

“Little Ice Age” glaciers in Kamchatka, northeastern Russia

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ABSTRACT. Lichenometry was used to date “Little Ice Age” moraines in the Kamchatka peninsula, northeastern Russia. The *Rhizocarpon geographicum* growth-rate curve was based on seven data points from lava flows and moraines, dated using historical records or tephrochronology (15–300 BP). No reduction in growth rate due to decreasing lichen age was observed, so a linear approximation was used. Accuracy test results yield differences between real and calculated dates up to, but not exceeding, five years. From eight “Little Ice Age” (LIA) moraines it was established that Kamchatka glaciers advanced in the 1690s, 1850–70 and 1910–20. Only one moraine clearly corresponded to the 1690s advance. The maximum stage of the LIA was during the mid- to late 19th century when glacier fronts were generally 100–200 m lower than at present. Glacier termini with ash and moraine layers, covered by lichens and vascular plants, have been preserved for 150–300 years, judging by the lichen sizes.

INTRODUCTION

The recent glacier history of Kamchatka, northeastern Russia, is poorly investigated. The first data concerning glacier-front positions date from the 1920s. Moraine dates from radiocarbon and tree-rings, etc., are still lacking. Until recently, the “Little Ice Age” (LIA) in Kamchatka was considered only as the final stage of Holocene glaciation. Then Braitseva and others (1968) and Melekestsev and others (1970) identified several units of various ages associated with glacial activity: traces of late-Pleistocene glaciation (~20 ka), moraines near the exit of trough valleys (presumably of late-glacial age, ~14–10 ka) and two stages of the Holocene. The Holocene maximum was roughly 2000 BP. A second complex of Holocene moraines includes ones with unstable surfaces and ice-filled cores, frequently bordering the fronts of recent glaciers.

REGION

The Kamchatka peninsula (Fig. 1) contains 29 active and more than 300 extinct volcanoes (part of the Pacific “Ring of Fire”) and is the largest glaciated region in northeast Asia, with 446 glaciers occupying an area of more than 906 km². The main nodes are the highest

Sredinny and Eastern ridges, and extend sub-meridionally throughout nearly the entire peninsula. Studies were carried out on volcanoes of the Klyuchevskaya groups.

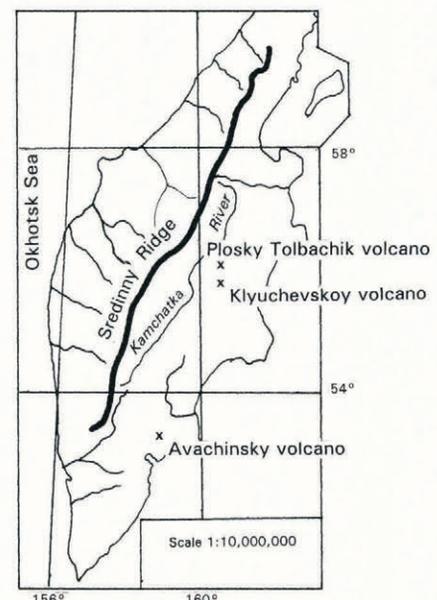


Fig. 1. The area of investigation.

METHODS

Lichenometry

Field studies in 1992/93 showed that the crustose lichen *Rhizocarpon geographicum* (*sensu lato*) could be used as an age indicator. It occurs widely on young deposits of differing genesis, including glacial and volcanic rocks. Maximum diameters of all the largest lichens were measured on moraine and lava-flow surfaces. For elliptical lichens, the major and minor axes were measured, and the arithmetical means calculated. If the variance for a sub-set of the five maximum dimensions did not exceed a few millimetres, the greatest diameter was taken as the surface-age index. If the maximum diameter was significantly greater than the other four measurements of the sub-set, it was eliminated and the sixth largest lichen was added to the sub-set. To make rough estimates of lichen-growth rate, lava flows of known age (Fig. 2) were explored: Plosky Tolbachik (1941), Yubileiny (1945), Apakhonchich (1946), Vernadsky (Klyuchevskaya volcano) (1956) and the Kozelsky glacier moraine (1976). Since no lichens have yet appeared on the young Kozelsky glacier moraine, the lichen measurements on the lava flows alone were used. Because diameters of 8–13 mm were attained by lichens on the lava flows of the 1940s to 1950s, the approximate rate of *Rhizocarpon geographicum* growth at its first stage of development is estimated as 0.25 mm a^{-1} .

