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New Evidence for the Structure of Conical Seamounts and Hills at the Foot of the Sea of Okhotsk Margin of the Kuril Island Arc: Continuous Seismic-Profiling Data

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Abstract—This paper is concerned with results from the interpretation of continuous seismic profiling (CSP) data that were acquired during the 21st cruise of the R/V *Pegas* in 1980. The data are of relevance for the structure of conical seamounts and sea-hills at the foot of the Sea of Okhotsk margin of the Kuril island arc. The seamounts are extrusive domes (volcanoes) or magmatic diapirs with thick sedimentary caps of contrasting (at the top) and transparent (at the bottom) Cenozoic deposits. They were mostly formed in the Cenozoic, largely during Pliocene to Quaternary time; they resulted from viscous magma being emplaced into the sediments. There are also several small, buried domes with flattened bottoms that were formed by liquid magma being emplaced into the sediments (laccoliths or subvolcanoes). We also touch on questions relating to the terminology, geography, and history of submarine volcanism in the region and its relationship to the Benioff zone.

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INTRODUCTION

The structure of conical seamounts and sea-hills, which are partly buried, that are found in the Sea of Okhotsk margin of the Kuril island arc or of its western zone (Gorshkov, 1967) and of the adjacent South-Kuril (Kuril) deep-sea basin has been studied by geological and geophysical techniques (bathymetric surveys, dredging, gravimetry and magnetometry, CSP, and CDP) since the 1950s–1970s (Bezrukov et al., 1958; Zatonskii et al., 1961; Ostapenko, 1976; *Stroenie* …, 1981; Kornev et al., 1982; *Geologo-geofizicheskii* …, 1987; *Tektonika* …, 2004). Many seamounts were given proper names (Vies, Gorshkov, Berg, Vavilov, and Lisnyanskii to name a few), others are identified by character strings (e.g., 162m, 6.1…). The seamounts are either discrete and multi-summit, frequently making chains and mountain massifs (*Geologo-geofizicheskii* …, 1987; *Podvodnaya* …, 1992). H.W. Menard (1964) proposed to classify seamounts in the Pacific Ocean as those standing more than 1 km above seafloor.[u1]

Livshits (1972) considered the buried domes in the eastern Deryugin Basin to be magmatic diapirs related the development of initial magmatism there (subvolcanoes and intrusions) to crustal extension.

Gnibidenko (1979) considered the conical seamounts in the Sea of Okhotsk as protrusions of the acoustic basement (which is composed of Mesozoic to Paleozoic volcanogenic–sedimentary rocks). At the same time, he noted that “…some basement protrusions in the sediments look like diapirs” (p. 45). The diapir origin of several seamounts (extrusive domes or volcanoes) was later supported by dredging and CSP data (Savostin et al., 1978; Kornev et al., 1982; Khomyakov et al., 1982; Lomtev, 2010). This can be detected from the uplift, penetration, and possible replacement of the Cenozoic rock sequence with magma, as well as from the absence of summit craters and of contrasting lava flows at the base. To choose an example, Belyankin Volcano is probably of extrusive origin. This volcano is composed of olivine basalts at the surface and penetrates the Cenozoic deposits, as can be inferred from CSP data (Rashidov and Bondarenko, 1998).

Most investigators consider conical seamounts and sea hills in the region to be young underwater volcanoes (Tuezov, 1977; *Stroenie …,* 1981; *Podvodnaya* …, 1992; Blokh et al., 2012], that is to say, accretionary lava and cinder structures, similarly to conical seamounts, sea hills, and abyssal hills in the Pacific seafloor (Menard, 1964). Some writers hold the view that these are of subaerial origin with subsequent immersion during Quaternary time (Ostapenko, 1976; Khomyakov et al., 1982; Emel’yanova, 2004).

We can thus see that different, frequently incompatible, views are held as to the structure and origin of conical seamounts and sea hills in the area of study. These geological features are related to the geology and history of volcanism at the Kurils and in the Sea of Okhotsk and the tectonics of the Kuril section of the Benioff zone, which is the greatest deep-seated, magma- and seismo-active section of the Benioff zone. Seismic profiling was carried out at frequencies of 80–100 Hz and at a speed of 5–7 knots (Kornev et al., 1982). The network of measurement lines is not ordered (Krasnyi et al., 1981), because the surveys were aimed at mapping exposures of the acoustic basement and their subsequent dredging (Fig. 1).

CSP DATA REVISITED

Conical seamounts. In CSP time sections (profiles, abbreviated PR below) these seamounts are identified as contrasting summits without any noticeable craters and semi-transparent vertical zones beneath these, as straight or slightly concave slopes that are composed of contrasting thin-bedded sediments and occasionally complicated by lateral cones, normal faults, or landslides. One may encounter at the base of seamounts occasional, buried, possibly still growing, domes and near-bottom flow-landslides that fill out small paleo-depressions. A new and key feature in the structure of the seamounts that so far have been studied is a slope cover that has not been heretofore described by investigators (see the references). The cover is identified in CSP lines mostly at the lower part of the seamount slope and near its base. The top of the slope cover is the surface of a local angular unconformity or, more rarely, that of gravitational slumping of the cover.

Individual seamounts at lines 55, 56. One of the best examples of a slope cover is furnished by a small (~1 km) conical seamount with straight (~10°), smooth slopes and without a summit crater that is 15 km across at the base, judging from primary reflection data. The seamount is traversed by line 55 near Raikoke I. (see Figs. 1, 2). Its slopes and summit are composed of thin-bedded sediments from the upper contrasting sequence of the Cenozoic sedimentary cover in the southern Sea of Okhotsk basin (slope cover); the thickness seems to be 1.0–1.5 s. The sediments lie parallel to the slope (line 83, see Fig. 2, see *Stroenie* ..., 1981). Deeper down and without a visible stratigraphic contact, these sediments are replaced with transparent sediments from the lower sequence of the cover. Consequently, this seamount is a young post-sedimentation extrusive dome (a magmatic diapir) that probably results from emplacement of viscous magma into the Cenozoic cover. However, the contrasting top of the penetration core is not recorded at line 55, that is, it lies deeper, beyond the region where reflections could be recorded. For this reason, should a well be drilled to depths of 1–2 km at the seamount summit, it would merely penetrate Cenozoic sediments (the sedimentary cap of the extrusive dome). Dredging the seamount would lift clastic material that would, whatever its composition and roundness, turn out to be allochthonous (ice rafting). We wish to emphasize that the slopes are smooth, as this can be used as a diagnostic sign of sedimentary caps on extrusive domes (clay in three dredged samples, see Krasnyi et al., 1981) compared with the obviously rougher slopes of the volcanic structures, e.g., Krylatka (Rashidov and Bondarenko, 2004).

