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The Eruptions of Sarychev Peak Volcano, Kurile Arc: Particularities of Activity and Influence on the Environment

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1. Introduction

More then 68 quaternary volcanic edifices are picked out in the Kurile Islands, among them 36 are active and potentially dangerous. During 45 thousand years not less then 12 large explosive eruptions, connected with the formation of the calderas, have occurred. During these eruptions a great amount of ash emitted and large pumice-pyroclastic covers formed, that caused the climate and landscape changes (Melekestsev et al., 1988).

During the historical time (about 250 years for the Kurile Islands) about 29 great and catastrophic eruptions were fixed (Gorshkov, 1967). In XXth century the volcanoes of the Central and Northern Kurils were the most active and productive by the volume of the erupted material. These tendencies have continued in current century. Explosive eruptions occurred many times on Chikurachki volcano (Girina et al., 2008). Phreatic and phreato-magmatic explosions were detected on the Ebeko, Berga, Chirinkotan, Severgin volcanoes.

Because of rare population of the Kurile Islands the damage at the eruptions was not so considerable as it usually was in densely populated island countries such as Indonesia, Japan and others. However, some cases were written in the historical documents, when the eruptions in the Kurile Islands caused the material damage and victims. In 1778 during the strong eruption of Raikoke volcano 15 Russian manufacturers died. There are the historical materials about the destruction of ainu settlements in Shiashkotan Island after the eruption of Sinarka volcano (Gorshkov, 1967). In 1933 at the eruption of Severgin volcano in Harimkotan Island the Japanese settlement was destroyed, tsunami waves formed by the eruption, caused the death of several people in the neighboring islands Onekotan and Paramushir (Miyakate, 1934).

During the eruptions of Sarychev Peak volcano in 1946 and 1973 the evacuation of military unit was conducted in Matua Island. At Tyatya volcano eruption in 1973 the military camp was destroyed on the Lovtsov peninsular (the north of Kunashir Island). In settlement Yuzhno-Kurilsk located at the distance of 60 km from the volcano, the ash fell and great panic among the population was. Great panic was also fixed at small phreatic eruption of Ivan Grozny volcano in Iturup Island in 1989 (Abdurakhmanov et al., 1990).

At present time the constant population in the Kurile Islands lives only in the southern (Kunashir, Iturup, Shikotan) and northern (Paramushir) islands, and practically all the settlements, excepting those located in Shikotan Island (the Small Kurile Arc) are in the zone of different volcanic danger.

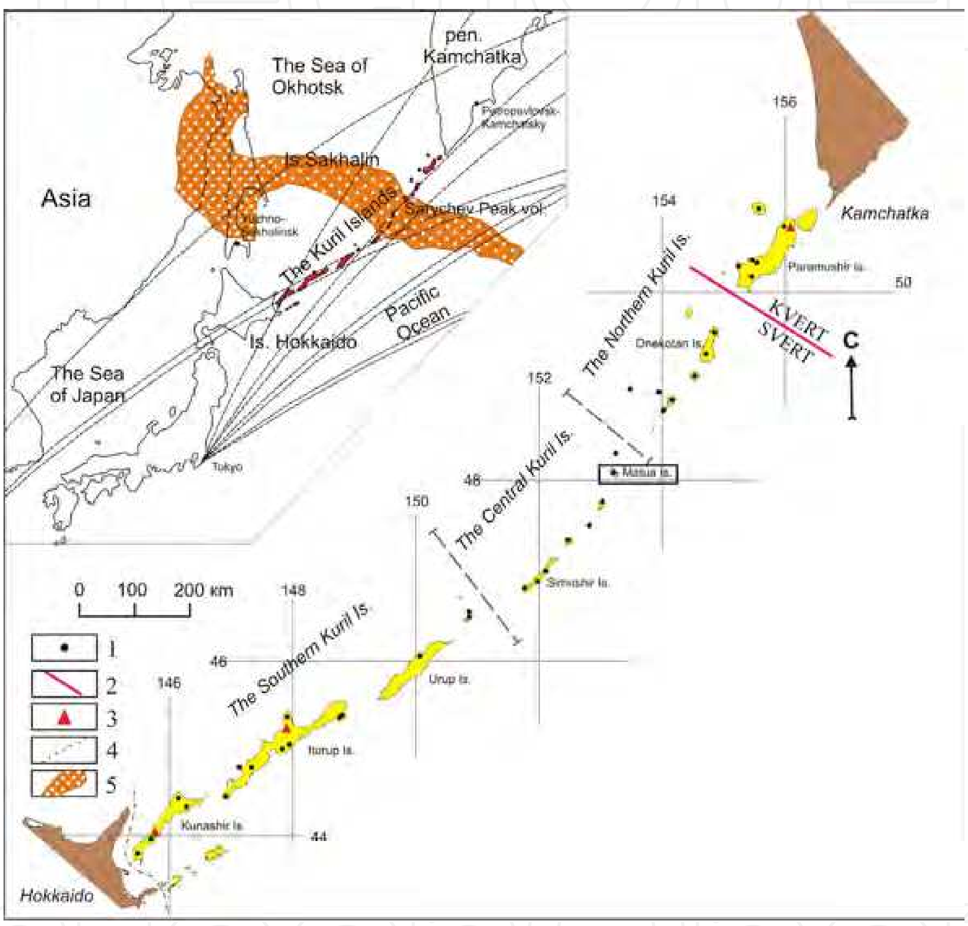

Fig. 1. Map of the Kuril Islands and the zone of the responsibility of the monitoring of the volcanic activity of Sakhalin Volcanic Eruption Response Team (SVERT) and Kamchatka Volcanic Eruption Response Team (KVERT). KVERT issues information for the northernmost Kuriles (Paramushir and Atlasova Islands). The remaining Kuriles are monitored by SVERT. Sarychev Peak is located on Matua Island in the central Kuriles. Inset shows a schematic version of the primary air routes in the vicinity of the northwest Pacific.

During last decades the cases when airplanes fall into the clouds of ash, become more frequent because of increasing of volume and geography of airtraffic. The last information is represented very important because the most part of air routs connecting the North America and the East-Asia region goes along the Kurile Islands (fig. 1). During passed 40 years 4 serious cases, when airplanes fell into the clouds of ash, occurred only on Alaska, three last incidents were during last 15 years.

After 33 years of break in eruptive activity, Sarychev Peak volcano, located in Matua Island in the Central part of the Kurile arc and being one of the most active volcanoes, began its work (fig. 1, 2). The eruption in 2009 several days impeded the work of airtransport passed along the Kurile arc (Salinas, 2009). Sulfur aerosols emitted as a result of explosive activity of the volcano could possibly influence to the climate of region (Haywood et al., 2010). Besides that a large emission of pyroclastic material such as pyroclastic flows and tephra produced considerable geological and ecological effects (fig. 2). The landscape structure of Matua Island underwent the cardinal changes: in the bounds of Sarychev Peak volcano edifice the full reconstruction of the landscapes occurred, the view of the adjacent surroundings was considerably changed (Ganzey et al., 2010).

