DYNAMICS OF FORESTS AFTER CATASTROPHIC ERUPTIONS OF KAMCHATKA'S VOLCANOES

Sergei Grishin and **Roger del Moral**

Abstract. -According to our data, in the twentieth century, the largest eruptions of Kamchatka's volcanoes have destroyed natural ecosystems on an area of about 0.2 x 10^6 ha, and have severely disturbed them on an area of about 1 x 10^6 ha. The volcanic eruptions of such magnitude (ejection more than 1 km^3 of volcanits) are local accidents for the ecosystems of the region, though their influence can be seen at a global level. Huge eruptions, like Ksudach 200-300 years AD (ejection more than 10 km^3 of volcanits), cause subregional or regional natural catastrophes. The area of devastation of ecosystems varies from hundreds up to hundreds of thousands of km^2. The rate of succession in subalpine habitats is slower than in forest ones due to harsh conditions and slow invasion rates. Succession on lavas is very slow, that on the blast deposits quite slow, and that on tephra more rapid. The great duration of successions was revealed: from a few centuries to a few millennia. That is connected with the severe climatic conditions of the northern boreal zone and high-mountains. Thus, on basalt aa-lava, as well as on dacite pumice, primary succession needs 2000 years at least, and on ash and scoria *ca.* 500 years. The revealed duration of the secondary successions after ash-falls varies from a few years to a few hundred years after catastrophic devastation.

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INTRODUCTION

The volcanic eruptions of the twentieth century in Kamchatka have destroyed the vegetation completely on an area of *ca.* 200 000 ha and partly on *ca.* 1 million ha (estimation of the authors). The forest vegetation of Kamchatka consists of *Betula ermanii* forests mainly, with coniferous ones of *Larix kamtschatika* and *Picea ajanensis* in central Kamchatka. The vegetation of forest and subalpine belts was studied on the active volcanoes Shiveluch, Ksudach, Kluchevskoy, Bezymianny, Tolbachik and Avachinsky in central, eastern and southern Kamchatka. Succession begins after volcanic events of different types (lava and pyroclastic flows, ash-falls, explosive air waves, deposits of exploded volcanic cones, lahars and others), resulting in the devastation of the vegetation. The vegetation of three recently erupted volcanoes (Tolbachik, Shiveluch and Ksudach) is described. Two volcanoes are located in the "coniferous island" of the central part of Kamchatka and the third in the southern part. These eruptions are among the four largest of this century on Kamchatka. More than 1 km^3 of volcanic materials were ejected from each. Some data on the effects of these eruptions on vegetation have been published (Hulten, 1974; Sidelnikov & Shafranovsky, 1983; Grishin *et al.*, in press).

