The Large Fissure Eruption in the Region of Plosky Tolbachik Volcano in Kamchatka, 1975-1976

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ABSTRACT

The paper describes the course of the Large Tolbachik fissure eruption taking place in Kamchatka from July 6, 1975 to December 10, 1976. The eruption zone extended for 30 km. The formation of monogenic scoria cones nearly 300 m high, lava tubes and basalt sheets up to 80 m thick and more than 40 km^2 in area and subsidence of the Plosky Tolbachik summit caldera to a depth of more than 400 m were observed during the eruption. The volume of eruption products amounted to more than 2 km^3. It was the largest basalt eruption which has taken place in the Kurile-Kamchatka volcanic belt in historic time.

INTRODUCTION

At the end of June, 1975, the seismic activity in the region of Plosky Tolbachik volcano increased abruptly. A network of seismic stations of the Institute of Volcanology recorded a swarm of shallow earthquakes. The frequency of tremors increased rapidly. A quick data processing and analysis made by P. I. TOKEREV, V. V. STEPANOV and V. I. GORELCHIK allowed prediction of the place and time of eruption beforehand. Owing to this, volcanologists arrived in the region of eruption before it began and installed instruments for intensive volcano monitoring. The eruption and related phenomena were observed and were studied continuously from the beginning to the end of eruption.

The eruption area (Fig. 1) lies south of Plosky Tolbachik volcano in a peculiar zone which is called the regional zone of scoria cones (PIIP, 1956) or the zone of basalt flood volcanism (ERMAKOV and VAZHEEVSKAYA, 1973). The zone extends for 20 km north-east and more than 40 km southwest of the Tolbachik crater. It is marked by the presence of the large number of linear faults of different orders and directions, chains of numerous scoria cones and extensive lava sheets. This zone resembles in many respects the rift zones of the Hawaiian volcanoes. According to MELEKESTSEV's data (1973), the flood type volcanic activity commenced in this region in the Early Holocene and it was predominantly effusive. Igneous rocks here correspond compositionally to basalts among which one can recognize high-alumina and magnesian series. In total, more than 100 km^3 of basaltic lavas have flowed out in the southern Tolbachik zone of scoria cones during Holocene time. The zone on the whole is superimposed on the Plosky Tolbachik stratovolcano, and its formation is compatible in time with formation of the Plosky Tolbachik summit caldera.

DESCRIPTION OF ERUPTION: NORTH VENT ACTIVITY

The eruption under consideration commenced on July 6, 1975, at 9:45 A.M. (local time) 18 km southwest of the Plosky Tolbachik crater at an altitude of 880 m above sea level. Within a few hours four explosive vents opened along a fissure trending north-westward (Fig. 2). A day later only one of them was active. A scoria cone began to grow around this vent. During the first three days an increase of explosive activity of Strombolian type occurred. Explosions followed each other at intervals from 1 to 0.5 sec. The average height of bomb ejections amounted to 0.3-0.5 km, the average height of ash column was 5 km and the maximum radius of bomb scatter was 0.7 km. At the end of this eruption stage the first scoria cone was 130 m high, the crater diameter amounted to 150 m and the basal diameter was 700 m. Continuous ejections of great volumes of scoria, bombs and ash along with gas jets have been occurring since July 9 (Fig. 3). Incandes-