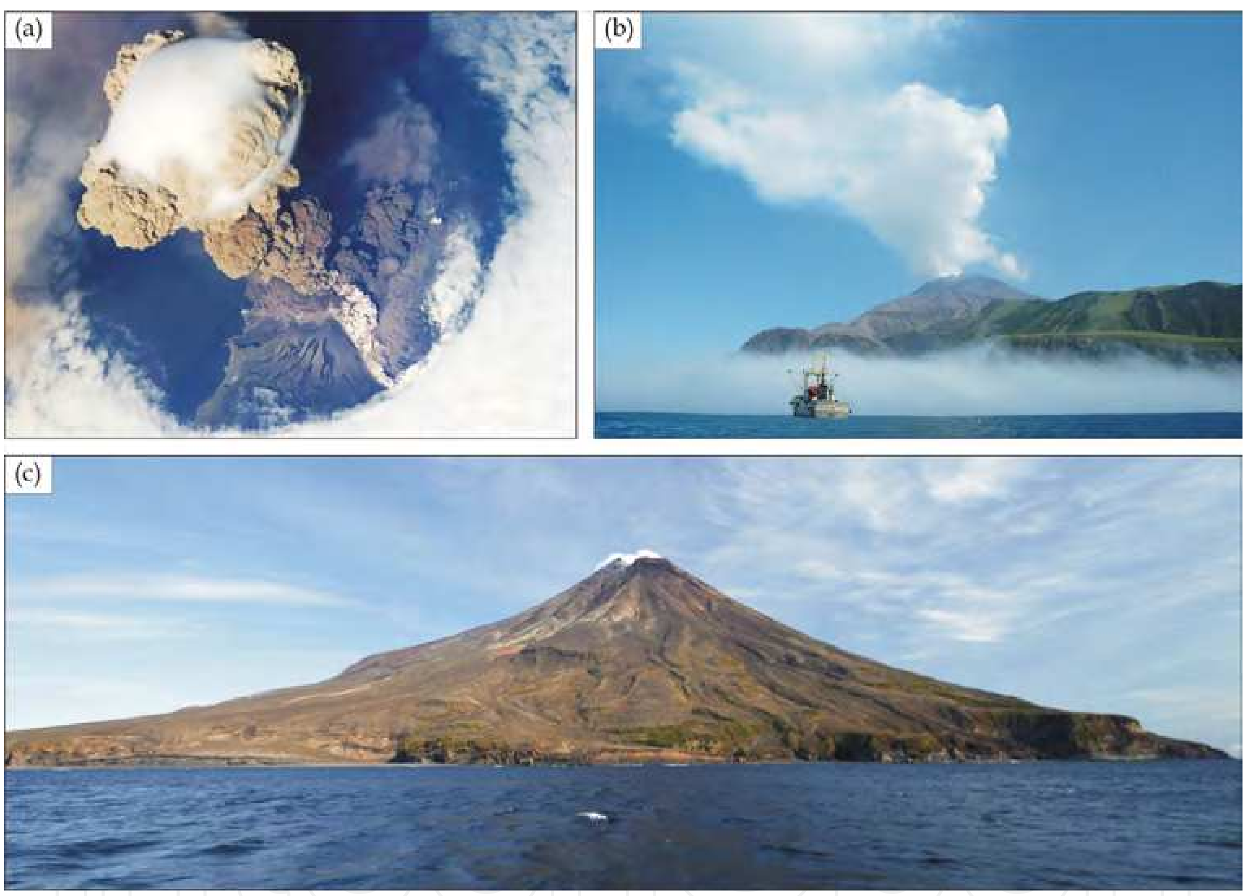

Fig. 2. Sarychev Peak volcano: A – explosive activity of Sarychev Peak volcano at the eruption in 2009. On the image made by the astronauts of ISS the eruptive column, reached the height of several kilometers, and pyroclastic flows, descended along the slopes of the volcano are seen, 12 June 2009. (Published by Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center, http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=38985);
B - Sarychev Peak after the eruption on June 27, 2009. Robust gas and water vapor cloud rises from the summit vent. The green vegetated terrain in the near ground is the southeastern sector of the island that was only minimally impacted by the eruption (fig. 2). Photo A.V. Rybin, IMGG FEB RAS; C – Sarychev Peak volcano in 2010, the north-western view. Photo A.V. Rybin, IMGG FEB RAS.

In given work we represent the results of the researches of Sarychev Peak volcano eruption in 2009: (1) a common characteristic of Sarychev Peak volcano is shown – geological structure, morphology, data about its historical eruptions; (2) the chronology of the eruptive activity at the eruption 2009 is described; (3) data of study of the eruption products, their facial and chemical composition are presented; (4) the influence of Sarychev Peak volcano eruption to the nature of Matua Island is described.

2. Common characteristic of Sarychev Peak volcano

Sarychev Peak volcano is one of the most active volcanoes of the Kurile Island arc (fig. 1). The edifice of Sarychev Peak Volcano occupies the north-western part of Matua Island that is located in the central part of the Kurile Islands. The island has a form of sublongitude ellipse with the sizes 6×12 km, the area of it before the eruption of Sarychev Peak volcano in June 2009 was 52.5 km^2 (fig. 2).

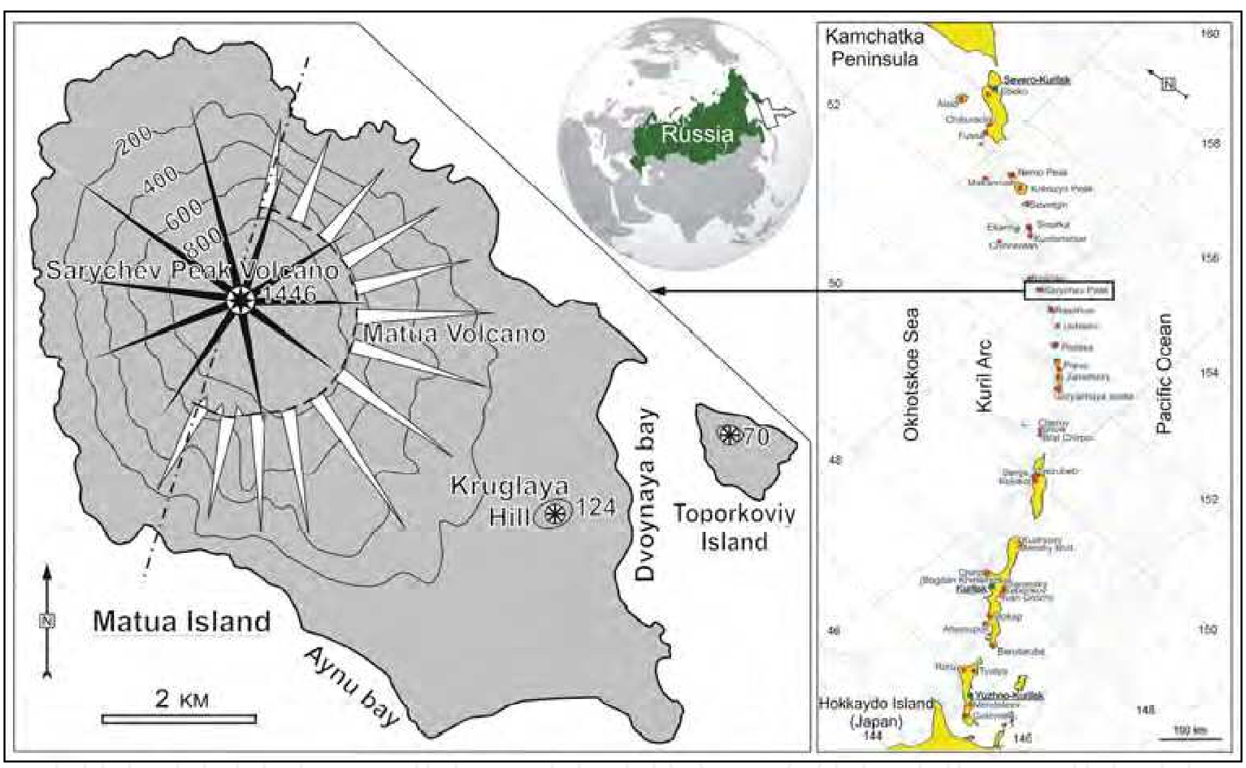

Fig. 3. Geological scheme of Sarychev Peak volcano, stroke shows the line of fault picked out by G.S. Gorshkov (1967). The map of the Kurile Islands is on the additional map.

Sarychev Peak volcano is intracalderal stratovolcano (elevation 1446 m; coordinates: 48.92° N., 153.20° E), formed mainly by pyroclastic material (fig. 3). The volcano is located in the caldera of Pleistocene volcano Matua, the ruins of which form the north-western part of Matua Isl. In spite of the volcano is formed by “Somma-Vesuvius” type, the characteristic elements of its structure is closed to a large measure. The north-western part of the island with a half of somma of Matua volcano was sank along the fault plane (fig. 3), detected by G.S. Gorshkov (1967) and overlapped by the formations of young cone – pyroclastic and lava flows. The basement of the volcanic edifices consists of volcanogenic rocks with absolute age according to data of K-Ar-dating Ishizuka et al. (2011) 1.61 mln. years.

