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SEISMIC REFLECTION PROFILING IN LAKE KURILSKOE

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Two calderas have been located in Lake Kurilskoe by seismic reflection profiling. One of them, Kurilskaya, is about 7 km across and occupies the central and southern parts of the lake. The other caldera, Il'inskaya, is situated in the northeast of the lake and extends beyond it. The volume of magma erupted before the formation of the Kurilskaya caldera is over 35 km . The Severnaya Bay is believed to be of erosional rather than explosive origin as was previously thought.

INTRODUCTION

Lake Kurilskoe, 76 km^2 in area, is situated in the eastern part of the Pauzhetka volcano-tectonic depression in the south of Kamchatka. In the last years extensive geological surveys and experimental studies were carried out in the area. They provided a thorough insight into the stratigraphy, structure, and volcanism, even though some points are still in dispute [1], [3], [6], [7], [8], [101, [12]. One of the questionable points is the origin and structure of the lake and of the Pauzhetka depression as a whole. Earlier [61, gravity measurements were made around the lake and on its islands; they indicated a gravity low. In 1978 an airborne magnetic survey was carried out and in 1979-1980 the lake floor was surveyed with an echo sounder. In spite of the far-spaced echo profiles and inadequate ground control, the echo survey revealed important features in the lake-floor topography [7].

In 1981-1983, Lake Kurilskoe was surveyed in detail by continuous seismic profiling (CSP) to study the lake-floor morphology and subbotom geologic structure. A total of 600 km of CSP lines were surveyed. A map showing location of the lines is presented in Figure 1. This paper presents the results of geological interpretation of the CSP data.

STRUCTURAL SETTING AND GEOLOGIC HISTORY OF THE PAUZHETKA VOLCANO-TECTONIC STRUCTURE

Previous investigators [6], [10] placed the Pauzhetka structure among the largest and oldest geologic features of Kamchatka. It is a low-relief dome of tectonic and volcanic origin, 35x55 km in size, with a depression in the middle measuring 20x25 km in area and 650 m in depth (Figure 2). The larger part of the structure is located in the

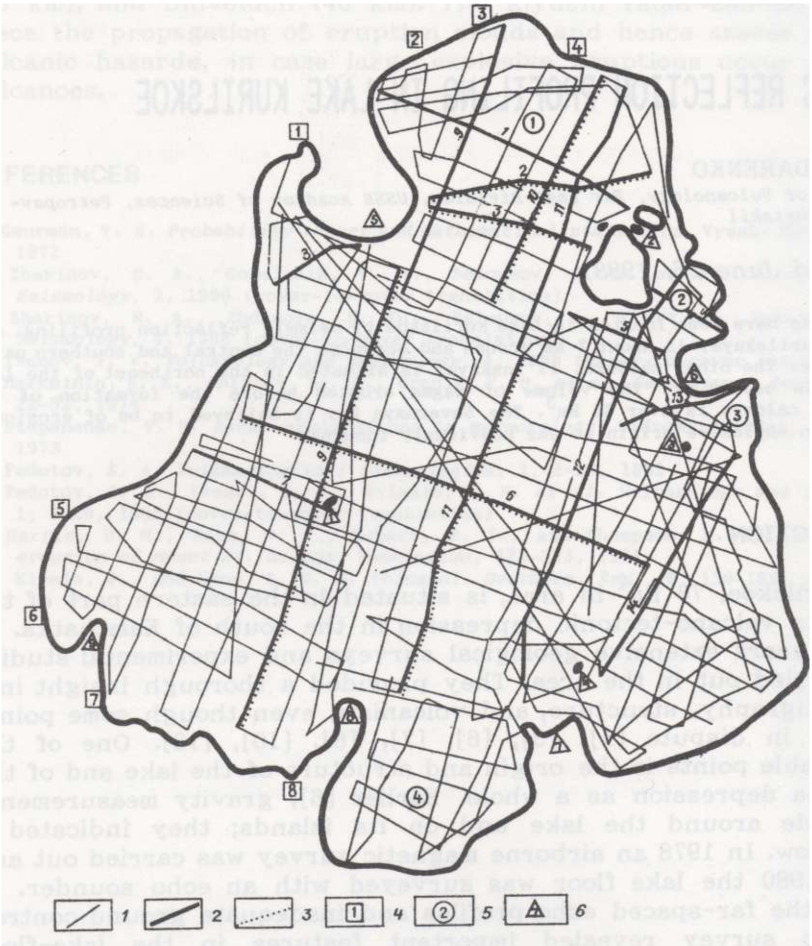

Figure 1 Location of seismic reflection profiles. 1 – reflection profiles; 2 – profile portions whose reflection sections are demonstrated in Figure 4; 3 – profile portions displayed in Figure 5; 4 – boxed figures indicate locations of the mouths of rivers flowing into the lake (mentioned in the text): 1 – Ozernaya R., 2 and 3 – Severnaya-1 R. and Severnaya-2 R., 4 – Vychenkiya R., 5 – Kumnynk R., 6 – Etamynk R., 7 – Khakytsin R., 8 – Kirushutk R.; 5 – circled figures denote bays: 1 – Severnaya, 2 – Zelenaya, 3 – Teplaya, 4 – Gavryushka; 6 – figures in triangles indicate capes and islands: 1 – Alaid's Heart I., 2 – Samang Is., 3 – Nizkiy I., 4 – Chayachiy I., 5 – Cape Pulomynk, 6 – Cape Teplyi, 7 – Cape Glinyanyi, 8 – Cape Tugumynk, 9 – Cape Siyushk.