In this context we wish to point out that the contrast in the upper rock sequence (1–2 km) of the Cenozoic sediment overlying the southern Sea of Okhotsk basin and the Sea of Okhotsk margin of the Kuril island arc after Seliverstov (1987) resulted from terrigenous sediments and local pyroclastics, including the erosion of the island-arc volcanoes. The latter appeared in the Late Miocene (10.5–11.0 Ma ago) on the Kuril Islands, judging from extensive bio- and radio-isotope dating of volcanic rocks sampled from Urup I. (Kovtunovich et al., 2004). The upper rock sequence was accumulating at a rate of 100–200 m/Ma in the L'vinaya Past' caldera, Iturup I. (Lomtev, 2010). The fact that the lower rock sequence (1–2 km) in the sedimentary cover, which is probably of Oligocene to Middle Miocene age (line 83, see (Chuiko et al., 1988; Vashchenkova, 2008; Bol'shakov et al., 1989)) may indicate the dominance of hemi-pelagic sediments or compaction of the same volcanogenic–terrigenous sediments, with layers becoming substantially thinner compared with the one-quarter wavelength, i.e., 3–4 m. The fact that the section is more transparent beneath contrasting mountain summits partly results from defocusing of seismic waves that are reflected at acoustic inhomogeneities beneath these convex summits.

Concluding our description of the mount at line 55, we note unconformities in near-bottom contrasting sediments at the base of the mount. For example, the unconformity on the right is probably due to the wall of the paleo-depression that was partly inverted during the formation of the mount. The unconformity on the left is a common occurrence for seamounts and sea hills (paleotopography), viz., the sediments that overlap the base of these seamounts. Since the sediments may be as thick as 0.6 s (~0.5 km with a compressional velocity of 1800 m/s), it follows that the total mount height as measured along the northern (left) slope would be ~1.5 km. As magmatic diapirs grow at a rate of 1–2 mm/y (Kukal, 1987), the mount's age must be 0.75–1.5 Ma (Early to Middle Pleistocene). When the age is determined from the rate of accumulation for bottom sediments (100–200 m/Ma) that overlie the mount's northern base, it would be somewhat greater (Middle to Late Pleistocene).

Near the above feature is one of the highest conical seamounts in the entire Sea of Okhotsk margin of the Kuril island arc. It was only partly traversed by line 56 owing to technical failures. The fragment of the seismic line shows its height to be in excess of 2.3 km (see Figs. 1, 2). The seamount is a regular stratovolcano in shape, but without a summit crater and with smooth concave slopes that look like a logarithmic curve in G.S. Gorshkov's phrase (Gorshkov, 1967). The flattened and possibly

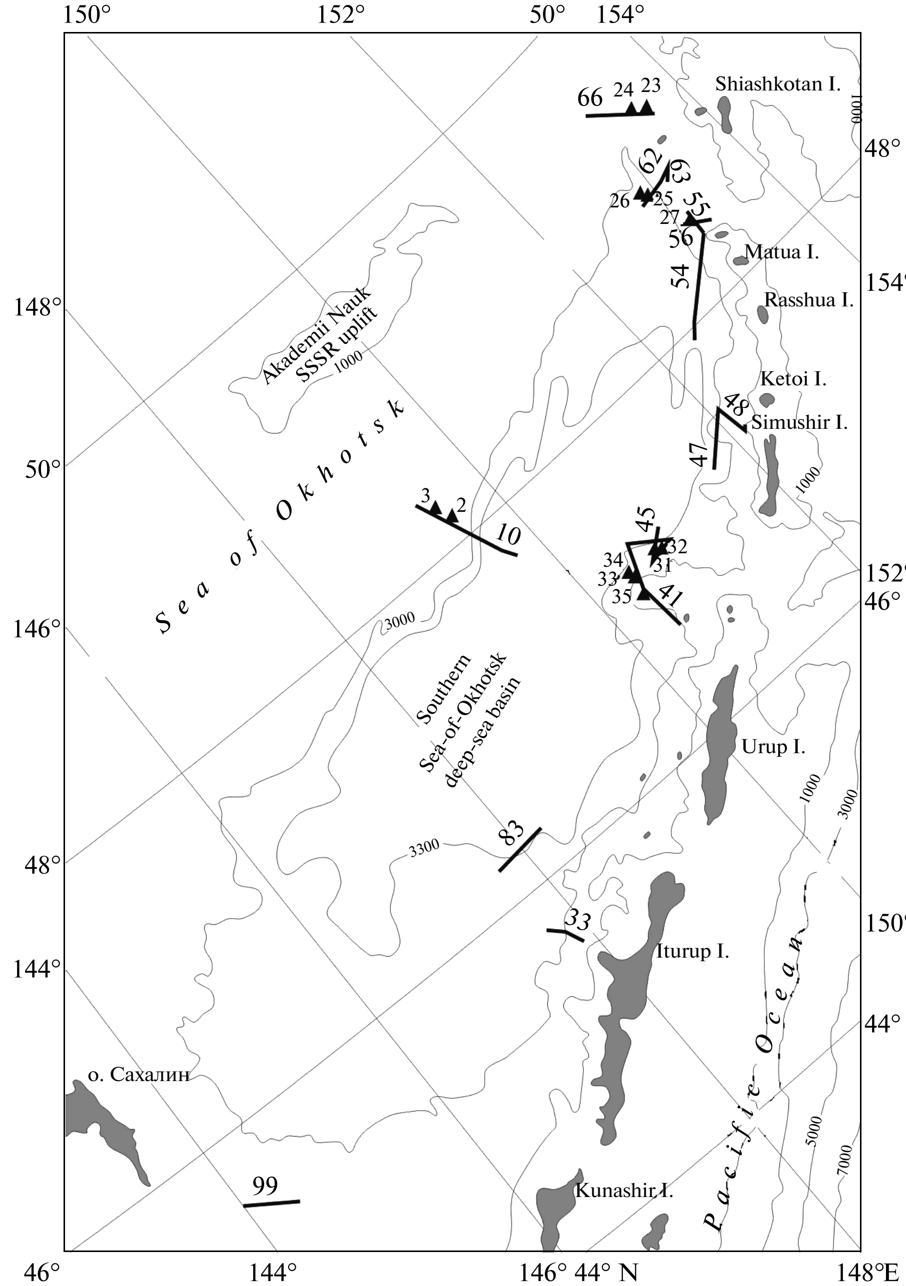


Fig. 1. A bathymetric map of the area of study with indication of CSP lines and dredging stations nearby (filled triangles) during the 21st cruise of the R/V *Pegas*-1980 (Krasnyi et al., 1981). The isobaths are in meters.

eroded summit (guyot bench) about 2 km in diameter is composed of horizontally lying contrasting sediments. The left slope of the mount contains a thin-bedded slope cover of visible thickness ~1 s whose layers of contrasting sediments lie parallel to the bottom (slope). The near-summit part of the mount has a contrasting aspect, while the underlying section is semi-transparent. By analogy with the preceding example, we may conclude that this conical mount (guyot?) is the sedimentary cap of a post-sedimentation extrusive dome (a magmatic diapir) that resulted from viscous magma being emplaced into the sedimentary cover. A fragment of the top to its penetration core can be tentatively identified at the 17 km recording site where low-contrast intermittent reflections appear at a time of 4.6 s, i.e., 3.7 s under the bottom, about the thickness of the Cenozoic sedimentary cover in the southern Sea of Okhotsk basin (Gnibidenko, 1979; *Tektonika* ..., 2004). It is of interest to note that the cover is appreciably thicker under the summit of that mount compared with the left slope (~3 and 2 s, respectively).

