and satellite altimetry exhibits only an arbitrary and approximate coincidence. Therefore, further mapping is needed for refining the shoreline.

The investigations show the maximum registered thickness of the water layer to be 1200 m. It is 680 m near Vostok Station (Figs. 3, 4). In the northern part of the lake, the water layer is sharply reduced at 77° S and then gradually pinches out northward. The thickness of sediments (assuming the velocity of seismic wave propagation to be 2.5 km/s) makes up about 100 m, reaching 330 m near the station (Figs. 3, 4).

The revealed parameters of Lake Vostok indicate that this natural body has a complicated structure. The data make it possible to understand its geological origin and choose the most favorable sites for penetrating into the lake. We believe the Vostok Station (BH 5G-1) can be such a site where the ice sheet is not very thick but the watermass and bottom sediments are substantial. Moreover, there is a well-developed logistic infrastructure at the station for carrying out various investigations.

## REFERENCES


1. Bogorodskii, V.V. and Fedorov, B.A., *Inf. Byul. Sov. Antarkt. Eksped.*, 1967, no. 65, pp. 105–114.
2. Bogorodskii, V.V. and Sheremetiev, A.N., *Priroda*, 1981, no. 12, pp. 49–51.
3. Kapitsa, A.P. and Sorokhtin, O.G., *Inf. Byul. Sov. Antarkt. Eksped.*, 1965, no. 51, pp. 19–23.
4. Kotlyakov, V.M., *Nauka, obshchestvo, okruzhayushchaya sreda* (Science, Society, and Environment), Moscow: Nauka, 1997, pp. 282–286.
5. Lukin, V.V., Masolov, V.N., Mironov, A.V., *et al.*, *Probl. Arkt. Antarkt.*, 2000, no 72, pp. 237–248.
6. Popkov, A.M., Verkulich, S.R., Masolov, V.N., *et al.*, *Materialy Glyatsiol. Issled.*, 1999, no. 86, pp. 152–159.
7. Popov, S.V., Mironov, A.N., and Sheremetiev, A.N., *Materialy Glyatsiol. Issled.*, 2001, no. 89.
8. Popov, S.V., Mironov, A.N., Sheremetiev, A.N., *et al.*, *Materialy Glyatsiol. Issled.*, 2001, no. 90.
9. Sheremetiev, A.N., *Tr. Sov. Antarkt. Eksped.*, 1986, vol. 78, pp. 127–132.
10. Carsey, F., Cutts, J., and Horvath, J., *Lake Vostok Study: Scientific Objectives and Technological Requirements. Int. Workshop*, St. Petersburg: Arctic and Antarct. Res. Inst., 1998, vol. 70.
11. Kapitsa, A.P., Ridley, J.K., Robin, G.De.Q., *et al.*, *Nature*, 1996, vol. 381, pp. 684–686.
12. Masolov, V.N., Kudryavtzev, G.A., Sheremetiev, A.N., *et al.*, *SCAR Int. Workshop on Subglacial Lake Exploration*, Cambridge, 1999.
13. Oswald, G.K.A. and Robin, G.De.Q., *Nature*, 1973, vol. 245, pp. 251–254.
14. Ridley, J.K., Cudlip, W., and Laxon, W., *J. Glac.*, 1993, vol. 39, no. 133, pp. 625–634.
15. Siegert, M.J., Dowdeswell, J.A., Gorman, M.R., *et al.*, *Antarctic Sci.*, 1996, vol. 8, no. 3, pp. 281–286.