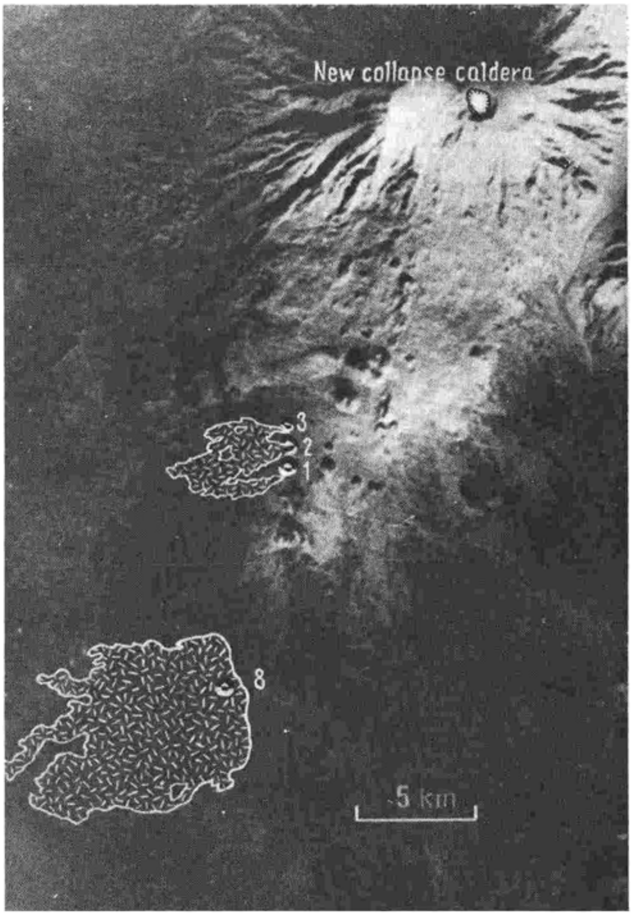

FIG. 1 - Space photograph of the eruption area. Ostry Tolbachik and Plosky Tolbachik volcanoes are seen from above. The southwestern Tolbachik rift zone is traced along chains of Holocene scoria cones. A new collapsed caldera at Plosky Tolbachik volcano is shown; 1, 2, 3 – new scoria cones I, II, III along with their lava flows at North vents (cone IV and lava pools; cones V, VI and VII are not shown because of their small dimensions); 8 – cone VIII and basalt lava field of South vent.

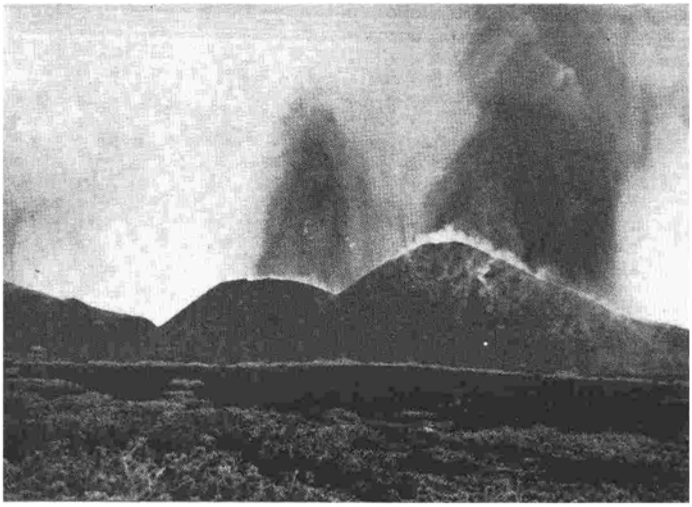

FIG. 2 - Explosive activity of the initial fissure 5 hours after the beginning of eruption. *Photo by P. KHRYAPAK.*

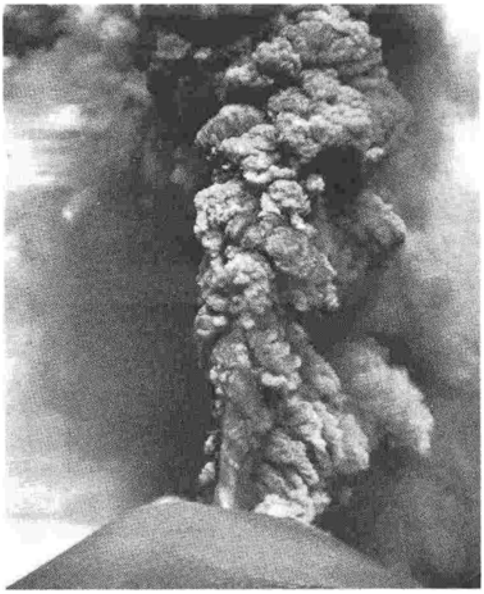

FIG. 3 - Strong jets of incandescent gases and pyroclastics ejected from cone I in a period from July 9 to 23, 1975. *Photo by N. SMELOV.*

cent pyroclastics formed a fiery candle 1 to 2.5 km high with a diameter varying from 50 to 150 m. Wreathing ash-gas clouds were rising rapidly reaching a height of 12-14 km. Strong lightnings pierced the eruptive cloud in all directions at intervals of a few seconds. Bombs up to 30 cm in diameter reached 2 km. A trail of fine ash from the eruptive cloud extended eastward for 800-1000 km. This character of volcanic activity was unchanged until July 23 when pauses in volcanic activity lasting from a few seconds to a few hours appeared. Pauses were marked either by absolute absence of ejection from the crater or by weak emissions of ash and gas clouds. Jet fountaining and solitary strong explosions continued to occur in the periods between pauses.