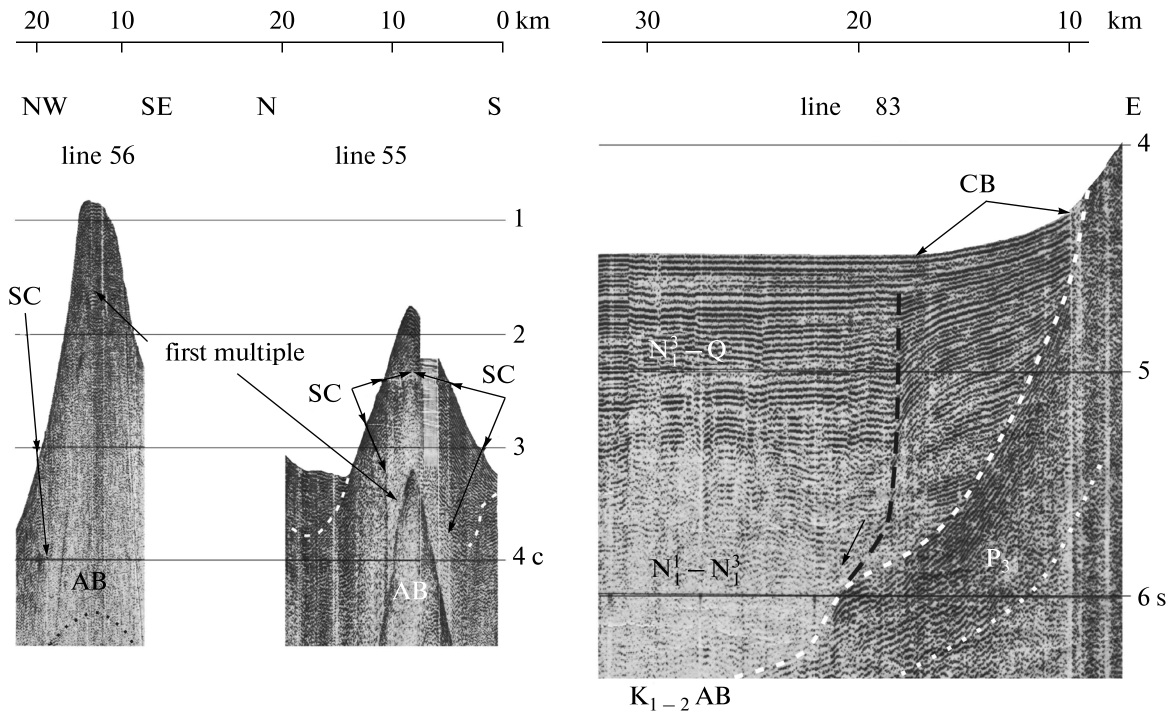


Fig. 2. CSP lines 55, 56, and 83 illustrating discrete extrusive (EX) domes with thick sedimentary caps and the stratigraphy of the Cenozoic cover and the top of the acoustic basement (AB).
SC, slope cover; CB, continental base; dashed line shows the surface of unconformity, small filled (left) and unfilled (right) circles mark the top of the penetration core; dashed line with an arrow beside it show a normal fault and the direction of slip. The vertical scales here and in Figs. 3 through 8 are in seconds of double travel time, the horizontal scale is in km.

The time of formation for the dome can be roughly evaluated as the late Pliocene to Early Pleistocene based on the rate of growth of magmatic diapirs (Kukal, 1987) or on the curve of paleo-Pacific depths with a delayed depth at –1 km in the Late Miocene to Early Pleistocene (Hoshino, 1986).

Seamount chains. Consider the structure of the chain of isolated conical seamounts and of the twin one (Obruchev Volcano (Krasnyi et al., 1981; Kornev et al., 1982)) at lines 41–45 at the base of the Sea of Okhotsk margin of the Kuril island arc north of Brouton I. (see Figs. 1, 2). The seamounts are more than 1–2 km high; they are 15–30 km in diameter, with the slopes dipping at ~15°. One key element in their structure also consists in slope covers that overlie all the seamounts except the northernmost one (line 45), with the covers being continuously followed beyond saddles. Their top at this location is a surface of an angular unconformity at the bottom of a horizontally lying intermontane near-bottom lenses of contrasting sediments that are 0.2–0.4 s thick (~0.2–0.4 km with a compressional velocity of 1800 m/s). Accordingly, that additional depth must be added to the total seamount height. At all the measurement lines the slope sedimentary covers can be followed as far as the summits in the form of stratified (parallel to the bottom) sediments in the lower and middle parts of the slopes and as a chaotically stratified contrasting sedimentary cover in the near-summit parts of the seamounts. For this reason, we must infer, similarly to the first case, a young, post-sedimentation age for the extrusive seamounts in this chain, which came into being as viscous magma was emplaced into the Cenozoic sedimentary cover.

It should be noted that the sedimentary cover rises onto the seamount slopes without any changes in thickness and even with the same number of phases. However, it appears to be thinner-bedded in the time section, giving an impression of a different character of its stratification and thickness. This difference in the images of the same sedimentary cover in intermontane troughs and on seamount slopes is due to differences in wave propagation in horizontally and obliquely layered media and to records of these in the time sections. For example, the seismometers record reflections that propagate parallel to the interfaces, while the respective times of the arrival are plotted along the vertical. In the time sections, this produces a shift of the boundaries of dipping beds relative to the horizontal ones, upward and downward along the dip. This displacement of dipping interfaces has been called migration. Moreover, a sequence of dipping beds experiences a shortening by the value $\delta t = 2H(1 - \cos\alpha)/V$ where H is the thickness of the sequence, α is the dip slope, and V is

