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An outline of Russo-Japanese joint glacier research in Kamchatka, 1996

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Abstract

A three-year Russo-Japanese joint glacier research was started in 1996, aiming at clarifying the glacial system and its variation in the Kamchatka Peninsula. The first year's field research was carried out at three regions of Kamchatka from June 21 to August 22, 1996 : the Kronotsky Peninsula, Ushkovsky Volcano and the Kozyrevka Range. The topics under study include: 1) mass balance, flow, heat balance and hydrological features of the Koryto Glacier in the Kronotsky Peninsula, 2) stratigraphic analysis of shallow firn core of Ushkovsky Ice Cap, 3) start of monitoring of east-west climatic contrast by setting automatic weather stations, 4) reconstruction of Quaternary glaciations in Kamchatka, 5) analysis of Quaternary eolian deposits in Kamchatka and 6) analysis of vegetation patterns with micro-scaling in central Kamchatka. The obtained results show that 1) the Koryto Glacier is characterized by an intensive mass exchange ; 2) potentiality of paleoclimate reconstruction over the circum Okhotsk region from the Ushkovsky Ice Cap was considered ; 3) Quaternary glaciation in the central part of Kamchatka was discussed ; 4) existence of extensive eolian deposits in the central part of Kamchatka was studied ; and 5) vegetation pattern in the Kozyrevka Range and its surroundings was examined.

1. Introduction

Glaciers in the Kamchatka Peninsula have long attracted the interest of Japanese glaciologists because of their nearness to Japan where no glaciers have existed since the Neoglacial period. During research works on "perennial snow patches" in Japan, some Japanese glaciologists have stressed the necessity of comparative studies of cryospheric environment between Japan and Kamchatka for a deep understanding of environmental conditions of snow patches and glaciers (*e.g.* Higuchi *et al.*, 1979).

Characteristics of the glaciers in Kamchatka have exclusively been studied by Russian scientists. After the compilation of glacier inventory of Kamchatka by Vinogradov (1968), attention has been paid to the climate-glacier relationships (Krenke and Chernova, 1980), and the characteristics of the glaciers in the volcanic regions (Vinogradov, 1975) and basic physics of a particular glacier there (Vinogradov and Muraviev, 1992). They have selected several glaciers in Kamchatka for the monitoring of mass balance, and continued to measure their response to climatic change. The results have been published through the World Glacier Monitoring Service as a contribution to the "Fluctuations of Glaciers" of IAHS (ICSI)-UNEP -UNESCO (1988).

In addition to the local features of the glaciers, global scale importance of the glaciers in Kamchatka should be emphasized. Accumulation on glaciers in the Kamchatka Peninsula is supplied by moisture originated from the Sea of Okhotsk and the Pacific Ocean. The vapor is supplied by frequent cyclones crossing the region during winter, which make the North Pacific Ocean as a center of the Aleutian low pressure system against the Siberian high pressure system on the continent. It suggests that the mass balance of the glaciers in Kamchatka can be related with the degree of pressure gradient between the two systems. In fact, a climatic shift occurred in the

North Pacific around 1977 (Trenberth, 1990), since then, there occurred an increase in the mass balance of glaciers in Alaskan coastal area whereas a decrease in the western coast of the North America (McCabe and Fountain, 1995). Then, what happened in the mass balance of Kamchatka glaciers? If there would be any trend in the mass balance of Kamchatka glaciers which is reflecting the climatic change like in the late 1970's, one can expect potentiality of the past climate reconstruction from the glaciers of Kamchatka.

As far as long-term glacial fluctuations during the last glacial-interglacial cycle are concerned, the Kamchatka Peninsula must be one of the most interesting and promising areas in the world. There are several Russian studies on this topic (Olyunin, 1965, 1966 ; Braitseva *et al.*, 1968), however, outside Russia almost no study is being done. The Kamchatka area may be said as a "missing link" area of the circum-Pacific Quaternary glaciation. Without the knowledge of the Kamchatka glaciation, it may be very difficult to correlate well the Alaskan glaciation with that in the Northeast Asia. Study on the Quaternary glaciation in Kamchatka has also a great advantage in chronological aspect, because the tephras from active volcanoes there may be used to date glacial deposits.