On July 27 eruption changed abruptly. Lava fountains started appearing repeatedly at the crater rim. Trenches appeared on the southern and northern flanks of the cone and a series of fissures formed on the northwestern flank of the neighbouring extinct scoria cone. A system of fissures and trenches on both cones has formed a line of meridional trend which cut off approximately two fifths of the first

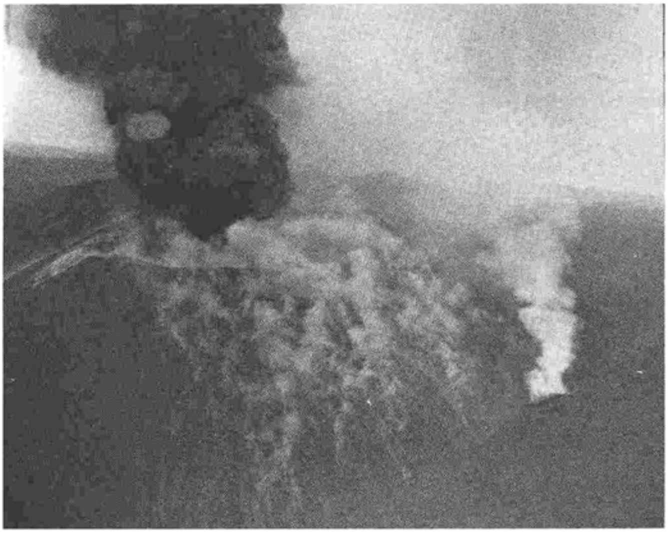

FIG. 4 - The first portion of lava which appeared on July 27, 1975. At the right is a fissure started to cut a saddle between cone I and extinct cone. At the left is the same fissure which started to cut off the western part of cone I along the rim of its crater. Crater activity is moderate explosive. *Photo by N. SMELOV.*

cone from its western side. At this point the new cone was nearly 300 m high. This portion of the cone started to move away and sink markedly. Judging from the character of cone I deformations, one can suggest that the cone was broken by the magma which intruded into the lower part of the new cone and Holocene lava strata. The magma intrusion was directed to the west along the inclination of country rocks and old lava fields.

This same day the first lava appeared at a saddle between cone I and an adjacent extinct cone (Fig. 4). It formed a short flow 20 × 30 m.

On July 29, during a few hours, a block of the extinct cone cut by fissures moved a distance of 50 m to the northwest and was elevated to a height of 25 m forming a deep crescent-shaped canyon. The first large flow of scoriaceous-blocky lava issued from its lower part. The eruption entered the explosive-effusive phase. The velocity of lava flowage near the vent was nearly 100 m/h. At a distance of 3-4 km from the vent the velocity of lava flowage 6 m thick was 40 m/h on 5° slope. The lava density was about 2 g/cm^3. The calculated effective lava viscosity was $2 \cdot 10^7$ poise.

On August 2 a new lava bocca formed near the base of the trench on the northern flank of cone I. Outpouring of the second lava flow started here. It was accompanied by lava fountaining from the bocca to a height of 150 m and occasionally by strong explosions and ash outbursts. The crater activity was like that before lava outpouring.

Pyroclastics and lavas that have been erupted before were magnesian basalts of moderate alkalinity.

Anticipating, it is interesting to note that during the eruption the composition of rocks changed, during two weeks, from magnesian basalts (North vents) to high-alumina subalkaline basalts (South vent). Concurrently the character of eruption changed abruptly. Rocks of intermediate composition in small amounts (5-10% of bulk volume) were found during changes in the dynamics of eruption (white ash)

TABLE 1 - Chemical composition of basalts.

	I	2	3	4	5
SiO_2	49.76	50.02	52.84	50.30	50.69
TiO_2	1.02	1.30	1.02	1.51	1.66
Al_2O_3	13.48	15.32	14.53	16.62	17.10
Fe_2O_3	3.06	3.47	4.37	3.14	3.55
FeO	6.99	6.88	4.62	6.95	6.99
MnO	0.16	0.17	0.15	0.18	0.17
MgO	9.88	7.69	5.86	6.44	4.87
CaO	11.60	9.83	9.07	9.20	8.65
Na_2O	2.44	3.14	3.21	3.30	3.60
K_2O	1.03	1.62	1.20	1.83	2.10
P_2O_5	0.25	0.35	0.33	0.40	0.53
H_2O^+	0.13	0.09	0.96	0.02	0.06
H_2O^-	0.18	0.11	1.36	0.19	0.11

I, 2, 3 - North vents: 1- predominant basalt, 2 - basalt ejected during the last days of eruption, 3 - white ash; 4, 5 - South vent: 4 - basalt ejected during the first days of eruption, 5 - predominant basalt.

mainly at the end of North vents activity and then at the beginning of eruption from South vent. «White ash» was a peculiar final product of the cone I eruption. Table I shows the average composition of these rock types (VOLYNETS *et al.*, 1975, 1978). On the evening on August 8 very fine ash of white and light-gray colour differing sharply in particle dimensions and colour from previously erupted ash could be seen thrown above the crater. About 5×10^6 ton of such ash fell for 12 hours. On the morning on August 9 the explosive and effusive activity of cone I ceased completely. Its height by that time amounted to 300 m, and its volume was 0.13 km^3.