3. Historical eruptions of Sarychev Peak volcano

Since 1760th not less than 10 eruptions of Sarychev Peak volcano were fixed in the historical chronics and described with different degree of details (Andreev et al., 1978; Glavatsky & Efremov, 1948; Gorshkov, 1948, 1967; Grishin & Melekestsev, 2010; Levin et al., 2009; Markhinin, 1964; Rybin et al., 2010; Shilov, 1962). Among them the most studied events occurred in the XXth century: 1946, 1960, 1976 и 2009. The behavior of these eruptions in comparison with previous events is reconstructed in details, and their sequences were studied soon by specialists-volcanologists. Lower the brief description of historical eruption of Sarychev Peak volcano is given.

3.1 The eruptions of the volcano in XVIII-XXI centuries

XVIII century

The eruption in 1760th: strong explosive eruption, the data about it are contained in the descriptions of Cossack sotnik I. Chyorny, visited the Kurile Islands in 1766-1769 and known about it from inhabitants (Polonsky, 1994). According to this information, as a result of this eruption in considerable degree in Matua Isl. the vegetation was destroyed, and Toporkovy Isl. was fully burnt.

XIX century

The eruptions in 1878-1879: weak effusive-explosive eruption, a brief mention about it is in the work of English trader G. Snow (1992). It was reported about lava flows slowly descended to the sea.

XX century

The eruptions on the 17-22 of January 1923: weak explosive eruption when "the explosions with emission of ash and scoria" were marked (Kamio, 1931; Gorshkov, 1967).

The eruptions on the 14th of February 1928: moderate explosive eruption, accompanied with "storm of bombs and lappili in the surroundings of the crater" (Tanakadate, 1931; Gorshkov, 1948).

The eruptions on the 13th of February 1930: explosive eruption is of moderate power. There are no the concrete estimations of volume of erupted products; it was reported only, that it was erupted "colossal" amount of volcanic material. The accumulation of pyroclastic in the southern part of the island caused the increasing of the shore line up to 30 m (Tanakadate, 1931; Gorshkov, 1948)

The eruptions on the 9-17th of November 1946: strong explosive-effusive eruption, the process and the sequences of it were reconstructed on the base of polling data, collected by S. Glavatsky in Kamchatka and G. Efremov in Sakhalin (Glavatsky & Efremov, 1948).

The eruption was accompanied by emission of large amount of heated clastic material, mainly pyroclastic flows and tephra. The accumulation of pyroclastic material in the shore zone caused to local increasing of the shore line, the sites of new formed surface were found by the eye-witnesses in the north-eastern, north-western and south-western parts of the island. Lava flows formed several new capes. The height of ash clouds according to data of the eye-witnesses reached 7 km. Ash-falls caused by this eruption were fixed on the territory of neighboring islands and even in Kamchatka (Glavatsky & Efremov, 1948).

The eruptions in 1954: weak explosive activity of the volcano at the end of summer and autumn 1954, expressed in weak ash emissions. Luminescence above the crater was fixed, however lava eruption did not occur, after lifting it solidified in the form of lava plug (Gorshkov, 1967; Shilov, 1962).

The eruptions from the 30th of August till the 3d of September 1960: moderate explosive eruption was accompanied by emission of ash and formation of pyroclastic flows. By the information of inhabitants of the island the first explosion elevated the eruptive column up to 4.5 km, the height of next emissions did not excess 0.5 km (Shilov, 1962).

The eruptions from the 23d of September till 2d of October 1976: moderate explosive-effusive eruption, the only historical eruption of Sarychev Peak volcano that was observed by the volcanologists (Andreev et al., 1978). The eruption consisted of series of explosions up to the height from 0.5 to 2.5 km. Along the north-western and western slopes of the cone the pyroclastic flows descended, they burnt the soil-vegetation cover on their way. Lava flows are fixed on the western, south-western and north-western slopes of the edifice; two of them (western and south-western) reached the sea and formed two new capes.

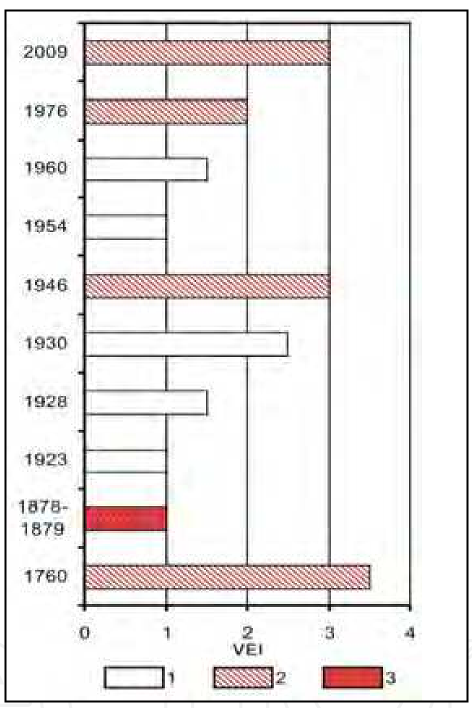

Fig. 4. The chronology of the eruptions of modern eruptive stage of Sarychev Peak volcano. Legend: 1 – explosive eruption; 2 – explosive-effusive eruption; 3 – effusive - explosive eruption. The evaluation of eruptions Volcanic Explosive Index (VEI) was done on the base of characteristics of historical eruptions found in the literature.

After the eruption in 1976 the information about the state of the volcano was received from local inhabitants and rare air observations. By data of SEAN Bulletin (Scientific Event Alert Network Bulletin), published by Smithson's Institute (USA) in 1986 and 1989 two episodes of volcano activity – weak phreatic eruptions were detected. (http://www.volcano.si.edu/world/volcano.cfm?vnum=0900-24=&volpage=var). It is probably that it was small activity expressed in increasing of steam-gas emission or in the form of weak phreatic outbursts.

In August 2007 A.K. Klitin (Yuzhno-Sakhalinsk) and S.A. Chirkov (Institute of volcanology and seismology FEB RAS, Petropavlovsk-Kamchatsky) visited the crater of the volcano. In 2008 the crater was researched by the scientists of the Institute of Marine Geology and Geophysics FEB RAS R.V. Zharkov, D.N. Kozlov and A.V. Degterev. Great fumarolic activity was observed in the crater of the volcano, but because of large gas-laden the fumarolic areas were not investigated. The temperature on the crater rim did not exceed 100°C.

As it is seen from the given data, the character of the eruptive activity of Sarychev Peak volcano is mainly explosive and explosive-effusive – from weak phreatic emissions with VEI 0-1 to strong explosive eruptions of sup-plinian type with VEI 3-4 (fig. 4). The characteristic features of the eruptions of Sarychev Peak volcano are their high explosiveness at which emitted fragmental material forms pyroclastic flows and long ash plumes. Sarychev Peak volcano is one of few volcanoes of the Kurile Island Arc at the historical eruptions of which the ash fell not only in the limits of the island arc but also to the north-east in Kamchatka (Glavatsky & Efremov 1948) and to the west on the territory of Khabarovsky Kray and Sakhalin (Levin et al., 2009). The products of all the historical eruptions of Sarychev Peak volcano are represented by andesite-basalts with 53.78 wt. %, SiO_2, 3.07 wt.% Na_2O, 0.96 wt.% K_2O (Table 1).