We started a three-year Russo-Japanese joint glacier research entitled the "Present and Past Cryospheric Hydrologic Cycle in Kamchatka" in the summer of 1996 to obtain knowledge of the glacial system and its variations with different time scales in Kamchatka and its surroundings. This report outlines the field researches conducted in 1996 and summarizes preliminary results.

2. Objectives of research and field study sites

In the course of several meetings between Japanese and Russian counterparts, it was agreed to study variations of the glaciers of Kamchatka and glacial environments with various time scales. This is because the glaciers of Kamchatka may play an important role in the change of terrestrial cryosphere with various time scales of, say, 10^0-10^1, 10^2-10^3 and 10^4 years. This approach in time scales was never applied to the glaciers of Kamchatka, so, both counterparts aimed to study temporal change of cryospheric environment of Kamchatka.

Multidisciplinary approach should be suitable for this research. Glacio-hydrometeorological methods were applied to the yearly to decadal variations of the glaciers and climate. Mass, heat and water balance observations of the glaciers are the subjects of this approach. The centennial to millennium variations of glaciers and climate will be clarified from ice-core studies because ice cores contain precipitation history and proxy climate signals over the long time. Glacial-interglacial variations of glaciers in Kamchatka will be studied by tracing geomorphological evidences such as moraines, terraces and other landforms. As ancillary works, volcanic soils and vegetation patterns in Kamchatka were studied to clarify the cryospheric environmental changes during the glacial-interglacial cycles.

In dealing with the present-day glacial system (time scale : 10^0-10^1 years), study areas were chosen in nearly meridional direction in the central part of the peninsula ; three intensive observation sites were established at three representative regions, naming Okhotsk, Inland and Pacific Sites (Fig. 1). This is because the main vapor sources to the glaciers in

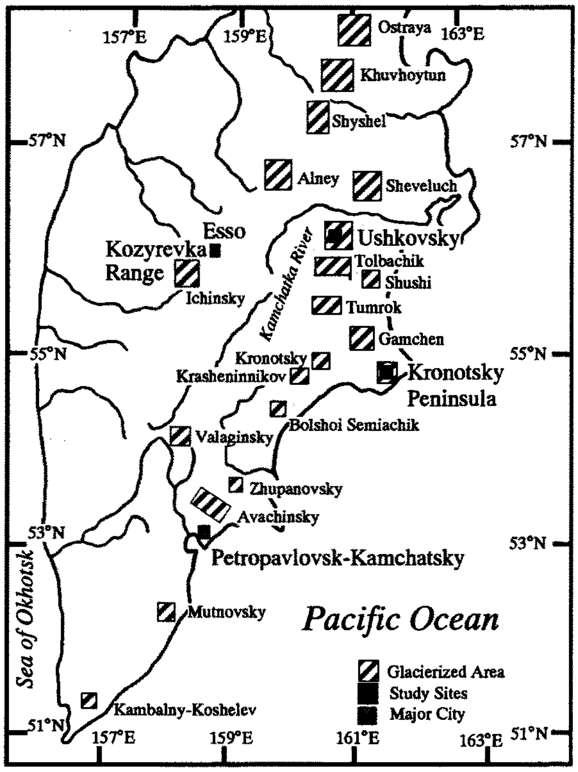

Fig. 1. Location map of the project. It also shows distribution of present-day glaciers in the peninsula (Vinogradov, 1968).

Kamchatka are the Sea of Okhotsk and the Pacific Ocean. In fact, there is a strong east-west contrast in the maximum snow depth in winter (Fig. 2). These three study sites are located at Kozyrevka Range (Okhotsk Site : 55° 35.6'N, 158° 17.4'E ; 1050 m a.s.l.), an ice cap at the summit of Ushkovsky Volcano (Inland site : 56° 4.5'N, 160° 28.7'E ; 3900 m a.s.l.) and the Kronotsky Peninsula (Pacific site : 54° 49.5'N, 161° 50.3'E ; 1155m a.s.l.). In the first year, we concentrated the field work at the Pacific Site, except the installation of automatic weather stations (AWSs) at three sites.

