Russian Geophysical Studies of Lake Vostok, Central East Antarctica

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Abstract. Since 1995, Polar Marine Geological Research Expedition has performed the geophysical investigations of Lake Vostok, Central East Antarctica. The study of this phenomenon is carried out by means of radio-echo sounding (RES) and reflection seismic. In total, 3 250 km of RES profiles and 194 seismic measurements have been made. These scientific works resulted in mapping the ice thickness, bedrock and sub-ice topography and the Lake Vostok shoreline. We fixed 195 fragments of grounding line, according to RES data, with 169 of them (86%) being reliable while 26 (14%) are questionable. These results are the base for contouring the lake shore. The water table square estimates at some 17 100 km^2. We also detected 22 small-size subglacial water cavities around the Lake Vostok. Sub-ice topography of the Lake Vostok bottom is divided into two main regions: the deep-water and shallow-water basins. The first one with depths from about −1 700 to −800 m is located in the southern part of the lake. We assume its northern part to be shallow-water with the bottom depth of about −940 m.

Introduction

Satellite altimetry (Ridley et al. 1993) revealed a large subglacial lake (named *Lake Vostok*) located northwest from the Russian station Vostok. Geophysical exploration of this phenomenon is important for fundamental scientific and practical problems. Geophysical investigations of the area were started in the middle of the last century. A number of Russian seismic reflections and British radio-echo soundings were carried out in the 1950s to 1970s (Oswald and Robin 1973; Kapitsa et al. 1996). In 1999 Italians produced the airborne geophysical observations to determine the ice thickness, bedrock topography, the lake shape, the amplitude of the bottom reflections and other characteristics (Tabacco et al. 2002). In 2000 Americans carried out the geophysical survey, which completely covered of the lake area (Studinger et al. 2003).

Polar Marine Geological Research Expedition (PMGRE) in framework of the Russian Antarctic Expedition (RAE) initiated and executed a new scientific project dedicated to the study of sub-glacial Lake Vostok region (Masolov et al. 1999, 2001; Popov et al. 2001). The objective of the first phase of this program was to develop the radio-echo sounding and reflection seismic equipment and methods to study the area as a geographical object: the lake geometry and morphology; ice thickness and the lake depth; velocities of the electromagnetic wave propagation in ice and acoustic waves in the Lake Vostok area. The second phase of the Lake Vostok project started in 2002. Its goal is to study Lake Vostok as a geological object: determination of its geological structure and evolution; mapping of ice thickness, bed relief and bathymetry of the Lake Vostok area as well as of its geomorphological features to better understand its nature and evolution.

Data Acquisition

Since 1998, 60-MHz ice radar with repetition frequency of 600 Hz, pulse length of 0.5 μs, pulse power of 60 kW, dynamical range of 180 dB and band of the reception channel of 3 MHz has been used for ice thickness measurements. The reflected signals are digitized by analog-digital transformation device with a sample interval of 50 ns and stacking rate of 256 traces and then registered on PC. The transformer has been developed based on the 12-bit analog-digital converter AD9042AST (Analog Devices Inc.) with SBC-8259 processor (Axiom Technology Co) (Popov et al. 2001, 2003). In total, 3 250 km of the RES data have been collected (Fig. 3.5-1). The first profiles followed the preliminary boundary of Lake Vostok defined by Siegert and Ridley (1998). However, the location of survey profiles was changed during the field work, which allowed us to investigate the lake boundary more effectively.

Reflection seismic investigations began in 1995. Between 1995 and 2002 we obtained 194 seismic measurements to estimate the water depth of the Lake Vostok. During the period of 1995–1999 the Russian seismic station SMOV-0-24 with the analogue registration on the magnetic tape was used. It had 24 channels, recording of 6 and 12 s, noise of the channel of 0.3 μV, cross-talk higher than −36 dB, frequency range of the recording of 10–200 Hz and dynamical range of 80 dB. The acoustic wave registration is performed by the geophone SV-20 with oscillation frequency 20 Hz fixed on the surface and covered by the snow. Starting from the year 2000 we use a digital station with the same technical characteristics. The seismic profiles are located along and across the lake with a dense shot spacing near Vostok Station (Fig. 3.5-1).