Date	1930	1946			1960	1976				2009		
№	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	53.4	50.85	53.84	52.95	53.6	54.82	54.72	54.76	53.22	54.04	54.41	54.85
TiO_2	1.09	1.07	0.96	0.8	0.93	0.88	0.93	0.93	0.85	0.87	0.88	0.93
Al_2O_3	19.14	18.88	18.58	19.14	16.3	18.02	18.1	18.16	17.95	18.27	18.23	17.78
Fe_2O_3	2.64	4.83	4.43	3.93	3.71	3.76	4.31	4.2	4.75	9.61	9.74	9.3
FeO	5.76	5.06	4.26	5.76	4.47	5.14	4.68	4.74	5.08			
MnO	0.28	0.42	0.22	0.18	0.11	0.2	0.2	0.2	0.2	0.2	0.2	0.2
MgO	4.42	4.38	3.96	3.65	3.83	3.74	3.7	3.75	4.13	4.16	4.12	3.86
CaO	8.7	9.3	8.91	8.8	7.89	8.76	8.82	8.72	9.24	9.17	9.1	8.91
Na_2O	3.22	2.88	3.24	3.23	2.95	3.06	3.18	3.13	2.98	2.97	2.84	3.25
K_2O	1.08	0.99	1.06	0.93	0.22	1.06	1.1	1.15	1.06	0.91	0.93	1.02
P_2O_5	0.21	0.1	0.08	0.07	0.17	0.36	0.3	0.36	0.48	0.21	0.21	0.23
Sum	100.11	100.35	99.61	99.57	100.38	100.07	100.29	100.34	100.15	100.52	100.76	100.33

Table 1. Summary composition of lavas and pyroclastic material of some historical eruptions of Sarychev Peak volcano (mas. %).

Note. All the analyses are given by reference data excepting № 12: 1. Volcanic bomb 1930 , analyst V.P. Enman, Institute of Volcanology (IV) (Gorshkov, 1967); 2. Matrix of pyroclastic flow 1946, analyst N.S.Klassova, IV (Gorshkov, 1967); 3. Volcanic bomb 1946 (average of two analyses), (Gorshkov, 1967); 4. The material of pyroclastic flows 1946(?),Sakhalin Complex Scientific Research Institute (SakhCSRI) (Fedorchenko et al., 1989); 5. Volcanic sand 1960, SakhCSRI (Shilov, 1962); 6. Lava 1976 (Andreev et al., 1978); 7. Lava 1976 (Andreev et al., 1978); 8. Volcanic bomb 1976 (Andreev et al., 1978); 9. Volcanic ash 1976, analyst T.S. Osetrova, IV (Andreev et al., 1978); 10. Volcanic bomb 2009, Alaska University (Fairbanks, USA) (Rybin et al., 2011); 11. Volcanic bomb 2009, Alaska University (Fairbanks, USA) (Rybin et al., 2011); Lava 2009, analysts Gorbach G.A., Tkalina E.A., Hurkalo N.V., Far East Geological Institute.

4. The eruption of Sarychev Peak volcano on the 11-17th of June 2009

Strong explosive-effusive eruption on the 11-17 of June 2009 came to the list of the strongest volcanic events occurred in the Kurile Islands during last 300 years and became the first eruption in the Central Kurile Islands in XXI century. Eruptive clouds by data of Tokyo VAAC (Volcanic Ash Advisory Center) raised the height 8-16 km, the plume of the volcanic ash stretched to the western and north-western direction at the distance of 1.5 thousand km, to the east and south-eastern direction at the distance more then 3.0 th. km, this corresponds with the sector of covering from Amur Region to Alaska Peninsula. For the first time during the historical period the ashfalls were fixed on the territory of Sakhalin Island and Khabarovsky Kray (Grishin et al., 2010; Levin et al., 2010).

4.1 The chronology of the eruptive activity of Sarychev Peak volcano at the eruption in 2009

The first signs of volcanic activity of Sarychev Peak volcano were fixed by Sakhalin Volcanic Eruption Response Team (SVERT): on satellite images of NOAA (spectroradiometer AVHRR) and Terra (spectroradiometer MODIS) on 11th of June, a thermal anomaly testified to the increasing of fumarolic activity (Rybin et al., 2010). Further monitoring of the eruptive process was also done on the base of data of distance sounding.

On 12th of June the increase of the activity of the volcano began, eight volcanic explosions occurred; their height above the rim of the crater was from 5 to 12 km (fig. 5). The largest explosion during this day occurred at 07:57, as a result of this a dense ash cloud with diameter 35 km formed on the height 12 km. 3.5 hours later the cloud without changing of form moved eastward 30 km from the volcano, further ash plumes stretched in two directions: to the south-east at the distance 200 km and to the south-west 185 km. Beginning from 14:57 the series of the explosions occurred and ash plumes from them increased in sizes and stretched to the south-eastern direction more than 500 km and to the south-western direction more 150 km. The eruption accompanied by the descending of heat pyroclastic flows along the slopes of the volcano.

On 13th of June between 01:30 and 04:50 a series of explosions occurred, the maximal height of ash columns above crater rim reached 10 km. At 01:30 on the satellite images the ash cloud with diameter more than 50 km was observed, in 2 hours it moved 80 km from Matua Island to the south-eastern direction.

Next two explosions had the same characteristics. Ash cloud of isometric form with diameter 18 km originated at the explosion which had occurred at 04:50. Over an hour the cloud had increased up to 60 km, them the dense part of it began to move eastward formed a plume more than 500 km in the south-eastern direction. 5 hours later the explosion with ash emission up to 10 km occurred, it formed ash cloud 60 km in diameter during 5 hours grew up to 120 km and also moved in the south-eastern direction, the width of originated plume reached 200 km. At 21:30 the greatest explosion for all the period of eruption was fixed, the diameter of dense part of ash cloud reached 65 km. During four hours it increased and reached 140 km in diameter. Ash plumes moved in two directions, the denser part stretched in the south-eastern direction, and the part with lower content of ash traveled in the north-western direction. After this explosion the considerable pause of volcanic activity was observed, it lasted 14 hours.

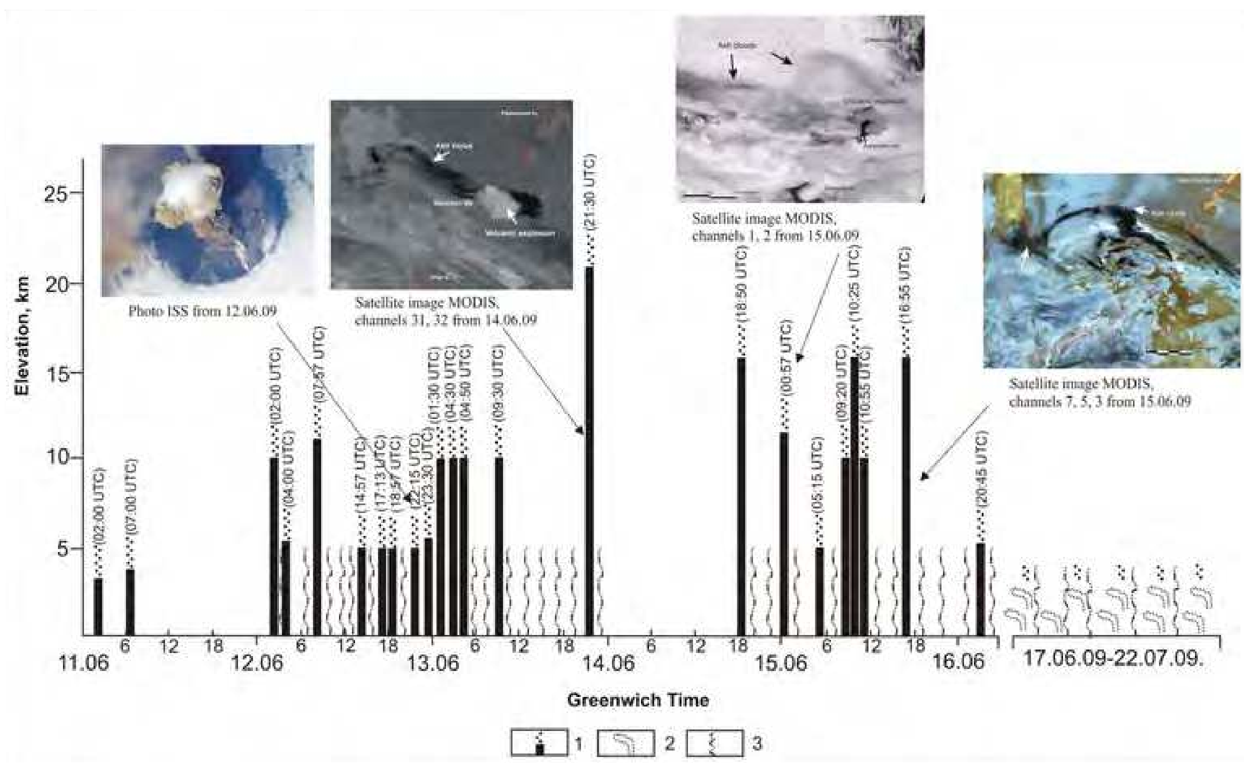

Fig. 5. Summary of satellite observations, inferred explosive events and representative imagery through the eruption, adapted from Levin et al. (2010). Heights of individual ash clouds were determined by using the altitude temperature (Kienle & Shaw, 1979; Sparks et al., 1997) and parallax (referred to in Oppenheimer 1998) methods from the MTSAT satellite data and those reported by the Tokyo VAAC. Symbols are as follows: 1 - gas–steam emissions, 2 - explosions, 3 - continuous ash emission, 4 - times are reported in Greenwich Time or UTC.

