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Recent Russian remote sensing investigations in Antarctica within the framework of scientific traverses

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Abstract This paper includes a short historical review of Russian and Soviet scientific traverses to study the Antarctic inland. The first traverse left on April 2, 1956. It resulted in the opening of the first Russian inland research station named Pionerskaya and provided the first geophysical and glaciological data on regions inland of the Antarctic coast. By 1965, a number of regional inland scientific traverses had been completed and the first Atlas of Antarctica was published in 1966. The atlas presented the main achievements of that time. After the discovery of Lake Vostok, Russian scientists commenced remote sensing investigations to study this unique natural phenomenon. The propagation of acoustic and electromagnetic waves in the glacier near Vostok Station were measured to provide important geophysical data. Radio-echo sounding data showed that Lake Vostok is isolated and separated from the rest of the Antarctic subglacial hydrosphere. The total area of the lake is 15 790 km^2, excluding 365 km^2 occupied by 11 islands. Reflection seismic soundings of Lake Vostok estimated a total volume of about 6 100 km^3, an average depth of about 400 m, and a maximum depth of 1 200 m. Since 2008, there have been a number of scientific traverses between Mirny and Vostok stations and between Progress and Vostok stations. The data collected during the traverses have provided new insights into sub-ice topography and ice sheet structure, and have led to the discovery of subglacial lakes near Komsomolskaya Station and under Pionerskaya Station.

Keywords **Russian scientific traverses, Lake Vostok, Antarctica, remote sensing, radio-echo sounding, seismic**

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1 Preface: retrospective view to the first traverses

For many centuries, the geographers of the antiquity and the Middle Ages assumed that an uncharted continent lay to the south of the known world. That continent was named Terra Incognita. On the map of Claudius Ptolemaeus (c. 90–168 AD), one of the greatest scientists of ancient Greece, this land mass extended as far south as the latitude of the African Great Lakes[1]. As years passed, the Age of Discovery pushed the boundary of the unknown continent farther and farther south. In 1773, the expedition of James Cook crossed the Antarctic Circle for the first time and casted doubt on the very existence of the Southern Land[2]. It was not until January 27 (January 15 on the Julian calendar), 1820 that Antarctica was first seen by human eyes[3-4]. On that auspicious day two Russian ships, *Vostok* captained by Faddey Bellingshausen, and *Mirny* captained by Mikhail Lazarev, came very close to the new continent. The ships approached the Bellingshausen Ice Shelf on the Princess Martha Coast[4], but sea ice blocked their progress beyond 69°21′28″S, 2°14′50″W.

The current phase of Russian Antarctic research started on November 30, 1955 when the ship *Ob* left Kaliningrad for Antarctica. It was the first vessel of the First Complex Antarctic Expedition. The leader of the expedition was Mikhail Somov. On January 5, 1956 the ship reached Antarctica, and about a month later, on February 13, 1956, the Soviet Union state flag flew over the construction site of the first Soviet Antarctic station, Mirny. The station was named in honor of one of the first Russian ships to enter Antarctic waters[4-5]. Since that time Soviet, and later Russian, scientists have continuously studied the icy continent.

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The logistics and the scientific activities during the first decade fundamentally impacted the future Soviet, and later Russian, scientific research. Keystone stations and field bases were established at that time. They provided the foundation for geophysical, geological, and glaciological studies, and some of the stations are still operational today.

The primary goal of the initial expeditions was the opening of Mirny Station along with three more stations located at two Antarctic poles: Vostok Station at the Geomagnetic Pole and Sovetskaya and Pole of Inaccessibility stations in the vicinity of the Pole of Inaccessibility. After preparatory work and reconnaissance flights, on April 2, 1956 the first Soviet traverse, led by Mikhail Somov, left Mirny for the inland (Figure 1a). This traverse (and most of the later traverses) combined logistics with basic scientific research. The vehicles stopped on May 4, 1956 having crossed about 400 km of the snowy and windy desert of the Antarctic plateau. Three weeks later, on May 27, 1956, the first Soviet inland Antarctic station Pionerskaya was opened[5]. Although providing logistics solutions was the main objective of the expedition, the implementation of the research program was also given high priority because ultimately, the primary goal of Antarctic expeditions is fundamental scientific research. Meteorological, glaciological, and geophysical studies were implemented during the traverse. Andrey Kapitsa performed 11 reflection seismic soundings between Mirny and Pionerskaya stations. He used analogue output seismographs with 24 channels[5]. Those surveys initiated Russian studies of the Antarctic bedrock and subglacial morphology. This first inland traverse during the austral autumn provided the pioneering scientists and logisticians with important experience for future projects.

