Landslides, Senneset (ed.) 1996 Balkema, Rotterdam. ISBN 90 5410 818 5

Large scale landslides on active volcanoes in the 20th century - Examples from the Kurile-Kamchatka region (Russia)

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ABSTRACT; In the 20th century, large scale landslides occurred at 3 active volcanoes of the Kurile-Kamchatka region: Harimkotan (in 1933, volume 0.4 km^3), Bezymianny (in 1956, volume 0.5 km^3) and Shiveluch (in 1964, volume 1.5 km^3). In all cases the landslides were provoked by intrusion of new batches of magma related to forthcoming eruptions. As a result of the landslides, lithostatic pressure on magmatic systems of the volcanoes was quickly reduced,, resulting in strong explosive eruptions.

INTRODUCTION.

On the Earth the most voluminous landslides (up to 100 km) occur on active volcanoes (Siebert 1984; Moore et al 1989). Commonly such landslides are transformed into fast moving debris avalanches that run out for large distances; these distances can exceed 100 km for subaerial cases, and 1000 km for subaquatic cases. Entry of a debris avalanche into a sea or lake produces a tsunami.

Landslides on active volcanoes are usually accompanied by strong explosive eruptions. Because many volcanoes are located in densely populated areas, landslides of volcanic origin belong to the most dangerous natural phenomena. The first direct evidence of this was provided by the famous landslide and eruption of Mount St Helens in 1980 (Cascade Range, USA) (Voight et al 1931). In the 20th century large scale landslides also occurred on Harimkotan, Bezymianny and Shiveluch volcanoes that are situated in the Kurile-Kamchatka region, on line less than 1000 km long (Fig. 1). These landslides were accompanied by strong explosive eruptions which were not directly observed, and in earlier papers, deposits of the landslides were interpreted as products of powerful directed blasts (Gorshkov 1963; Bogoyavlenskaya et al 1985). The aim of our work was to reconstruct the place of the landslide in the succession of eruptive events, to determine the reasons for instability of the volcanic edifices, and to document the impact of the landlides on the course of eruptions.

Fig. 1. Map showing locations of Harimkotan, Bezymianny and Shiveluch volcanoes of Kurile-Kamchatka region.

THE 1933 LANDSLIDE AND ERUPTION ON HARIMKOTAN VOLCANO.

Harimkotan volcano (in Russian literature also Severgina volcano) is an uninhabited island 10 km across in the northern part of the Kurile arc.

Before the 1933 events it was composite volcano (mainly andesitic and dacitic in composition) with a horseshoe-shaped crater 1.7 km across. The crater was opened to the east and partially filled by the old lava dome which was the highest point of the island - 1213 m. Maximal slope angle of the dome was about 45°. The volcano was dormant since 1931 (Gorshkov 1967).

Frequent earthquakes were felt during 3 months prior to the 1933 events (Miyatake 1934). Seismic activity was probably connected with ascent of new batches of magma beneath the volcano. Because volcanic activity before the the landslide was not re-

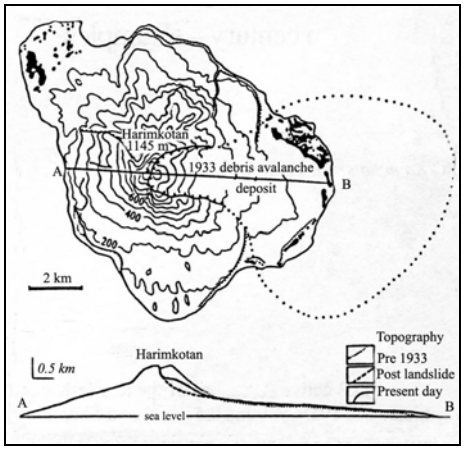

Fig. 2. Sketch map of 1933 debris avalanche deposit of Harimkotan and topographic profile across its crater (line A-B)

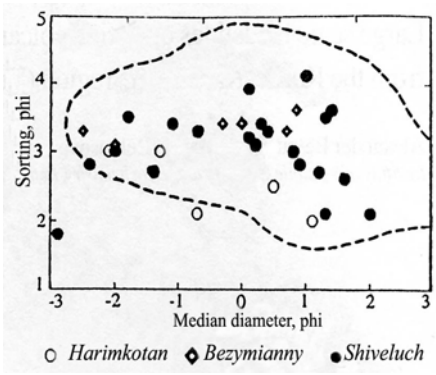

Fig. 3. Relations between sorting and median diameter (Inman coefficients) for the debris avalanche deposits of Harimkotan, Bezymianny and Shiveluch volcanoes. Dashed outline is the pyroclasric flow field at Walker (1971)

ported, and juvenile material in the debris avalanche deposit was not found, we assume that this magma was situated at a relatively deep level at the moment of slope failure.