The volcanic explosion in June, 14 at 18:57 began the next series of the events. Ash cloud of the first explosion had the diameter about 20 km, then in 3 hours its size increased to 120 km and at 21:30 ash cloud lost its round form and stretched in the western and eastern directions.

On 15th of June seven explosions were detected, ash clouds had diameters from 62 to 170 km (fig. 6). Ash plumes move in the north-western and south-eastern directions. Continuous emissions of ash occurred between the explosions. Last large explosion was at 16:55.

On the 16th of June the eruption lasted. A continuous supply of volcanic material and weak volcanic explosions were fixed during this day. Such situation remained until June, 19.

Since June, 20 the volcano went to the stage of large steam-gas activity, which was accompanied by rare explosions with small amount of ash. During the period from June, 20 till October the thermal anomaly, connected with heated pyroclastic flows on the slopes of the volcano, was often detected in the satellite images.

Ash falls during the period of eruption (collections of the material and the eye-witness accounts) were detected in Raikoke, Rasshua, Ushishir, Ketoi, Simushir, in the northern part of Urup and on all the territory of Sakhalin and in Khabarovsky Kray.

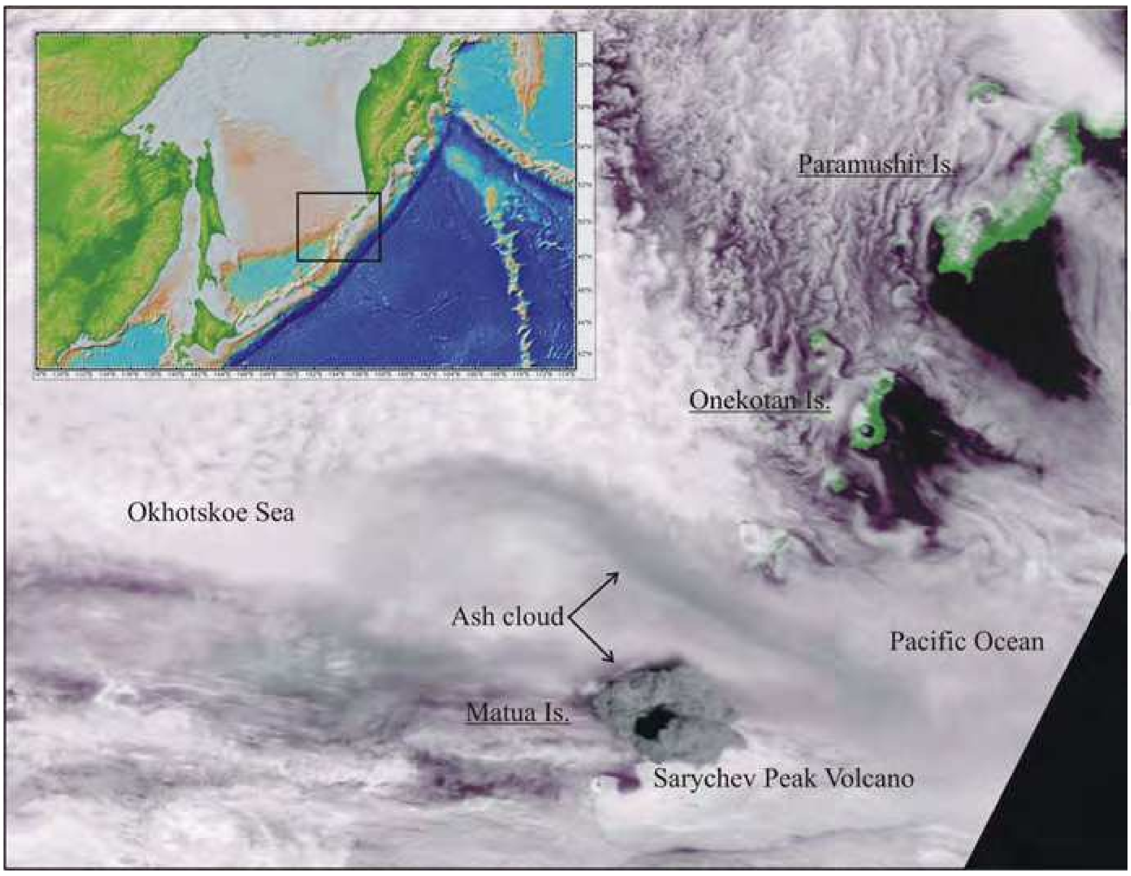

Fig. 6. Explosive activity of Sarychev Peak volcano on 15th of June 2009. Ash cloud formed above the volcano and its diameter is more then 100 km (satellite image MODIS).

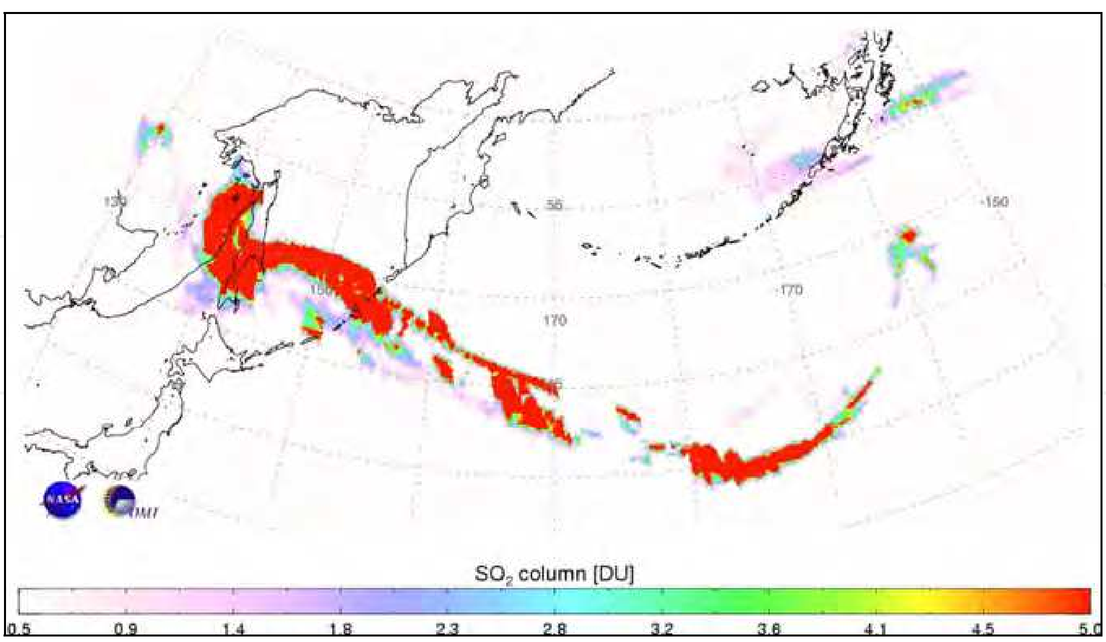

Fig. 7. Summary concentration of sulfur dioxide from 11th till 17th of June 2009, emitted during the eruption of Sarychev Peak volcano (by data Aura – OMI, published by Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center, http://earthobservatory.nasa.gov/IOTD/view.php?id=38975).