southern end of a NE-trending trough in the Cretaceous basement, known as the Kambalno-Gorelovsky graben after Aprelkov *et al* [1]. The Cretaceous basement is lowered to a depth of 3.5 km or more and

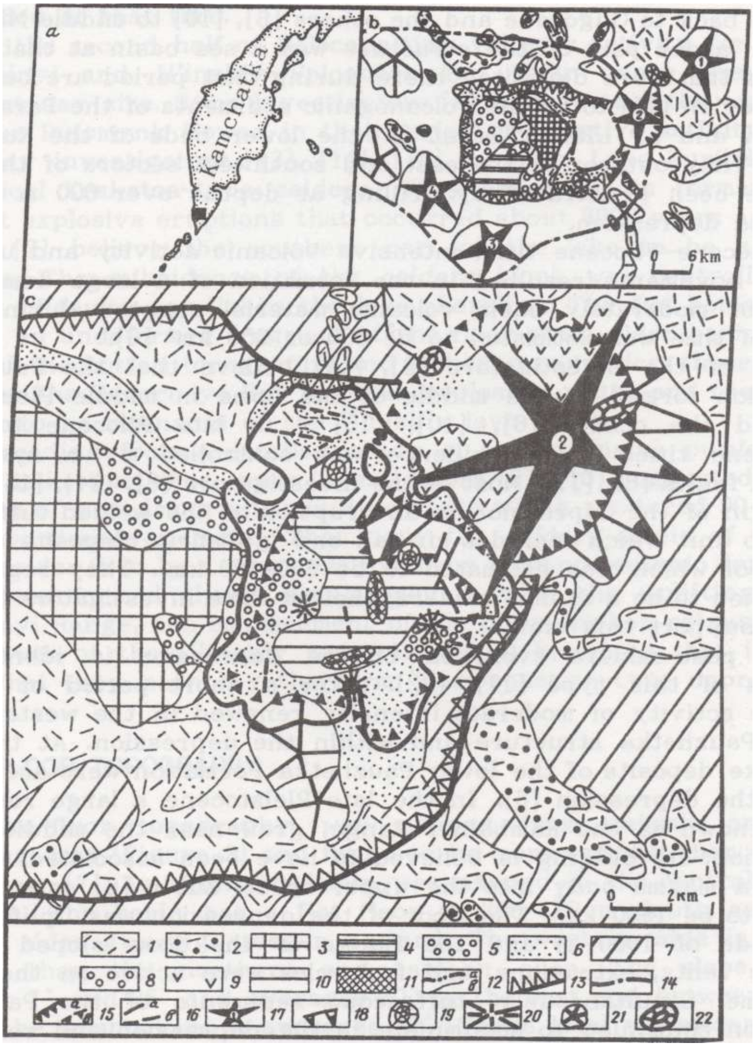

Figure 2 Location of study area (a), map of Quaternary volcanics (b), and geologic map (c). 1 - pumice; 2 - ignimbrite; 3 - Dikiy Greben; 4 - Kambalnyi Range; 5 - Pauzhetka Formation; 6 - recent sediments; 7 - Tertiary; 8 - slump; 9 - lava flow; 10 - central basin; 11 - hydrothermal activity; 12 - outline of Lake Kurilskoe: a - in Figure 2 b, b - in Figure 2 c; 13 - limits of Pauzhetka depression; 14 - Limits of Pauzhetka volcano-tectonic structure; 15 - caldera-forming faults: a - proved, b - inferred; 16 - other faults: a - proved, b - inferred; 17 - recent volcanoes: 1 - Zheltovskiy, 2 - Il'inskiy, 3 - Kambalnyi, 4 - Koshelevskiy; 18 - remnants of Il'inskiy old cone; 19 - lake-floor pumice (cinder) cone; 20 - extrusion; 21 - Pleistocene volcano; 22 - explosion crater. Maps (b) and (c) were prepared by the writer using data from [6], [8] and [10].

is deeper there than in the other places of the graben [6].

Some investigators [8], [15] trace the geologic history of the structure back to Oligocene and the others [6], [10] to middle Miocene time. The larger part of the structure was a sea basin at that time; the rocks that were deposited there during that period are believed by Sheimovich [15] to be the volcanogenic sediments of the Paratunka Formation and by Litasov *et al.* [6] the lower beds of the Kurilsky complex. They outcrop in the east and southwest sectors of the lake and have been penetrated by drilling at depths over 600 m in the Pauzhetka depression.

In Miocene-Pliocene time, intensive volcanic activity and upward tectonic movements resulted in the formation of a large dome. The volume of moderately basic volcanic material erupted during that period of time was estimated to be 600 or 650 km^0 [6].

Some of the investigators [8], [14] believe that the Pauzhetka depression formed in the middle of the dome in middle Pleistocene time and the others [6], [10], [15] - in late Pliocene to early Pleistocene time. The subsidence was controlled by a system of regional faults [6], [12]. Most of the investigators [8], [14], [15] relate the origin of the depression to an eruption of the welded tuff of the Golygino unit which includes air-fall and ignimbrite deposits and the volume of which was estimated to be 300-450 km . They regard the depression to be a typical caldera, though some investigators [6], [10] do not support this view.