The landslide, with a volume 0.4 km^3 occurred on January 8, 1933 (Table 1). It involved 4 % of the volcanic edifice (mostly the. material of the old dome) and spread in the eastern direction beyond the shoreline, triggering tsunami up to 20 m high. The landslide was followed by a strong explosive eruption that continued until January 12,1933. In the first stage of the eruption, pyroclastic flows of dacitic pumice with a volume 0.03 km^3 were deposited, and these deposits were covered by a Plinian fallout pumice with a maximal thickness up to 1 m and a volume about 1 km^3 . After the explosive eruption, a new volcanic dome was extruded at the site of the old one.

As a result of these events the height of the volcano diminished from 1213 m to 1145 m (Miyatake 1934) and the eastern shoreline of the island was extended up to 1 km (Fig.2). The hummocky deposit of the debris avalanche forms a broad fan with a subaerial area of 20 km^2 (Fig. 2). The heights of hummocks are 3-15 m. In the central part of the fan, hummocks are grouped in multiple subparallel longitudinal ridges. Along the newly formed shoreline, hummocks form transverse ridges. The submarine part of the landslide deposit was not studied. The average thickness of the deposit is about 10 m. The landslide deposit is represented mostly by coarse-grained poorly sorted debris (Fig.3) of strongly alterated andesite of the old volcanic dome. Most of the avalanche is composed of block facies (terminology after Glicken 1981, 1991). Mixed facies forms a layer with a thickness up to 1 m, along the lower contact of the avalanche deposits. A layer of relatively well sorted, normal graded yellow-gray sand with a thickness of 10-30 cm rests on the upper part of the avalanche deposits. This layer was probably deposited from a "dust cloud" rising above the avalanche during its motion. Large scale landslides are common for Harimkotan volcano. They occurred more then 5 times during its Holocene history. Deposits of multiple ancient debris avalanches occupy north-western (C14 age 2000 BP), eastern (C14 age 1100 BP), and probably, northern sectors of Harimkotan island.

THE 1956 LANDSLIDE AND ERUPTION ON BEZYMIANNY VOLCANO.

Bezymianny volcano is located in the central part of the Kamchatka peninsula.

Before the 1956 events the volcanic edifice was a rather regular cone 3085 m in height. It was a stratovolcano, mainly andesitic in composition, with summit and flank lava domes. Slopes of the edifice were not steeper then 35°. Long and intensive seismic precursors, frequent ash outbursts, growth of the dome in the crater, and strong bulging of the south-eastern slope of the volcano (up to 100 m), preceded the landslide during a period of about 6 months (Gorshkov 1959). This eruption was the first during historical time (in this region beginning in 1697) and, according to data from tephrochronological investigations, it occurred after about 1000 ys of dor-

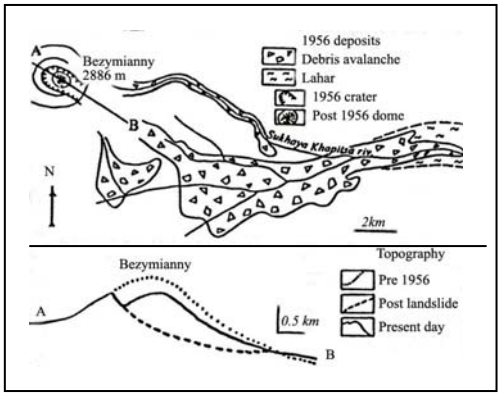

Fig. 4. Sketch map of 1956 debris avalanche deposit of Bezymianny and topographic profile across its crater (line A-B)