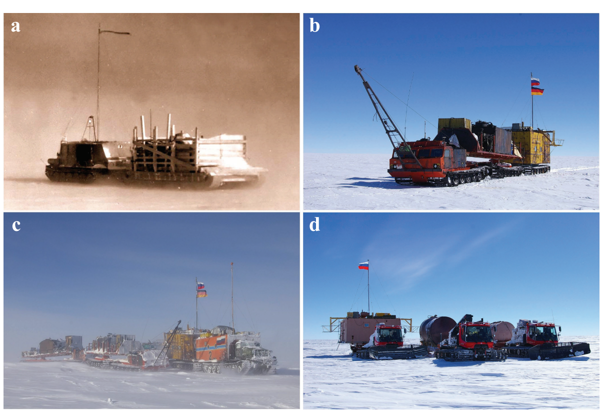

Figure 1 Russian Cariers used in Antarctic traverse expeditions. **a**, Tractor “Pinguin”, the participant of the first Soviet Antarctic Expedition (from AARI archives); **b**, Mobile geophysical laboratory “Vityaz” (photo by S. Popov); **c**, Traverse returning to Mirny Station from Vostok Station (photo by S. Popov); **d**, Scientific traverse from Progress Station to Vostok Station (photo by S. Popov). 118 mm×78 mm (300×300 DPI).

The goal of the Second Complex Antarctic Expedition was the opening of new inland stations and commencement of the expansive scientific investigations within the framework of the International Geophysical Year. The leader of the continental part of the expedition was Alexey Treshnikov. Three more stations were opened: Vostok-1 on April 12, 1957; Komsomolskaya on November 6, 1957; and Vostok on December 16, 1957. Vostok-1 Station was initially set up as a stopover station on the route to the Geomagnetic Pole, to provide shelter from the harsh weather conditions in the Antarctic inland during the winter. At the end of the austral spring, the logistic traverse moved Vostok-1 Station to its target location (the Geomagnetic Pole) and it was renamed Vostok Station. However, for more than 50 years the original location of Vostok-1 continued to serve as a site for short recovery stopovers during logistic traverses supplying Vostok from Mirny. A number of scientific programs were performed during the traverse to move Vostok-1 Station to the Geomagnetic Pole[4,6-7].

In retrospect, it is interesting to note that Vostok Station was fortuitously located. If that historical traverse had moved only 10 km farther, or had stopped 90 km earlier, the station would have been built beside the lake rather than over the lake. The borehole drilling performed by Russian scientists would have hit the lakeshore and Lake Vostok may not have been discovered for many years.

The leader of the next Antarctic Expedition was Yevgeny Tolstikov. The main logistic achievement of the Third Antarctic Expedition was establishing the stations in the vicinity of the Pole of Inaccessibility. Sovetskaya Station was opened on February 16, 1958 and Pole of Inaccessibility Station on December 14, 1958[8-9]. The former was intended as an intermediate stopover location. The most important scientific achievement of that expedition was the discovery of the Gamburtsev Subglacial Mountains[8]. This geological discovery was of utmost importance and key to understanding the structure and evolution of East Antarctica and the Antarctic continent as a whole. Further data on the Gamburtsev Subglacial Mountains were not collected until 30 years later, when regional geophysical flights from the Russian Molodezhnaya Station to the American McMurdo Station commenced in 1987. Two years later, this area became the subject of a regional-scale airborne geophysical survey[10]. The location chart is shown in Figure 2.

Another 20 years passed before researchers returned to this area. The first decade of the new century was marked by the first detailed radio-echo sounding (RES) survey of the Gamburtsev Subglacial Mountains by Chinese scientists in 2004/05 and 2007/08[11]. On January 27, 2009 the remarkable station Kunlun was established on the top of Argus Dome (Dome A), the highest ice feature in Antarctica and thought to be the coldest place on Earth. The establishment of Kunlun required a large amount of preparatory work and a number of traverses to the Antarctic inland[12]. The next major project was the airborne geophysical survey over the Gamburtsev Subglacial Mountains (2008/09) within the framework of the international project AGAP (Antarctica’s Gamburtsev Province). Without doubt, the data collected advanced the understanding of the structure of this vast region and East Antarctica as a whole.