The post-caldera evolution of the depression is identical to calderas of this type [17], [22]. After a short period of repose, volcanic activity of moderate intensity renewed in the western part of the Pauzhetka structure and within the depression. At the same time, lake deposits of the lower Pauzhetka Formation were accumulating in the depression [6]. In the late Pleistocene a large resurgent dome, known as the Kambalnyi Range, grew near the middle of the depression. Its bulging is believed to have been associated with the rise of a magma body into the upper crust. Zubin [6] estimated its volume to be 1500 km . The floor of the depression was uplifted to a magnitude of 1000 m and the flanks of the dome sloped at 30°. Volcanic vents, extrusions, and fumaroles were active on the top of the dome. Simultaneously, tuffaceous sediments of the Pauzhetka Formation continued to accumulate in the depression and reached a thickness of 650 m [6]. The cone of Il'inskiy Volcano grew during that period of time.

In early Holocene time volcanic activity in the Pauzhetka structure grew more intense. A complex extrusive body, probably a resurgent dome, known as Dikiy Greben, was formed east of the Kambalnyi Range. Its bulging brought the Miocene sediments and volcanic rocks to the surface; they outcrop in the southwest sector of the lake at the foot of Dikiy Greben [6]. Approximately 8000 years ago an outbreak of acid lava eruptions took place in the eastern part of the depression. A 120- or 130-meter pumice cover was deposited around the lake and Il'inskiy Volcano [6], [7]. Two calderas were formed: one in what is now Lake Kurilskoe and the other on Il'inskiy Volcano. The rhyolite bodies that fringe the lake are believed to have been extruded at that time.

In the second half of Holocene time volcanic activity continued on Kambalnyi and Il'inskiy Volcanoes and their cones grew to the present-day size. Some investigators [6] believe that the welded tuff of Cape Pulomynk flowed in that period of eruptive activity.

Many investigators [13], [14], [15] consider Lake Kurilskoe to be a typical Krakatoa-type caldera. They associate its formation with violent explosive eruptions that occurred about 8000 years ago. Zubin *et al.* [7] believe the southern part of the lake to be a collapse caldera. The subsidence of the caldera block was controlled by a system of faults parallel to the lake shoreline. The flat bottom of the lake is an undeformed fragment of the floor of an older basin. On the basis of the bottom topography and airborne magnetics, these authors consider the Severnaya Bay to be an explosion crater and the Samang Islands to be remnants of the Il'inskiy lava flows.

Proceeding from a detailed study of the extensive pumice fields around Lake Kurilskoe, some investigators [6], [101 suggested several locations of most important eruptive vents which produced 90 percent of the pumiceous material. They deny the caldera origin of the lake and consider it to be a compensation-type volcano-tectonic depression which was formed almost simultaneously with the uplifting of the Kambalnyi Range, the emplacement of the Dikiy Greben extrusion, and the growth of the iPinskiy cone. It should be noted that it is not clear what they meant by the term "compensation-type depression".

LAKE-FLOOR TOPOGRAPHY

The lake-floor topography was mapped from seismic and echo sounding data (Figure 3) and found to be more complex than believed previously [71. An extensive basin was mapped in the central part of the lake. The basin has a flat floor at 300-320 m depth and step-shaped sides growing steeper upward. The western side is notably gentler than the northern and eastern ones. The slope ranges between 7° and 35° and averages 20° in the east and between 5° and 20° in the west where it averages 10°. Three local elevations, known as the Alaid's Heart, Chayachiy, and Tugumynk extrusions, extend into the basin. The basinward sides of the extrusive bodies are very steep, 40° to 60°. Two canyons were mapped in the western side of the basin. One of them extends from the Ozernaya River source into the basin floor. It is as deep as 130-150 m in some places. Its fan forms a gently sloping landform rising above the flat floor of the basin. The second canyon extends eastward from the mouth of the Kumnynk River to the basin floor. An extensive positive landform, a large alluvial fan of the Etamynk and Khakytsin Rivers was mapped near Cape Siyushk.

The central basin is connected with Gavryushka Bay by a narrow

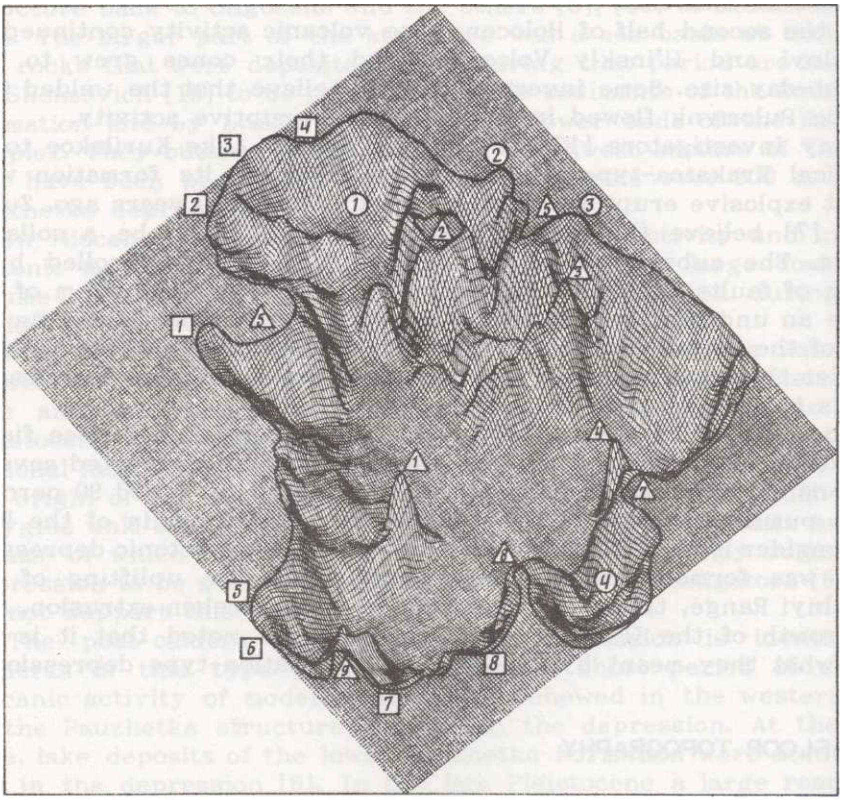

Figure 3 Lake-floor topography plotted by A. Palueva, Computer Center, Institute of Volcanology. For explanation of figures see Figure 1.

depression 270 to 300 m deep. The bay has a cirque-like form, its east and west sides being very steep and south side very gentle. It has a maximum depth of 300 m in the north.

