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Forty-seven new subglacial lakes in the 0–110° E sector of East Antarctica

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ABSTRACT. During the summer field seasons of 1987–91, studies of central East Antarctica by airborne radio-echo sounding commenced. This scientific work continued in the 1990s in the Vostok Subglacial Lake area and along the traverse route from Mirny, and led to the discovery of 16 new subglacial water cavities in the areas of Domes Fuji and Argus and the Prince Charles Mountains. Twenty-nine subglacial water cavities were revealed in the area near Vostok, along with a feature we believe to be a subglacial river. Two subglacial lakes were discovered along the Mirny–Vostok traverse route. These are located 50 km north of Komsomolskaya station and under Pionerskaya station. We find high geothermal heat flux in the vicinity of the largest of the subglacial lakes, and suggest this may be due to their location over deep faults where additional mantle heat is available.

1. INTRODUCTION

Subglacial lakes in Antarctica are one of the last unexplored frontiers on Earth. They attract attention because they are unusual. They are a point of contact between various scientific branches: biology (searching for potential exotic life forms), geology and geophysics (the age and tectonic aspects of the formation of the lakes), glaciology (basal motion, ice-sheet stratification) and others. There have been 145 relatively small (approximately several tens of kilometers long) subglacial lakes discovered in Antarctica during the last 30 years (Siegert and others, 2005). Interest in the study of these subglacial lakes was increased with the discovery of Vostok Subglacial Lake (VSL), located in central East Antarctica (Ridley and others, 1993; Kapitsa and others, 1996). Approximately 280 km long and 80 km wide, VSL is the largest subglacial water cavity in Antarctica. Its discovery and investigation are changing our understanding of the continental structure. Vostok station and the deep ice borehole, 5G-1, are situated over VSL. Glaciological and geophysical investigations directed at studying the lake are based at the station. Analyses of the Vostok ice core are the basis of many climatic and glaciological reconstructions (e.g. Petit and others, 1999). Studies of the lake are important for better understanding the structure, formation and glaciation of East Antarctica.

The existence of basal melting and the filling of negative sub-ice relief forms beneath the Antarctic ice sheet by meltwater were predicted almost half a century ago (Zotikov, 1963). The first evidence in support of this prediction was obtained a few years later when airborne radio-echo soundings (RES) in central East Antarctica were carried out in December 1967 under the framework of the British–American scientific program. These investigations discovered subglacial water cavities in the Sovietskaya station area (Robin and others, 1970). Similar results were obtained in the Vostok station region. The interpretation of these scientific measurements can be found in the classical papers describing the positions of the first 17 subglacial lakes discovered in Antarctica (Oswald and Robin, 1973; Oswald, 1975). Later investigations resulted in the discovery of similar features near Ridge B, Domes Argus, Concordia, Fuji, Talos, etc. The location of all subglacial lakes identified up till 2003 has been presented by Siegert and others (2005).

2. DATASETS

A wide range of geophysical investigations in central East Antarctica in the 0–110° E sector have been carried out. Initially, seismic and gravity measurements were obtained along scientific traverse routes in the 1950s and 1960s by Russian and Australian scientists (Walker, 1966; Grushinskii and others, 1972). In the 1970s and 1980s, a number of ground-based RES scientific traverses were made between Mirny and Komsomolskaya stations, between Mirny and Dome Concordia, and from Mirny to Ridge B (Bogorodskiy and Sheremet'yev, 1981; Sheremet'yev, 1989). The outcome of these investigations was an understanding of ice thickness and subglacial surface topography from the coast to 2000 km inland, and between Novolazarevskaya and Mirny stations. RES traverses in the Ridge B area were directed towards searching for and studying subglacial lakes (Sheremet'yev, 1989).

During the summer field seasons of 1987–91, the Polar Marine Geological Research Expedition (PMGRE) commenced airborne RES, gravity and magnetometer studies of central East Antarctica using a long-range Ilushin IL-18D aircraft (Popov and others, 2002). This work was designed to study the sub-ice features and deep structure of this area. Flight-lines were separated by approximately 50 km (Fig. 1). Regional flights from Molodezhnaya station to Vostok and McMurdo stations were also undertaken (Fig. 1). Global positioning system (GPS), electronic and Doppler navigation were used. The positioning accuracy was approximately 4700 m (33rd Soviet Antarctic Expedition (SAE), 1987/88), 150 m (34th SAE, 1988/89) and <100 m (35th and 36th SAE, 1989/91). Ice radar with an operating frequency of 60 MHz and registration on photographic film was used. The total area covered by the scientific program was $\sim 4 \times 10^6$ km^2. These efforts resulted in mapping a wide area, and an understanding of the deep Earth crust structure.

PMGRE continued investigations in central East Antarctica by geophysical methods in the mid-1990s. The