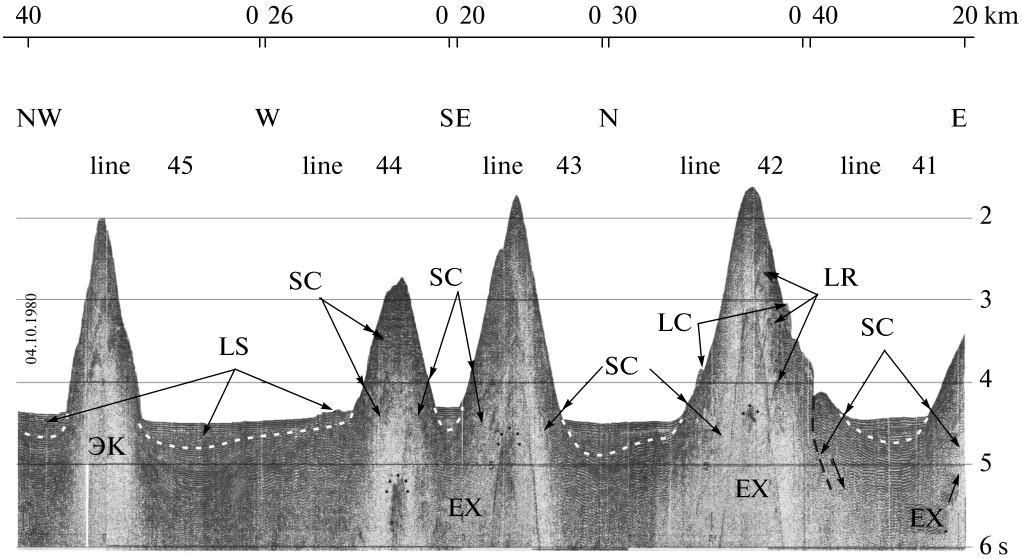


Fig. 3. CSP lines 41–45 illustrating the structure of a chan of extrusive conical seamounts. LC denotes lateral, probably extrusive, cones, LR stands for lateral reflections, LS denotes a small landslide at the base of the mount on the right of it and flow landslides; for the other notations see Fig. 2.

the interval velocity. This shortening of dipping beds is commonly overlooked by investigators. However, it not only affects the character of the layering, but also can result in complete loss of phase correlation for larger angles of the dip, even when a plane-layered sequence of beds is in question.

The thinning (by factors of 1.5–2) of beds in the upper rock sequence that underlie the surface of the unconformity of the sedimentary cover toward the northern seamount at line 45 has recorded a con-sedimentation regime of viscous magma emplaced into the cover. The top of the penetration core seems to lie deeper than 1–2 km, there also, apart from the southern seamount (Vavilov Volcano (Krasnyi et al., 1981; Kornev et al., 1982)) with several lateral, probably extrusive, cones on the slopes (mostly on the southern one). There is a local transparent spot at line 41 in the transparent section under its summit at 4.3 s level, with this spot probably pointing to the top of the penetration core. The seamounts can be dated from the mean rate of growth of magmatic domes (1–2 mm/yr) and from the rate of sedimentation (100–200 m/Ma) for sediments in the intermontane lenses (see above). This would be 0.5–3.0 Ma in the former case and 1 to 4 Ma in the latter, which is similar to radio isotope datings of the volcanic rocks (0.9–4.1 Ma) that were dredged from conical seamounts in the southern Sea of Okhotsk basin (Emel'yanova and Lelikov, 2010).

At the same time, there are older forms at lines 83, 62, and 63 (see Figs. 1 and 2, Table 4). For example, the slope cover on the pre-Miocene seamount (paleo-topography) at line 83 is composed of Oligocene marine deposits, while the underlying acoustic basement consists of subaerial Cretaceous traps in the Sea of Okhotsk plate (Lomtev et al., 2002), when inferences are based on materials from parametric drilling conducted in the northern Sea of Okhotsk deep (Bol'shakov et al., 1989). Another example is furnished by lines 62 and 63 that traverse a complex-structured, two-summit sea hill or an almost buried seamount (see Fig. 4). Its slopes are overlain by Cenozoic sediments 1.5 s thick (~1400 m, assuming the compressional velocity to be 1800 m/s). With the above rate of contrasting sedimentation, one may date the structure as Middle to Late Miocene.

Summing up, we wish to give a brief account of lines 66, 47, and 48 (see Figs. 1, 4, 5). The first of these lines traverses one of the cones of a two-summit conical seamount that stands about 1.8 km high in the Atlasov Deep northwest of Shiashkotan Island. It has a contrasting section, a semi-transparent zone under it, and relatively smooth slopes. At the base of the northwestern (left) slope it has layers of sedimentary filling of the deep rising onto it, or else the layers consist of a correlate complex that is bounded by an angular unconformity at the bottom. The complex or the slope cover of this seamount is 0.6 s thick (~0.5 km assuming a compressional velocity of 1800 m/s). The slope cover when studied at the base of the southern (right) slope is, unlike the situation on the left slope, draped by contrasting sediments of the near-bottom lens 0.4 s thick (or ~0.35 km), which lie nearly horizontally and with an angular unconformity at the base. Consequently, this cone too is an extrusive dome (a magmatic diapir) with a thick sedimentary cap. The cone resulted from viscous magma being emplaced in a con-sedimental manner into the Cenozoic cover. The dome stopped growing (paleo-topography), because its age as determined from the rate of growth for magmatic diapirs

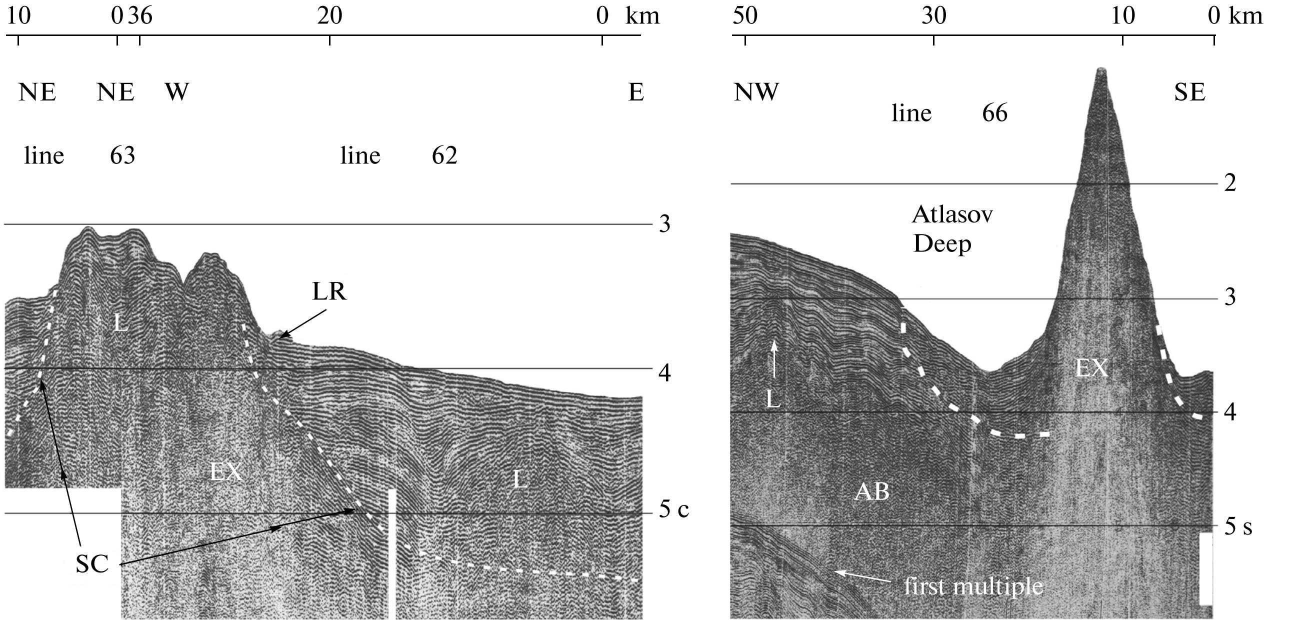


Fig. 4. CSP lines 62, 63, and 66, which illustrate the structure of laccoliths (L) or of subvolcanoes and of a cone of the two-summit extrusive mount in the Atlasov Deep.
For the other notations see Fig. 2.