A basin with a maximum depth of 260 m was mapped in the northeast of the lake, near the Zelenaya and Teplaya Bays. It is separated from the central basin by a narrow subaqueous ridge less than 180 m deep which extends from the east shore of the lake through Nizkiy I. to the Samang Islands.

The Severnaya Bay is separated from the central basin by an isometric mount rising to a height of 110-200 m above the lake floor and having a minimum water depth of 105 m. An absolutely flat and even area having a depth of about 210 m borders it on the north. This area is restricted in the east by the steep sides (max 45°) of Samang Island. Two canyons 1.5 to 2 km long were mapped in the western half of the bay. They extend eastward from the mouths of the

Severnaya-1 and Severnaya-2 Rivers and are divided by a narrow subaqueous ridge. The Vychenkiya River alluvial fan was mapped as a gently sloping apron on the north slope of the bay.

GEOLOGIC STRUCTURE OF THE LAKE FROM FROM SEISMIC REFLECTION PROFILES

Seismic data indicate that the subbottom sediments in the central basin comprise two sequences (Figure 4 and 5; profiles 6, 9, 11, 12 and 14). The upper sequence consists of flat-lying sediments which are marked on seismic records by numerous, long lineups of high reflectivity and marked on-strike persistence. This sequence varies in thickness from 90 to 160 m.[d] Its seismic pattern changes gradually nearing the west shore of the lake. The record becomes less regular and short, often randomly oriented lineups appear. The sequence grows thicker in the same direction. Some reflection profiles show rather distinct, acoustically uniform wedge-shaped bodies which seem to be voluminous subaqueous slumps (see profiles 6 and 7 in Figures 4 and 5). The fact that the bodies occur at different stratigraphic levels suggests that they were produced by more than one slumping event. The reflector identified as the base of the upper sedimentary sequence can be traced on some profiles as an undisturbed interface extending westward as far as 1.5 or 2 km beyond the area of its morphological expression. This evidence indicates that the sediments that accumulated there consisted of huge amounts of loose, unsorted material transported from the Dikiy Greben ridge and a minor amount of material produced by slumping, Some profiles (e.g. profile 6 in Figure 4) show that the supply of material from Dikiy Greben decreased with time. In the southwestern part of the lake the margin of the central basin is overlain by acoustically semitransparent deposits of the Khakytsin and Etamynk Rivers alluvial fans. A somewhat smaller fan was produced by the Kirushtk River.

The seismic records show distinct wedge-shaped, acoustically uniform bodies also at the base of Cape Glinyanyi and Cape Tugumynk. They resemble the wedges from the western part of the lake and are interpreted as large slumps. Particularly large is a wedge in the Cape Glinyanyi area which outcrops at the lake floor at depth less than 300 m near the shore (see profiles 9, 11 and 12 in Figures 4 and 5). The bottoms of the wedges occur on the same level with the base of the upper flat-lying sequence the sediments of which overlie the wedges. This indicates that slumping occurred immediately before the deposition of the flat-lying sediments and was an active process.

The seismic pattern of the lower sedimentary sequence shows rather long reflectors of weak or moderate reflectivity which break it into several comparatively uniform beds. They form a fan which

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[a] Here and below the sound velocity in the sediments is assumed to be 2 km/s.