Meanwhile, on August 2 the second earthquake swarm commenced, the development of which indicated the possibility of the resumption of eruption. It resumed about 12 hours after cessation of the cone I activity; a fissure nearly 400 m long with 300° strike opened 350 m north of its foot. First, gas and steam emission was observed from eleven migrating vents. A few minutes later this turned into lava fountaining reaching a height of 50-150 m. Ejections of incandescent materials were pulsatory and the frequency of pulses was 60-80 per minute. The fissure activity concentrated afterwards in a vent which served as a center during the formation of cone II. Immediately after this viscous lava flows began to squeeze out slowly (2-3 m/h) at the northern and southern foot of cone II, but this stopped soon after. A few hours later the crater explosive activity became like that of cone I. The height of pyroclastics fountaining from the two active vents, by August 11, reached the altitude of 1.5 km. Measurements made with optical pyrometer (probably underestimated) showed their temperature to be 980°C. On August 12 a very viscous lava flow nearly 40 m thick began to pour out at a velocity of 10 m/h from the central vent of cone II. Fresh lava carried away the western sector of the volcano. The width of the flow at a distance of 1.5 km from the cone was of about 1 km (Fig. 5).

The time and place of the third magma outburst were predicted with an accuracy of a few hours on August 16 according to seismic data (the main precursor was a sharp decrease of the third earthquake swarm). On this day a system of yawning fissures of meridional trend was formed north of cone II. Their length was 0.7-1.2 km and width was up to 1.5 m on the pyroclastic surface and up to a few tens cm in underlying lavas. On the evening on August 17 lava again flowed out onto the surface near the eastern margin of the fissure field. It is noteworthy that the third outbreak was preceded by white ash emission from cone II. (This ash is similar to that observed at the end of cone I activity, but its amount was considerably smaller). Lava fountaining from 13 vents on a 250 m-long fissure followed gas, steam and ash emissions. In comparison to cone II activity the development of cone III eruption was more intense although the character of their formation was identical. During three hours the fissure fountaining occurred from four vents which later became a center of cone III formation. Its effusive activity resulted in two short (300 m and 500 m), 3-5 m thick lava flows. The explosive activity resembled that of cones I and II. On the evening on August 20 the paroxysmal activity of cone III was observed, namely extraordinarily strong explosions accompanied by shock waves, the great amount of gas in jets of incandescent material, and bombs thrown out at a distance of 1.5-2 km from the foot of the cone. The ground tremor was felt at a distance of 3 km from the volcano. The paroxysm ended in a 5-hour pause after which only periodical pulsatory outbursts were observed until the end of cone III activity.

During the night of August 21 to 22 a new system of fissures of latitudinal trend 1.5×0.7 km^2 in area was formed west of cone III. The width of these fissures increased at a rate of a few cm per hour, and the width of the main fissure reached 5 m in pyroclastics and 1.5 m in rocks (Fig. 6). On August 22 cone IV appeared 300 m west of cones II and III. Its development was identical with previous outbreaks, although the intensity and duration of cone IV activity was considerably smaller. On August 23 three groups of lava pools 500 m in overall length appeared on the same fissures. Lava splashed in pools, lava bubbles nearly 3 m in diameter swelled and burst, and occasional fountaining could be seen up to a height of 70 m. Small lava flows were pouring out from pools, the largest of them was 1 km long and 5 m thick. On August 25 the eruptive activity of cones III, IV and of lava pools ceased almost simultaneously.