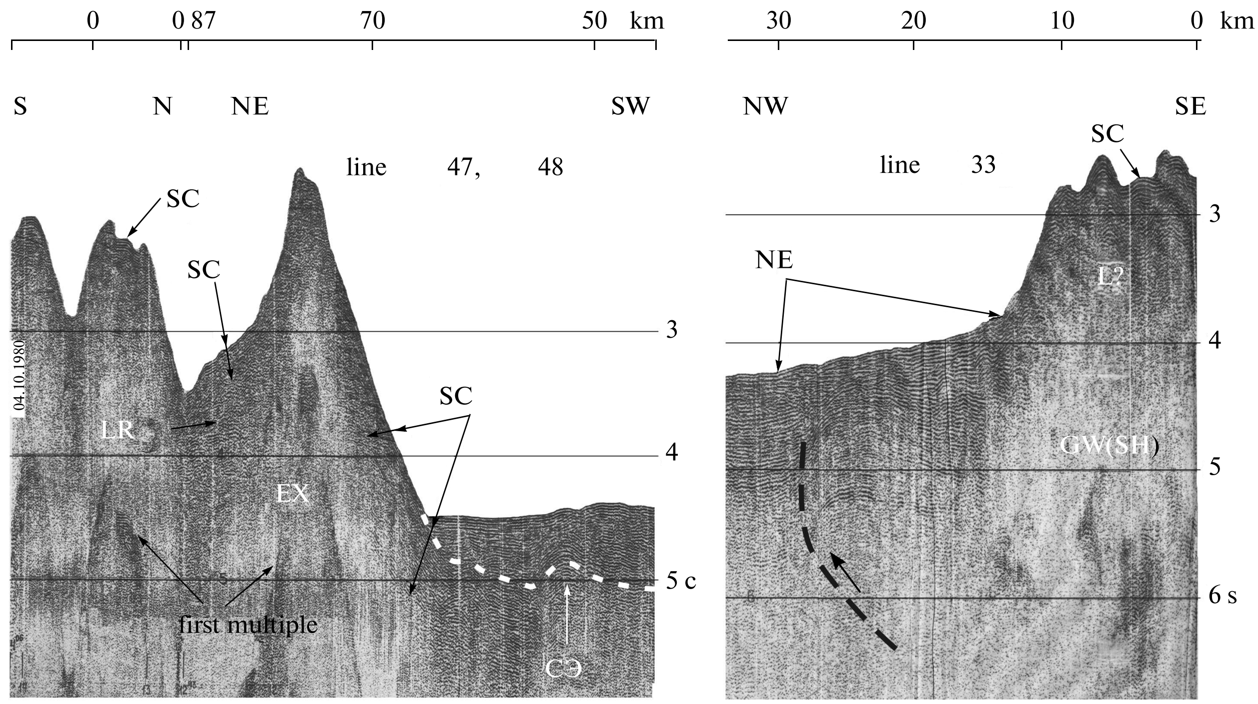
(see above) reaches 0.9–1.8 Ma (the Late Pliocene to Middle Pleistocene). When we try to find the age from the rate of deposition for the near-bottom lens contrasting sediments (see above), we obtain a higher figure, 1.75–3.5 Ma (the Late Pliocene).

Lines 47 and 48, which pass near the northern end of Simushir I., traverse the margin of a massif at the base of the Sea of Okhotsk margin of the Kuril island arc (see Figs. 1, 5). The massif consists of a set of conical seamounts and sea hills. At line 47 one can mention a young and possibly still growing blind extrusion of probably viscous magma near the 50 km distance, the only one in the CSP materials discussed here, and an appreciable (by a factor of nearly 2) difference in height between the outer slope of the massif and of the conical seamount at its base on the one hand and the slopes of the inner cones. The seamount base measures 23 km at the base, its height is ~2 km, and the outer slope dips at ~11°. At the base of the latter the slope cover is draped by contrasting near-bottom sediments 0.5-s (or 450-m) thick that are nearly horizontal and involve an angular unconformity at the bottom. The seamount has a contrasting, possibly abraded, summit and smooth, in part differently dipping, slopes (below 3 s or 2250 m). By analogy with the foregoing examples this can be regarded as the sedimentary cap of an extrusive dome (magmatic diapir) that results from viscous magma being emplaced into the cover. Two cones within this massif at line 48 also possess contrasting summits and smooth slopes (sedimentary caps of extrusive domes). The summit crater on one of these is possibly related to the sliding of sediments localized in the intermontane depression, possibly at the opposite slope, which dips at a lower angle.

Summing up the foregoing CSP data and their interpretation, we may emphasize the fact that the slope covers of the conical seamounts and the underlying Cenozoic cover have no contrasting lava flows or major pyroclastic discharges with rough seismic facies as inferred by Seliverstov (1978) and Bondarenko (1991), respectively, from CSP observations. Consequently, the emplacement of viscous magma into the Cenozoic cover and the formation of extrusive domes (magmatic diapirs) near the base of the Sea of Okhotsk margin of the Kuril island arc occurred in a comparatively quiet manner.

<u>Laccoliths (subvolcanoes).</u> These are widely known in continental geology, have been defined in many ways, and result from the emplacement of viscous magma in sediments where they form anticline (dome) structures (*Formy* ..., 1977). However, they are not known to occur so far in the geological structure of the ocean floor (see the references).

The area of study probably contains laccoliths at lines 62, 63, and 66 south and north of Chirinkotan I. (see Figs. 1, 4). For example, the laccolith at line 62 is a small buried dome between 0 and 10 km and the summit at 4.4 s. Its nearly horizontal bottom at ~5.2 s is recorded by short contrasting reflections in the Cenozoic cover. The laccolith body is identified in a complex wave field with micro-diffractions and rising host deposits (brachyanticline). It thus appears that this small dome has a structure that conforms to the definition of A.M. Daminova as having "...a flat bottom and a dome-shaped top" (*Formy*



1 **Fig. 5.** CSP lines 47, 48, and 33 across the edge of an extrusive rock massif and a single laccolith.
SC summit crater, BI blind intrusion, GW(SH) possibly a gas window or steam–gas hydrothermal occurrences, dashed line with an arrow beside it indicate a bottom overthrust and the direction of slip on it; for the other notations see Fig. 2.