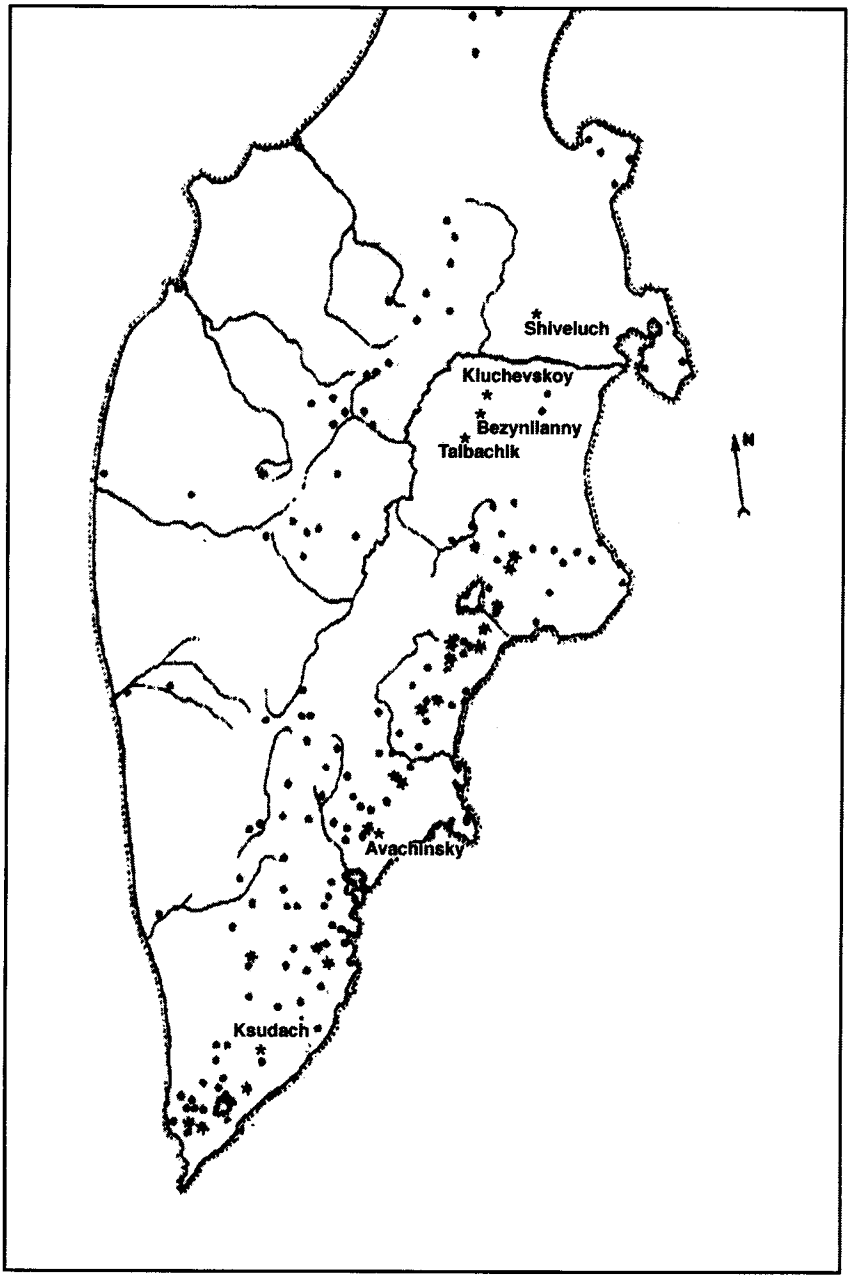

Fig. 1, Location of study area.

STUDY AREA

The Kamchatka Peninsula is a modern geosynclinal area of volcanic origin. The major part of Kamchatka territory consists of volcanic ecosystems of various age and genesis, forming volcanic deposits of 29 active and *ca.* 100 'sleeping' volcanoes (Fig. 1). Thus, the newest effusives cover *ca.* 25% of the territory. The highest elevation of the region is the young Holocene giant Kluchevskoy (4750 m).

The Tolbachik eruption (summer, 1975) occurred in the central part of a lava plateau (elevation 900 m). New lava flows covered about 9 km^2 and tephra fell over 470 km^2 to a depth of at least 10 cm. The vegetation was completely destroyed on 400 km^2 (Fedotov, 1984). Shiveluch Volcano (3283 m) is the most northern active volcano on the Kamchatka Peninsula. The eruption of November, 1964, was a directed blast similar to the well-studied one of Mount St. Helens (1980). The strata produced by the blast covered an area of about 100 km^2 to an average depth of about 20 m. Subsequently, andesitic pumice from pyroclastic flows covered much of this area to an even greater depth (Gorshkov & Dubik, 1969). On March 28, 1907, the Shtyubel' Cone within the Ksudach Volcano caldera in Southern Kamchatka ejected 1.5-2 km^3 of material. Prevailing winds caused most to be deposited to the north near the caldera (Bursik *et al.*, 1993), but Petropavlovsk-Kamchatsky, over 160 km to the north, received 2-3 cm of coarse tephra (Vlodavets & Piyp, 1957; Melekestsev & Sulerzhitskii, 1987; Bursik *et al.*, 1993).

The climatic condition of the central part of the Peninsula reveals a continental middle boreal pattern, similar to the climate of Middle Siberia, while the eastern and southern parts have a marine northern boreal one with short cool summers, and moderately cold long winters (Table 1). Some glaciers descend from the Kamchatka mountains to 500 m a.s.l.

Montane vegetation in the central part of Kamchatka is dominated by forests of *Larix kamtschatika* and *Picea ajanensis* up to 600 m a.s.l. and by *Betula ermanii* up to 800-900 m. The subalpine belt, in which alder and pine thickets (*Alnus kamtschatika* and *Pinus pumila*) dominate, occurs between 800 and 1100 m. Alpine vegetation occurs at altitues of up to 1500-2000 m.

Table 1. The mean monthly air temperature and precipitation at the meteorological stations "Khodutka" (southern Kamchatka) and "Kluchee" (central Kamchatka) according to Reference book on a climate of the USSR, V. 27 (Leningrad, Gidrometeoizdat. 1966, 1968)

	Month												
	1	2	3	4	5	6	7	8	9	10	11	12	Year
Air temperature (°C)													
Khodutka	-8.1	-8.2	-5.8	-1.5	2.3	7.3	11.2	12.0	9.0	4.3	-1.5	-5.8	1.3
Kluchee	-16.9	-15.0	-10.5	-2.7	4.1	10.8	14.7	13.8	8.6	1.4	-7.5	-14.6	-1.2
Precipitation													
Khodutka	123	83	144	123	104	63	119	79	122	154	165	151	1430
Kluchee	60	48	40	27	29	30	56	61	45	50	52	64	562

METHODS

Vegetation was sampled along several transects on each volcano. Transects were arrayed along a gradient of increasing tephra thickness. In the subalpine zone, on each transect 20 by 20 m plots were established. Cover was determined from 20 1 m^2 subplots. In addition, the density, size of woody species, and the age of tree species was determined. In the forest zone, where there was significant plant survival, we studied secondary succession. Sample plots of 25 by 100 m were established.