Afterwards the eruption was concentrated at cone II (Fig. 7). Its activity was marked by strong blowing off and ejections of incandescent bombs to a height of 2-2.5 km. Ash clouds rose to a height of

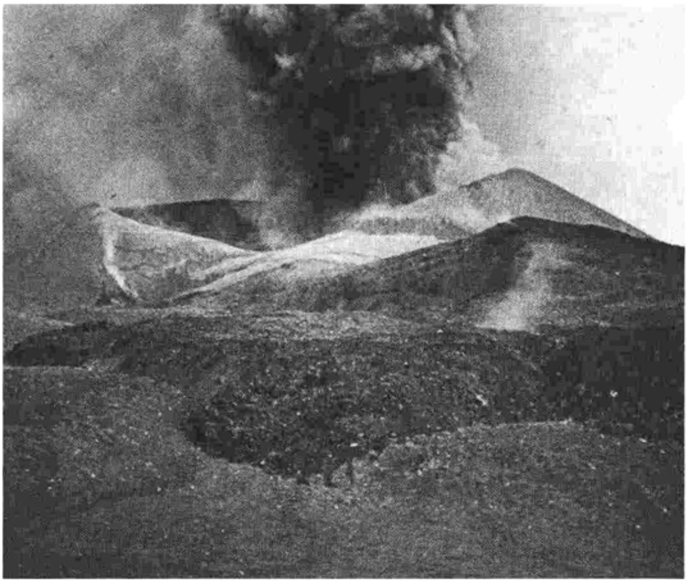

FIG. 5 – Crater of cone II, from west, August 17, 1975, two hours before the beginning of cone III eruption. At the right is the foot of cone I. In the foreground is margin of scoriaceous-blocky flow of cone II. A hill on the floor is a cone II portion carried away a day earlier. This hill sank in a few days. It is seen that pyroclastics filling up a breach in the crater ring is carrying away slowly by moving lava flow. *Photo by S. FEDOTOV.*

10-12 km. Scoria nearly 5 cm in size fell at a distance of 8 km from the crater. Strong solitary explosions accompanied by shock waves frequently visible in a gas-pyroclastic jet. The number and duration of pauses increased gradually. A viscous lava flow continued to pour out from the central crater. The height of its front at a distance of 3-3.5 km from the vent reached 60-80 m.

A sudden change in the character of effusive activity at cone II occurred at night from September 7 to 8 when a series of five small boccas formed on a submeridional fissure cutting the cone. During a few hours lava fountains were ejected from them. Within two hours a thin fluid lava flow 1.5 m thick, 1 km long and 20 m wide was pouring out from a bocca at the northwestern extremity of the fissure. A lava flow 1.5 m thick and 200 m long poured out from a bocca located on the southern side of the cone. On September 11 at 15:30, the most fluid lava flow of this eruption stage commenced outpouring from new northern and

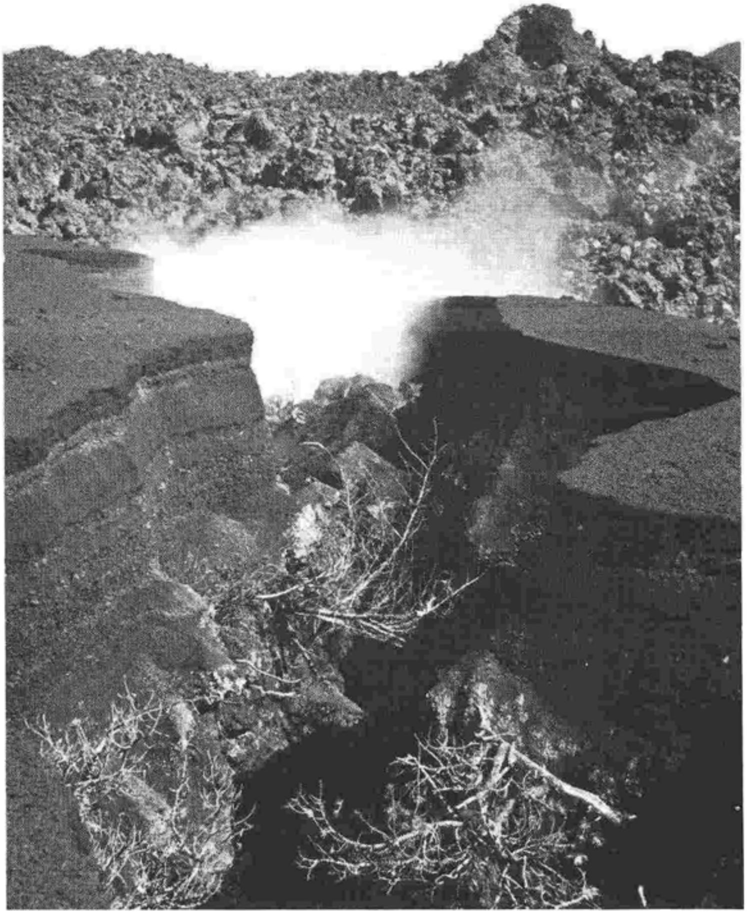

FIG. 6 - August 24, 1975. A fissure from latitudinal fissure system. Its width is nearly 5 m at the surface and 1.5 m in old dense lavas (beneath vegetation). The fissure is buried by lava from lava pools. *Photo by O. SELYANGIN.*