..., 1977, p. 39). Considering that the host sediments are young, one can tentatively define it as dating back to the late Quaternary.

1 A much larger laccolith or possibly a group of laccoliths (cluster) makes up the left and possibly the right summit of a Middle to Late Miocene conical seamount at lines 62, 63 that is nearly buried under sediments. Its extrusive (magmatic diapir) origin is emphasized by a slope cover, an angular unconformity at its top, and a nearly vertical, semi-transparent zone beneath the right summit. The structure of this two-summit dome may imply, apart from the emplacement of viscous magma, the emplacement or injection of liquid magma as well. The latter can be inferred from a contrasting sedimentary section with short, nearly horizontal, and dipping reflectors beneath the two-domed summit of this seamount.

1 A buried laccolith that is approximately 4 km wide was
2 detected at line 66 in the area of the Helquist anticlinorium (after I.K. Tuezov) in the lower strata or near to the bottom of the Cenozoic cover. The emplacement of liquid magma into the Cenozoic cover gave rise to a local anticlinal bend of the layers that reaches nearly as far as the
1 bottom (see Fig. 4). A much larger laccolith can be seen along the same line 40 km northwest of that discussed above (see Fig. 4 in (Kornev et al., 1982)). It is at a depth of about 2 km beneath the bottom in an adjacent deep with a thick (~3 km) sequence of contrasting (the upper part) and semi-transparent (the lower part) Cenozoic deposits.

One of the more difficult (for geological interpretation) conical sea hills with a height of about 1 km can be seen at line 33 near to the base of the Sea of Okhotsk margin of Iturup I. with a young bottom overthrust (an asymmetrical ridge in Cenozoic sediments, see Fig. 5). In the structure of this sea hill one notes a truncated and rather uneven summit (extrusive cones and a summit crater?), an extensive transparent zone at depths of 4–6 s superimposed on the first multiple zone and somewhat displaced toward the base of the Sea of Okhotsk slope of the Kuril island arc, and an absence of any slope cover related to the emplacement of viscous magma into the Cenozoic cover (see above). The formation of the transparent zone can, in addition to the causes mentioned above (the lower transparent part of the Cenozoic cover and wave defocusing), be related to hydrocarbon gases (a gas window) or to steam hydrothermal occurrences around the hot intrusion. In this way, this sea hill can tentatively be treated as a
large and probably young laccolith or a cluster of lacco- 1
liths (subvolcano) that crowns the bottom overthrust at the base of the Kuril arc Sea of Okhotsk margin.

Summing up, we can state that the identification of domes on flattened bases, domes that are related to injection of liquid magma into the Cenozoic cover (laccoliths or subvolcanoes), furnishes an independent justification for identifying extrusive domes (magmatic diapirs) with

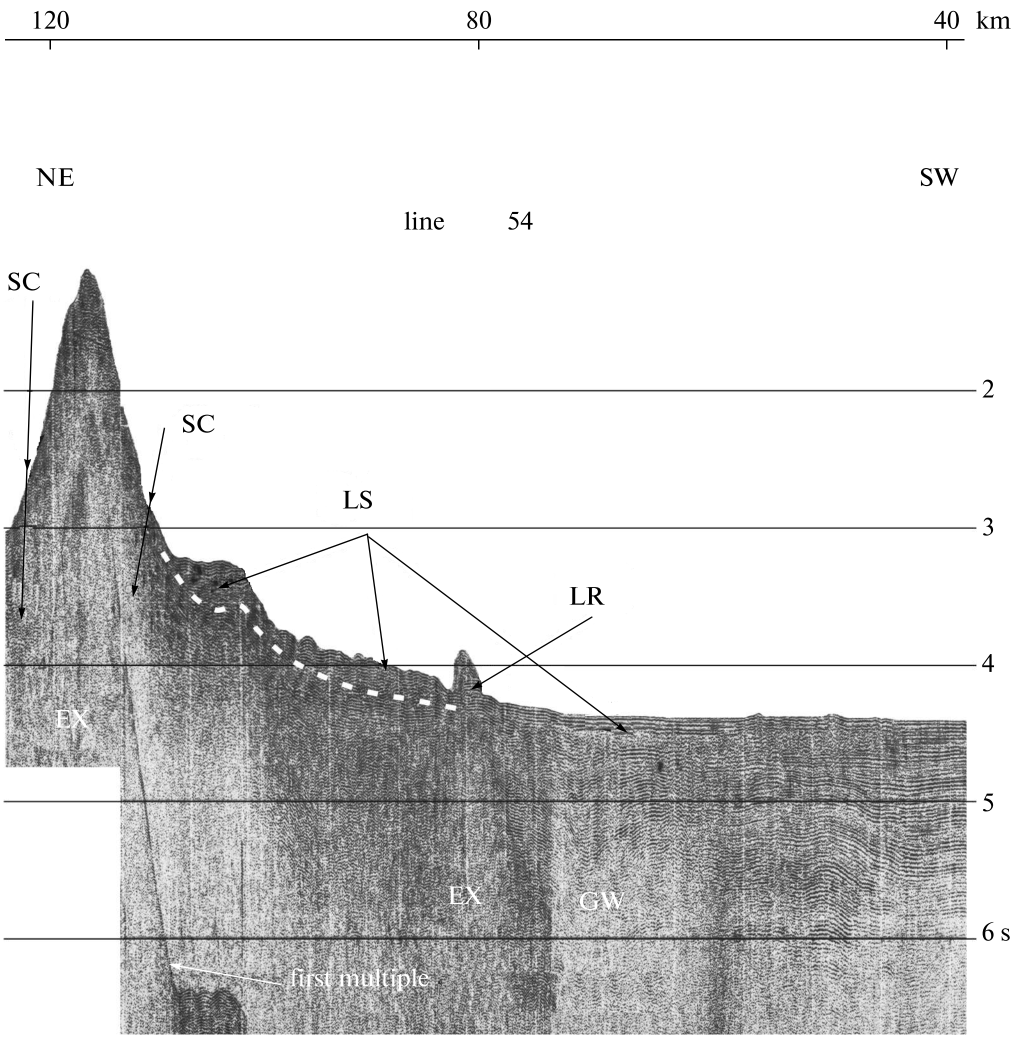


Fig. 6. A fragment of CSP line 54 across a block landslide at the base of an extrusive conical seamount and a flow landslide in the paleo-depression of the southern Sea of Okhotsk basin. For the notation see Figs. 2, 3, and 5.

sedimentary caps that result from viscous magma being emplaced into the cover.