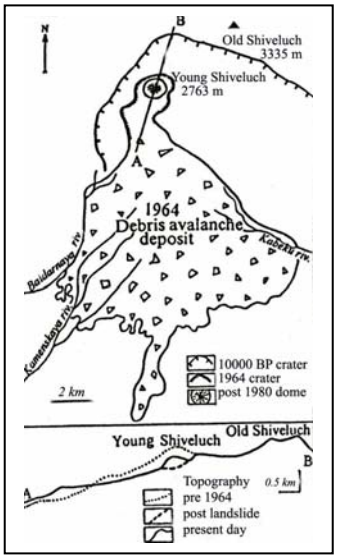

Fig. 5. Sketch map of 1964 debris avalanche deposit of Shiveluch and topographic profile across the Young Shiveluch summit (line A-B)

mancy (Braitseva et al 1990). A large scale landslide with a volume 0.5 km^3 (10% of volcanic edifice) occurred on March 30, 1956 (Table 1). The following strong explosive eruption, connected with fast unloading of the fresh dome and cryptodome, consisted of a powerful directed blast (volume 0.2 - 0.4 km^3), and deposition of pyroclastic flows (volume 0,5 km^3) and ashfall deposits (volume 0,3 km^3).

As a result of the landslide, the height of edifice was decreased from 3085 m to 2886 m, and a horseshoe-shaped crater 1.8 km across was opened to the east. After the explosive eruption, a new composite dome began to extrude in the crater, and its formation continues to the present.

The landslide dropped 2.4 km and travelled a distance of 22 km. Its deposits form 3 narrow branches enclosed in the river valleys on the eastern slope of the volcano (Fig.4). The northern branch of the landslide is 11 km long, 200 m wide and 20-30 m thick, covers an area about 2 km^2, and has a volume 0.06 km^3. The central branch is the largest, 22 km long, 1-15 m thick, 29.5 km^2 in area, and 0.4 km^3 in volume. On the sharp bends of the valley, the landslide debris was thrown up 200 m. In accordance with this runup height, the speed of the landslide was about 60 m/s. The southern branch is 8 km long, 3-10 m thick, 4.5 km^2 in area, and 0.04 km^3 in volume.

The debris avalanche deposits have a hummocky relief up to 15-18 m high. They consist mainly of porly sorted (Fig.3) strongly crushed andesite of the old volcanic edifice. In proximal zones, debris avalanche material is represented mainly by block fades. Blocks are distinguished by different colours (red, green, yellow, black, etc.) connected with composition, degree of oxidation, or hydrothermal alteration of the rocks of the former volcanic edifice. The distal part is composed mainly of mixed facies. Some juvenile andesite from the directed blast became incorporated in the deposits in the distal zone.

The large scale landslide on March 30, 1956 was the first such event in the history of Bezymianny volcano.

THE 1964 LANDSLIDE AND ERUPTION ON SHIVELUCH VOLCANO

Shiveluch volcano is located at a distance 70 km to the north of Bezymianny volcano. The edifice of Shiveluch volcano has two main parts: Old Shiveluch and Young Shiveluch. Young Shiveluch (2763 m) is situated in the horseshoe-shaped crater, 7 km across, of Old Shiveluch (3335 m) (Fig.5). All modem volcanic activity is connected only with Young Shiveluch, which is composed mostly of andesite lava domes and flows.

A large scale landslide with a volume 1.5 km^3 (15% of volcanic edifice) occurred on November 12, 1964, after 14 years of dormancy (Table 1). This event was preceded by intensive seismic activity over 9 months, connected with the ascent of new batches of magma (Tokarev 1967). Because volcanic activity

Table 1. Characteristics of edifices, landslides and processes before and after landslides at Harimkotan, Bezymianny and Shiveluch volcanoes.