Among 32 glaciers in the Kronotsky Peninsula (Vinogradov, 1968), Koryto Glacier was selected for the study, because this glacier was previously studied in 1970−71 by Vinogradov and Khodakov (1973) and in 1981−82 by one of the authors (Y.M.) (IAHS(ICSI)-UNEP-UNESCO, 1988), so that the temporal change of glacial conditions can be studied. The present observation was conducted from July 8 to July 21 on

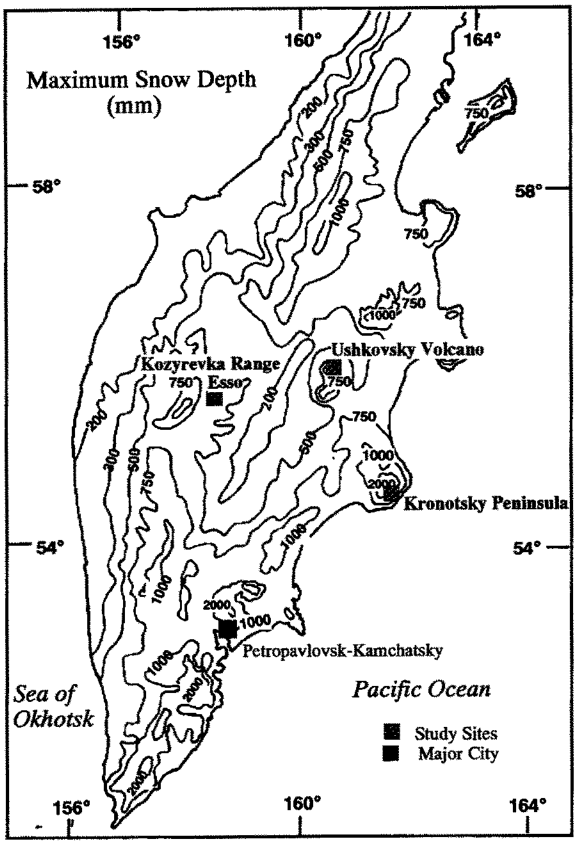

Fig. 2. Distribution of the maximum snow depth (mm) in

the Koryto Glacier and its terminus. Shallow corings, ablation measurement, glacial flow survey, heat balance measurement, discharge observation and mapping of moraines were carried out. The glaciers in the Inland and Okhotsk Sites will be studied in the second and the third year of the project.

The Ushkovsky Ice Cap was selected for the study of centennial to millennium scale variations of the glacial system, because the ice cap is one of the highest and thickest glacier in Kamchatka. In the summit area of 43 km^2, the glacier covers approximately 24.2 km^2 (Murav'ev and Salamatin, 1990). We stayed at the summit of Ushkovsky Volcano from July 24 to August 4, and conducted a shallow coring (27 m deep), snow temperature measurement, mass balance study, radio-echo soundings and installation of an AWS.

Glacial-interglacial-scale variations of the glaciers of Kamchatka were investigated in 1996 at Inland Site of Kamchatka. Glacial landforms were preliminary surveyed at the valley of Bystraja River around Esso and its catchment area in the Kozyrevka Range. Vegetation patterns were also studied in conjunction with the geomorphological works. We also conducted a research on volcanic deposits and soils in the same area and also along the Kamchatka River.

3. Outline of research results

3.1. Mass balance of Koryto Glacier

As a preliminary study on the mass balance of Koryto Glacier, the amount of seasonal snow was measured. Shallow corings at several altitudes on the glacier indicate that the net balance increases linearly with increasing altitude in the accumulation area (Shiraiwa *et al.*, 1997). More than 600 cm water equivalent of snow was deposited at the highest part of the glacier in July 1996. The ablation of the glacier was intensive because of high air temperature. The altitude dependence of ablation in the accumulation area was not large, but there was a significant difference in the ablation between the terminal bare ice and the clean snow above firn line. Valley-wall effect on the ablation was found only near the terminus. The degree-day factor of ablation was 0.72 (cm day^{-1}°C^{-1}) at an elevation of 545 m and 0.55 (cm day^{-1} °C^{-1}) at 1005 m.

A simple estimation of mass balance from the end of summer 1995 to the end of summer 1996 suggests that the extremely high positive balance can be ascribed to heavy snowfalls in the winter of 1995/1996.

3.2. Flow of Koryto Glacier

Ice-flow velocity was measured at two snow-stake transections between 11th and 17th of July, 1996. The lower line was set near the firn line, and measured ice-velocity was about 70 m/a. The upper line was located near the steady-state equilibrium line at an altitude of 780 m, where the ice-velocity was about 60 m/a. Comparing these velocities with those in 1970's measured by Russian scientists, the ice-velocity at the equilibrium line has decreased by about 30 m/a (Yamaguchi *et al.*, 1997).