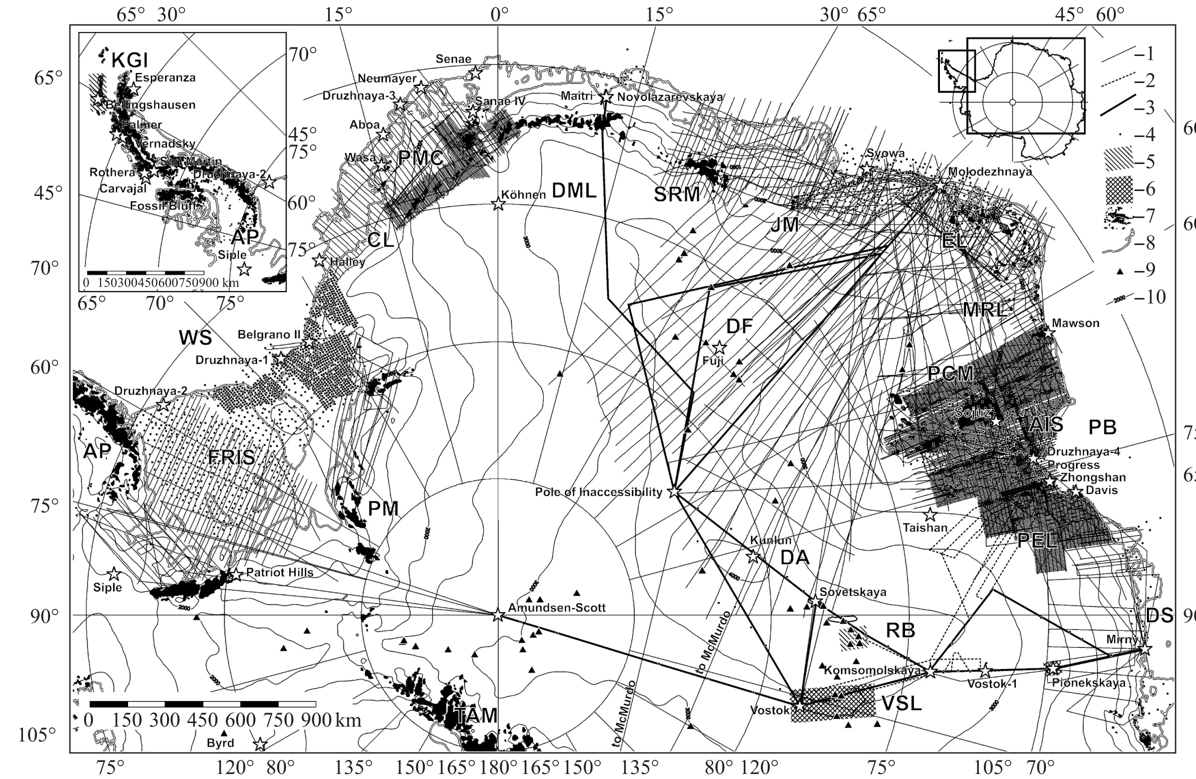

Figure 2 Russian remote sensing investigations in Antarctica. **1**, Airborne RES profiles; **2**, Ground-based RES profiles; **3**, Reflection seismic and gravimetric profiles; **4**, Reflection seismic soundings; **5**, Regions of detailed ground-based RES investigations; **6**, Regions of detailed ground-based RES and reflection seismic investigations; **7**, Outcrops on reference [59]; **8**, Ice front and grounding line on references [59]; **9**, Subglacial lakes on references [25, 47]; **10**, Ice surface elevation on reference [60]. Contour space is 500 m. 266 mm×408 mm (300×300 DPI).

At this point, let's turn our focus back to the late 1950s. The three early Antarctic Expeditions mentioned above were of utmost importance. Those expeditions initiated the Soviet, and later Russian, Antarctic pursuits and laid the foundation for all future research. The first three Russian expeditions achieved incredible success, even from today's perspective. Not only was a network of inland stations established and a number of incredibly complex transport operations carried out, but also the methodology and procedures for future fieldwork in inland Antarctica were developed. These principles are still being used today. Regular traverses are carried out to supply the inland research stations. Three more scientific stations were opened during the four years after the third Antarctic Expedition (Lazarev Station on March 10, 1959; Novolazarevskaya Station on January 18, 1961; and Molodezhnaya Station on February 23, 1962). By 1965, a number of regional scientific traverses had been carried out, with the main focus on the structure of the East Antarctic inland. The most challenging traverse was led by Andrey Kapitsa and ran between Vostok and Molodezhnaya stations via Pole of Inaccessibility Station (Figure 2). It lasted 78 d from January 3 to March 21, 1965 and covered 3 300 km[13-14]. Meteorological, glaciological, and geophysical data were collected along the route. Analogue output seismographs with 24 channels were used to collect reflection seismic data. The first Atlas of Antarctica[15] was published in 1969 and is well known and respected in the scientific community. It reflected the knowledge about Antarctica amassed by Russian scientists at that time.

Up to 1965, the main body of Soviet scientific research was conducted along the routes between Mirny Station and the South Pole via Vostok Station, between Mirny and Pole of Inaccessibility stations via Komsomolskaya Station, and between Vostok and Molodezhnaya stations via Pole of Inaccessibility Station. The data collected along these routes compiled with input from expeditions organized by other countries provided the initial insights into the ice thickness and the structure of the bedrock of Antarctica. Later, the data gathered by the first 10 Soviet expeditions were used to provide exclusive information about this vast area of the Antarctic inland as part of the important international project BEDMAP, which aimed to produce complete maps of the ice sheet and topography of the bedrock of Antarctica[16-17]. The results of the BEDMAP project formed the basis of the comprehensive interpretation charts the Tectonic map of Antarctica[18] and the first Geomorphological Atlas of Antarctica[19].