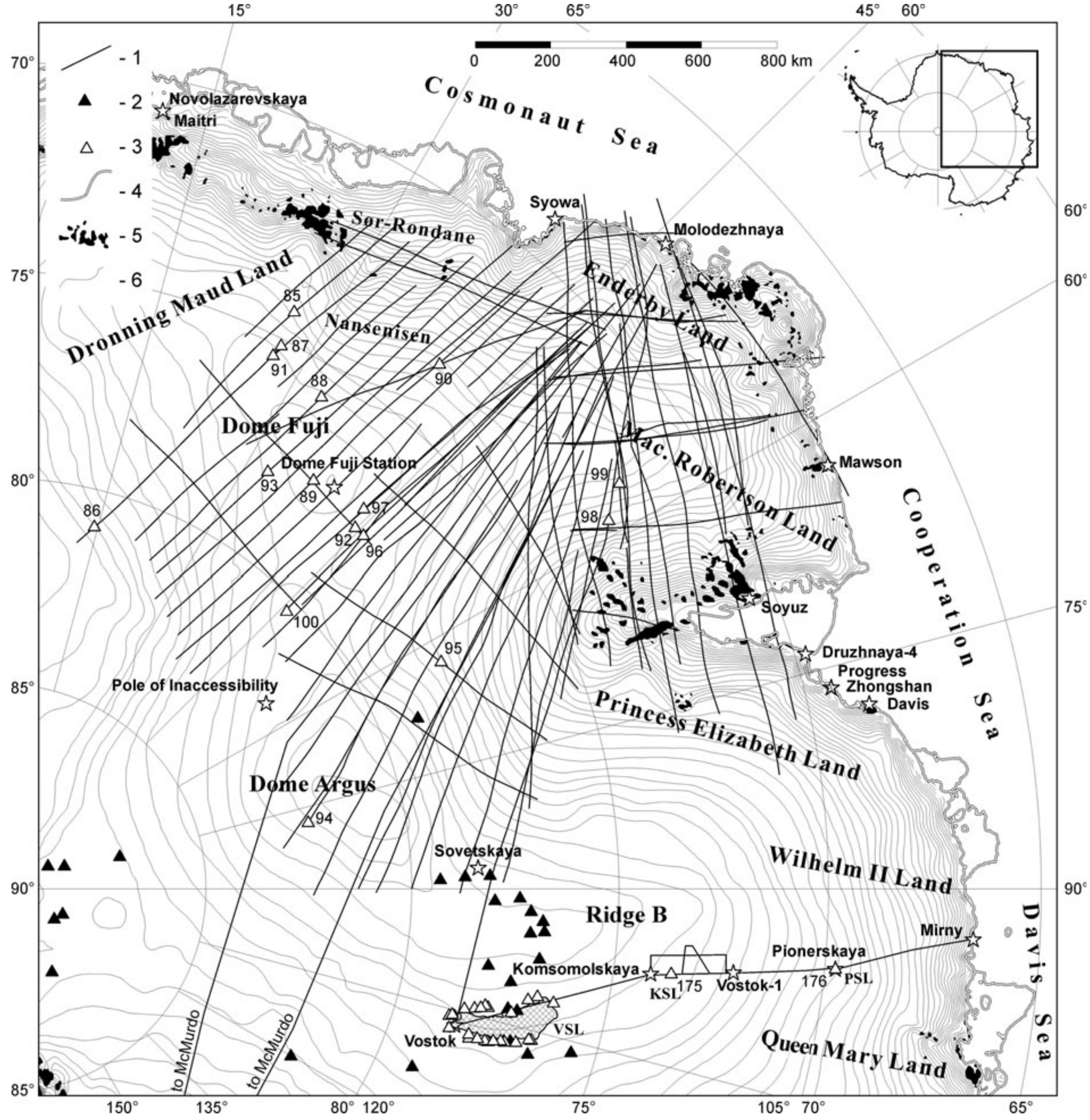

Fig. 1. Russian small-scale RES investigations and the newly discovered subglacial lakes in central East Antarctica. 1: RES profiles of small-scale surveys from 1987–91; 2: subglacial lakes from Siegert and others (2005); 3: subglacial lakes discovered using revised Russian RES data (the numbers beside each lake follow the numbering system of Siegert and others (2005)); 4: ice front and grounding line from the Antarctic Digital Database (ADD); 5: outcrops on ADD; 6: ice surface elevation contours with 100 m spacing from GTOPO30.

scientific program focused on VSL which had been discovered several years previously (Ridley and others, 1993; Kapitsa and others, 1996). Seismic investigations commenced in 1995 and in 1998 ground-based RES studies began (Masolov and others, 1999, 2001, 2006; Popov and others, 2003). The locations of scientific transects in the VSL area are shown in Figure 2. These surveys mapped the ice thickness, ice base and bathymetry, aimed at determining the shape of VSL (Masolov and others, 2006; Popov and others, 2006). RES also revealed a number of isolated subglacial water cavities around VSL (Fig. 2).

In 2004, Russian scientists recommenced RES and glaciological observations in central East Antarctica utilizing regional scientific traverses. Four traverses within a band between Mirny and Vostok stations were undertaken during three field seasons from 2004 to 2006. The locations of RES profiles (total length 2400 km) are shown in Figure 1. This is the next stage in our studies of sub-ice relief of this area, and has resulted in the discovery of two subglacial water cavities. A 60 MHz ice radar was used, with a repetition frequency 600 Hz, pulse length 0.5 μs, pulse power 60 kW, dynamical range 180 dB and reception channel band 3 MHz. The reflected signals were digitized and saved on a PC by an analog–digital transformer at a sample period of 50 ns and an accumulation of 256 frames. The transformer was developed (Popov and others, 2003) from a 12-bit analog–digital converter AD9042AST (Analog Devices Inc.) with SBC-8259 processor (Axiom Technology Company).

Airborne geophysical investigations in this area of central East Antarctica were undertaken in the framework of the British–American scientific program in the 1960s and 1970s. Consequent investigation of the bed exposed subglacial