Short-term variations of ice-flow at the terminal part were served at an interval of 3 hours. Observed daily variations of flow rates suggested the existence of basal sliding. The maximum flow rate was 0.024 m/h and the minimum was 0.012 m/h. Correlation between the ice-flow velocity at the terminus and the river discharge at the glacier terminus was poor.

3.3. Heat balance of Koryto Glacier

To understand the characteristics of heat balance of the glacier, two meteorological stations were established ; one station (the ablation station) was located at an altitude of 545m a.s.l. (Fig. 3), and the other (the accumulation station) was at 1005m a.s.l. (Kodama *et al.* 1997).

The bulk transfer coefficients at the accumulation station were 5.5×10^{-3} and 8.8×10^{-3} for the sensible and latent heat fluxes, respectively. At the ablation station, they are 2.3×10^{-3} and 3.8×10^{-3}, respectively. The bulk transfer coefficient depends on the surface roughness and the turbulent intensity as well as the measurement heights of temperature, humidity and wind speed. The coefficients may have some errors originated from inaccurate snowmelt measurement, where the density of snow was assumed to be constant.

Calculated heat balance showed that the largest heat component for the ablation was the net radiation, giving an average of about 45 % of the total ablation heat. The second largest was the sensible heat flux and the third was the latent heat flux, which were about 30 % and 25 %, respectively. At the ablation station, a large daily snowmelt was observed on July 18. On this occasion, the largest heat source for the snowmelt was not the radiation but the sensible heat flux. When the daily snowmelt was intensive, turbulent heat fluxes (sensible and latent heat fluxes) were large. The snowmelt heat balance of Koryto Glacier was compared with those for seasonal snow in Spitsbergen, Moshiri Experimental Forestry, Hokkaido, Japan and Hisago Snowpatch, Hokkaido, Japan. The net radiation was the largest heat component at all of the three places, whereas, at Koryto Glacier the net radiation contribution was the smallest. This is due to large wind speed which caused large turbulent fluxes.

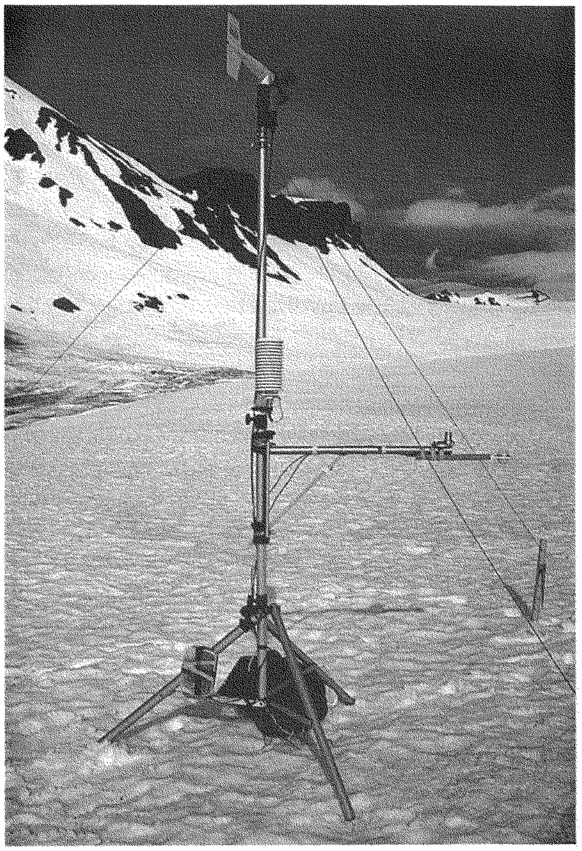

Fig. 3. Meteorological station at the ablation area of Koryto Glacier (Site No. 5 : 545 m a.s.l.).

3.4. Hydrological features of Koryto Glacier

Hydrological observations were carried out at two runoff streams from Koryto Glacier ; stream A (Fig. 4), which had greater discharge, flows from the center of the terminus, and stream B flows on the right side of the valley. Water level, water temperature and specific electric conductivity (SEC) of stream A were measured from July 8 to 19 at 10-minute interval. During this period, discharge of stream A increased gradually from $5.5m^3/s$ to $7.5m^3/s$. The daily maximum discharge occurred around 1500 to 1900 (local summer time, solar noon is about 1400), but diurnal cycles were not clear. Water temperature was fairly stable and remained between 0.0 and 0.4 °C, while SEC decreased gradually throughout the observation period.