We determined species composition, vegetation cover, woody species density and stem sizes. The soils were described from sample pits in each plot to determine the degree of impact and the nature of the old soils. The degree of vegetation damage by ash-fall was described and the degree of recovery was estimated. We made large-scale vegetation maps on the basis of interpretation of aerial photography and on additional field transects.

SOME RESULTS

Our studies on the directed blast and pyroclastic deposits of Shiveluch volcano were confined to sites lacking surviving plants and thus constitute studies of primary succession. The Tolbachik studies include sites destroyed and merely damaged by tephra in both subalpine and alpine zones, and studies of damaged, recovering forests at lower elevations. Aerial photo interpretations indicate that primary succession is occurring on about 100 km^2 around Shiveluch and on about 400 km^2 surrounding Tolbachik. The zone of secondary succession surrounding Tolbachik is estimated to be about 1000 to 1200 km^2. Ksudach eruption, one of the largest of twentieth century on Kamchatka, has produced the most catastrophic loss of forest vegetation: about 600 km^2 was completely lost, and about 1800 km^2 was essentially destroyed (see below). Thus, at Ksudach we investigated both primary and secondary successions.

SECONDARY SUCCESSION AT TOLBACHIK

Secondary succession at Tolbachik occurs where the thickness of deposited tephra has not exceeded 30 to 50 cm in forest and subalpine zones and 10 cm in the alpine zone. In *Betula ermanii* forests there was a strong correlation between tephra thickness and the degree of destruction (Fig. 2). There was total destruction with over 25 cm, and a 50% decline of trees at 15 cm. As little as 2 to 3 cm of tephra

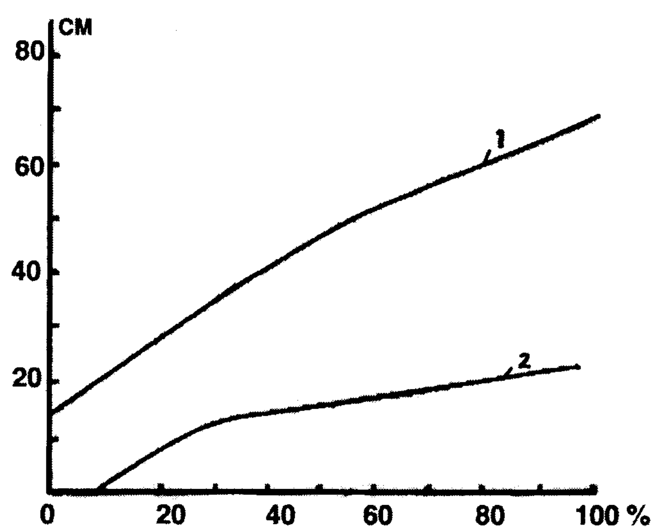

Fig. 2, The dying (% of total stems) of stone birch (1) and larch (2) forests after Tolbachik eruption of 1975 (thickness of tephra, cm).

resulted in partial damage to the canopy species. This effect probably results when tephra is deposited wet during rains caused by the eruption. The tephra coats branches and foliage, causing crown damage. The resultant opening of the canopy has permitted an intensive development of the herb (e.g., *Calamagrostis langsdorffii* and *Chamerion angustifolium*) and shrub (*Alnus kamtschatica*) layers. In the subalpine and alpine zones, surface meso- and micro-relief conditions are much more heterogeneous. This has resulted from the mix of ancient and recent lava flows being covered with tephra, followed by erosion from crests and ridges and accumulations in gullies and depressions. Deeper deposits remained nearly barren of vegetation, while little impact was noted on sites with little accumulation. Therefore, some areas of the long-term primary lava succession now have a secondary succession developing adjacent to older primary succession.