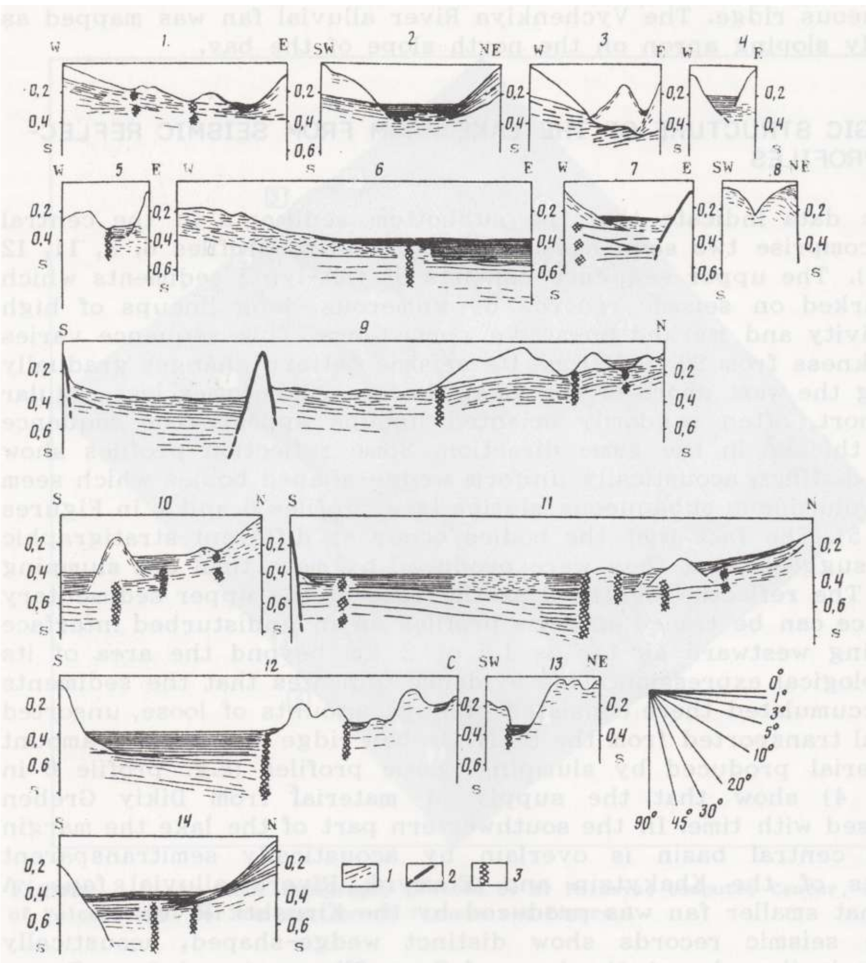

Figure 4 Reflection time sections. (See Figure 1 for location). 1 - reflectors; 2 - acoustic basement; 3 - fault.

opens out northward as they dip at a progressively larger angle with depth (see profiles 11 and 12 in Figure 4). The total thickness of the sequence is at least 400 m. We have not recorded its base. Apparently, it lies at a depth greater than the depth of penetration of the equipment we used. The observed pattern may be indicative of a rapid deposition of large portions of loose unsorted material without any significant intermissions in their supply. Deposition might occur in an asymmetrically subsiding basin, subsidence being most active in its northeastern part. The seismic records show distinct large faults in that area. They have magnitudes of displacement reaching

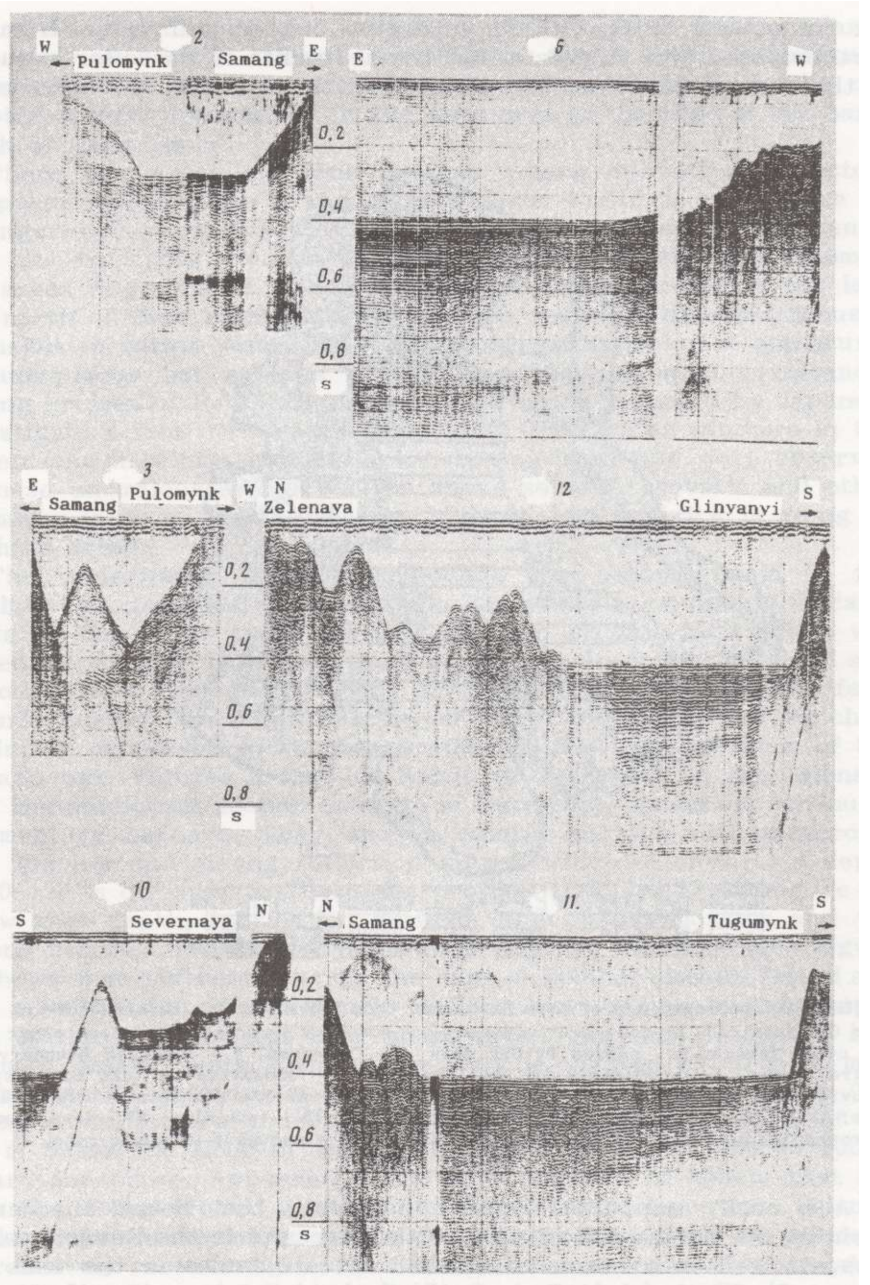

Figure 5 Portions of seismic reflection profiles (see Figure 1 for location).

hundreds of meters and bound the basin in the north extending approximately in the W-E direction (Figure 6). They cut the rocks of the underwater ridge which separates the central basin from the northern one. This suggests that the sediments of the lower sequence in the central basin are not older than these rocks.