Discharge of stream B remained around $1.2m^3/s$ at the same period. Water temperature was higher than that of stream A, whereas SEC was generally low throughout the period (Kodama *et al.*, 1997).

3.5. Shallow coring of the Ushkovsky Ice Cap

A firn-core of 27 m long was retrieved at Gorshkov crater at the summit of Ushkovsky Volcano (Fig. 5). The core was composed mainly of firn and interbedded by ice layers. The analyses of $\delta^{18}O$ and δD of firn/ice samples are under way. The core

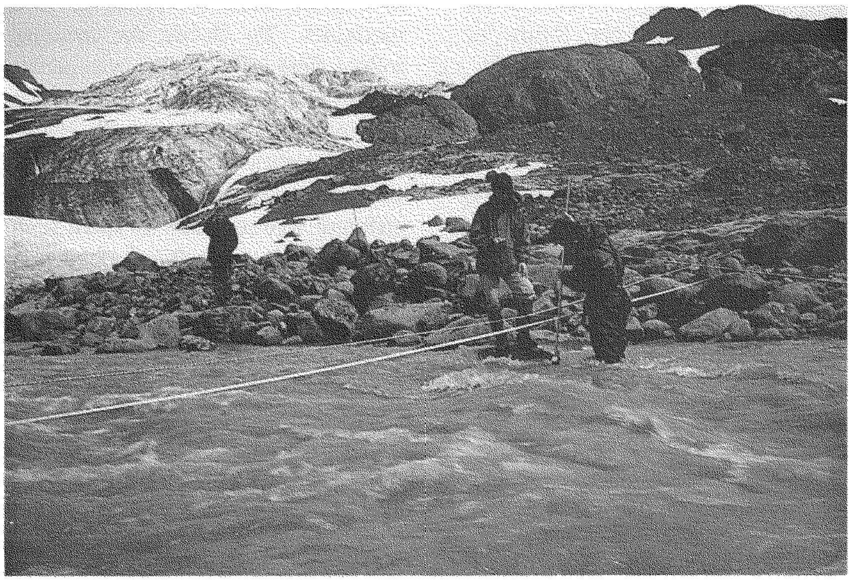

Fig. 4. Hydrological observation at stream A of Koryto Glacier.

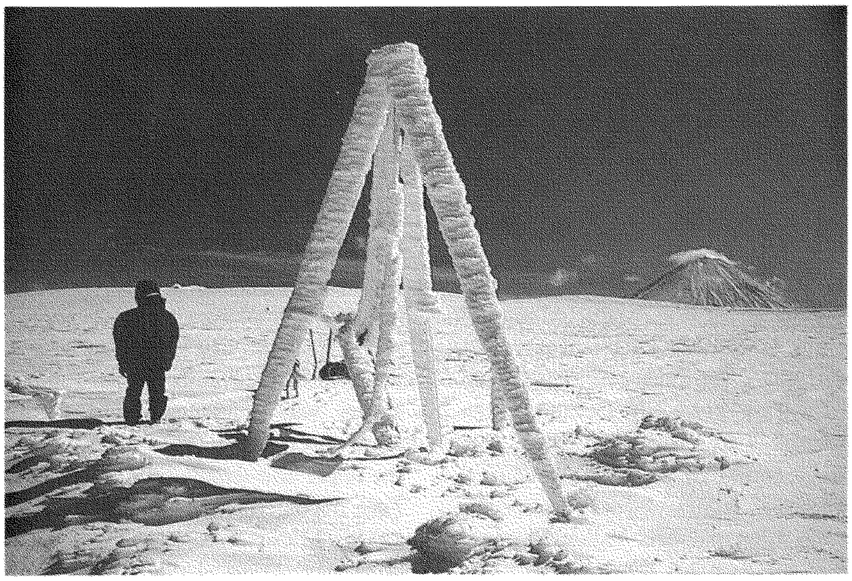

Fig. 5. Drilling tripod heavily coated with rime ice at Gorshkov crater, Ushkovsky Ice Cap.

contained 20 ash layers which will be analyzed by mineralogical methods. Average annual accumulation rate during the last 30 years was estimated to be 0.57 m/a water equivalent by using dated ash layers in the core. We observed the rise of snow surface from 20 to 50 cm during July 25 to August 2, 1996, which suggested that the ice cap was growing even in summer. Because of low snow temperature (−16°C at 10 m deep), it was possible that surface melt water percolated in the snow and accumulated immediately below the surface as refreezed ice layers (Murav'ev and Salamatin, 1990 ; Shiraiwa *et al.*, unpublished).