PRIMARY SUCCESSION ON TEPHRA DEPOSITS AT TOLBACHIK

On Tolbachik, we investigated succession on deep friable tephra deposits. Deep deposits occur in the subalpine and alpine zones where accumulation is favoured, for example, near the edges of lava flows and other depressions and on gentle slopes. The main feature of this substratum is its instability, connected with its constant movement caused by gravity, wind, water and the accumulation and melting of snow. Erosion is significant and can exceed 10 cm yr^{-1}. Only a few pioneer species survive in these conditions. The principal species is *Leymus interior* (loose bunch grass). In sites with more stable substratum, this grass gradually forms a high tussock. The height of these tussocks now exceeds 70 to 80 cm above the new tephra surface. The most common and actively invading woody pioneer is *Populus suaveolens*, which forms clumps that have slowly grown to several metres in diameter and up to 2 m in height. On these somewhat favourable sites, the vegetation cover can reach 30-40%. On sites with more dynamic slopes, chronic disturbance and damage of new plants occurs continuously and cover is sparse (not more than 5-10%).

The progress of primary succession on Tolbachik is associated with the rate of closing of tussocks of *Leymus interior* and clumps of poplar. These key species are centres of substratum stabilization and of invasion by other pioneer species. These include woody ones (*Salix* spp., *Betula kamtschatika*), the seeds of which become trapped in the vegetation. This early stage of succession will require several decades for maximum canopy closure by tussock and poplar to occur. The next stage of succession will be connected with the rate of development of subalpine dominants such as *Alnus kamtschatika*, *Pinus pumila*, *Larix kamtschatika* and *Betula ermanii*. Their invasion and the development of maturity and dominance will require at least 150 to 200 years. The last (climax) stage will require several additional centuries of development without major disturbances. In this volcanically active zone, it is not likely to be achieved.

PRIMARY SUCCESSION ON THE LAVA FLOWS AT TOLBACHIK

During the Holocene, lava flows formed a lava plateau with an area of 875 km^2 near Tolbachik volcano. The age of the flows was determined by the tephrachronology method, based on radiocarbon dating (Braitseva *et al.*, 1981). With this method, we could distinguish the stages of succession and estimate their duration (Grishin 1992, 1994).

The study of the young lava flows (10 and 50 years old) showed that herbaceous plants (*Chamerion angustifolium, Poa malacantha, Leymus ajanensis* and others), mosses (*Polytrichum* spp.) and lichens (*Stereocaulon vesuvianum*) establish most actively initially. Woody plants such as poplar (*Populus suaveolens*), some willows, and very occasionally larch and stone birch establish less readily. All the plants settle on the friable substratum (tephra, products of weathering of lava and others). Seedlings of *Pinus pumila* were rather rare, appearing a few years after the eruption. These were dispersed by animals and seed sources occur 5-10 km away. Five hundred years later, scattered herbaceous and shrubby vegetation is formed on the lava surface and isolated (about 10 trees ha^{-1}), extremely stunted (3-5 m height) larch trees occur. Low thickets of *Pinus pumila* (0.3-0.5 m height) dominate the vegetation, covering about 30 percent of the surface. *Pinus pumila* fills all potential habitats with friable substratum and forces out the herbaceous pioneer species. Under the tephra deposit on blocks and plates of lava, a thin layer (1-3 cm) of primitive soil develops. *Pinus pumila* is rooted in voids between blocks on concentrated friable substratum enriched with organic matter.

On the 1000-year old lava flows, more closed vegetation can be observed. *Pinus pumila* is the dominant species and covers 60-90 percent of the surface. Its height reaches 1-1.5 m. The characteristic feature of this stage of succession is the appearance of dominants of new communities. The most important plant in the new communities is alder krummholz. It settles on the substratum prepared by *Pinus pumila* which eventually disappears from the slopes of the lava ridge and occurs only in the flat bottoms between ridges. Together with stone pine, slowly growing small larch trees (a few dozen of trees ha^{-1}) are found. The abundant leaf fall of the alder and of the undergrowth plants (*Calamogrostis langsdorffii*) prepares the substratum for stone birch, a very important dominant tree in the subalpine forest. The depth of the soil on different lava flows is 5-15 cm.

During the next 500 years, the rate of succession increases noticeably, leading to differentiation of vegetation in the subalpine zone. On the 1,500 year old lava flows, typical subalpine communities can be distinguished. Besides the dominant *Pinus pumila* thickets, the single clumps of alder, and the open woodlands of larch; communities of stone birch, covers of alder, subalpine meadows, and fragments of alpine heath appear. At this point, the coverage of *Pinus pumila* decreases, occupying its own typical habitats such as rock crests, concave hollows with frozen soils, and wind-exposed sites. The thickness of the soil profile increases to 20 cm, and the levelling of volcanogenic micro-relief begins to occur. Both coenotical and vertical differentiation of vegetation takes place. During the earlier stage of succession *Pinus pumila* dominated at altitudes from 200-1,000 m, but at this stage the forest belt below 800 m is formed, composed of larch and stone birch.