Within that first decade of exploration, in January 1964, an ice radar designed by the Russian Arctic and Antarctic Research Institute (AARI) was tested in Antarctica for the first time. It was an RLS-100 pulse radar with analogue registration. The main frequency was 100 MHz, the following frequency was 100 kHz, the pulse power was 7 W, and the pulse width was 0.3 μs[20]. Since that time, the RES technique has become the most effective geophysical method to study ice sheet structure and sub-ice relief. It has been used by Russian researchers, not only in Antarctica but also in the Arctic and on mountain glaciers.

The next series of RES investigations was performed from 1978 to 1984 between Mirny and Vostok stations and towards Ridge B, Denman Glacier, and Dome Concordia, under the leadership of A.N. Sheremetiev. These missions identified a number of subglacial water caves in the Ridge B area[20-21]. In addition, RES was used to measure the ice flow velocity in the area at about 1 $m \cdot s^{-1}$[22]. Wide-angle reflections were performed to measure the velocity of radio-wave propagation in Ridge B at 165.9 ± 2.3 $m \cdot \mu s^{-1}$[23]. These investigations improved the calculation of the ice thickness based on the RES data. An RLS-60-74 pulse radar with analogue registration was used. The main frequency was 60 MHz, the following frequency was 0.4–2.0 kHz, the pulse power was 1–60 kW, and the pulse width was 0.3–1 μs[22].

2 Recent ground-based remote sensing investigations in the Lake Vostok area

Lake Vostok, about 300 km long and 60 km wide and covered by 4 km of ice, is one of the most incredible geological structures on Earth. To date, more than 400 subglacial lakes have been discovered in the Arctic and the Antarctic[24-28], but Lake Vostok remains the largest. The ice temperature in glaciers increases with depth and some of the subglacial lakes in Antarctica could have been formed because the thickness of the covering ice exceeds the limiting thickness. As glaciers become thicker, there is a point at which bottom melting occurs. This process is well described by Robin[29] and Zotikov[30-31]. Some of the lakes could have been formed by neotectonic processes, with local amplification of the heat flux in the area of deep crevasses in the Earth's crust. Lake Vostok is situated along a rift zone, which was confirmed by airborne geophysical surveys[32-33], seismological observations[34], and geomorphological deductions[35-36].

The existence of a large body of water in the area of Vostok Station was first proposed based on the analysis of airborne RES data[37]. However, the data was not investigated further for 20 a. It was only after a satellite altimetry survey by European Remote Sensing Satellite-1 (ERS-1)[38] that scientists reviewed the old data. The old and new data supported the presence of a vast body of water located under the ice to the northwest of Vostok Station[39]. Extensive historical reviews can be found in Zotikov[30] and Siegert et al.[40]

Just after the discovery of Lake Vostok, the Polar Marine Geosurvey Expedition (PMGE) together with the Russian Antarctic Expedition (RAE) commenced a remote sensing survey to study this natural phenomenon. The mobile scientific laboratory Vityaz (Figure 1b) was established for these investigations. From 1995 to 2008, reflection seismic data were collected to measure the depth of the lake. A total of 318 measurements were carried out[41-42]. A Russian 24-channel SMOV-0-24 seismograph with analogue registration was used from 1995 to 1999. The range of the reflection seismic data acquisition recording was 6 s and 12 s, the noise of the channel was 0.3 pV, the cross-talk was higher than −36 dB, the frequency range of the recording was 10–200 Hz, and the dynamical range was 80 dB. The acoustic wave registration was performed using a Russian SV-20 geophone with an oscillation frequency of 20 Hz, fixed on the surface and covered by the snow. Since 2000, digital seismographs with the same technical specifications have been used[43].

Between 1998 and 2008, RES investigations were carried out to study bedrock topography and the structure of the ice sheet. The total length of the RES profiles of Lake Vostok is about 5 190 km[44-47]. Since 1998, a 60-MHz RLS-60-98 ice radar with a repetition frequency of 600 Hz, a pulse length of 0.5 μs, a pulse power of 60 kW, a dynamical range of 180 dB, and a 3 MHz reception channel, has been used for ice thickness measurements. The reflected signals are digitized using an analog-digital transformation device (ADC) with a sample interval of 50 ns and a stacking rate of 256 traces[42-44]. Since 2008, a new RLS-60-06 ice radar with the same technical specification but increased power of up to 80 kW and an ADC with a 25 ns sample interval has been used[42].