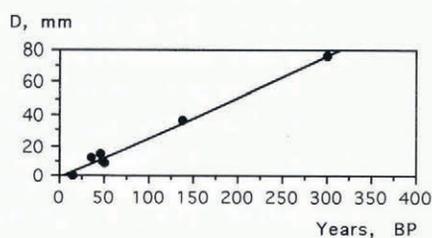


Fig. 2. The growth curve of *Rhizocarpon geographicum* (*sensu lato*) for the Kamchatka mountains (see text).

Tephrochronology

As a result of tephrochronological studies by the Institute of Volcanic Geology and Geochemistry, Petropavlosk-Kamchatskiy, a generalized soil-pyroclastic section was constructed for the Avachinsky volcano. Pyroclastic layers associated with its eruptions in 1945, 1855, 1779 and 1737 were detected in the upper part (Melekestsev and others, 1993). Individual moraines from the stratigraphic sequence were correlated with these tephra horizons. Sections of the overlapping soil-pyroclastic sequence at the surface of moraines were studied and then compared to the generalized sections.

RESULTS

Kozelsky glacier, Avachinsky group

Direct observations of the dynamics of Kozelsky glacier

show that it retreated from the late 1940s to the early 1960s, then settled into a steady state, advanced from 1971 to 1976, and then returned to a steady state (Vinogradov and Muravyev, 1992).

The first moraine (Fig. 3; No. 1), bordering the glacier terminus, formed as a result of glacier displacement in the 1970s. Morphologically it is a series of ice cliffs and ridges covered with a thin cinder layer also containing large boulders. It grades into the stagnant ice surface formed since the glacier's retreat from 1940 to 1960 (Fig. 3; No. 2). Here, the first patterns of lichens (*Rhizocarpon geographicum*) were found, the maximum diameter of individual lichens being 8 mm. A new "rung" begins 50 m lower along the chute, where more coarse, fragmented material is seen and some vascular plants appear. This moraine rampart is better-defined, having more distinct outlines and a steep outer slope, and is clearly expressed in aerial photographs (Fig. 3; No. 3).