On the 2000- and 2500-year-old lava flows the vegetation was destroyed completely by the ash-fall of 1975. Its remnants give evidence that vegetation cover had been approaching the climax stage. It had mature communities developed according to their altitudinal position. For example, on one of the flows at the altitude of 700 m a well developed birch-larch subalpine forest with some spruce was observed. The

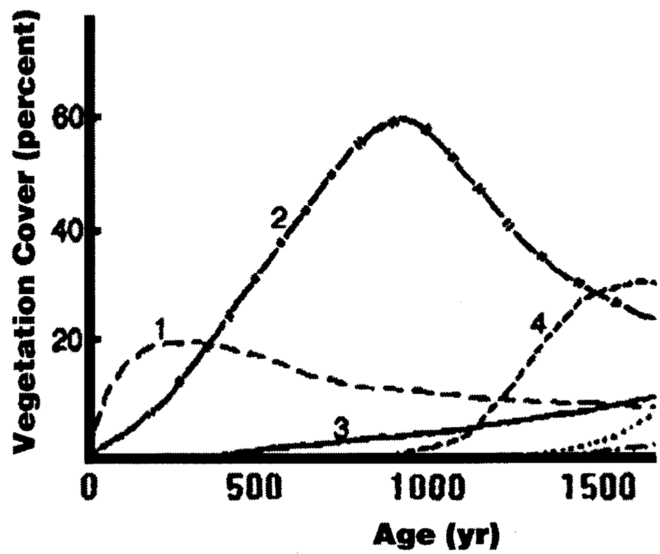

Fig. 3, Generalized chronocline of succession on lava flows of the Tolbachik area. 1. pioneer unclosed groups of grasses, mosses, lichens, 2. communities of *Pinus pumila,* 3. woodlands of larch, 4. communities of alder krummholz, 5. birch forests, 6. subalpine meadows.

birch trees had a height of more than 10 m and a diameter at breast height of 25-40 cm. The larch trees were about 20 m and 30-40 cm, respectively. The *Alder* krummholz under the forest layer had a height of 2.5-3 m, and *Pinus pumila* 1.5-2 m. These examples show that under such conditions, beginning at the age of 1500 years, the vegetation tends to approach the climatic climax similar to the neighbouring localities (Fig. 3).

The peculiarities of succession are determined mainly by the pattern of lava cover and the accumulation of friable substratum on the lava surface. On pahoehoe lava, establishment of plants on smooth monolith surfaces is an extremely slow process. After the first 1,000 years of such a lithosere, the lava is commonly covered only by crustaceous lichens. Higher plants settle on friable substratum in cracks and cavities and that is in fact the beginning of a psammosere. Even if these plants are rooted in lava, they cannot populate all the surface of the pahoehoe, and the next stages of succession are dependent on the space correlation between lithosere and psammosere. On aa lava this correlation changes to psammosere more quickly, and that accelerates succession. The final stage of succession on soil-tephra profiles is gradually formed, smoothing out the irregularities of the lava. In the area studied, the duration of succession is two to three times longer than in the oceanic climate of the Japanese subtropics, where it continues for only 700 years (Tagawa 1964).

A very important factor following volcanism is ash-fall damage to vegetation. For example, in the Tolbachik area, about ten eruptions took place during the last 2,000 years. Four of them were similar to the eruptions of 1975; in that period the tephra of volcanoes Shiveluch, Kluchevskoy, and Bezymyanny was also deposited. The negative influence of major ash-falls on vegetation was shown by the 1975 eruption. *Pinus pumila* krummholz and subalpine birch forests were killed under the tephra deposit of more than 20 cm, alder krummholz more than 30 cm, and larch forests more than 40 cm. Smaller amounts of tephra (10-15 cm) led to the death of vegetation in subalpine meadows and alpine heaths. After moderate ash-fall a secondary succession is possible, and thus lithosere may be transformed to psammosere. There are other essential factors such as climatic fluctuations of forest and subalpine vegetation at their upper limit and forest fires. Fires may originate from volcanic activity especially on krummholz *Pinus pumila* with dry lichens and dwarf ericaceous shrubs.