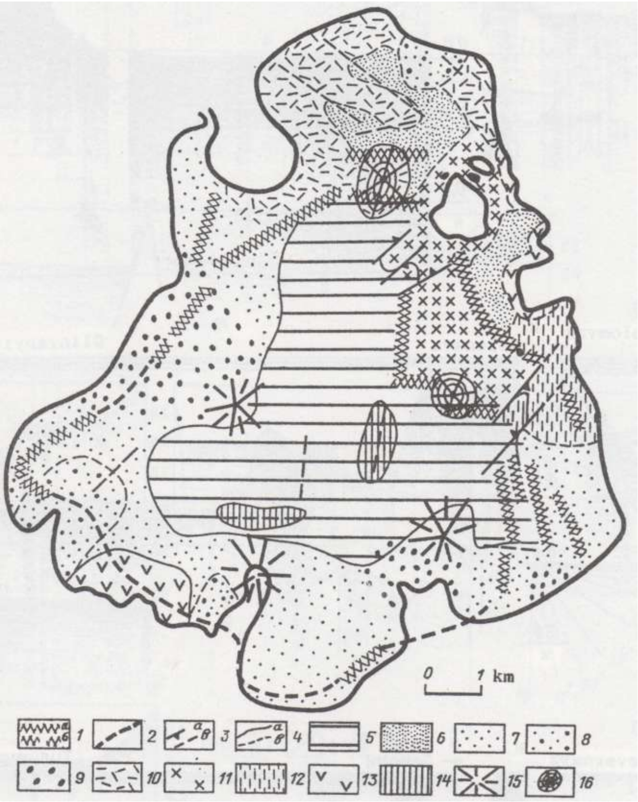

Figure 6 Geologic map of Lake Kurilskoe from CSP data. 1 - caldera-forming fault from CSP data: a - proved, b - inferred; 2 - boundary fault inferred from other data; 3 - other faults: a - proved by CSP data, b - inferred; 4 - geologic boundary; 5 - central basin; 6 - sediments in small basins; 7 - sediments on lake margins; 8 - alluvial fan; 9 - slump; 10 - pumiceous pyroclastics; 11- remnants of old Il'inskiy cone; 12 - loose material of recent Il'inskiy cone; 13 - lava flow; 14 - area of modern hydrothermal activity; 15 - extrusion; 16 - small subaqueous volcanic cone.

Also easily mappable are the ring faults that bound the central basin in the northwestern part of the lake and in the Severnaya Bay area, as well as a series of smaller arcuate faults in the east, (see Figure 6). In the west and south of the lake, boundary faults can only be inferred from or have not been detected by seismic data. It is not unlikely that they are masked by thick slumps or alluvial deposits. Fragments of such faults have been traced there from airborne magnetic data [7]. The northeastern side of the basin is disturbed by graben-shaped troughs southwest of the Samang Islands and east of Nizkiy Island (see Figure 6). A small acoustically transparent hill, possibly a cinder or pumice cone produced by one eruptive event, was mapped in the same area at the edge of the basin south of Cape Teplyi.

There are areas on some profiles where subbottom reflectors disappear (see profiles 6 and 11 in Figures 4 and 5, and Figure 6). Stronger reflectors appear there within the sedimentary sequence; they are especially pronounced in the behavior of multiples. Anomalous areas of this kind are most extensive in the middle of the lake and north of Cape Tugumynk, where echo sounding detected acoustic anomalies in bottom water [9]. The anomalies resemble the signatures of subaqueous hot springs recorded on some submarine volcanoes during cruises of R/V *Vulkanolog* [4] and those reported by Japanese investigators from the Aira caldera [16]. Open water windows in the frozen lake in winter and early ice melting in spring were observed in these anomalous areas [91. The above seismic, acoustic and other anomalies indicate that submarine hydrothermal activity is going on in these areas.

The underwater ridge that bounds the central basin in the northeast is composed of acoustically impermeable, obviously volcanic rocks. In the north the ridge is cut by an arcuate fault which was traced by the CSP data from the Samang Islands to Nizkiy Island and in some places, though with less certainty, east of Nizkiy. The fault extends further toward the scarp of the Il'inskiy caldera which is distinctly expressed in the topography of the eastern flank of the volcano (see Figures 2 and 6). North of this fault, in the Zelenaya Bay, the subbottom section consists of flat-lying, stratified, obviously sedimentary deposits. They show a seismic pattern with numerous, long lineups and strong reflection signal, which extends to a depth of 80-100 m on some profiles (see profiles 4, 5, 12, 13 in Figure 4). Below that depth, correlation between lineups deteriorates and the record becomes dominated by irregular signals. Profile 4 (see Figure 4) shows that sediments overlie the base of Bolshoi Samang Island and that a wedge-shaped acoustically uniform body occurs in the eastern part of the profile at the base of the lava flows that descended into the lake from Il'inskiy Volcano. The body is covered by 40 to 60 m of sediments and outcrops at the lake bottom closer to the shore. The subbottom reflectors underlying the body in a depth interval of 60-100 m below the floor of the basin extend as far as 100 to 300 m toward the shore. Apparently, the body consists of debris that fell from the steep frontal part of the Cape Teplyi lava flow. A small thickness of the sediments at the foot of the flow (40-60 m) points to its relatively recent origin. The CSP data do not indicate any relation between the Samang Islands and the Cape Teplyi lava flows.