Landslides and flow landslides. Landslide occurrence is limited on the slopes of conical seamounts at the base of the Sea of Okhotsk margin of the Kuril island arc. For example, a block (structural) landslide was identified at line 54 on a gently dipping (at ~1°) base off Matua I. close to a small seamount (see Figs. 1, 6). Its visible thickness is within 0.2 s (within 200 m) with a length of 27 km and a depth variation of 0.7 km. The landslide can be identified from characteristic rough seismic facies (landslide folds) that overlie the top of the slope cover (gliding surface) and a back step. The landslide masses have identical acoustic contrasts with the underlying slope cover and are possibly related to its upper part gliding down. At the same time, it is possible that the gliding might involve the sedimentary cover (contourites), which was formed on the slope of this seamount by a bottom contour current that flows out of the Atlasov deep erosional depression (line 66, see Fig. 4). A wide (30 km) bottom lens of probably landslide sediments 0.1 s (within 100 m) thick was identified at the front of the block landslide on the adjacent southern Sea of Okhotsk floor, with the lens having typical rough seismic facies (flow landslide or a destructive landslide (Lomtev, 2012)). This near neighborhood (in map view) of the flow landslide and the block landslide can be explained by fluidization of the landslide as it descended.

A slow gravitational sliding of landslide masses may also be hypothesized for the Sea of Okhotsk margin, e.g., off Iturup I., if we treat the asymmetrical overthrusted anticline more than 15 km wide on its base as a slope-foot fold (line 33, see Fig. 5). Slow downward sliding is also observed on the northern side of the southern Sea of Okhotsk basin at line 10 (Fig. 7); this has also involved the upper part of the acoustic basement composed of sedi-

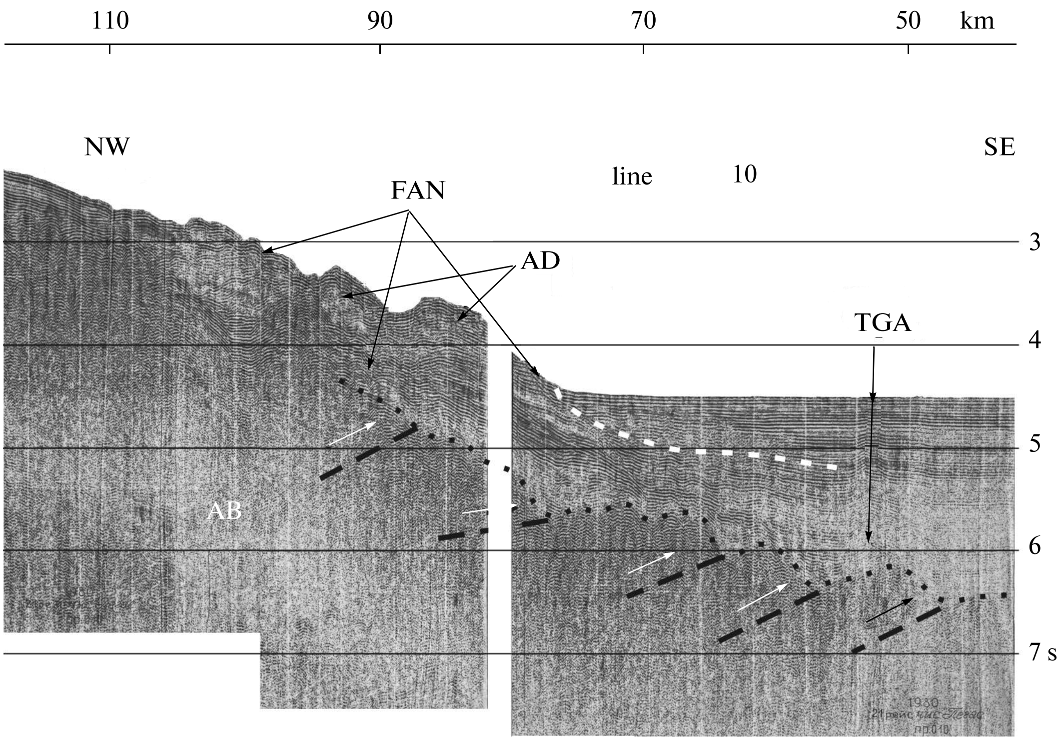


Fig. 7. A fragment of CSP line 10 across the accretion base with a fan of the canyon and the adjacent Sea of Okhotsk seafloor basin. AD aggradation dams that surround the fan valleys, TGA through-going anticline, dashed lines with arrows denote low-amplitude overthrusts of the acoustic basement (AB) and the direction of associated slip.

mentary–volcanogenic Mesozoic rocks (Gnibidenko, 1979).

RESULTS AND DISCUSSION

To sum up, revised interpretation of time sections that were acquired during the 21st cruise of the R/V *Pegas* led us to the inference that the conical seamounts and some sea hills at the base of the Sea of Okhotsk margin of the Kuril island arc are young, mostly Pliocene to Quaternary, extrusive domes (magmatic diapirs) with thick sedimentary caps (see Figs. 1 through 6). The best example of this is the dome at line 55, which is composed (at the surface) of exclusively Cenozoic deposits (see Fig. 2). The tops of the penetration cores of these diapirs seem to be rather deep (> 1–2 km) and they are only occasionally identified from contrasting, short reflections (spots) in the transparent lower part of the cover. From the viewpoint of methodology, the discovery of sedimentary caps on extrusive domes is a caution to the seismologist to deal more carefully with published dredging materials and their interpretations (highs of the Mesozoic to Paleozoic basement), integrating whenever possible with data from CSP, CDP, gravimetric and magnetic observations. Can these conical seamounts and sea hills be treated as volcanoes? We believe that they can very well be termed extrusive volcanoes (seamounts and sea hills), since their origin was dominated by dome-generating viscous magma (Maleev, 1975). One additional argument is furnished by marine geothermal observations, which were left unpublished in part (Cand. Sci. (Geol.–Mineral.) O.V. Veselov, Institute of Marine Geology and Geophysics, Far East Branch of the Russian Academy of Sciences, personal communication, 2012). According to these data, thermal gradient probes easily penetrated the soft bottom sediments (sedimentary caps) to depths of 3–4 m on seamounts in the Sea of Okhotsk margin of the Kuril island arc. The measured heat flow was high, occasionally abnormally so (346 and 323 mW/m^2 s at the Hydrographer Ridge seaward of Iturup I.), but involving sudden (up to 38.5 mW/m^2 s at the same feature) contrasts in space (*Geologo-geofizicheskii* ..., 1987).

A confirmation (independent in part) of the extrusive (diapir) origin of seamounts in the area of study is furnished by laccoliths, which are small, mostly buried, domes on flattened bases that were formed by liquid magma being injected into the cover. Their occurrence in the Sea of Okhotsk margin and in the Sea of Okhotsk seems to be wide as well, but this needs further revision and analysis of previously acquired CSP and CDP observations.