PRIMARY SUCCESSION AT SHIVELUCH

On Shiveluch, two types of deposits have resulted in distinct successions. On light dacite pumice, both herbaceous and woody plants (*Larix kamtschatika, Picea ajanensis, Alnus kamtschatika, Salix* spp., *Populus suaveolens*) invade rapidly. The larch and alder thickets establish earlier than the other species, within eight to 10 years after eruption. On deposits of the directed blast, the establishment of plants is much more difficult. Here only isolated shrubs of alder and small-sized undergrowth of larch, poplar and willows grow. Herbaceous plants (*Anaphalis margaritacea, Chamerion angustifolium, Calamagrostis purpurea*) are sparse. The mosses and lichens (from the genera *Polytrichum, Racomitrium, Pogonatum, Stereocaulon,* etc.) are more common. The best conditions for the establishment of deciduous and herbaceous species on the pumice of pyroclastic flows appear to be associated with the accumulation of organic matter and moisture in the upper layers of deposits between pieces of pumice. The rate of succession on pumice flows is connected with the formation of closed cover by alder thickets in both the subalpine and forest zones. We estimate that this will take from 50 up to 150 years, depending on distance from an intact forest. Subsequently, or simultaneously in sites closer to forests, the stage of invasion by trees, such as *Betula ermanii*, larch and spruce into the thickets will begin. The process of restoration of forest vegetation can last for many centuries, probably not less than 1000 years. On explosive directed deposits it can be even longer.

VEGETATION DAMAGE IN THE KSUDACH AREA

Where pumice deposits were less than 30 cm thick, most trees, though damaged, survived (fig. 3). Isolated surviving trees occurred where deposits ranged from 30 to 70 cm depth. At these depths, most understorey species were killed. At a depth greater than 70 cm, apparently all trees were killed. Damage and death can be attributed to mechanical damage from coarse tephra and the occasional large bomb, effects of the high speed of falling tephra, burial of the soil, and alterations of soil chemistry, temperature, and aeration. On Ksudach, it appears that some large trees survived even 1.5 m deposits for a short while. Trunks and stumps of these rarities remain well preserved, whereas trees killed in 1907 are decomposed or barely intact. The dynamics of tree death are unclear now. On Mount St. Helens, trees with roots buried by mudflows took two to three years to die (del Moral, pers. obs.). By noting the presence of a few survivors, and the state of preservation of fallen trees in a young wood and in the lichen desert, we infer that death occurred gradually over several years, at rates proportional to depth of the deposit. The impact of tephra and of volcanic bombs on trees of different sizes was differential. The size structure

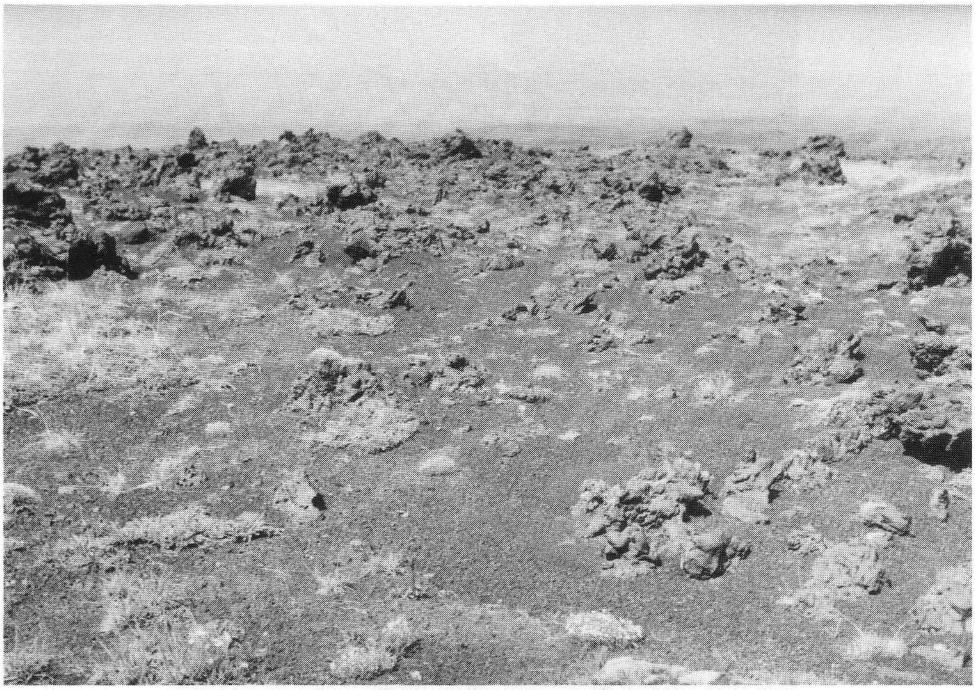

Fig. 4, The tephra fields crossed by lava flows on Tolbachik volcano, Kamchatka Peninsula.

Fig. 5, *Betula ermanii* stands, damaged by ash-fall of 1975. *Alnus kamtschatica* is at the understorey, and the tussok grass is *Calamagrostis langsdorffii*. Photo taken in 1995.