The eastern part of the basin is filled to a great extent by the material of the present-day cone of Il'inskiy Volcano. These deposits overlap the side of the basin in the easternmost part of the lake where its floor is lowered in a graben-shaped depression east of

Nizkiy Island. Relations between these deposits and the sediments filling the central basin can be seen on profile 14 shot along the depression (see Figure 4): the cone deposits and the basin fill sediments are interbedded near the edge of the basin at a depth of 50 to 120 m below its floor. The topmost basin fill sediments overlap the lower part of the cone.

The seismic reflection section from the Severnaya Bay is markedly different from the sections elsewhere. The lowermost unit consists of stratified, obviously sedimentary deposits mapped in the south and middle of the bay. Its top is marked on the CSP records by a reflection interface which has been traced over a large portion of the bay at depths of 250-350 m below the modern level of the lake. In the east of the bay this interface coincides with the bottom of the Samang Islands formations. The subaqueous base of the islands looks as a wedge-shaped body in the seismic pattern. It is not uniform but consists of consolidated effusive and extrusive rocks and unconsolidated deposits of volcanic and possibly rockslide origin. Some profiles show facies changes from the foothill deposits of the Samang Islands to the sediments identified over the larger part of the bay which seem to have been deposited simultaneously with the foothill material (see profiles 1 and 2 in Figure 4). The sediments vary from 50 to 150 m in thickness, are similar to the deposits underlying the Samang Islands, and seem to be of sedimentary or volcanic origin.

In the western part of the bay these sediments are overlain by a rather thick sequence of acoustically transparent rocks (see profiles 1, 2, 3, 9 and 10 in Figures 4 and 5). Practically everywhere they occur as bottom sediments. They have a maximum thickness in the Cape Pulomynk area and a not larger than 200 m thickness near the shore. They become thinner rapidly south and east of the cape and pinch out at 0.8-1 km from the shore. Their thickness decreases slowly in the northern direction, from 100-200 m on the submarine ridge between the canyons extending from the mouths of the Severnaya Rivers to a few tens of meters in the NW corner of the bay. The acoustically transparent sediments that were traced by the CSP data to the very shore were identified as pumice by a geological survey on Cape Pulomynk [61. Pumiceous deposits have been found to be widespread around the whole of the Severnaya Bay [6], [81, [10]. This supports the view that the acoustically transparent sequence consists of pumiceous sediments. The mode of occurrence of the inferred pumiceous sequence suggests that the source of pumice might be somewhere near Cape Pulomynk. The above mentioned canyons cut the whole of the pumice sequence and expose the underlying deposits in some localities.

No pumice has been found in the central and southern parts of the bay. Apparently, it was eroded, in some places together with the underlying deposits. Profiles 2 and 3 in Figures 4 and 5 show old erosional forms that cut the side of the central basin in the mouth of the bay. They reach a depth of 120-150 m below the present-day lake floor in the Severnaya Bay. They served as the routes along which sedimentary material was transported into the central basin. An acoustically transparent, nonmagnetic cone has been located in the mouth of the bay (see profiles 3 and 10 in Figures 4 and 5). It seems to be a monogenetic cinder or pumice cone similar to the Taketomi cone [51 or to the cinder cones of Ile-de-Sandre Volcano [2]. Its deposits overlie the pumiceous sequences of Cape Pulomynk and the Samang Islands. Apparently, the cone grew on a fault that bounds the central basin. The southern edge of the cone rests on its side. The topmost sediments of the basin overlap the piedmont of the cone, the base of the cone corresponding with their lower boundary. The cone does not exhibit any signs of erosion.

After the growth of the cone and the separation of the Severnaya Bay from the central basin, a sequence of sediments accumulated north of the cone: sediments filled old hollows produced by erosion and leveled the bottom in that part of the bay at a depth of about 210 m (see profiles 2 and 10 in Figures 4 and 5). The seismic records obtained from this part of the section show numerous, persistent, subhorizontal lineups of rather large amplitudes, typical of sedimentary sequences. The sediments vary from 60-80 m in flat areas to 100-150 m in old topographic depressions. A similar seismic pattern has been observed from a somewhat thinner sedimentary sequence in the middle of the canyon which originates in the mouth of the Severnaya-2 and Vychenkiya Rivers; the sediments accumulated after the canyon was dammed by the alluvial fan (see profile 9 in Figure 4).

DISCUSSION OF RESULTS

Most of investigators associate the origin of the Lake Kurilskoe basin with large explosive eruptions that took place about 8000 years ago. They believe that the voluminous eruption of pumice occurred at Il'inskiy Volcano at approximately the same time when the old cone of the volcano was destroyed and a caldera was formed. The CSP data indicate that the underwater ridge extending from the east shore of the lake through Nizkiy I. to the Samang Islands is a subaqueous continuation of the caldera rim, a remnant of the old Il'inskiy cone. The map in Figure 2 outlines a caldera 5 or 6 km across the existence of which was postulated earlier within approximately the same limits [8]. The basin expressed in the bottom topography in the north-eastern part of the lake is believed to be an area where the pumice cover was thinner than elsewhere.

The results of the CSP study carried out in the central basin of the lake can be summarized as follows.

1. The lower strata of the deposits filling the basin, at least several hundred meters thick, are younger than the old cone of Il'inskiy Volcano and older than its new cone. The sediments accumulated within a rather short period of time as a result of a rapid deposition of large portions of loose unsorted material in an

asymmetrically subsiding basin without significant intermission in the supply of sedimentary material.

2. The subsidence of the basin floor was controlled by ring faults whose magnitudes of displacement were in places as large as hundreds of meters. The boundary faults consist of arcuate and straight-line segments of approximately E-W and N-S trends inherited from the pre-existing regional fault system.