American researchers have made an important contribution to the study of Lake Vostok. During the 2000/01 austral summer field season, American scientists conducted an airborne geophysical survey including RES. In total, the flights covered 12 465 km[32]. In the previous year, Italian scientists carried out an airborne geophysical survey and produced a number of geophysical profiles[48]. The areas of the Russian and U.S. geophysical investigations are shown in Figure 3a.

Two major challenges were faced in the geophysical investigations of the Lake Vostok area. The first was to accurately measure ice thickness in the vicinity of the 5G drilling site. This was crucial to penetrating the lake without incident. The second challenge was to improve RES and reflection seismic data acquisition. To address these challenges it was necessary to measure the velocity of acoustic and electromagnetic wave propagation in the local glacier, because only general estimates of these values were available at that time. Vertical seismic profiling and wide-angle reflections were performed and acoustic velocities in meteoric ice and water were measured as 3 920 ± 20 $m \cdot s^{-1}$ and 1 490 $m \cdot s^{-1}$, respectively. The average acoustic velocity in the glacier was measured as 3 810 ± 20 $m \cdot s^{-1}$ [45], and the average velocity of the electromagnetic wave propagation in the glacier was 168.4 ± 0.5 $m \cdot \mu s^{-1}$ [46]. Ice thickness in the drilling site vicinity was predicted to be 3 760 ± 30 m based on the seismic data, and 3 775 ± 15 m based on RES data[46]. During the penetration of Lake Vostok on February 5, 2012, the total ice core length was 3 769.3 ± 0.5 m and the ice thickness was 3 759 ± 3 m (V. Lipenkov, 2014; personal communication). Therefore, the reflection seismic data was extremely accurate. However, the RES data was less accurate than expected, and the reason for this requires further investigation.

Following the completion of the reflection seismic and RES studies, Russian and U.S.[32] remote sensing data collected in the Lake Vostok area were compiled. The data were used to map the ice thickness, the ice base, the depth of the lake, and the bedrock topography[42,44]. The ice thickness in the Lake Vostok area ranges from 1 950 to 4 350 m. Absolute heights of the lake water table range from approximately −600 m in the north to −150 m in the south. The total volume of Lake Vostok is about 6 100 km^3, the average depth is about 400 m, and the maximum depth is 1 200 m[42-44]. The most important charts are shown in Figure 3. Based on the bedrock topography, an orographic chart was compiled as the first step in the geomorphological interpretation of this area[35-36]. This was the next step to understanding the structure and evolution of the bedrock.