According to data of the group of ozone monitoring of NASA, the total concentration of sulfur dioxide in aerosol from 11th till 17th of June was the maximal for the Pacific region in 2009, aerosol clouds by the instrumental methods (satellite AURA) were fixed up to the western shore of Alaska (fig. 7). Data of satellite CALIPSO corroborate the emission of ash material on the height up to 15 km and possibly up to 21 km. The ions of sulfur on such heights can live for a long time and, reflecting the sun light cause the fall of temperature.

Eruptive clouds, connected fine-dispersed pyroclastic material and lifted during the explosive activity on the considerable height, represented a serious danger for airplanes. By data (Salinas, 2009) at the eruption of Sarychev Peak volcano in 2009 65 routs, passed along the Kurile Islands, were changed; 6 changed the course; 2 planes returned to airports of departure; besides 12 non-planed landings were made for re-fuelling. Additional expenses of air-companies because of eruption were evaluated $1.8 mln (Salinas, 2009). Due to operative acts of Sakhalin Volcanic Eruption Response Team (SVERT) in collaboration with Alaska Volcano Observatory (AVO) the negative sequences were avoided.

4.2 Pyroclastic deposits of the Sarychev Peak volcano eruption in 2009

Occurred eruption also as previous events of Sarychev Peak volcano was characterized by high explosiveness, at which the material, erupted by the volcano, formed numerous pyroclastic flows. The process of their formation was fixed in photographs, made by ISS astronauts (fig. 1 a). Ten days later after the ending of active phase of the eruption the products of the explosive activity of the volcano were studied by us during the field works (fig. 8). On the base of the complex of stratigraphical and lithological data the next types of fascias were detected (according to the classification in the work (Fisher & Schminke, 1984): the deposits of pyroclastic flows; the deposits of ground surge; the deposits of ash cloud surge; the deposits of ash cloud of pyroclastic flow; tephra fall. Tephra of the eruption 2009 are represented by two benches of ashes: brown and grey, the bound between them is rather clear. The ash of brown color was probably connected with the initial stage of the eruption, when the voiding of volcanic vent had occurred after considerable pause in its eruptive activity. The ash of brown color is covered with the ash of grey color. Its fall possibly occurred during the final stage of the eruption.

Total volume of volcanites erupted during the active phase of the eruption (11-17 June 2009) was, according to different estimations from 0.1-0.2 (Grishin et al., 2010) to 0.2-0.4 km^3 (Levin et al., 2010b; Rybin et al., 2010). The products of the eruption were presented by andesite-basalts that are typical rocks of its modern eruptions with the content 54.04-54.41 wt.% SiO_2, 18.23-18.27 wt.% Al_2O_3, and 0.91-0.93 wt.% K_2O (Rybin et al., 2011).

The deposits of pyroclastic flows strip mainly in the bounds of near-shore part of the island, forming new-formed surface in the small harbors of shore line. On one of the sites of such surface we found a small lake (~10×25 m), its formation occurred as a result of supply of storm water or, that is more probably, by local tsunami of volcanogenic origin (fig. 8). Tsunami of such type, but in considerably larger quantity, was fixed at the eruption of Severgin Peak volcano (Harimkotan Island) in January 1933, when the supply of pyroclastic material of directed explosion to near-sea water caused the formation of tsunami waves with height ~20 m (Gorshkov, 1967).

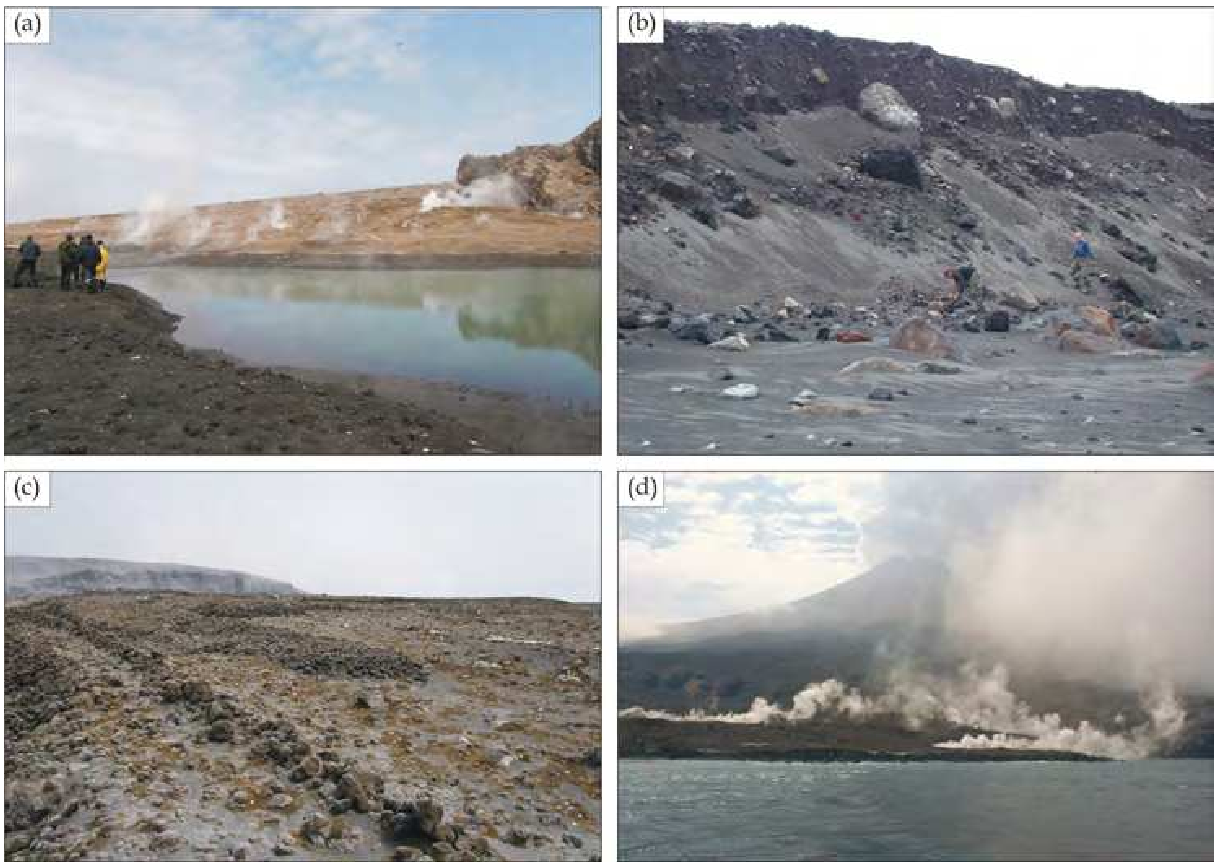

Fig. 8. Pyroclastic deposits: (a) the site of land formed as a result of accumulation of pyroclastic material in near-shore area and the lake appeared on its surface; (b) the frontal part of pyroclastic flow; (c) the surface of pyroclastic flow covered by the ridges of fragments; (d) fumaroles activity of new pyroclastic deposits. Photos (a, c, d) were made 10 days later after the end of the eruption.

The analysis of satellite images allow to mark out, at least 8 pyroclastic flows, the most of them occupy the northern and western slopes of the volcano. This estimation in definite degree is conventional, because the flows cover each other and in the lower part of the cone form practically interflowing cover, setting off the foot of the volcano. The total area of pyroclastic flows is about 25 km^2 (Ganzey et al., 2010). During the period of conducting of the field works in 2009 the intensive solfataric activity connected with residual heat of pyroclastic material was seen on the flows (fig. 8). By measuring of R.V. Zharkov the maximal temperature of output of gases was 476°C. Visible thickness of the flows in the near-shore part of the island varies from <1 to 4 m, depending on their distance from eruptive center. They are formed by porous lightly rounded fragments of andesite-basalts with size 15-30 cm and account for about 50-80% of total volume of visible thickness. The separate blocks >1 m are met. The maximal concentration of the fragments is characteristic for the surface of the flow, where they form lengthwise stretched ridges (fig. 8).