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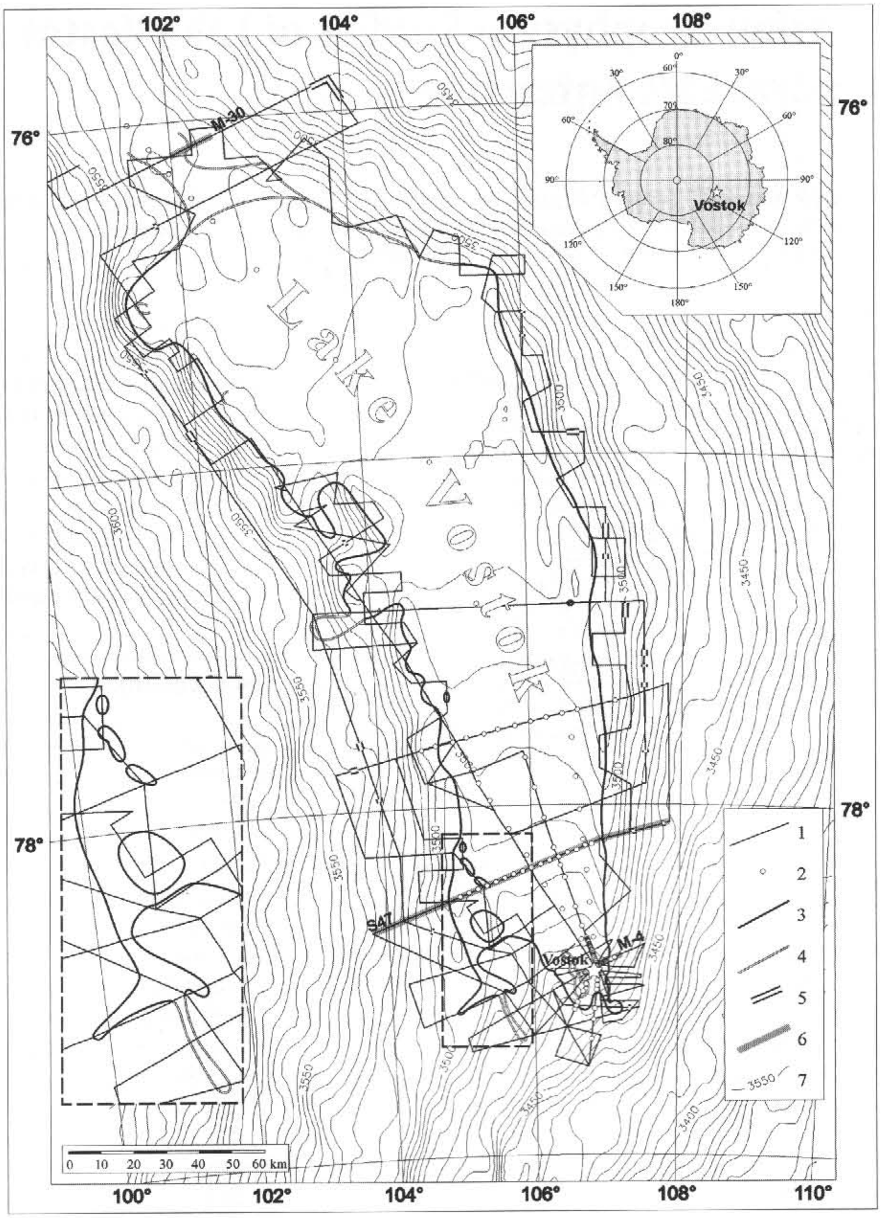

Fig. 3.5-1.
Location map with surface elevation contours. *1:* Russian RES profiles of 1998–2004; *2:* Russian reflection seismic points of 1995–2002; *3:* reliable Lake Vostok boundary; *4:* boundary questionable; *5:* fragments of water cavities; *6:* sections shown in Fig. 3.5-2 and 3.5-3; *7:* surface elevation contours with 5 m spacing