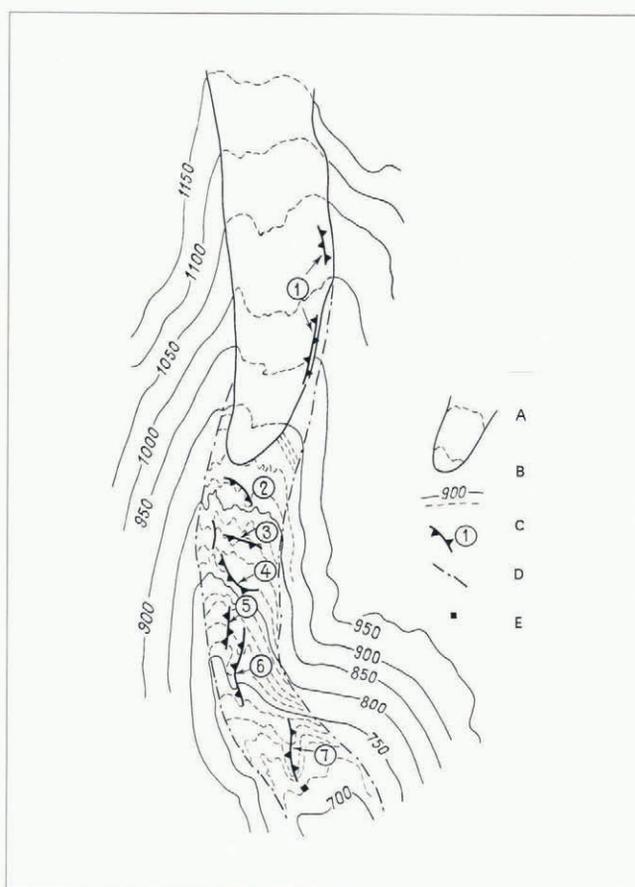


Fig. 3. Moraine complex of Kozelsky glacier. A, Tongue of glacier; B, topography contours in m; C, moraines of different ages (numbers explained in the text); D, limits of moraine complex; E, site of meteorological observations.

Below, at about 820 m, lies a new belt of moraines containing two distinct ramparts (Fig. 3; Nos. 4 and 5), chiefly composed of large fragments of grey andesites produced by the Kozelsky volcano. The size of the lichens and rough assessments of the growth rate (0.25 mm a^{-1}) suggest that these moraines formed in the 19th century. This is corroborated by the soil-pyroclastic sequence on the older outer moraine rampart (Fig. 3; No. 6). A 50 cm thick sequence that contains two tephra layers is

associated with the 1945 Avachinsky eruption and the 1907 Ksudach eruption (Fig. 4a). The lower ash layer is underlain by a thin layer of talus deposits which overlies the moraine. Tephra from the 1855 Avachinsky eruption was not observed here, so the moraine must have formed between 1855 and 1907.

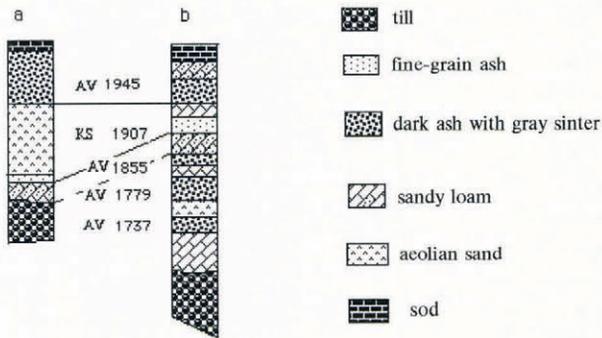


Fig. 4. Soil-pyroclastic sequence on moraines of Kozelsky glacier. (a) moraine of the second half of the 19th century; (b) moraine of the end of the 17th century. AV, ash from Avachinsky eruptions (1945, 1855, 1779 and 1737); KS, ash from Ksudach eruption (1907).

On the outside, a complex of young, unsodded moraines (Fig. 3; Nos. 1–6) lies adjacent to the older, sodded moraine which is covered with elfin-wood cedar (Fig. 3; No. 7). This moraine has smooth outlines and the ridge itself apparently lacks an ice core; the base of the moraine lies at 715 m. The morphological difference between these two generations of moraines is so great that despite their close proximity the corresponding stages of glacier advance would normally be expected to be separated by a significant time interval. Yet, lichenometric and tephrochronological studies of the older, sodded moraine (Fig. 3; No. 7) imply quite a different

interpretation. From the observed maximum lichen diameter of only 76 mm, and using a lichen growth rate of 0.25 mm a^{-1} , the age of the moraine is roughly 300 years, i.e. within the LIA. A soil-pyroclastic sequence on it is about 60 cm thick and contains five pyroclastic layers (Fig. 4b) from top to bottom as follows: cinder lapilli from the 1945 Avachinsky eruption; a layer of transition ash from the 1907 Ksudach eruption; and tephra from the Avachinsky eruptions of 1855, 1779 and 1737. The other, older ash layers are missing. Thus, the moraine predates 1737 and is at least 255 years old. The lower pyroclastic layer is underlain by a 12 cm layer of sandy loam which grades into the moraine deposits, indicating that the moraine was formed a few decades earlier than the upper age limit (1737). The lower age limit is 320–340 BP, as determined by radiocarbon dating (Geological Institute, Moscow, sample 6983). This value was obtained on the upper part of the buried soil layer (16 cm thick) underlying the tephra of 1737. Thus, two additional points used as time markers were obtained for constructing the lichen-growth curve (Fig. 2). The relationship between substratum age and maximum lichen diameter is nearly linear, and may be described by the equation, $y = 5.5 + 3.8x$, where y is the age of the surface (years BP), and x is the maximum lichen diameter (mm). This curve was the basis for dating the moraines formed by other glaciers in the region.