Fig. 6, The slope of the lava flow, recovered by tephra of Tobalchik eruption of 1975. The dead branches of *Alnus kamtschatica* and *Leymus interior* are shown. Photo of 1985.

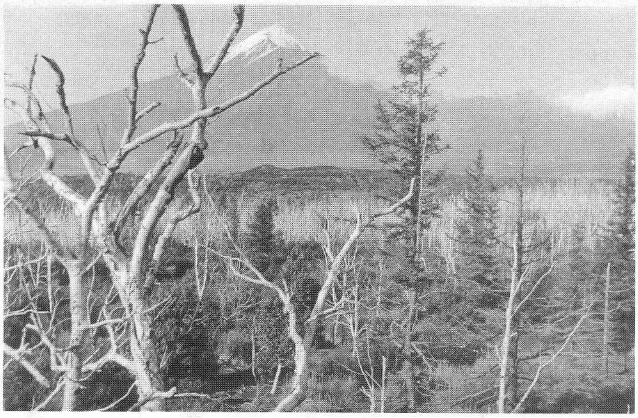

Fig. 7, Tolbachik volcano; the dead trees of *Betula ermanii* and mainly live *Lathrix* trees are shown.

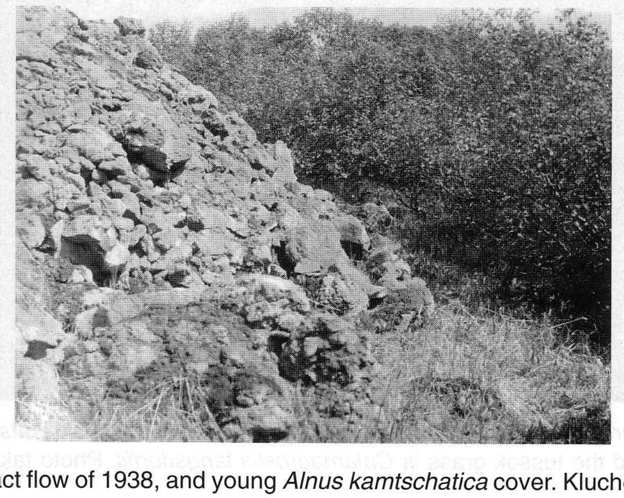

Fig. 8, The contact flow of 1938, and young *Alnus kamtschatica* cover. Kluchevskoy volcano.

of trees in stands impacted by about 20 cm of tephra differs appreciably from typical climax forests of Kamchatka. There are many more younger trees (d.b.h. 4-16 cm) and there are size gaps that correspond to the loss of a generation of young birches, killed in 1907. The analysis of tree age has shown that eruptions are often followed by regrowth of stems of about 2 cm d.b.h. This suggests that very small trees also survive, either by protection from the larger trees or by snow. As a result, impacted stands have a more varied age structure than mature, relatively undisturbed stands. Tephra deposits less than 30 cm had major impacts on shrub, herb, and moss-lichen communities near Petropavlovsk-Kamchatsky (Komarov 1912). Most such understorey species are likely to have reinvaded after the eruption, and are not survivors. Studies of the moss-lichen layer on 20th Century eruptions of Kamchatka volcanoes (e.g., Kluchevskoy, 1932, 1938; Avachinsky, 1945; Bezymianny, 1956; Shiveluch, 1964; and Tolbachik, 1975) show that less than 10 cm is sufficient to cause their complete elimination. Herb layers may be eliminated by even 10-20 cm of tephra, while the shrub layer died at thickness of 20-30 cm. While the tree canopy survived, decline is observed as a result of drying out. For example, 10 years after the summer Tolbachik eruption, we found that 8% of the stand had dried out with only 3 cm of tephra, while 20% dried out with 10-12 cm of tephra. Moderate tephra deposits of the February 1945 eruption of Avachinsky volcano killed saplings and seedlings, but many adults survived deposits of over 55 cm.

GEOGRAPHICAL EXTENT

We estimate the extent of the effects of the 1907 eruption on forest vegetation by combining our field studies with data from volcanologists on the distribution and depths of deposits (Melekestsev *et al.*, unpubl. Table 2).