3. The period of time between the deposition of the lower sedimentary strata and the accumulation of the upper sequence was characterized by active sliding and slumping on the south and west sides of the basin.

4. The Alaid's Heart, Tugumynk and Chayachiy extrusive bodies were evidently emplaced along the ring fractures during approximately the same period of time.

According to geophysical data [7], the central basin shows a negative gravity anomaly and slightly negative magnetic values. This evidence suggests that the central basin of Lake Kurilskoe was formed as a caldera using the term "caldera" as it was defined by Kraevaya *et al.* [11], Sheimovich [15], Lipman [17], Oide [18], Williams [21], and other investigators. The caldera is similar to the well-known Crater Lake, Santorin and Krakatoa calderas [18], [21], [22]. Huge amounts of pumice were discharged during the caldera-forming eruption both from the central vent and from ring fractures on the flanks [6], [10]. As a result, thick pumice deposits were laid down around the lake (see Figure 2) and inside the caldera (lower sequence). The caldera is estimated to be about 45 km in area and at least 35 km3 in volume. Approximately 11 km of the total volume are occupied by the modern basin of the lake, about 6 km by the post caldera sedimentary deposits, and at least 18 km by the lower pumiceous strata of the central basin. When corrected for a density difference between pumice and magma [17], [21], [22], the total volume of the erupted material (the pumice around the lake estimated at 18-24 km [6], [14] and the pyroclastic material inside the caldera) turned out to be smaller than the volume of the caldera basin. Obviously, the volume of the erupted material has been underestimated.

The evolutions of the Kurilskaya and Il'inskaya calderas were different in the periods that followed. Intensive volcanic activity in the northeastern part of the Il'inskaya caldera resulted in the growth of a volcanic cone which filled it almost completely and overlapped part of its side. The CSP data contradict the previous view concerning a genetic relation between the Cape Teplyi lava flows and the Samang Islands. The islands are likely to be remnants of the old Il'inskiy cone or of lava bodies that were extruded or outpoured on the old cone remnants from the ring fractures.

The postcaldera period of the Kurilskaya evolution was dominated by the accumulation of sedimentary and volcanogenic material: 120 to 160 m of sediments have accumulated since the caldera formation. Assuming the age of the caldera to be 8000 years, the rate of sedimentation averages 15-20 m in a thousand years but was evidently higher immediately after the caldera formation and during the active growth of the recent Il'inskiy cone. By and large it is not different from sedimentation rates in calderas elsewhere, e.g., in Ayarza, Guatemala, [19] or in Lvinaya Past, the Kurils.

There is no evidence of volcanic activity in the Kurilskaya caldera since its formation except the growth of two small pumice (cinder ?) cones on the northern segment of the boundary fault. The CSP data indicated manifestations of hydrothermal activity on the caldera floor.

The CSP data did not confirm the proposition by Zubin *et ah* [7] concerning the explosive origin of the Severnaya Bay. The geological interpretation of the seismic data resulted in the identification of several stratigraphic units. The oldest rocks are the deposits that underlie the base of the Samang Islands, the old Il'inskiy cone, and the deposits synchronous with it. They are of Pleistocene age and can be correlated with the lake deposits of the Pauzhetka Formation [61. Next follows a stratigraphic unit supposedly consisting of pumice discharged by the caldera-forming eruption of 8000 years ago. It is not unlikely, however, that the pumiceous sequence in the Cape Pulomynk area was deposited somewhat earlier.

After the formation of the Kurilskaya caldera, intensive erosive activity took place in the Severnaya Bay. It was responsible, to a great extent, for the shaping of the present-day bottom topography. Obviously, the canyons located in the western part of the bay were formed in that period of time. The canyons that had existed in the south of the bay were transformed to one canyon which cut the caldera wall. The unconsolidated pumiceous deposits were removed and part of the underlying rocks eroded over an extensive area of the bay. Being a large-scale process, erosion did not last long. It ceased when a supposedly monogenetic volcanic cone grew at the entrance to the bay and the water level in the lake rose. Later, the bottom topography in the south of the bay was leveled by the sediments deposited behind the cone. An extensive and thick alluvial fan was deposited by the Vychenkiya River in the north. It dammed the Severnaya-2 River canyon in the middle and the dammed segment was filled with sediments.

CONCLUSIONS

1. Two calderas have been located in Lake Kurilskoe on the basis of the CSP data and other geological and geophysical evidence. One of them, Kurilskaya, is approximately 7 km across and occupies the central and southern parts of the lake. The other, Il'inskaya, is about 6 km in diameter and is restricted to the northeastern sector of the lake, the larger part being situated outside it.

2. The excavated volume of the Kurilskaya caldera and the volume of the pyroclastics discharged during its formation, computed in terms of magma, exceed a value of 35 km . The magnitude of subsidence of

4the caldera floor along the ring faults amounts to several hundred meters. The process was terminated by the collapse of the southern and western parts of the caldera and by the extrusion of acid lavas along the boundary faults.

3. The postcaldera evolution of the Il'inskaya caldera was characterized by intensive volcanic activity in its northeastern part during the period of 4-6 thousand years that followed. Volcanic activity resulted in the growth of a new cone at Il'inskiy Volcano. An active process of sedimentation occurred in that period of time in the Kurilskaya caldera. Volcanic activity was very weak there. Evidence has been obtained that hydrothermal activity is still going on inside the caldera.

4. The bottom topography of the Severnaya Bay owes its origin to intensive erosion which took place immediately after the Kurilskaya caldera was formed, to the subsequent sedimentation, and to the growth of a subaqueous volcanic cone at the entrance to the bay. The CSP data contradict the explosive origin of the bay proposed earlier.

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