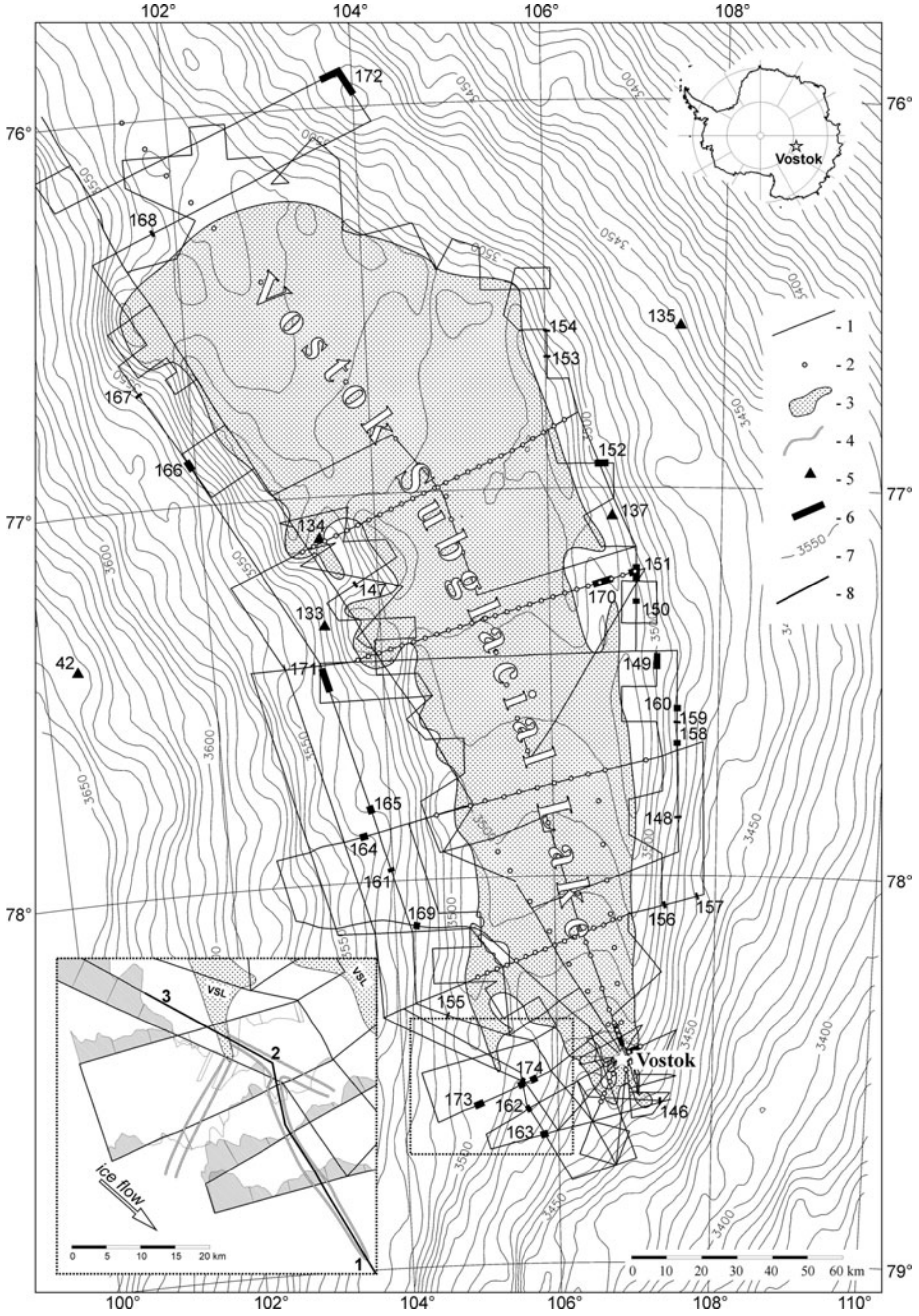

Fig. 2. Russian measurements and newly discovered subglacial lakes in the VSL area. 1: Russian RES profiles of 1998–2006; 2: Russian reflection seismic shots of 1995–2006; 3: the most reliable shape of VSL; 4: likely shape of VSL; 5: subglacial lakes from Siegert and others (2005); 6: subglacial lakes discovered using revised Russian RES data (the numbers beside each lake follow the numbering system of Siegert and others (2005)); 7: ice surface elevation contours with 5 m spacing from Rémy and others (1999); 8: RES profile 1–2–3. The insert is a magnification of the rectangle shown to the southwest of VSL.

water cavities (Robin and others, 1970; Oswald and Robin, 1973; Oswald, 1975). Airborne surveys in the VSL were also undertaken by Italian scientists in 1999 (Tabacco and others, 2002) and US scientists in 2000 (Studinger and others, 2003a). The US measurements yielded an improved understanding of the deep structure and glaciology (Studinger and others, 2003b).

3. SUBGLACIAL LAKES

Russian airborne RES data collected in 1987–91 were reanalyzed for a project dedicated to the study of the East Antarctic bed. This revision led to corrections to the previously measured ice thickness and subglacial surface structure (Popov and others, 2002), and revealed 16 previously unknown subglacial water cavities (Fig. 1). Their numbering corresponds to Siegert and others (2005). As mentioned by others (Oswald and Robin, 1973; Oswald, 1975; Bogorodskiy and Sheremet'yev, 1981; Sheremet'yev, 1989), the different dielectric coefficients of bedrock, water and ice allow us to follow the radio reflections from the ice base. If the water layer is flat, the reflections are close to coherent. These signs have been found in RES records collected at Domes Fuji and Argus and in the Prince Charles Mountains region in Mac. Robertson Land (Fig. 1). A radio-echo time section of subglacial lake 93 is shown in Figure 3.

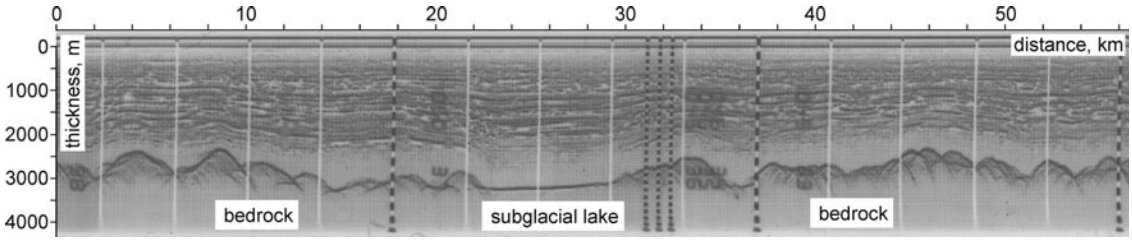

Fig. 3. RES record collected from the area of subglacial lake 93. (Location shown in Fig. 1.)