northwestern boccas of cone II. Lavas represented the first basalts of intermediate composition. The flow was moving in numerous branches. Its thickness was 0.5 to 0.8 m and the width of its front amounted to 1 km. At a distance of 2.5 km from the vent the flow velocity reached 1 km/h on 5-7° slope (lava viscosity was $6 \cdot 10^4$ poise). The explosive activity of cone II at that time had not diminished and in some respects continued to increase, although its character became spasmodic, with predominant periods of complete dormancy. On September 15 the explosive-effusive activity of cone II ceased thus completing a 72-day eruption of this group of craters. Because of the ensuing events we had to call this group of craters North vents.

As a result of the North vents activity three scoria cones were formed, the first 300 m high, the second 275 m high and the third 120 m high, and their total volume was 0.25 km^3. About 0.65 km^3 of ash and scoria was ejected (the volume of ash which was carried away to long distances is not included). The volume of pyroclastics was 0.9 km^3. The volume of issued lavas was 0.22 km^3. The total volume was thus more than 1.1 km^3. Taking the average densities of lavas and pyroclastics to be 2.0 g / cm^3 and 1.1 g/cm^3 respectively, the overall weight of the material erupted will be nearly $1.4 \cdot 10^9$ ton. The total heat energy of eruption accounted for $2.1 \cdot 10^{18}$ J. Index of explosiveness E = 69 wt. per cent. The average discharge rate of pyroclastics and lava accounted for 155 ton/sec ($13.5 \cdot 10^6$ ton/day) and 53 ton/sec ($4.6 \cdot 10^6$ ton/day), respectively.

SOUTH VENT ACTIVITY

On September 18, after renewed seismicity the eruption resumed at South vent 10 km southwest of cone I (Fig. 8). A fissure of meridional trend opened at an altitude of 360 m within the regional fissure zone extending from the summit crater through North vents. (A chain of Holocene scoria cones testified to the presence of this fissure zone). Lava fountains could be seen all along the fissure. The length of the fountaining area first increased from 220 m to 600 m then began to de-

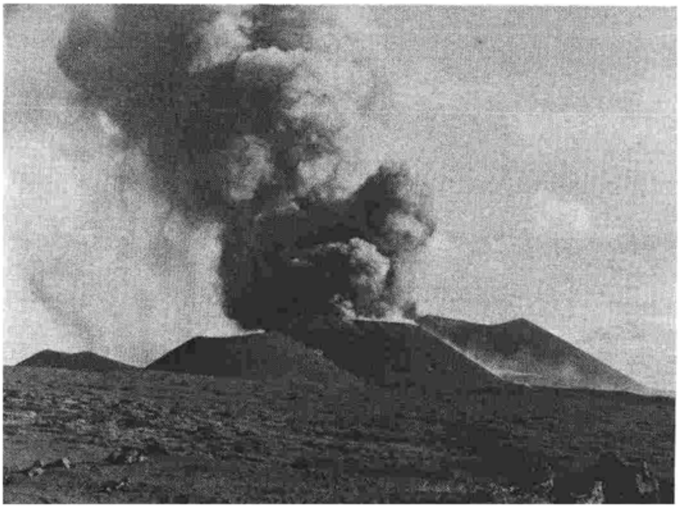

FIG. 7 – August 26, 1975. North group of cones, from NW. In the foreground is cone III, then cone II, near the foot of which, at the right, is small cone IV; behind is cone I. At the left is the extinct Holocene cone. *Photo by V. PODTABACHNY.*