During the first phase we optimized the generation of the seismic waves using detonating cord positioned on the snow surface in contrast to explosive charge put in boreholes, as was practiced before (Popkov et al. 1999). In order to increase the accuracy, we measured the propagation velocities of both seismic and electromagnetic waves. We used the vertical seismic profiling in the 5G-1 borehole located at the Russian station Vostok. Acoustic velocities in ice and water are 3 920 and 1 490 m s^{-1}, respectively. The average velocity within the section (with the snow-firn layer) is 3 810 m s^{-1}. Based on reflection seismic measurements in the borehole we estimated the distance between the borehole bottom (3 623 m) and the water table to be 130 m (Masolov et al. 1999, 2001; Popkov et al. 1999). The velocity of electromagnetic waves in ice, including a snow-firn correction, estimated using a wide angle reflection technique, is 168.4 ±0.5 m μs^{-1} (Popov et al. 2003).

The most typical and interesting profile is the S47 profile across the Lake Vostok (Fig. 3.5-1). The RES and seismic records and the ice sheet section are shown in Fig. 3.5-2. The profile crossed the small island located in south-west part of the lake. It is nicely seen both in the RES (Fig. 3.5-2a) and the seismic records (Fig. 3.5-2b). The lake bottom is flat with about −600 m and −1 300 m height in the western and central parts respectively. The central part is complicated by sub-water valley 400 m deep as shown in Fig. 3.5-2c.