The length of the lakes is typically of the order of 1–10 km. The surface of the water layer in the subglacial lakes is between 300 m below sea level and 1060 m a.s.l. (see Table 1).

VSL is the largest subglacial lake so far discovered. Russian RES investigations resulted in mapping its shape (Popov and others, 2003; Masolov and others, 2006). We estimate its area to be 17.1×10^3 km^2. It is necessary however, to note that new field seasons yield new features of the lake shoreline. VSL's shape is very complex. It is not simply a deep structure of the Vostok basin. We have discovered a number of islands concentrated in the southwest of VSL. One of them is most important because it is on the flowline which passes via the 5G-1 borehole bottom. The mineral inclusions detected in the ice core (Jouzel and others, 1999) could be captured by the glacier and carried away from the island (Leitchenkov and others, 2005). This island is located near the western part of the VSL shoreline (Fig. 2, near water cavity 169).

Twenty-nine subglacial water cavities have been discovered in the vicinity of VSL (Fig. 2). Their lengths are typically about 1.5 km (see Table 1). An RES-derived ice-sheet profile over subglacial lake 152 is shown in Figure 4. The height of the water layer is between –220 and 745 m on the east side, and between –280 and 335 m on the west side. The largest of the newly discovered water cavities, 172, detected along two RES routes, is positioned to the northeast of VSL. The lengths of the RES sections are about 8 km, so the area of this lake may be more than 10×10 km^2. In 2005 we crossed subglacial water cavity 151 to estimate its size, which proved to be $\sim 2 \times 5$ km^2. Water cavity 169 is situated on the flowline which passes via the 5G-1 borehole bottom (Fig. 2).

Special attention should be paid to four subglacial water cavities: 162, 163, 173 and 174. They are situated in the southwest part of VSL and are concentrated in a small area about 20×20 km^2 (Fig. 2 insert). The cavities 162, 163 and 174 are practically on a straight line. During the 2005/06 field season, RES data were collected along transect 1–2–3 (Fig. 2 insert). The ice-sheet profile and RES record are shown in Figure 5. For much of the section (i.e. between point 1 and VSL), the data are indicative (because of different dielectric coefficients) of an ice/water interface reflection (labeled 'w' in Fig. 5a). This section of the transect is along a bedrock valley that is aligned across the ice-flow direction (Fig. 2 insert). We suggest that the moving ice deposits excavated debris into the valley, providing a rough, sediment-rich surface. We would normally, then, expect a weak return echo, as seen between VSL and point 3 in Figure 5b. Here however, we have an ice/water interface despite the sloping bedrock relief, and we believe it to be due to a local, 40 km long, narrow under-ice water system – a subglacial river which meanders across the point 1 to VSL transect – probably linked to VSL. Water cavities labeled 1 and 2 (in Fig. 5b) are expected to be on the same surface since their heights are similar and they are nearby. Furthermore, with the exception of only a few rises between point 1 and VSL, the slope of the bedrock is always down. Linearity of the system suggests the subglacial river lies in a deep fault, where higher geothermal heat flux contributes to ice melting.

A number of seismic reflection shots were obtained over the water cavities around VSL (Fig. 2). They revealed subglacial water cavities ~1.5 km long, covered by an ice sheet ~3.5 km thick. As a rule, the cavities are located in the bottom of valleys with a depth of several hundred meters. In that case, a very complex acoustic wave field is registered by the seismic record (personal communication from A. Popkov). It is essential to carry out seismic profiling to study the

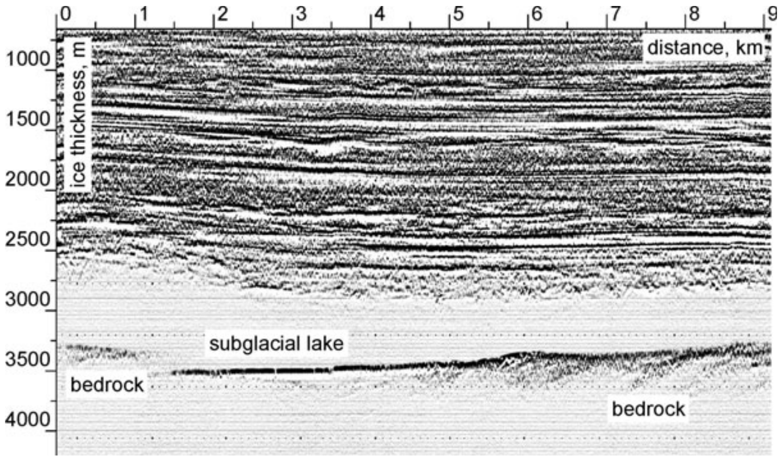

Fig. 4. RES record collected from the area of subglacial lake 152. (Location shown in Fig. 2.)