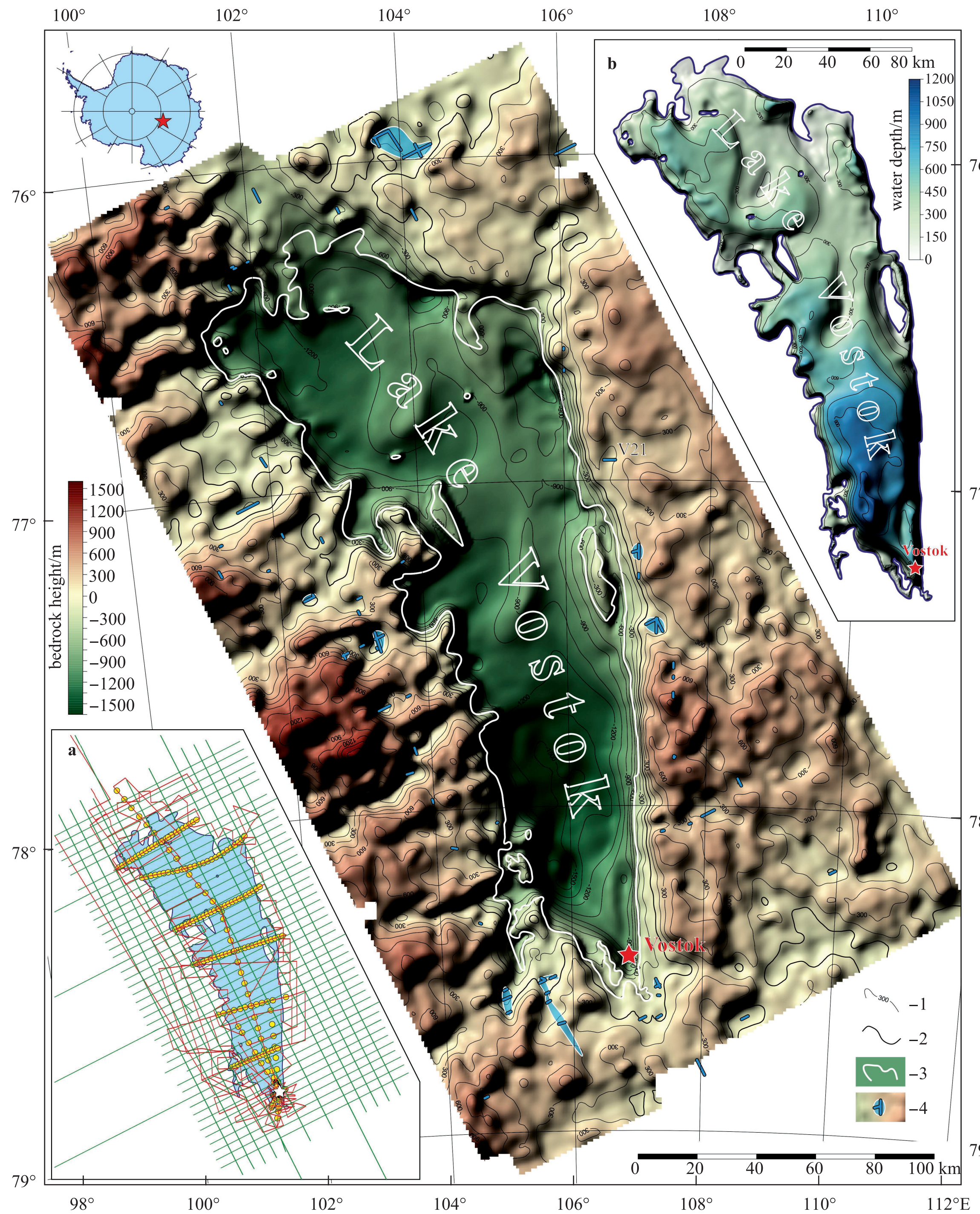

Figure 3 Bedrock topography and subglacial water caves in the Lake Vostok area. **1**, Bedrock topography contours in meters; the contour space is 150 m; **2**, Sea level (surface of WGS-84); **3**, Lake Vostok shoreline; **4**, Subglacial lakes. Location chart is shown in the section **a**; Russian RES profiles are shown by red lines; US airborne profiles on reference [32] are shown by greenlines; Seismic sounds are shown by yellow dots. The depth of Lane Vostok is depicted in the section **b**. Contour interval is 150 m. 234 mm×285 mm (300×300 DPI).

Another important scientific challenge in the preparation for the penetration of Lake Vostok was the charting of its coastline. It was important to determine whether the lake is isolated and separated from the rest of the Antarctic subglacial hydrological network. If the lake were connected to the network, the entire hydrological system could be contaminated in the case of an unsuccessful penetration of the lake. The grounding line was defined by 621 points from the joint Russian and U.S.[32] dataset. It revealed that the lake is completely isolated (Figure 3), with a total area of 15 790 km^2, excluding 365 km^2 occupied by 11 islands[47].

Fifty-six isolated subglacial water caves have been identified outside Lake Vostok. Most were represented by just one radio-echo profile that crosses the cave and the typical size of the caves is about 2.8 km[47]. Russian studies used 60 kW and later 80 kW deep-penetrating pulse radars[42]. Theoretically, these radars have enough power to register a mirror reflection from the bottom of freshwater basins not deeper than 15 m[49]. However, it was found that only one radio-echo time-section could be interpreted as the bottom of a subglacial water cave (Figure 4). Therefore, there are three main possibilities: (1) the caves are deeper than 15 m, (2) the bottom surface is very rough, or (3) the water is not so fresh. The current level of understanding does not allow us to exclude any of these possibilities.

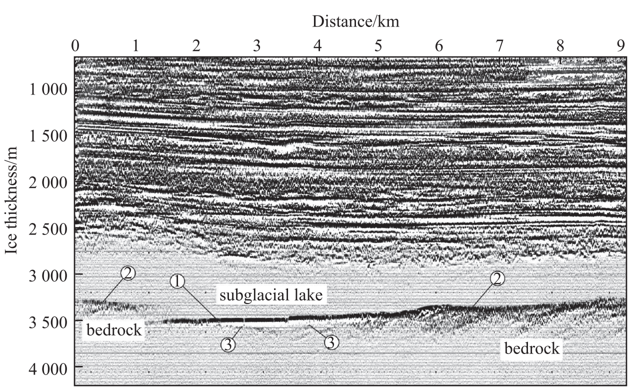

Figure 4 The radio-echo time-section of Lake Vostok's subglacial water cave. **1**, Reflection from the lake water-table; **2**, Reflection from the ice-bedrock interface; **3**, Supposed reflection from the lake bottom. See location in Figure 3. 132 mm×77 mm (300×300 DPI).

It is important to mention the current and future Russian remote sensing projects. Upon the conclusion of reflection seismic studies in 2009, Russian researchers commenced the accumulation of refraction seismic data to measure acoustic velocities in the Lake Vostok area. These data will enable a better understanding of the geological structure of this region.

A new direction in Russian scientific activity is ground-penetrating radar (GPR) investigations. These investigations were carried out for the first time during the 2012/13 austral summer field season to study the structure of the snow-firn layer. The investigations were concentrated in the mega dune area east of Vostok Station and within Lake Vostok. Regional profiles have also been surveyed between Vostok and Progress stations and in the vicinity of Progress Station[50].