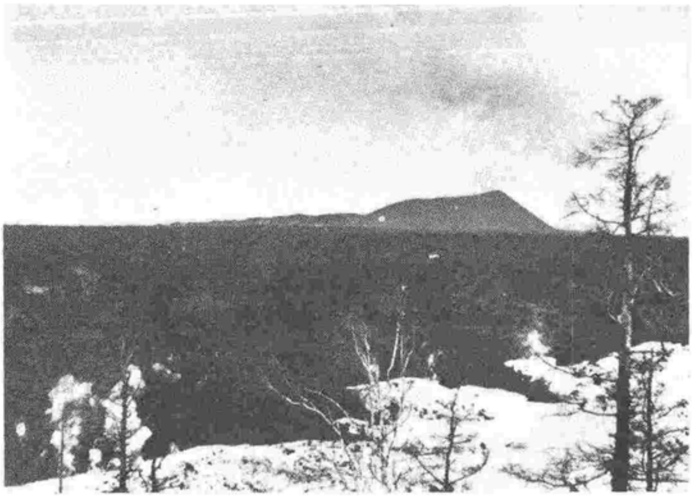

FIG. 8 – December 1975. South vent, from SW. In the distance is cone VIII in a state of slight explosive activity and adjacent scoriaceous-agglutinant hills. In the foreground is a basalt lava sheet formed by that time. *Photo by N. SMELOV.*

crease rapidly. Immediately after this, outpouring of basaltic lava of intermediate composition started. Soon it turned compositionally into high-alumina subalkaline lava that was characteristic of South vent eruption. In comparison to North vents this lava was less viscous. This was one of the main causes of monotonous, prolonged (450 days) and predominantly effusive character of eruption and formation of extensive lava sheet more than 35 km^2 in area.

On the second day a scoriaceous-agglutinant swell along the fissure began to trasform into a horseshoe-shaped cone and formed a single vent. Scoriaceous- agglutinant masses were carried away by hidden lava flows a distance up to a few hundred meters. As a result, a zone of lava-agglutinant hillocks nearly 80 m high appeared west of the cone (see Fig. 8). This zone, confined by distinctly expressed scarps has retained its morphological isolation during the entire eruption. The formation of the horseshoe-shaped cone ceased by September 30. A flow of scoriaceous-blocky lava with visible discharge averaging 25 m^3/sec was pouring out of its vent, open to the southwest, until November 7, 1975. On November 8 the cone closed and until December 27 lava outpouring occurred through boccas which opened alternately in the vicinity of the cone foot. Each bocca gave rise to a lava river which flowed within a few weeks. During that period the longest, up to 9 km, lava flows have been formed. That period also was marked by minimum lava viscosity (up to $1 \cdot 10^4$ poise). The cone activity was persistent, with a frequency of 10-12 outbursts per minute averaging in height from 150 to 200 m.

In a period from December 27, 1975, to early April, 1976, considerable deformation could be seen in the vicinity of the cone, consisting of heaves and deep fracturing of scoriaceous-agglutinant hillocks and lava plateaux surrounding the cone. Boccas opened, each of them was active not longer than a day, however their number amounted to 3-4 simultaneously. The average lava discharge diminished constantly until April 9. Short-term discharge splashes alternated with intervals a week long when visible lava flowing was absent. The crater activity was monotonously declining; the number of outbursts decreased to one per minute, and their average height reached 5-100 m. The viscosity of lavas during the whole period remained within the range of 10^4-10^5 poise.

On April 6 an abrupt increase of explosive activity was observed. The effusive activity increased on April 9. The frequency of outbursts amounted to 20 per minute and their average height reached 200-300 m. The lava discharge amounted to 80 m^3/sec and then during a month it gradually decreased up to 20 m^3/sec. Intensification of eruptive activity was accompanied by a number of qualitative changes.

The viscosity of lavas increased suddenly by approximately an order of magnitude. Long-lived lava rivers appeared again but they became blocky. The deformation of the cone and zone of lava-scoriaceous hillocks increased sharply. Collapses of crater walls were accompanied by issuing of great amounts of black ash. Large blocks were pulled out of the foot of the cone. This was accompanied by subsidence and slump of its flanks and probably was connected with a large hidden subsurface discharge of lava which dragged the cone. On April 19 a segment of the cone, somewhat lower in height than the cone itself has removed to a distance of 100 m (Fig. 9). Blocks amounting to thousands of square meters in area were torn off and carried away with lava from

FIG. 9 - April 20, 1976. Dragging of cone VIII during the increase of its activity. At the right is cone VIII, at the left is its segment 70 m high which has removed from the cone during a few hours. *Photo by Yu. SLEZIN.*

the zone of scoria hills. Lava plateaux and the hills themselves were covered by a series of wide and deep fissures. A removal of the hills area from the cone occurred simultaneously. Later on, until early July, lava discharge and intensity of deformations decreased. The explosive activity of the cone was invariable.

On July 9, an abrupt increase of lava discharge was noted again. It was accompanied by intense deformation of the near-cone plateau, consisting of dragging aside, heave and subsidence of its sectors.