Table 1. Inventory of Antarctic subglacial lakes in the sector 0–110° E

Lake ID	Location and name of subglacial lake	Lat.	Long.	Length of lake	Ice thickness	Ice base	λ_{geo}	$\delta\lambda$
		°	°	km	m	m a.s.l.	mW m^{-2}	mW m^{-2}
85	Dome Fuji area	–74.300	26.939	10	2427	955	95.7*	41.1*
86		–80.903	14.467	8	2340	350	87.2*	32.6*
87		–75.167	27.289	10	2770	815	93.4*	38.8*
88		–75.745	33.091	5	2560	1062	53.8	–0.8
89		–77.499	37.432	20	3125	645	45.2	–9.4
90		–73.424	39.892	18	2180	970	110.0*	55.4*
91		–75.463	27.032	20	2830	790	91.5*	36.9*
92		–77.704	44.461	15	2860	745	48.8	–5.8
93		–77.962	32.617	15	3070	560	45.9	–8.7
94	Dome Argus area	–82.343	77.891	5	3575	305	52.0*	–2.6*
95		–77.958	62.728	5	2834	360	75.1*	20.5*
96	Dome Fuji area	–77.700	45.766	5	2640	935	52.4	–2.3
97		–77.236	43.698	8	3130	500	45.2	–9.4
98	Prince Charles Mountains area	–72.784	58.797	15	1750	810	114.1*	59.5*
99		–72.096	56.768	8	2535	310	93.0*	38.4*
100	Dome Fuji area	–80.302	45.825	7	3240	495	62.0*	7.4*
146	VSL area	–78.583	107.131	0.6	3635	–175	50.4	–4.2
147		–77.232	103.724	0.7	3720	–195	55.3	0.6
148		–77.853	107.531	0.7	2915	570	60	5.4
149		–77.468	107.259	4.5	3515	–20	51.2	–3.4
150		–77.301	107.012	1.5	3435	75	54.0	–0.6
151		–77.199	107.013	~2 × 5	3305	200	56.7	2.1
152		–76.938	106.696	3.8	3540	–45	58.0	3.4
153		–76.659	106.020	0.5	3735	–220	60.4	5.8
154		–76.596	106.019	0.5	3400	100	64.6	10.0
155		–78.325	104.593	0.5	3605	–100	52.9	–1.7
156		–78.080	107.351	1.0	3295	190	54.3	–0.3
157		–78.054	107.798	0.6	3345	115	55.1	0.5
158		–77.666	107.509	1.5	2740	745	62.4	7.8
159		–77.602	107.509	0.6	3135	350	56.3	1.7
160		–77.577	107.508	1.8	3100	385	56.6	2.0
161		–77.975	103.985	1.0	3280	250	53.3	–1.3
162		–78.598	105.368	1.2	3600	–45	53.4	–1.2
163		–78.665	105.859	2.0	3320	200	56.1	1.5
164		–77.884	103.617	2.1	3650	–110	49.3	–5.3
165		–77.804	103.757	2.3	3740	–210	48.5	–6.1
166		–76.907	101.962	3.1	3715	–160	63.4	8.8
167		–76.699	101.433	0.7	3835	–280	64.4	9.8
168		–76.292	101.74	0.8	3720	–180	65.6	11.0
169		–78.118	104.299	1.7	3190	335	54.8	0.2
170		–77.251	106.510	5.8	3740	–235	52.6	–2.0
171		–77.503	103.360	6.8	3720	–180	48.3	–6.4
172		–75.908	103.864	>10 × 10	3770	–290	66.0	11.4
173		–78.584	104.996	1.8	3880	–380	50.8	–3.8
174		–78.534	105.586	~4.0	3740	–220	52.2	–2.4
175	KSL	–73.618	97.2864	4.3	3590	–96	71.7	17.1
176	PSL	–69.746	95.5366	>10	2400	310	104.9	50.3

Notes: Lake IDs correspond to Siegert and others (2005). Subglacial lakes numbers 85–100 were obtained by re-examining the RES records collected in 1987–90; numbers 146–174 were discovered after revision of the RES data collected in 1998–2005 in the VSL area; numbers 175 and 176 were discovered during scientific transverse 2003/04. The geothermal heat fluxes marked * are estimated based on Bakaev (1964).

subglacial water cavities. Subglacial lake 172 and PSL (see below) are the most promising for seismic exploration because of their relatively large size. Two seismic shots of subglacial lake 170 resulted in a depth estimate of ~150 m.

As noted above, two subglacial water cavities were discovered along the scientific traverse route between Mirny and Vostok during the 2003/04 field season (Fig. 1). The first, 175, is located 50 km to the north of Komsomolskaya station and is designated Komsomolskoe subglacial lake (KSL). It is ~4.2 km long (Fig. 6). The second, 176, is under Pionerskaya station (Fig. 1) and is designated Pionerskoe subglacial lake (PSL). The RES record and the ice-sheet section along profile LP49 (a section of the Mirny–Vostok traverse route) are shown in Figure 7. Discovery of the water layer under the ice sheet stimulated studies of the Pionerskaya station area. During the 2004/05 field season, eight RES profiles were obtained over a total length of 30 km, aimed at understanding the bed and shape of the lake. In 2005/06 a large-scale RES survey was carried out in this region. The profiles were oriented across the lake with 2 km spacing. The area covered was 17 × 22 km^2 with total length 312 km (Fig. 8). Ground-based RES is significantly more precise than airborne RES.