3 Mirny-Vostok scientific traverses

In 2004, Russian scientists recommenced regional scientific traverses to perform RES and glaciological observations in the East Antarctic inland. Initially they operated between Mirny and Vostok stations (a distance of 1 410 km). Subsequently, the main logistic base was moved from Mirny to Progress Station for the five austral summer field seasons of the 49th to 53rd Russian Antarctic Expeditions (2004–2008). Old Russian vehicles were used for those traverses (Figures 1b, 1c). During this period about 3 000 km of RES profiles were constructed using the same RLS-60-98 and RLS-60-06 deep-penetrating ice radars used in the Lake Vostok investigations (Figure 2). Almost all of the RES profiles were obtained together with glaciological observations and geodetic measurements conducted to study the ice sheet[51].

The profile between Mirny and Vostok stations crosses five major orographic regions (Figure 5). The lowland extends from the coast to 205 km inland. The height of this area is just above or below sea level. The bedrock is very rough with a slope of about 7–10 degrees. The Golitsyna Mountains are located south of the lowland in the 205 to 420 km section of the traverse. Two main ridges with peak heights of 850 m and 1 350 m are located in that area. Relative heights are often more than 550 m. A number of deep valleys and canyons (800 m and deeper) cut across the mountains. The Shmidt Subglacial Basin extends to the 990 km point of the traverse. The bedrock is weakly rough and the average height is about 200 m. The Vostok Mountains extend up to Lake Vostok. They also consist of two ridges with peak heights of about 600 m and 820 m, and are crossed by deep valleys and canyons. Lake Vostok and the spurs of the Vostok Mountains lie to the south of the end of the section. This area was well described in earlier studies.

The most significant outcome of these scientific traverses was the collection of data on the ice sheet structure and the bedrock formation between Mirny and Vostok stations. The radio-echo time-section and the ice sheet section are shown in Figure 5. These studies resulted in the discovery of a lake located about 50 km north of Komsomolskaya Station (Figures 2 and 5). It is 5 km long and is named Komsomolskoe Subglacial Lake[52-53].

In addition, a system of subglacial lakes was discovered in the vicinity of Pionerskaya Station (Figures 2 and 5). The main lake, which is located underneath the station, is named Pionerskoe Subglacial Lake[54]. During the 2005 and 2006 austral summer field seasons, an area of 17 × 22 km^2 was superimposed with ground-based survey data with an interval of 2 km between the main profiles[54-55]. The ice thickness in this area ranged from 1 450 to 2 450 m, and the bedrock elevation was estimated to be from 300 to 1 300 m. A reflection seismic sounding survey was carried out in the field season of 2007/08. According to this survey, the depth of the