Radio-echo soundings were operated at the center of Gorshkov crater by a 4 MHz impulse radar to measure the ice thickness of the crater (Matsuoka *et al.*, 1997). Although Murav'ev and Salamatin (1990) estimated the thickness of the ice to be from 40 to 90 m by numerical simulation, we sounded the thickness to be from 180 to 230 m deep. If we believe the thickness obtained by the soundings, the ice cap at the summit of Ushkovsky Volcano has a potentiality of paleoclimate reconstruction during the last several hundred years.

3.6. Installation of AWS

Automatic weather stations (AWS) were installed at three sites from July to August, 1996 : Okhotsk, Inland and Pacific Sites. The system includes sensors on global radiation, wind speed, wind direction, air temperature, relative humidity, snow surface temperature and air pressure. Snow depth and snow temperature sensors were additionally installed only at Inland Site. The data will be recorded in data-loggers every 1 hour for more than one year, and will be collected in the summer of 1997.

3.7. Mapping of glacier-related landforms around Esso

A preliminary survey of the Quaternary glaciations along the Bystraja River was conducted around the town of Esso and in the west of the Kozyrevka Range (Sone *et al.*, 1997). Moraines originated from tributaries of the Bystraja River are located at the western end and about 6 km south of Esso. The moraines were likely deposited in the Last Glacial Age, because Holocene tephra layers cover the moraines. Remnants of U-shaped valleys remain along the left side of the Bystraja River valley.

No glaciers exist in Mt. Kozyrevka (2015 m a.s.l.), the highest peak in the Kozyrevka Range. Cirques near the summit were probably formed in the Little Ice Age. Whaleback landforms (roches moutonnées) are observed around 1350 m a.s.l. Some periglacial phenomena such as earth hummocks, solifluction lobes and patterned ground are distributed at Mt. Kozyrevka.

3.8. Quaternary eolian deposits of Kamchatka

A large area of Kamchatka Peninsula is covered by volcanic ash soils, mainly composed of pyroclastic materials. To clarify the forming process of the soils, a field investigation was performed in the vicinity of Ushkovsky Volcano and the western area of the volcano (Yamagata, *et al.*, 1997). The following characteristics of the soils suggested that the soils were composed of the particles derived from several different sources, such as small scale eruptions, bare ground in the river floor, alpine area, and surroundings of glaciers : (1) the poor sorting of the soils, (2) lithofacies and thickness change of the soils with increasing distance from the volcanoes, (3) the presence of several different types of volcanic glasses and rounded lithic fragments. There was no evidence in support of the addition of the eolian dust transported from the arid region of the Asian continent to the soils in Kamchatka.

Black colored volcanic ash soils were recognized at altitudes of below 500 m. The basal age of the black soils was estimated to be about 2000 years ago, taking account of stratigraphic relationships with the Shiveluchi 4 ash fall layer (*ca.* 2ka). Plant opals originated from *Pooideae* were found in the black soils and lower brown soils. The formation of the black soils are expected to be influenced by climate change, vegetation change, and human activity.

3.9. Vegetation patterns with micro-scaling in central Kamchatka

We started phyto-geodiversity cooperative study between Kamchatka and Japan, with particular references to plant species diversity and vegetation patterns associated with glacier topography. The first survey was conducted on descriptions of vascular plant species composition and their spatial patterns at the upper and middle basins of Bystraja River around Esso during July 23 and August 6, 1996 (Sato *et al.*, 1997). Micro-scale measurements showed five types of forests ; *Pinus, Alnus, Betula, Salix* and the mixture ; mosaic coexistence of herbaceous plants and simple shrub vegetation types. A total of about 200 vascular plant species were recorded and the phyto-geodiversity decreased from the middle to the upper basins and from the low (500 m) to the high (1700 m) altitudes in the central Kamchatka.

4. Members of the Project

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