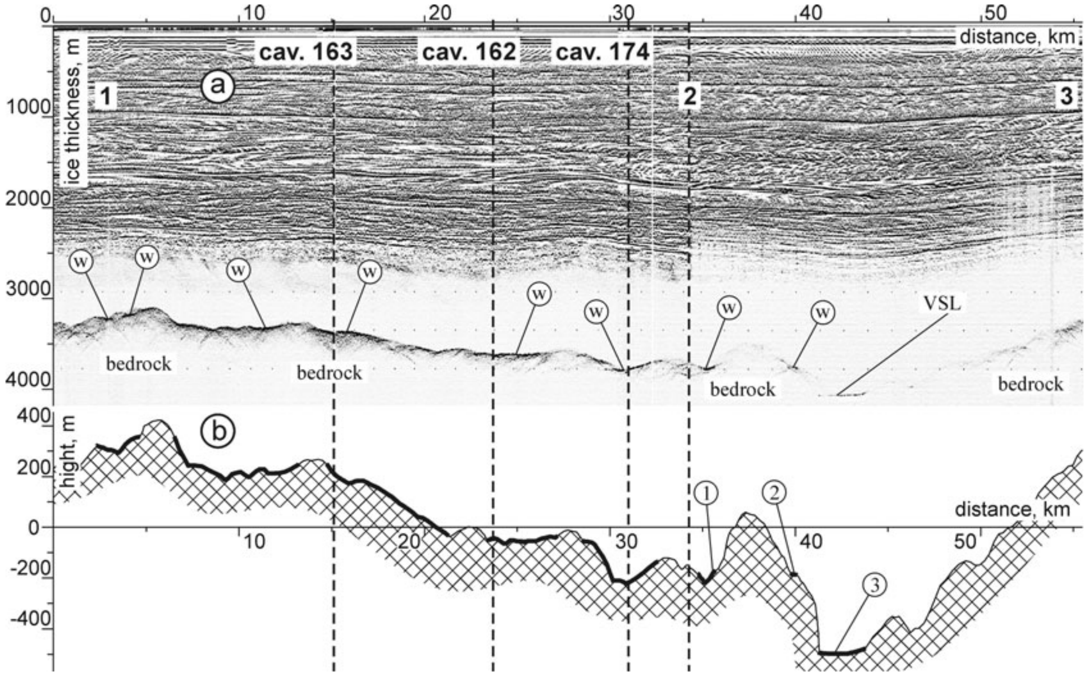

Fig. 5. (a) RES record and (b) ice-base profile along the 1–2–3 profile. (Location shown in Fig. 2 insert.)

The standard measurement error of the ice thickness, based on 64 cross-points, was ~9 m. These investigations resulted in detailed mapping of ice thickness, ice base and shape of the subglacial lakes. Four more water cavities were revealed in the area.

Ice thickness in the PSL area is 1450–2450 m, with the maximum in a valley located in the central part of the region. A 300 m deep valley (Pionerskaya valley) is the dominant landform in this area. Its bottom is very flat (with roughness of tens of meters), ranging in height from 400 to 500 m (Fig. 8). Four subglacial water cavities are located in the valley. The largest, PSL, is 9 km long and 2.5 km wide. Its shape is near-circular and its area is about 26.5 km^2. Another subglacial lake, west of PSL, is 2 km long and 0.6 km wide. Three RES profiles cross this lake. Yet another subglacial lake is situated southwest of PSL. It was detected in two profiles but its western boundary has not yet been determined. The estimated size of this lake is more than 3×3 km^2. Two short (about 600 m long) ice/water interfaces were discovered southeast of PSL. They were detected in one profile. Steep slopes (ranging from 150 m high in the west to 500 m in the east) indicate the tectonic nature of the valley. All the lakes are located on a flat-bottomed valley, 300 m deep, with a roughness of several tens of meters, suggesting that the lakes in the valley have depths of the order of 10 m.

4. ESTIMATION OF GEOTHERMAL HEAT FLUX

Following the procedure outlined by Zotikov (1963) and Siegert and Dowdeswell (1996), the geothermal heat flux under the newly discovered lakes, Λ_{geo}, is estimated by

$$\Lambda_{\mathrm{geo}} = c(T_{\mathrm{B}} - T_{\mathrm{S}})\sqrt{\frac{2w_{\mathrm{S}}}{\pi k z}}\left[\mathrm{erf}\left(\sqrt{\frac{w_{\mathrm{S}} z}{2k}}\right)\right]^{-1}, \qquad (1)$$

where

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}}\int_0^z \exp\left(-y^2\right)\mathrm{d}y \qquad (2)$$

describes the Gaussian error function. T_{B} is the ice base temperature (°C), T_{S} is the mean annual surface temperature of the ice sheet (°C), w_{S} is the mean annual surface

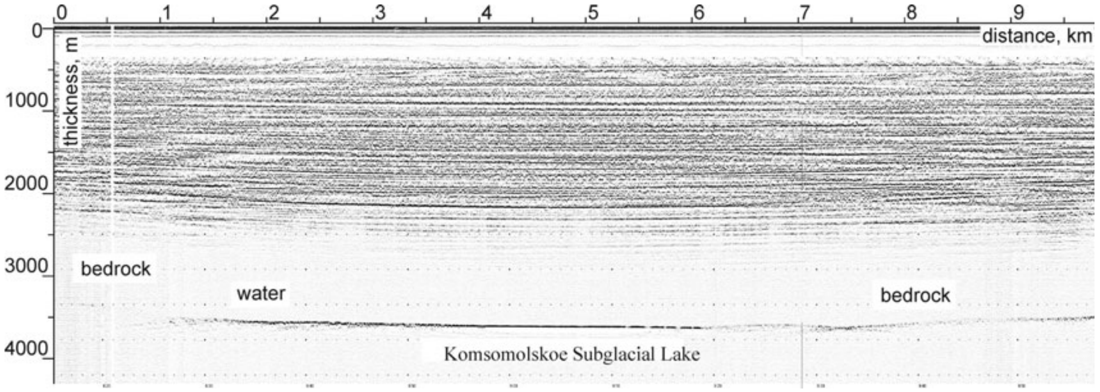

Fig. 6. RES record from the KSL area. (No. 175 shown in Fig. 1.)