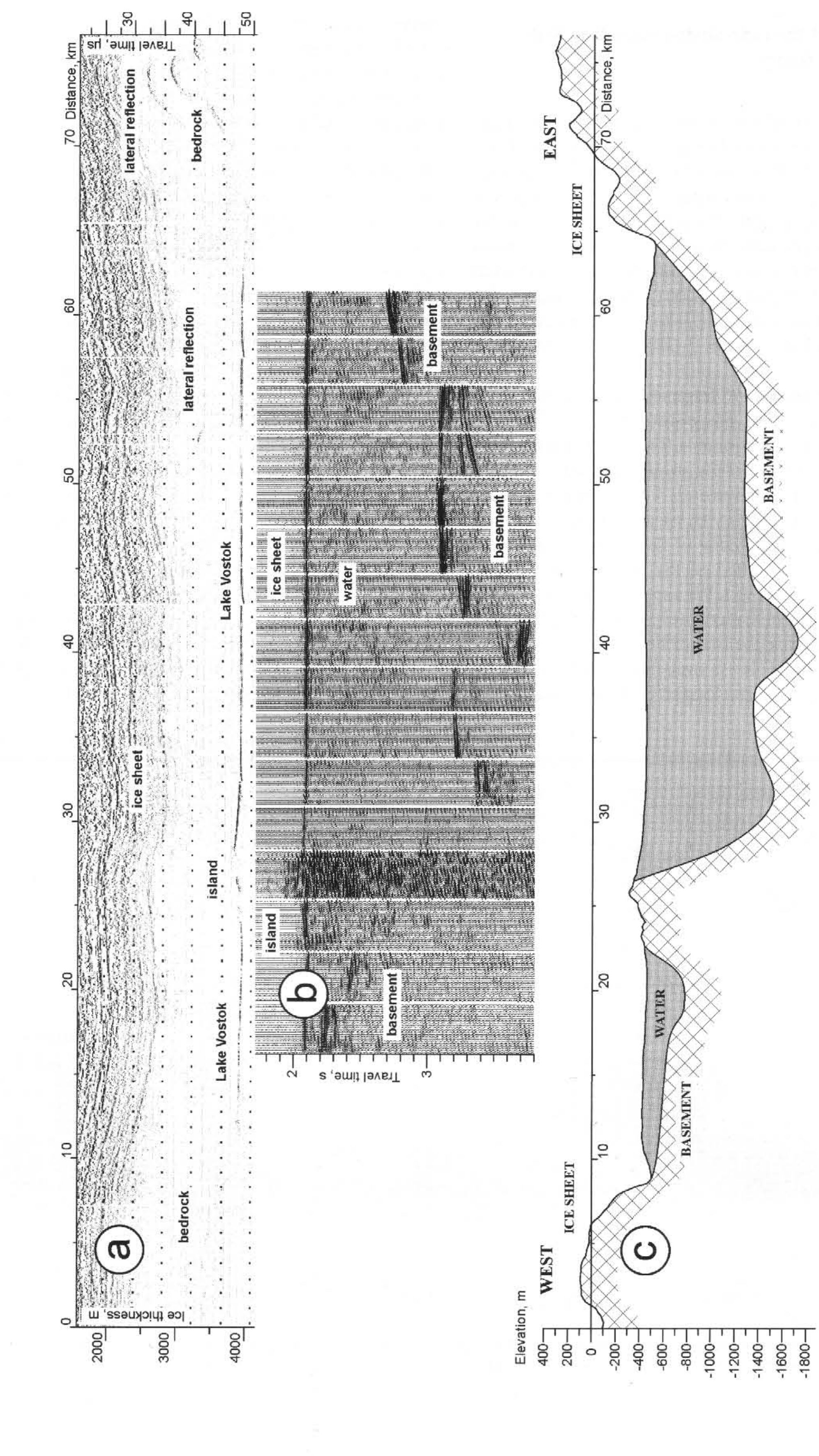

Fig. 3.5-2. Radio-echo (**a**) and seismic (**b**) time sections and interpeted section (**c**) of Lake Vostok and the ice sheet along S47 profile. For location see Fig. 3.5-1

The Features of the Lake Vostok Boundary and Bedrock Topography

One of the main results of the first stage of our investigations was the Lake Vostok boundary charting. Two techniques were used. We analyzed radio-echo sounding reflections from the ice base and morphological features of the subglacial topography. The reflections from ice-water and ice-bedrock are quite different: flat and intensive from the lake water table and weak from the bedrock (Oswald and Robin 1973; Popov et al. 2001). Abrupt slopes, as a rule, mark the boundary of the lake, thus indicating a tectonic nature of Lake Vostok (Masolov et al. 1999, 2001; Popov et al. 2001).

In total we detected 195 fragments of grounding line, according to RES data. 169 points (86%) are reliable while 26 (14%) are questionable. The RES records with a sample of the both types of the grounded zones are shown in Fig. 3.5-3. The points were used to construct a shoreline of Lake Vostok (Fig. 3.5-1). We also identified several islands inside the lake. Some of them are situated near Vostok Station and located on the ice flow line passing through the borehole 5G-1. We suppose that the mineral inclusions detected in the ice core (Jouzel et al. 1999) have been originated from the islands bedrock.

Lake Vostok shore line is oval-shaped complicated by capes, bays and peninsulas located in the west and south. Interestingly, the eastern, northern and northwestern parts of the lake boundary are relatively rectilinear. This suggests the presence of the deep faults along this shoreline that is confirmed by American airborne geophysical data (Studinger et al. 2003). The lake covers about 17 100 km^2.

The northern part of the shoreline of Lake Vostok is still not defined completely. Hypothetically, it could be continued to the north, but most likely the lake is limited as shown in Fig. 3.5-1. The exploration of the northern border of the Lake Vostok will be completed by means of the RES in the nearest future.

Some 30 km to the south-west from Vostok Station three fragments of the water cavities were detected (see the inset in Fig. 3.5-1). The fragments fall in line crossing all the three quasi-parallel RES profiles, where they are observed. The northern fragment joins to the Lake Vostok. The ice base elevations of the mentioned fragments are −270, −116 and +175 m a.s.l. respectively. We assume these water cavities are an appendix of the Lake Vostok (for example, narrow estuary or river). Data to confirm or reject this assumption will be collected during the coming field seasons.

Twenty-two small sized subglacial water cavities with a typical size close to ten kilometers were observed around the Lake Vostok (Fig. 3.5-1). Their elevations range between sea level and +800 m for those located in the east and between −300 and +300 m for the cavities located in the west. An isolated subglacial lake on the cross RES