Novograbenov glacier, Avachinsky group

Novograbenov is a surging glacier with a northwestern orientation, and terminates at 850 m. Much of the snout, broken up by crevasses into individual blocks, is covered with a cinder layer. No terminal moraines occur below the tongue. The lateral moraines appear as a long rampart approximately 15 m high and 20 m wide extending along the left flank, and as two ramparts of somewhat poorer preservation along the right flank. The left lateral moraine (Fig. 5a; No. 1) formed simulta-

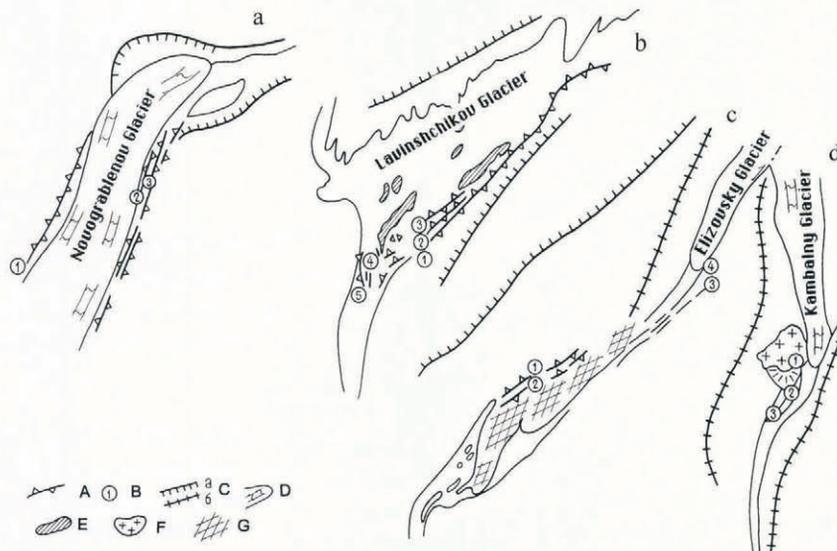


Fig. 5. Scheme showing the dated moraines of some glaciers at Avachinsky volcano: (a) Novograbenov, (b) Lavinschikov, (c) Elizovskiy and (d) Kamalnyi glaciers. A, moraine ramparts; B, points of lichenometric studies; C, cliffs (i) and crests (ii); D, glaciers; E, nunataks; F, rocks; G, "dead ice".

neously with the englacial moraine on the right (Fig. 5a; No. 2), after an advance at the beginning of the 20th century. The older moraine rampart probably dates from the second half of the 19th century. Novograbenov glacier is larger now than at the beginning of the 20th century, since the left lateral moraine is overlapped by the modern terminus of the glacier. No lichens were found on this moraine.

Lavinshchikov glacier, Avachinsky group

Lavinshchikov is a small foot glacier in the Elizovskaya river valley. It is segregated into two near-slope glaciers, which were united in August 1993 by a drifting snowpack that descended to the terminal moraine, outlining the contours of the glacier during the LIA. The upper moraine has no lichens, but lichens up to 23 mm in diameter occur on the lower moraine. The moraines on the left flank are preserved as several ramparts a few tens of metres long, with pointed ridges and steep slopes. The ages of three of them were estimated at roughly 50, 70 and 120 years (Fig. 5b; Nos. 1, 2 and 3, respectively). Two fragments of moraines (Fig. 5b; Nos. 4 and 5) have been identified on the right flank near the glacier front. Their ages correspond to those of moraines 2 and 3 (Fig. 5b), and they are better preserved, but lichens found here show their stages of advance to be somewhat older, about 75 and 140 years, respectively.