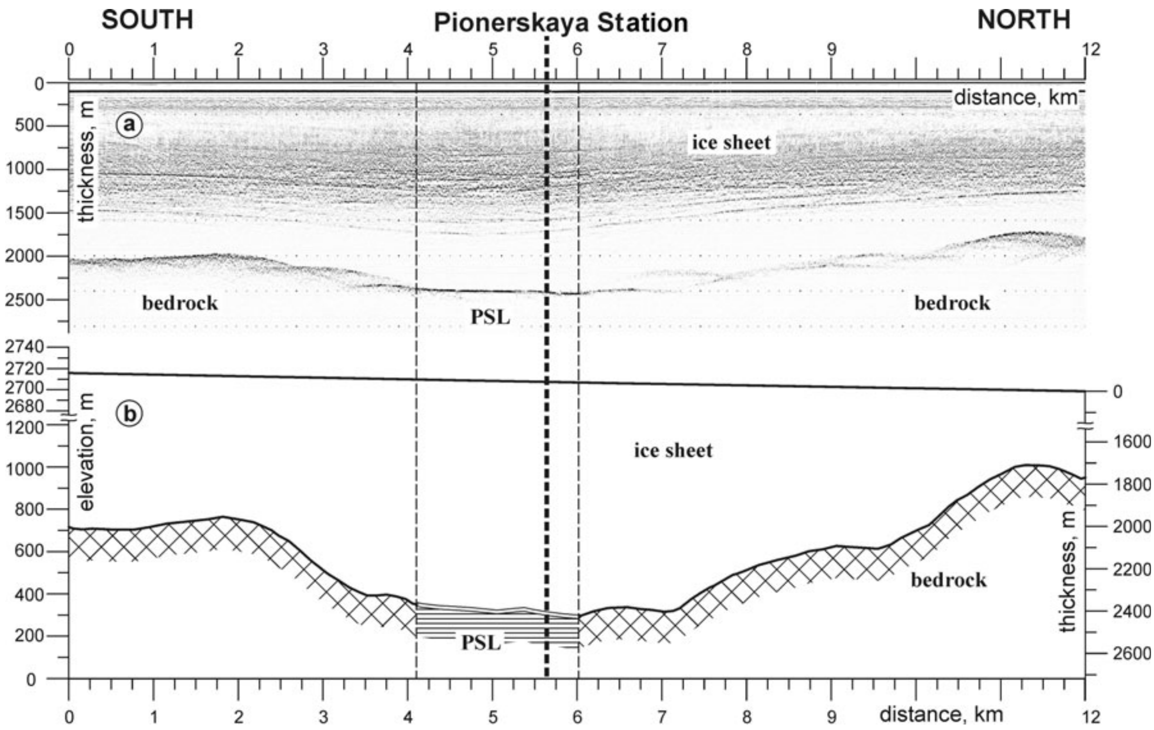

Fig. 7. (a) RES record and (b) ice base profile along the LP49 route. (Location shown in Fig. 8.)

accumulation rate on the ice-sheet surface (m a^{-1}), z is the ice thickness (m), k is the thermal diffusivity of the ice (36.3 m^2 a^{-1}) and c is the thermal conductivity of the ice (2.1 W m^{-1} °C^{-1}). Following Paterson (1994), the pressure-melting temperature (T_{pm}) of pure ice, in °C, is given by:

$$T_{\mathrm{pm}} = -\frac{z}{1149}. \tag{3}$$

We assume the water cavities to be in steady state, in which case $T_{\mathrm{B}} = T_{\mathrm{pm}}$ and z is the measured ice thickness. A mean annual ice-sheet surface temperature of –57.3°C was adopted by the Dome-F Ice Core Research Group (1998) for the Dome Fuji area (subglacial cavities 88, 89, 92, 93, 96 and 97). For subglacial cavities 146–172, surface temperature was assumed the same as at Vostok station, –56.8°C (Lipenkov and others, 2004). We used the mean surface temperature at Komsomolskaya (–52.6°C) for subglacial cavity 173, that at Pionerskaya (–38.1°C) for subglacial cavity 174 (Lipenkov and others, 1998) and values from the *Atlas of Antarctica* (Bakaev, 1964) for all other subglacial cavities.

The mean annual surface accumulation rate was adopted from Hondoh and others (2002) for the Dome Fuji area (3.2 cm a^{-1}). Data from Lipenkov and others (1998) and Popov and others (2003, 2004) were used for the water cavities around VSL and along the Mirny–Vostok traverse route. Data from Bakaev (1964) were adopted for other cavities.

The mean snow surface density, ρ_{S}, was used to convert the mean annual surface accumulation from g cm^{-2} a^{-1} to m a^{-1}. This was adopted from Lipenkov and others (1998) for subglacial lakes 146–176. We assume the snow density in the VSL area to be the same as at Vostok station (Popov and others, 2003, 2004). Following Lipenkov and others (1998), the dependence of the snow density on the mean annual surface temperature for subglacial cavities 85–87, 90–91, 94–95 and 98–100 was used to estimate ρ_{S}. These cavities are in two areas: $T_{\mathrm{S}} \leq$ –47°C (region I) and –47°C < $T_{\mathrm{S}} \leq$ –30°C (region II) and the relationships are:

$$\begin{aligned} \rho_{\mathrm{S}} &= 0.0059 T_{\mathrm{S}} + 0.66, \text{ region I} \\ \rho_{\mathrm{S}} &= 0.0034 T_{\mathrm{S}} + 0.52, \text{ region II}. \end{aligned} \tag{4}$$

The mean continental geothermal heat flux, λ_{geo}, of 54.6 mW m^{-2} was adopted from Siegert and Dowdeswell (1996). The excess heat flux over the mean value ($\delta\lambda$) was estimated as

$$\Delta\lambda = \Lambda_{\mathrm{geo}} - \bar{\Lambda}_{\mathrm{geo}}. \tag{5}$$

The geothermal heat-flux estimations and the principal characteristics of the cavities are shown in Table 1.