	Harimkotan 8.01.1933	Bezymianny 30.03.1956	Shiveluch 12.11.1964
EDIFICE			
Type of edifice	dome	stratovolcano complicated bv flank and summit	group of domes
Height before / after (m)	1213/1145	3085/2886	3000/2763
Composition	dacite & andesite	andesite	andesite
Max angle of slope	45°	35°	35°
Ancient landslides	5{1100 BP}	0	7{600 BP)
Years of repose	2	1000 .	14
BEFORE LANDSLIDE			
Fumarolic activity .	not reported	absent	intensive
Seismic activity	3 months	6 months	9 months
Strong deformations	not reported	100 m	absent
Volcanic activity	absent	5 months	absent
LANDSLIDE			
Drop height H (km)	1.25	2.4	2.3
Travel distance L (km)	>7	22	16
Coefficient H/L	<0.17	0.12	0.14
DEPOSITS			
Max thickness (m)	10-20	20-30	20-150
Max hummock heights (m)	15	18	15
Area S (km^2)	>20	36	98
Volume V (km^3)	0.4	0.5	1.5
Landslide volume versus edifice volume (%)	4	10	15
GRANULOMETRY			
Median diameter (phi)	-2.1-2.9(0.3)	-2.5-0.8 (-0.5)	-2.9-2 (0)
Deviation (phi)	2-3.2 (2.8)	3.1-4.8(3.5)	1.8-3.9(3.0)
Gravel (%)	15.8-60.0(38.0)	2.0-59.0(43,7)	9.3-76.4 (38.2)
Sand (%)	32.1-80.1(58.2)	37.2-61.5(49.1)	22.5-81.6(54.7)
Mud (%)	0.6-8.9(4.8)	3.8-12.5 (7.2)	1.1-14.9(7.0)
AFTER LANDSLIDE			
Crater (km)	1.7	1.8	1.7
Eruption (km^J)	>1	1	0.8

The latest avalanches in parentheses, the average values in braces.

before the landslide was not reported, and juvenile material in the debris avalanche deposit was not found, we assume that magma was situated at a relatively deep level at the moment of failure.

After the landslide, a weak phreatic explosion due to pressure release from the hydrothermal system occurred, followed by a Plinian eruption with a volume of 0.3 km^3. At the end. of the eruption, pyroclastic flows with a volume about 0.5 km^3 were deposited, After the explosive eruption, only fumarolic activity was observed in the crater. In 1980-1981 a new lava dome was formed in the 1964 crater.

As a result of the landslide, a horseshoe-shaped crater 1.7 km across was formed; the broad fan of debris avalanche deposits cover an area of 98 km^2 (Fig. 5). The debris avalanche dropped 2.3 km and travelled 16 km toward the undissected foot of the volcano. Its distal thickness is up to 20 m and its volume is about 1.5 km^3. Near the crater there are large blocks of avalanche material in the form of 3 steep steps, up to 50 m high. Here the thickness is probably up to 150 m. Farther from crater the landslide deposits have a hummocky relief. Many of the hummocks have a conical form up to 15 m high. In the distal part of the debris avalanche hummocks are grouped in radial ridges. The front of the deposit is steep and its height reaches 3-4 m. The debris avalanche deposit consists of porly sorted (Fig.3) crushed rocks of the old volcanic edifice. Landslide material is represented mainly by block fades. Some blocks are composed of old tephra and pyroclastic flow deposits with undisturbed primary layering. A small volume of mixed facies was found only along the south-eastern edge of the deposit, and it also

forms a layer with a thickness up to lm at the base of the avalanche.

Large scale landslides are common for Young Shiveluch volcano. They occurred 7 times during its Holocene history: 6000 BP, 3500BP, 2600BP, 1600BP, 1000BP, 600BP and 1964 AD.

CONCLUSIONS

1. Landslides at volcanoes Harimkotan, Bezymianny and Shiveluch were triggered by the intrusion of new magma into or below the edifice.
2. The common precursor for these landslide events was an unusually long and intensive seismic swarm. This swarm can be interpreted as the result of intrusion of very viscous magma, that strongly disturbed the edifice.
3. The landslides strongly intensified the subsequent eruptions in all cases.

ACKNOWLEDGEMENTS

The research described in this publication was made possible in part by Grant RMF300 from International Science Foundation and Russian Go vermen t.

The authors are grateful to Bokuishiro Takano for translation of Japanese paper about Harimkotan volcano, to Tadahide Ui for providing of old Japanese map of Harimkotan island, to Leopold Sulerzhitsky for radiocabon dating of our samples and to Barry Voight for having improved the English text.

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