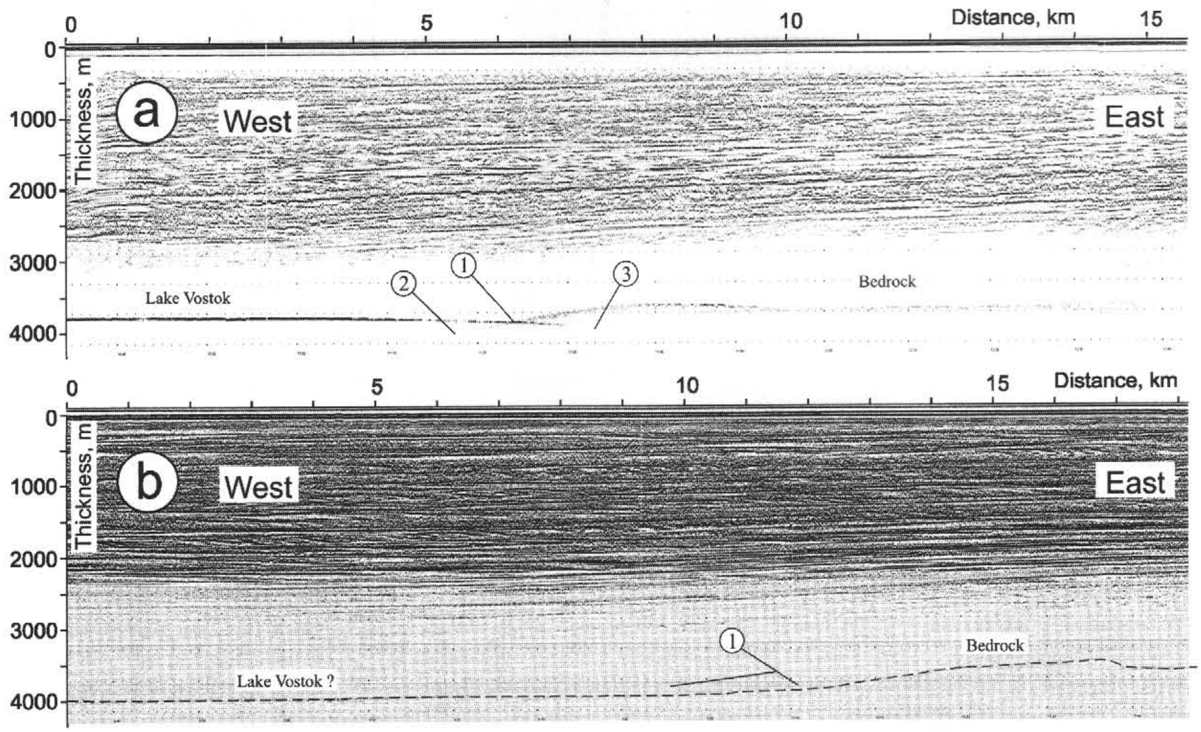

Fig. 3.5-3. RES records with reliable (**a**) and assumed (**b**) grounding zones. *1:* Position of the grounding line; hyperbolic reflections from the lake slope (*2*) and from the Lake Vostok water table (*3*). For location see Fig. 3.5-1; **a** along route M-4; **b** along route M-30