A small conical sea hill 0.2 km high and 4 km across at the base was discovered at line 99 in the southern underwater margin of Sakhalin I. (see Figs. 1, 8). It is overlain by

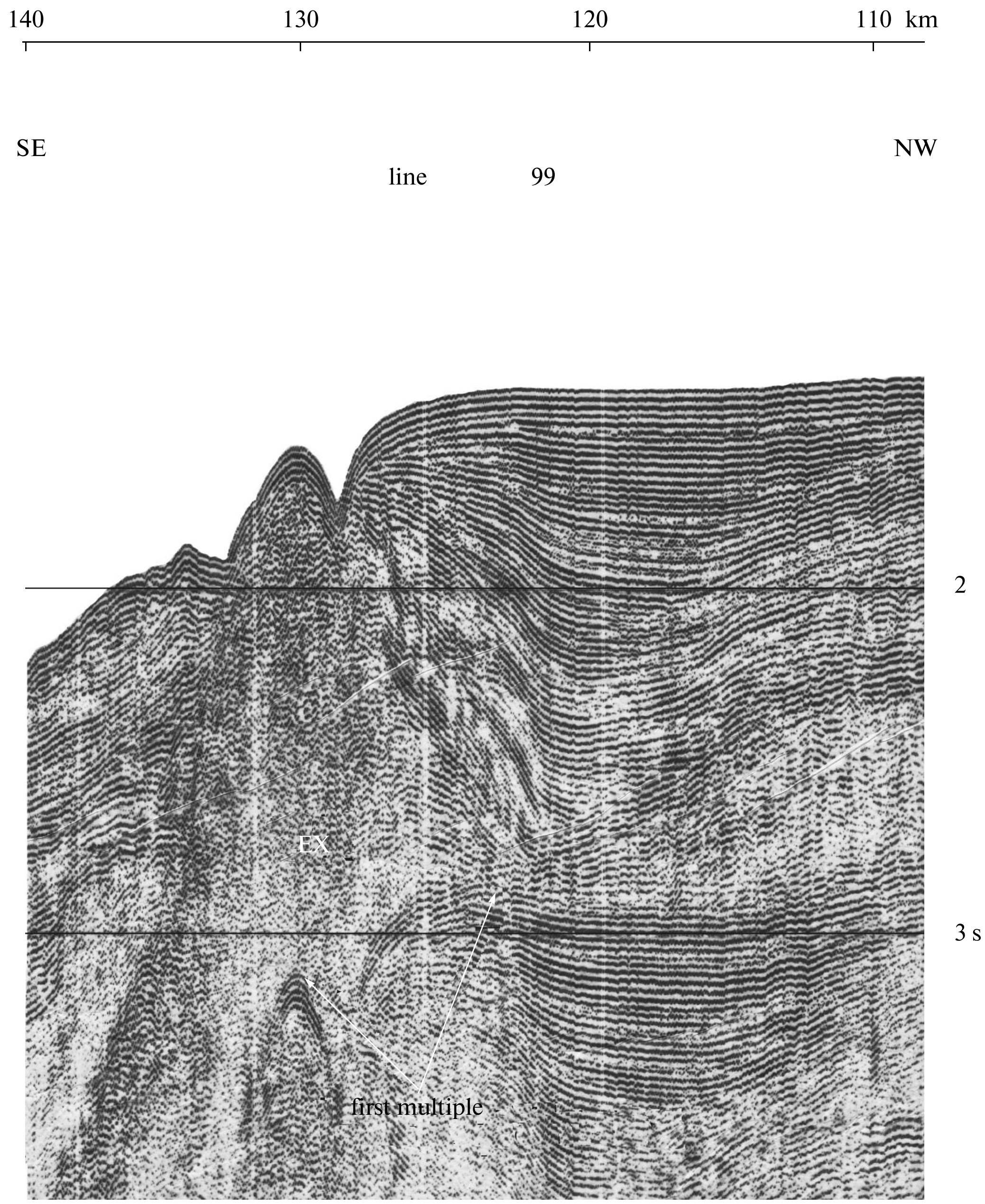


Fig. 8. A fragment of CSP line 99 with a small extrusive sea-hill on the southeastern undersea margin of Sakhalin I.

a thick, partly inverted, Cenozoic cover of the southern Sea of Okhotsk basin (line 100, see (*Geologo-geofizicheskii* ..., 1987)). The sea hill is probably composed of contrasting sediments with a complex (uncorrelated) wave field. No clear-cut stratigraphic contacts with the host deposits of the upper, contrasting sequence of the cover are available that could be hypothesized beneath the sea hill slopes (exocontacts of the extrusion, Lomtev (2010)). Consequently, the sea hill is a sedimentary cap of a young extrusive dome (magmatic diapir) that is composed of contrasting sediments of the same upper sequence. Its extrusive origin can be determined from the post-sedimentation uplift of contrasting sediments, especially on the right slope. When combined with the buried conical seamounts in the off-Sakhalin part of the southern Sea of Okhotsk basin (Tuezov, 1977; *Geologo-geofizicheskii* ..., 1987), this example allows us to expand the geography of extrusive undersea volcanism. In map view, this sea hill is near the 300-km seismic isobath of the Benioff zone (*Geologo-geofizicheskii* ..., 1987), which is the main source of magmas for the Kuril, island, and undersea volcanoes (*Podvodnaya* ..., 1992). Consequently, the extrusive conical seamounts and sea hills in the Kuril–Sea of Okhotsk region and, hypothetically, in the northern Japan Sea, can be considered as belonging to a common volcanic province in the overhanging part of the Benioff zone. If we suppose that viscous magma was rising at a rate of 1–2 mm/yr (Kukal, 1987), then the associated magma generation can be dated back to Mesozoic time or to the Vendian for the northern Japan Sea. From this it follows that the above rates of growth of magmatic diapirs will obviously apply to near-surface conditions only (the Cenozoic cover).

CONCLUSIONS

We can thus conclude that a revision of data that were acquired during the 21st cruise of the R/V *Pegas* in 1980 showed that the conical seamounts and sea hills at the base of the Sea of Okhotsk margin of the Kuril island arc are Late Cenozoic extrusive domes or magmatic diapirs with thick (> 1–2 km) sedimentary caps. The relevant diagnostic signs include thin-bedded slope covers that can occasionally be followed between seamounts, smooth slopes that are occasionally disturbed by landslides, normal faults, and lateral extrusive cones, among other features. The seamounts and sea hills have stopped growing at present (paleo-topography); this provides evidence of the subhorizontal attitude of bottom sediments on their base. Several smaller domes are described here for the first time in the literature; they are classified as laccoliths (subvolcanoes) that were formed by liquid magma being injected into the cover.

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SPELL: 1. laccolith, 2. anticlinorium, 3. @ [u1]У Менарда нет данных по Курильской котловине, редакция