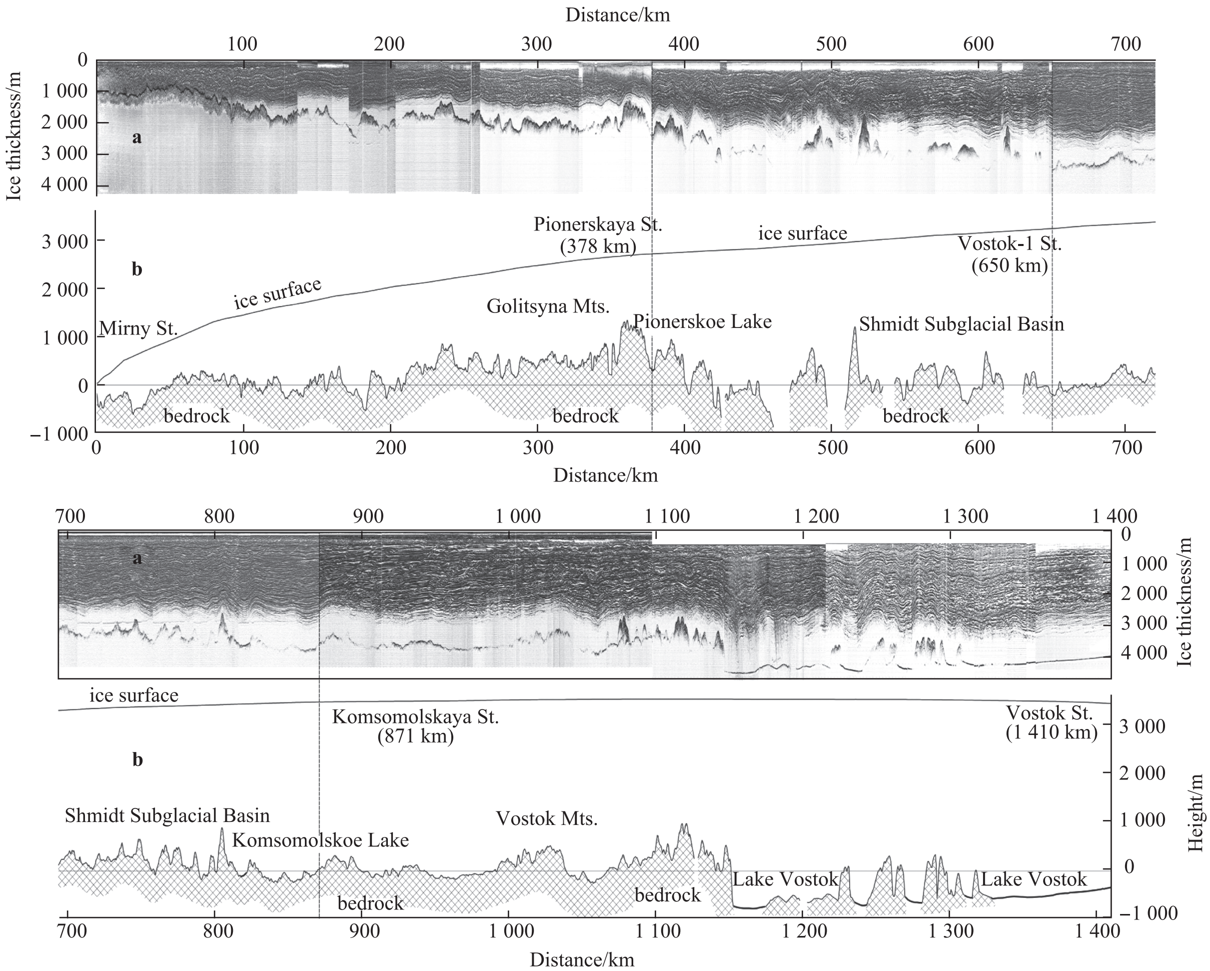

Figure 5 Radio-echo time-section (**a**) and ice sheet section (**b**) between Mirny and Vostok stations. See location in Figure 2. 197 mm ×281 mm (300×300 DPI).

lake is about 30 m and the bottom of the lake is covered by sediments about 300 m thick[55]. The flat tops of the subglacial landforms point toward intensive ice abrasion secondary to relatively fast movement of the ice sheet (about 20 m·a^{-1})[56]. The border of Pionerskoe Subglacial Lake has been plotted at 21 points. The area of the lake is about 26.5 km^2, and its dimensions are about 9.0 × 2.5 km^2. Four more small water caves have been identified in the area and two of them have been fully mapped[54-55].

4 Progress-Vostok scientific traverses

According to the strategy of Russian exploration in Antarctica, the main logistic base has been moved from Mirny Station to Progress Station. The Kässbohrer Pisten Bully (Figure 1d) is now used for logistic and scientific traverses instead of the older Russian vehicles (Ishimbay, STT-1 Kharkovchanka, STT-2 Kharkovchanka-2, and ATT). In 2007, the first cargo of fuel drums was brought to Vostok Station from Progress Station. In addition to logistic tasks, the extensive glaciological and geodetic scientific program was completed. Since that time, traverses deliver cargo and fuel to Vostok Station twice per field season. As a rule, scientific research is carried out within the framework of the traverses, and includes RES, glaciological observations, and geodetic measurements. Geophysical profiles are located within the broad band encompassing the main logistic route. The total length of the RES profiles is 4 426 km, and they are concentrated in an area about a 1 000 km from the coast (Figure 2).

Figure 3 shows a section of the scientific traverse from Komsomolskaya Station to a point about 300 km from the coast. This 550 km section is most interesting because of its novelty. According to the RES data, there is a mountainous area beneath the ice. The bedrock height varies from −200 m to 1 100 m. The subglacial landscape is very rough and some valleys are more than 800 m deep. There is a wide subglacial hill or mountain ridge located between the Grove Mountains and the Vostok Mountains, indicating that perhaps these formations belong to one bigger mountain ridge. Currently, there is insufficient geophysical data to make any definite conclusions but the recently published Antarctic Moho depth map[57] indirectly supports this possibility. The area of the intended subglacial ridge is correlated with increased Moho depth. Antarctic bedrock topography maps compiled within the framework of the BEDMAP2 project[58] provide further support for this expansive mountain ridge.

5 Concluding remarks

Scientific traverses are a key component in the study of the Antarctic environment. Glaciological, geodetic, meteorological, and certain geophysical data could not be collected by any other means. Soviet and Russian logistic and scientific traverses (which traditionally run jointly) have a long and glorious history. It is impossible to do justice to this history in one paper. Rather, this is a topic deserving of a book. Nonetheless, here the author has attempted to highlight the most important historical events in Soviet and Russian Antarctic exploration and to provide a snap shot of Soviet and Russian scientific activities from the past to the present.

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