Elizovsky glacier, Avachinsky group

Elizovsky is a cirque glacier of southwest orientation, terminating at about 1300 m. It descends in the form of three "rungs" into a narrow valley. The only datable feature is the lateral moraines, which give an approximate upper age limit (Fig. 5c). Three or four "rungs" of lateral moraines were identified, but they are interrupted by eroded areas, and cannot be traced along the entire tongue. The lower moraine rampart, nearest the ice front, has no lichen growth and probably formed recently. The second generation (Fig. 5c; Nos. 2 and 4), which left traces on both sides of the valley, formed at least 50 years ago, but is probably older, given the sizes of the two largest lichens (19 and 17 mm). The higher level of marginal moraines (Fig. 5c; Nos. 1 and 3), deduced from the size of lichens, is attributed to activity in the mid- to late 19th century.

Kambalny glacier, Avachinsky group

Kambalny glacier terminates at 1180 m, near an exposure of rock on the right flank of the chute. Comparison with 1974 aerial photographs shows that over the last 20 years it has advanced about 250 m, corresponding to a drop of 100 m. Its front, a steep lobe of pure, till-free ice, suggests that the glacier was advancing in 1993. A small, roughly 10 m long, fresh moraine rampart was seen under the ice near the left side. No other moraines were found near its front.

A cliff promontory (Fig. 5d; No. 1) near the terminus has a fresh surface with traces of glacier polishing and scouring. No lichens were found on the lower part of the cliff, but 15–20 m above the chute floor *Rhizocarpon geographicum* of 25–27 mm diameter was observed. A low

terrace (up to 3–5 m), eroded in some places by slope wash, borders the cliff (Fig. 5d; No. 2). It lies directly adjacent to talus deposits, which probably supply part of the terrace's surface material. The size of lichens indicates that the terrace formed in the mid-20th century, but the landform is partially rejuvenated by fragments from the slope, complicating the age determination. This terrace formation is linked to glacier retreat from a previous lower position, as supported by the half-eroded moraine line (Fig. 5d; No. 3) surrounding it. The age of these moraines is about 140 years. No consistent moraine line was found on the left side of the valley, but subtle traces of sediment-accumulation features exist at about the same level.

The other three glaciers studied lack any such moraine complexes from which a glacial history could be reconstructed.

Cheremonshny glacier, Klyuchevskaya group

Moraine-like features, most of them apparently created by volcanic activity, were discovered near Cheremonshny glacier. Only one moraine (~50 years old) could be dated by lichenometry, but this date is unreliable because of the lack of lichens.

Popkov glacier, Klyuchevskaya group

The Popkov glacier area (Bolshaya Zimina volcano) is covered by lava flows of different ages, so traces of glacial activity are partially obscured. However, lichens are abundant on the large boulders that comprise part of the mixed moraine debris, volcanic ash and recently formed soil covering the surface of the snout. Also, the maximum lichen size on the front is nearly consistent with that on the oldest moraine of Kozelsky glacier. This suggests that the maximum advance of Popkov glacier also occurred in the 17th century, but that its margins have not changed since. Probably, the surface gradually lowered during the last three centuries, and the englacial till melted out, building thicker moraine cover at the terminus.

Erman glacier, Klyuchevskaya group

A similar picture is evident from Erman glacier, the largest in Kamchatka. In spite of its unusual activity, viz. advance during the past 50 years, large masses of "dead ice" exist along its margins and are presently stationary. Preliminary data show that the maximum diameter of lichens on the "dead ice", is 35 mm. A tephra layer from the 1854 Shiveluch volcanic eruption (Belousov, 1985) was detected in a 60 cm thick layer of supraglacial moraine overlying the "dead ice" so the age of the "passive-ice" surface is near the mid-19th century.