5. DISCUSSION

The geothermal heat-flux estimations are comparable with the estimates of Hondoh and others (2002) for the Dome Fuji area and Siegert and Dowdeswell (1996) for a general assessment. The heat-flux results presented in Table 1 are based on in situ measurements. The mean is ~56 mW m^{-2}, i.e. about the same as the mean continental geothermal heat flux. Five subglacial lakes, three in the VSL area, KSL and PSL, have an additional geothermal heat flux of >10 mW m^{-2}.

The geothermal heat fluxes calculated using data from Bakaev (1964) are not as reliable as the other measurements. They are generally higher than expected. Russian (Popov and others, 2003) and US (Studinger and others, 2003b) data indicate maximum ice thickness in the VSL area, off the lake, to be about 3900 m, but ice basal melting does not take place. Therefore, the estimation based on Equation (1) and the glaciological data mentioned above limits the geothermal heat flux to <49 mW m^{-2}. Thus, the excess heat over the subglacial lakes is about 20%.

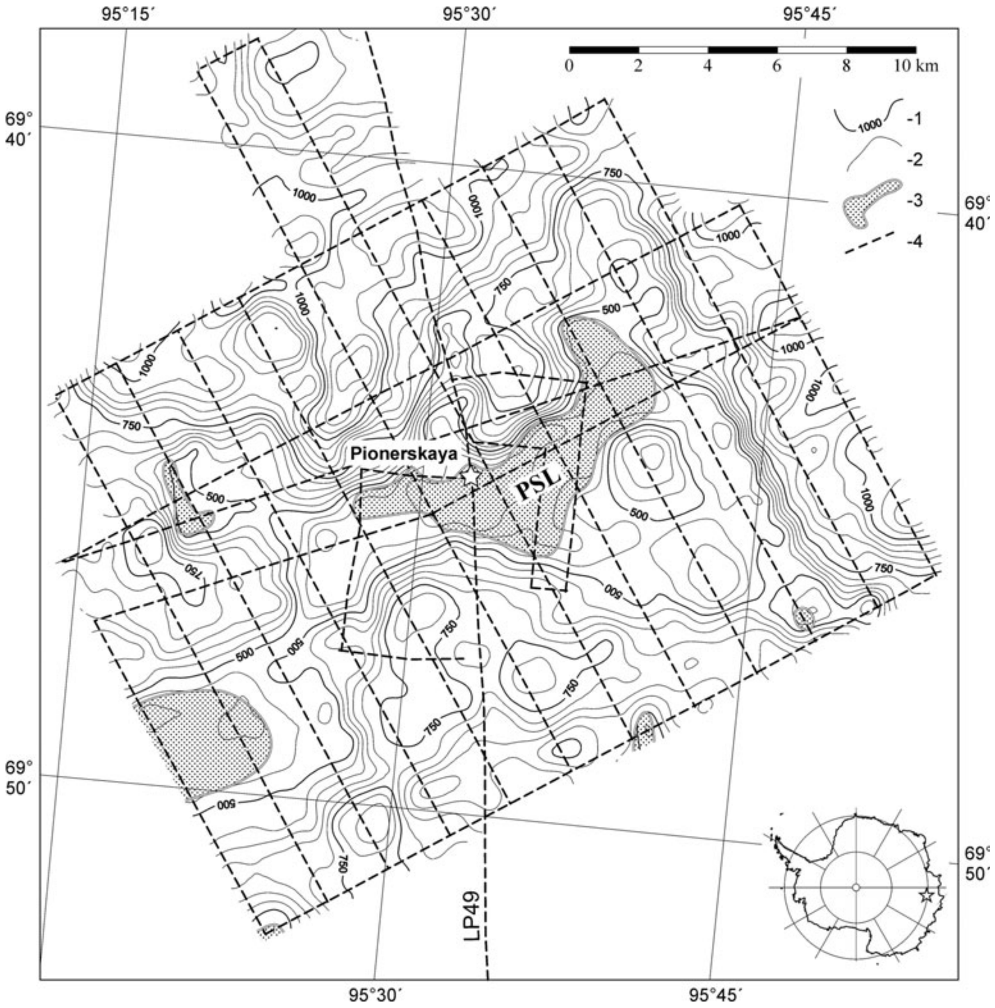

Fig. 8. Subglacial surface structure of the PSL area. 1: main ice base contours with 250 m spacing; 2: additional ice base contours with 50 m spacing; 3: subglacial lakes; 4: RES profiles.

The maximum measured ice thickness in the Dome Fuji area (Popov and others, 2002) is about 4300 m. The geothermal heat flux in that region is expected to be about 35 mW m^{-2}. Thus the excess heat over the subglacial lakes is about 40%.

Analysis of the ice thickness along the Mirny–Vostok traverse route shows that the geothermal heat flux for the KSL and PSL regions is about 70 and 88 mW m^{-2}, respectively. This value is higher than expected, especially for PSL. Salamatin and others (1982) calculated the temperature in the ice sheet along the flowline from Ridge B to Mirny. They obtained melting zones near Pionerskaya station at heat fluxes of 55–60 mW m^{-2}. The model accounts for ice-sheet dynamics. Salamatin and others assume there is no extra geothermal heat under Pionerskaya, and that extra heat results from the ice motion.

Whatever the means, increased heat flux is observed under the newly discovered subglacial lakes. We suggest that a number of these subglacial lakes lie over deep faults because of increased mantle heat. This result might be of interest in understanding the tectonics and formation of the continent.

6. CONCLUSION

We have (1) announced the discovery of 16 subglacial lakes in the areas near Domes Fuji and Argus and Prince Charles Mountains, (2) announced the discovery of 29 subglacial lakes in the VSL area and 2 between Vostok and Mirny, (3) analyzed RES results indicating a local subglacial river or fiord, probably connected to VSL, (4) estimated geothermal heat flux in the subglacial lake regions and (5) proposed that additional mantle heat may be contributing to ice melt in the subglacial lakes.

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