Table 2. The connection between pumice deposits and devastation of vegetation in the Ksudach area

Thickness of deposits, cm	Area of deposits, km^2	Character of devastation
1-5	8460	Oppression and destruction of some components of herb, dwarf shrub and moss-lichen vegetation
5-10	1458	Devastation and change of some components of herb and dwarf shrub vegetation
10-20	954	Significant devastation of herb, dwarf shrub and partly of shrub vegetation, as well as some drying of trees
20-30	228	Total devastation of herb and basic part of shrub vegetation, and significant drying of trees
30-70	484	The devastation of all formations of vegetation and all components of forest communities, with the exception of single surviving trees
70-100	62	Total devastation of vegetation
Over 100	54	The same, forming of volcanic desert

The vegetation on the western and much of the eastern and southern external slopes of the caldera was not damaged significantly by the eruption. The exception is the large (about 50 km^2) sector of the southeastern slope, that was transformed into a volcanic desert. In 1910, Konradee and Kell' (1925) noted that some vegetation on the southern inner slope of the caldera had survived the 1907 eruption. The deep, snow-filled canyons on internal slopes served as refugia for *Alnus kamtchatica* thickets. Based on aerial photography, we estimate that about 1800 km^2 of stone birch forests were impacted. Much of this area was impacted to a minor degree, but an area of 500-600 km^2 (deposits over 30 cm) was substantially impacted and total destruction occurred on about 124 km^2 (deposits over 70 cm), including sites that remain lichen deserts. About 71 km^2 includes devastated terrain with a few surviving trees (deposits 30-70 cm). These values include the caldera, sites along the northern axis and southeast sector of deposits formed when the wind changed during the 1907 eruption. Thus, the total area of forest vegetation that was destroyed is about 200 km^2. The remaining territory of nearly complete destruction was covered by subalpine and high-mountain vegetation, alluvial meadows, valley woods and bogs.

Pumice thickness of more than 30 cm eliminated the prevailing *Betula ermanii* forest thickness of deposit of more 100 cm led to volcanic desert. The main factors of devastation were: bombing by large (up to 10 cm in diameter and probably larger) pumice pieces, that resulted in breaking off crowns and damage to the bark of trees, change of edaphic conditions owing to pyroclastic deposits of significant thickness (from several centimetres up to several metres). After the eruption an eccentric structure of devastated forest vegetation, according to thickness of deposit and sizes of pumice pieces, was formed.

SUCCESSIONS

We have allocated three zones of devastation. In Zone 1 (more 100 cm of deposits) vegetation was lost completely and almost at once. The volcanic desert was formed there and primary succession was begun. The Zone 2 (100-30 cm of deposits) represents transition from volcanic desert up to a partially damaged forest. The single surviving trees were preserved here at deposits less than 70 cm. The Zone 2 successions are complex, are primary on major pumice deposit, and have features of primary and secondary simultaneously. In the Zone 3 (less than 30 cm of small-sized pumice) woody plants basically escaped destruction and secondary succession was begun.

The main stages of primary succession are as follows: 1. settling of herbaceous and moss pioneers (first years), 2. formation of lichen cover (first decades), 3. formation of clumps of dwarf shrubs and bunch grasses, and their gradual closing (first centuries), 4. formation of xeromesophytic meadows with participation of shrubs and dwarf shrubs, 5. introduction of trees (both species of birch) in the meadow, gradual increase of the sizes and duration of life of trees, closing of forest canopy, 6. development of structure and composition of climax forest communities. On a number of sites the succession stays at the stage of xeromesophytic meadows. These are plains and local depressions, where complex adverse climatic and edaphic factors develop.

The primary succession in a transitive Zone 2, proceeds faster the closer the site is to a Zone 3 area, i.e. then more they are surrounded by forest. The mixed succession in a Zone 2 area begins almost as primary succession, but during the first decades the roots of the young trees, reach buried soil and exploit its resources. That is an attribute of secondary succession. The trees can then develop more quickly, producing a strong influence on processes in subordinated layers of the communities. The secondary succession proceeds to replace the generation of trees that was lost as a result in the eruption, restoring the floristic composition and structure of the climax communities.

The duration of primary succession in volcanic deserts can be estimated at a period of 1500-2000 years. Mixed succession in Zone 2 - 500 years, secondary succession - about 100-150 years.

Based on our results, it is possible to reconstruct on isopachs (Bursik *et al.*, 1993) the effects on vegetation of the largest eruption on Kamchatka in the last 2000 years (Ksudach, 1700 - 1800 years ago), which was more powerful than the famous Krakatau eruption in 1883. The deposit of pumice, erupted almost in the same direction as in 1907, formed a volcanic desert that stretched more than 30 km, down to Khodutka volcano; completely destroyed forest vegetation up to a distance not less than 70-80 km, and, in some degree, up to latitude of Petropavlovsk-Kamchatsky (160 km from Ksudach). The herb, dwarf shrub, moss-lichen vegetation were affected for some hundreds of kilometres to the north, up to a region of central Kamchatka. On our data, we can see the influence of this eruption in the structure and dynamics of the vegetation of Southern Kamchatka down to our century, when this territory suffered again from the catastrophe of 1907.

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