Kronotsky glacier, Kronotsky volcano

An analogous preservation of superficial cover on Kronotsky glacier moraines was reported by Tsiurupa (1988). The glacier lobe, 100 m from the front, is covered by volcanic cinder supporting abundant vegetation: *Oxitropis* sp., *Vaccinium uliginosum* L., *Oxiris digina* (L.) Hill., *Saxifraga purpurasoens* Kom. and two species of dwarf

willow, *Salix ovalifolia* Trautv. and *S. berberifolia* (?) Pall. ssp. *Kamchatica* A. Skvort. The age of one of the species of *Salix ovalifolia* Trautv. was estimated at 151 BP.

DISCUSSION

The principal question from this study is the reliability of the lichen-growth curve and limitations on its spatial and temporal application. Tephrochronology can verify the lichen growth-rate assessments. In two cases, the results are in good agreement. First, on Erman glacier, as reported above, the age of the "passive-ice" surface is 139 years (1853) according to lichenometry and 138 years (1854) according to the tephrochronological data. In the second case, on the surface of a lava flow in the Khalaktryka dry river valley, Zavaritsky (1977) showed that this flow formed in 1827. Lichenometry corroborated his speculation, the age from lichen sizes being determined as about 169 years (1823). The error in both cases is no more than a few years.

Plausible results have been obtained for the dating of moraines. Moraines of the glaciers studied are grouped according to age: young, low and indistinct moraines (36–59 BP); a distinct and well-shaped/defined generation of moraines (70–79 BP); and one or two older, non-drained outer moraines (120–146 BP). Based on the reconstructed mass-balance history of Kozelsky glacier (Vinogradov and Muravyev, 1992), the glacier must have undergone considerable mass accretion (+1060 mm w.e.) during 1955/56, a date which coincides with the age of its newest moraine (1956, from a lichen size of 8 mm). The second (earlier) generation of moraines could be associated with the period of positive glacier mass balance in 1910–20 (+1680 mm w.e. a⁻¹). This mass-balance peak probably coincides with the 1912 Katmai eruption in Alaska, which was followed by a lowering of the atmosphere transparency coefficient by a factor of 1.4 over Petropavlovsk-Kamchatskiy. A fall in temperature and glacier advance in the Northern Hemisphere in that year may be connected with that eruption. The glaciers of Kamchatka apparently advanced from 1918 to 1920 as well, as corroborated by the reconstruction of mass balance by Vinogradov and Muravyev (1992). The third previous generation of moraines, formed in the mid-19th century (according to lichenometric dating), coincides with the widely recognized LIA glacier advance.

CONCLUSIONS

1. Lichenometry can be used to date recent moraines in Kamchatka.
2. Kamchatka glaciers repeatedly advanced during the

LIA. The peak was at the end of the 17th century (approximately 1690), but moraines of this period have not been preserved on many Kamchatka volcanoes. The first generation of moraines with reliable ages usually formed in the mid-19th century. The younger, small-scale advance of glaciers in Kamchatka is dated at 1910–20. Small-sized moraines of the mid-20th century are preserved near most present-day glaciers. All the identified glacier advances occurred at or near the time of well-known stages of high glacial activity in other mountain regions of the Northern Hemisphere (Grove, 1988).

3. Vertical magnitudes of glacier retreat (100–200 m) indicated by moraines deposited during the peak phase of the LIA are similar to those in other mountain regions with a maritime climate (e.g. the Alps and the Caucasus). However, some glaciers in Kamchatka have advanced since then, often to the limits of or even beyond LIA moraines.
4. Other important features of glaciation in Kamchatka include termini of glaciers covered with moraines and volcanic material, and "dead-ice" masses. These are the same age as certain moraines from the 17th and 18th centuries.

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