4.3 The changes of the landscapes of Matua Island after the eruption of Sarychev Peak volcano in 2009

As a result of Sarychev Peak volcano eruption the landscapes of Matua Isl. underwent the considerable changes. The full reconstruction of the landscapes occurred in the bounds of the Sarychev Peak volcano cone that is connected with moving of pyroclastic flows, which effected thermal (in June, 28 in the northern part of the island on the pyroclastic flow on the depth 30 cm the temperature was 420°C) and mechanical influence. All the vegetation and soil cover were destroyed (fig. 9). The summit part of the volcano was occupied by the landscapes of stratovolcanic cone with thick layer of pyroclastic deposits. The landscapes of steep slopes and slopes of average steepness are dominant on the slopes of the volcanic cone; they are covered with loose and weakly lithified pyroclastic deposits (fig. 9). In separate sites the landscapes of steep slopes and average steepness slopes of lava flows and disjoint scarps remain. (Levin et al., 2010).

Near the south-eastern foot of volcanic cone the belt stretched, which represented the ecoton between the zones of full ("dead zone") and the least reconstruction of the landscapes. The boundary of distribution of the brush-woods of alder descended again and now it was located on the mark about 450 m. In transition zone we observed shrinkage of practically all the brushes of alder. Low plants suffered larger from the ash-falls especially such small bushes as Rhododendron *aureum*, *Empetrum sibiricum*, *Cassiope lycopodioides*, *Phyllodoce aleutica* et al. Some of them near "dead zone" were covered with the layer of ash, but continue to blossom. Projective vegetation on the sites, where ash cover reached 10-12 cm, was only 10-15%. Low bushes such as cowberries suffered mostly; part of them on the sites of intense ash-fall was buried fully (Levin et al., 2010).

The landscapes of terraces surfaces in the south-eastern part of the island subjected to the least volcanic transformation. They remained in previous boundaries, a fall of volcanic ash did not considerably influence to vegetative and soil covers. The bushes of alder *(Duschekia fruticosa)* suffered least of all in the southern part of the island; they on the same sites in contrast to mountain ash *(Sorbus sambucifolia)* have not the signs of negative influence (fig. 10 a, b, c). The leaves of mountain ash have yellow edging, though such changes do not influence greatly to the vegetation of the bushes.

The brush-woods of alder, growing in the zone of fall of rudaceous ash and scoria, have on the leaves the signs of shrinkage and spots. Thin layer of ash of silt size remains on some of them. High-grasses, located in the south-eastern part of the island did not suffer from ash falls. In given zone the elementary plants (green moss and lichens) were subjected to great influence, they were fully covered with ash (Levin et al., 2010).

Before the eruption along all the shore of the island, the landscapes of abrasion- denudation cliffs with boulder-pebble beaches and storm ramparts with meadow associations with high-grasses on the meadow-sod soils were located (8,31 % of island area). Passing of pyroclastic flows to the shore destroyed them in the northern part of the island (0,89 % of island area).

Before the eruption practically all central cone was covered with numerous firn. It is probably that during the initial stage of the eruption (sooner on 12th of June) as a result of temperature rising on the surface after the influence of erupted volcanic material, several lahars descended along the slopes of the volcano, the signs of their movement were retained in the eastern and south-eastern parts of the island. The analogues process was marked by E.K. Markhinin (1964) after the eruption in November 1960. The thickest and longest flow was observed on the southern slope of the volcano up to old runways at the distance 2,4 km. The width of the zone of lahars influence was not more than 10-15 m, the vegetative and soil cover in the zone of lahars movement was fully destroyed (fig. 11 a, b). Intense melting of the firns during the eruption caused the formation of numerous temporary water flows on the surface of small bog in Ainu bay; this was not observed in 2007-2008.

During the year and a half after the volcanic event, the view of the island considerably changed. The pioneer landscapes began to form, because of loose composition of volcanic material the erosion processes develop intensely on the different hypsometrical levels, the change of shore line is observed. The formation of system of ravines goes on the slopes of the volcano. Their depth can reach 5-6 m. Weak lithification of pyroclastic deposits and great amount of atmospheric precipitations cause the formation of small mud flows, descending along the slopes and penetrating to the zones with remained vegetation and soil cover. The signs of mud flows are seen on the slopes of southern and south-eastern expositions (Ganzey et al., 2011).

The eruption of lava flows did not cause the considerable changes in geomorphologic view of the island. The flows of lava are clear seen on the landscape maps. There are no vegetation and soil cover on their surface. The trunks of alder with the sings of charring on the side close to the flow are found near the foot of the north-eastern flow. As S. Yu. Grishin with co-authors (2010) noticed, the restocking of vegetative-soil cover can lasted many hundreds years, but "it is not real in the conditions of very intense activity of the volcano".

Main changes of geomorphic structure of the island are expressed in smoothing of shore line. It is connected with that the frontal parts of pyroclastic flows, penetrated to near-shore zone (the area of the island was increased at the cost of this), began to destroyed because of loose character of forming rocks and active development of abrasion processes. The material began to redeposit by alongshore currents in nearest bays. As a result of this the sharp increasing of beach zone occurred. In some bays these widths reached more than 150 m. In spite of increasing of beach zone, in total the decreasing of Matua Island area is observed from 53,67 km2 in 2009 to 53,48 km2 in 2010.

Vegetative cover on the slopes of Sarychev Peak volcano began to restock, but this process has a local character. The appearance of grass vegetation occurs in the zones, where the deposits of pyroclastic material have small thickness. These zones are the sites of volcano edifice with projections of the relief, characterized by the presence of rather steep slopes, which are not able to keep great amount of loose material. And also the scarps such as frontal parts of old lava flows are turned to opposite side from the volcano (Ganzey et al., 2011).

From remained root system the new shoots began to grow through the deposits of pyroclastic flows, waves and volcanic ash. In the near-shore zone in the northern, north-western and north-eastern parts of the island, for example on Lisiy Cape, the vegetation was burnt by pyroclastic waves; the trunks of alder with the sings of charring were found. Here greatly thinned grass vegetation without soil cover or on the primitive-turf soils began to form in the conditions of the landscapes of steep and average steep slopes of weakly lithofying pyroclastic deposits and sub-volcanic bodies

The analogous tendency of restocking of the vegetation along the shore line was noticed by E.K. Markhinin (1964), who had visited the island in the autumn 1960. After the eruptions in 1930, 1946 and 1960 the low parts of volcano slopes were covered with thick grass vegetation. In separate sites the branches of the alder had the signs of burning and charring by volcanic material. Grass vegetation was represented in the area of Lisiy Cape and Sivuch Cape.

On the south-eastern slopes of Sarychev Peak volcano, where in 2009 ecoton zone had been marked, the vegetation began to penetrate on the slopes of the volcano. The restocking of vegetation is seen along the boundaries of pyroclastic flows, where the thickness of deposits is lesser and the vegetation is destroyed by pyroclastic waves. At present time the thin grass cover with separate greatly depressed bushes of alder are met on the height up to 650 m.

Fig. 9. The landscapes of the volcanic cone (the southern slope) before (upper photo, August 2008) and after (low photo, June 2009) the eruption 2009.

Fig. 10. The state of vegetative cover buried under the layer of ash: (a) rhododendron goldish (Rhododendron aureum Georgi); (b) Cassiope lycopodioides (Pall.) D. Don; (c) blueberry (Empetrum).