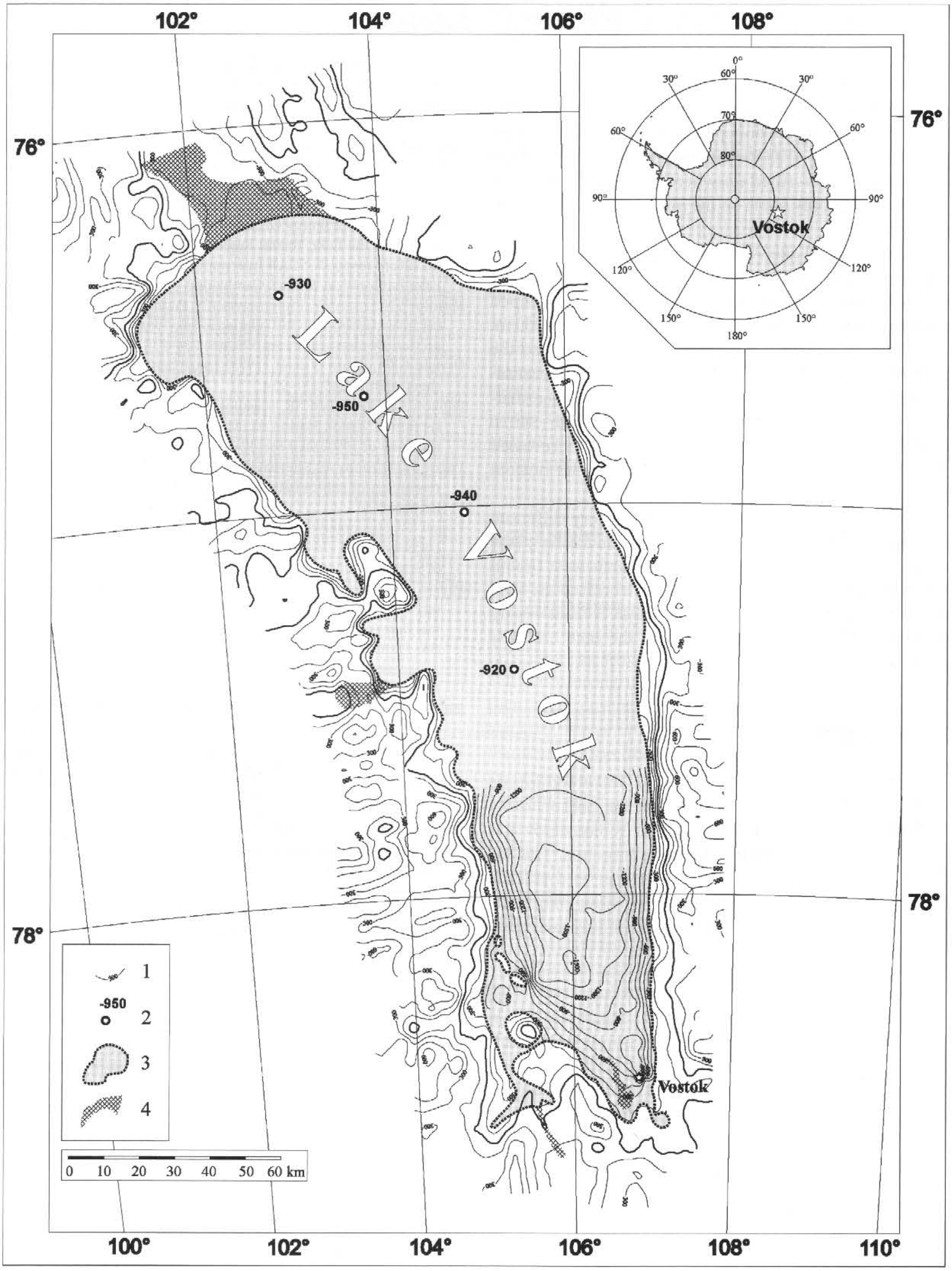

Fig. 3.5-4. Bedrock topography map. *1:* bedrock topography contours with 150 m spacing (*thick line* is the sea level); *2:* reflection seismic measurements with the bedrock elevation; *3:* reliable Lake Vostok water table; *4:* assumed water table

routes is detected to the north-east from the Lake Vostok. The lengths of the fragments of this lake are about 10 km (Fig. 3.5-1).

We used RES and ground reflection seismic data to draw ice thickness, lake depth and bedrock topography maps. In this paper we only present the bedrock topography map (Fig. 3.5-4) as the most interesting. The bedrock morphology is described elsewhere in this volume (Popov et al. 2006). We only focus on the main aspects of the bedrock relief.

Generally, the Lake Vostok bottom is divided into two regions: the deep-water and shallow-water basins. The first one is located in the southern part. It has pear-shaped configuration with depths from about –1 700 to –800 m. The lake depth under the Vostok Station is 680 m and the bottom is about –960 m. Based on four seismic measurements we assume the northern part of the lake is a shallow-water pool with the bottom height of about –940 m (Fig. 3.5-4). The next shallow-water basin was revealed 30 km to the west from the Vostok Station. Its bottom height is about –600 m.

The bedrock relief outside the lake is very different. In general, it is divided into mountain and hilly plane areas. The first one is situated in the north-west (about 800 m in height) and in the central part both to the west and east from the Lake Vostok. Its height is from 400 up to 1 100 m. Other territories around the lake are hilly planes.

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