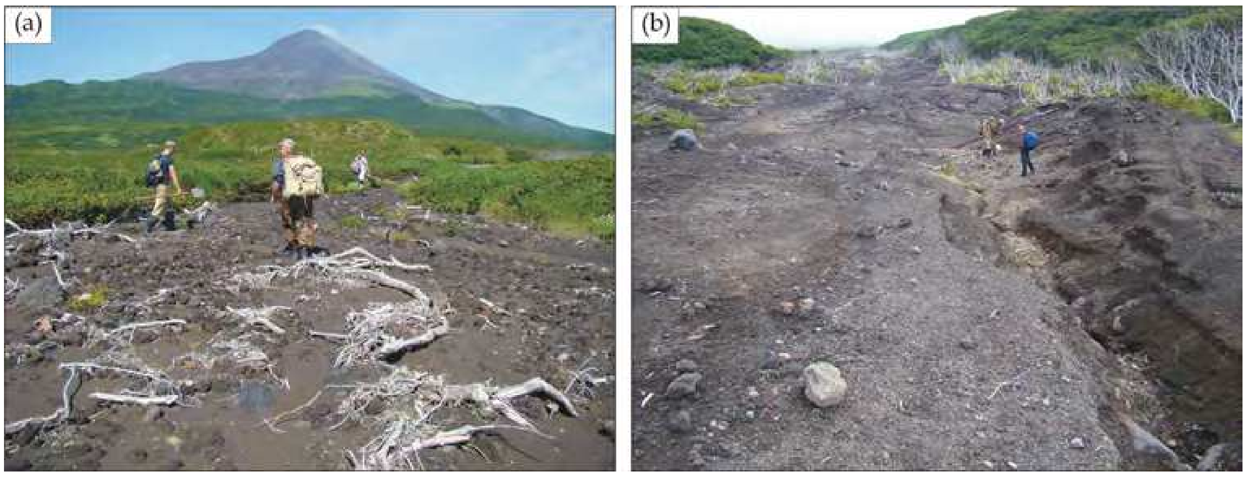

Fig. 11. The largest lahar of the eruption 2009: (a) the frontal part. The edifice of Sarychev Peak volcano is seen on the background; (b) the valley along which the mud flow moved.

The analogous processes as on the slopes of the volcano are found in the zones of lahars movement. Washing out of the floor of the valleys along which the lahars descended is of small-scale manifestation, the restocking of the vegetation has dotted character. The representatives of cereals prevail in the vegetation; the bushes of alder and mountain ash are met in the single cases. The restocking goes more actively owing to ferns *(Drypteris expana)* (fig. 12 a).

The different species of mushrooms intensely grow on the separate sites (fig. 12 b, c). The analogous vegetative associations form on the boards of the valleys, but the processes go considerably quicker. Soil cover was either destroyed fully both on the board and floors of the valleys, or buried under the great thickness of pyroclastic material. Only in the places with conserved soil cover the pioneer vegetation forms. In the valleys dried bushes of alder are met everywhere, the trunks of them are polished. The view of damage of the trees shows that pyroclastic waves were the main damage factor; the surface of the trunks is smoothly polished, the ends of the branches are sharpened, but the integrity is not damaged. Such character of damage is caused by high speed of the waves and small size of the particles of solid components.

So, after the analysis of the landscape structure of Matua Isl. from 1964 till 2009 the definite evolutional tendencies of the landscapes were revealed. The landscapes in the south-eastern part of the island were subjected the least change by the eruption. Even at the strong eruptions in 1946 and 2009 the thickness of fallen volcanic ash did not exceed 1 sm, this did not considerably effect to vegetative and soil covers. At the influence of volcanic activity the changes of the landscapes occurred in the bounds of Sarychev Peak volcano edifice, first of all they expressed in destroying and burying of vegetative and soil cover. The boundaries of the distribution of alder bushes on the southern slopes of Sarychev Peak volcano changed from 600 m in 1964 to 840 m in 2008. Catastrophic eruption in June 2009 sank this boundary to the height 450 m (Ganzey et al., 2010).

By 2010 the greatest transformations are connected with the change of shore line after the destruction of the frontal parts of pyroclastic flows, penetrated to near-shore zone and redeposition of the material in small bays. It is observed the development of active erosion processes on the slopes of the volcano that connected with weak lithification of deposits.

Restocking of vegetative and soil components of the landscapes on the slopes of Sarychev Peak volcano has dotted character and goes in the zones where the thickness of volcanic deposits is not large. There is no doubt that vegetative groups penetrate to new hypsometrical levels. However, given scheme is possible only in the condition of absence of volcanic activity in the nearest time.

Interesting data were received after the quantitative analysis of built landscape maps. In the table the indexes for 2009 were obtained two weeks later the eruption of Sarychev Peak volcano. As it was noticed above, a year later the eruption the decrease of the area of Matua Island was by 0,19 km^2, this was connected with washing out of the frontal parts of pyroclastic flows and redeposition of the material along shore line.

Number of landscape contours increased twice. During a year after the eruption the complexity of landscape picture of Matua Isl. increased more than five times. Given index shows the interaction between quantity and average area of landscape contours. Analogous situation relates to the coefficient of breaking up, which since the moment of eruption increased two times (index has the reciprocal dependence).

The process of increase of given values complex is connected with that after the eruption the restocking of vegetative and soil cover goes on the small sites, where the thickness of pyroclastic deposits is not large. However the increase of amount of natural-territorial complex (NTC) is not so considerable. This is connected with that the formation of pioneer landscapes goes on identical scheme all over the island. It is probable that given index in future will also vary in the analogous limits.

The eruption of Sarychev Peak volcano caused the increase of index of entropic degree of complexity of landscape picture. It reflects the probability of change of one landscapes site by another, we can indirectly judge about the balance and stability of landscape structure. So, the tendency of increase of entropic degree of complexity shows the increase of instability of formed system NTC at present time.

The estimation of landscape variety for Matua Island was done during finishing stage of the works. As it is seen from the table the tendency of its increase remains, this is caused by the increase of quantity of landscape contours, NTC, dotted character of restocking of the landscapes. It is probable that in future the tendency of increase of landscape variety will remain up to reaching of climax of the system, when landscape complexes will reach stable state and will be in equilibrium with the conditions of environment. It is very difficult to say about time periods for this process. Will it last decades or centuries? However, reaching of such state is possible only under the conditions of absence of strong volcanic events in the island, this is hardly probable, data on the activity of the volcano corroborate about this not only during the historic time but also in Holocene.

It is necessary to notice that the change of landscape contour of Matua Island went under the influence of inner forces during the volcanic silence. For characteristic of the process of landscape change of islands-volcanoes it is expedient to use term “relaxation of environment” of theory of island biogeography (MacArthur, Wilson, 1967; Diamond, 1972), which the nature is subjected after their separation from the continent. Only the process of relaxation of the landscapes during volcanically quiet periods favors the decrease of landscape areas, breaking of landscapes, their complexity and variety; and the eruptions of the volcanoes cause a sharp sometimes one-moment increase of given indexes.

Fig. 12. Restocking of vegetative cover and penetration of vegetation to the territory of volcanic desert: (a) Drypteris expana; (b, c) mushrooms.

5. Conclusions

Occurred eruption is a characteristic episode of the newest stage of the eruptive history of Sarychev Peak volcano, which is the most active volcano. Sarychev Peak volcano intensely worked, during last 250 years in average its eruptions occurred every 25 years; in connection with this the possibility of its eruptions is high in the nearest future.

The peculiarities of the eruption 2009 is analogues to previous events, such as strong eruptions in 1765±5, 1930 and 1945, that also characterized by emissions of great amount of pyroclastic rocks and the considerable influence to nature of the island.

Considering a high activity of Sarychev Peak volcano during historical period, it is unlikely that in nearest time it will change cardinally its regime of the eruptive activity and become less dangerous. Taking into account a high explosiveness of the volcano, nearly all of its eruptions will represent a hazard in different degree for the aviation. Also people in the island will be subjected danger at the strongest eruptions (periodically scientific and tourist groups visit Matua). The main striking factors near the edifice will be pyroclastic flows and waves, also lahars, at the distance – volcanic ash with its highly expressed abrasive features and eruptive gases. So, at monitoring of the volcanic activity, much attention must be paid to this object.

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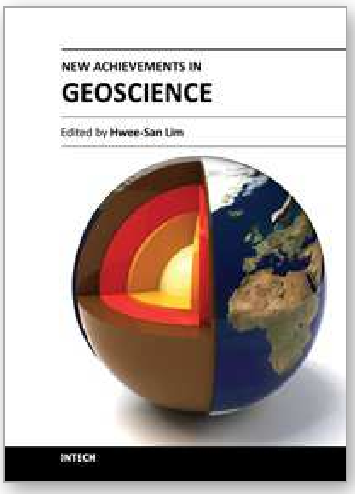

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