During the final stage of eruption, from early October to December 10, 1976, some peculiarities in the South vent activity were marked. The activity had a cyclic character with periods gradually decreasing from 14 to 8 days. Each ensuing maximum was generally less intense than the previous one, indicative of natural and consistent waning of volcanic activity. Exceptions were only the last days of eruption when the visible lava discharge increased twice. A second peculiarity was the formation of a chain of craters on the flank of the cone and their subsidences coinciding in direction with the primary fissure. Lava intruded along this line from the cone's interiors into beds of lava sheet. As a result, a large arch-shaped uplift of lava sheet, individual blocks of which rose tens of meters above its surface, appeared at the foot of the cone.

During the South vent activity systematic measurements of lava temperature and viscosity were carried out. Chromel-alumel thermocouples were used for temperature measurements. For a qualitative check of the upper limit of the temperature, samples of pure copper (fusion temperature 1083°C) were sunk into lava. Fusion did not occur. The lava temperature varied within the limits of 1030-1070°C. The temperature of gases separated from lava is generally close to the temperature of lava but in some cases it was higher reaching 1180°C. This points apparently to exothermal reactions proceeding in gas when it interacted with air.

The effective viscosity of flowing lavas was calculated using the well-known for-

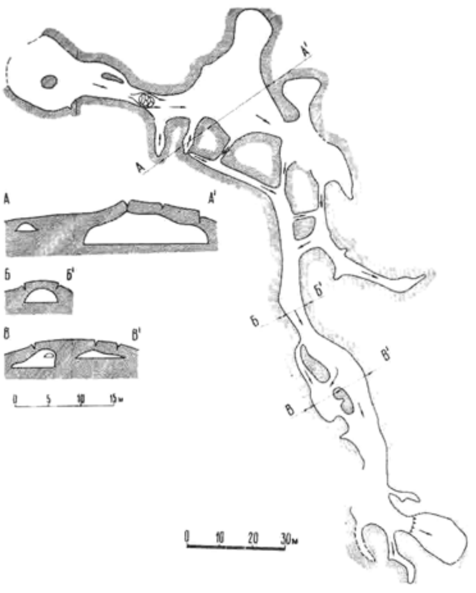

FIG. 10 - Plan and cross sections of a labyrinth of lava tubes and caves formed during a previous eruption. Vertical and horizontal scales are equal. (The labyrinth has been found by S. A. FEDOTOV).

mula for a layer of flowing viscous fluid (LANDAU and LIVSHITS, 1954). The viscosity of lava at vents located near the cone was in the range of 10^4-10^5 poise. The viscosity of lava flowing out from secondary boccas at a distance of 2-3 km from the cone varied from 10^6 to 10^7 poise.

Daily measurements of visible lava discharge were started in the second half of November, 1975. The average visible lava discharge accounted for $36 \cdot 10^3\ m^3/h$ and the total volume of issued lava was expected to be 0.42 km^3. However, in reality it was close to 1 km^3. This divergence implies that about half of lava discharge occurred along lava tubes and channels hidden under the surface inside the beds of lava sheet. Lava flowing along the tubes a few hundred meters long appeared within separate steps of lava sheet at all distances from the cone. Some lava tubes reached a few kilometers in length. When lava flowing had ceased, lava tubes emptied partially and in some places their roof collapsed. These windows permitted observation of their composite structure. Figure 10 shows the plan of a typical labyrinth of empty lava tubes and caves in a lava sheet formed during the eruption of the neighbouring cone a few hundred years ago. The height of some passages in the cave was 0.5 to 4.5 m, averaging 1.5-2 m. The ceiling was arched, in some places, sagged, fused with lava stalactites nearly 15 cm long and 0.5-1.0 cm in diameter. The floor was flat with predominant ropy lava surface. The thickness of the roof reached 2-3 m. It is most likely that the heave, arching and cracking of the roof and the formation of caves and new lava passages were caused by plugging up the lava channels (by collapse, increase of lava viscosity and so on).

During the South vent eruption a lava basalt sheet covering an area of more than 35 km^2 the average thickness of which was 20-30 m has been formed here. In general, the lava field had a step-like structure. Some steps represented fronts of lava effused at a relatively small flow rate from boccas. When the lava discharge was considerable, about 10-20 m^3/sec, several steps could appear on the same lava flow. In this case secondary lava effusions originated on the front of a practically stopped flow. The lava surface was complicated by numerous structural elements characteristic of mobile basalts, namely gently sloping domes, bands of smooth lavas up to a few hundred meters, small pit craters, empty lava channels and tunnels, hornitos, lava toes, squeezed lava guts, tongues and other squeeze-ups of various forms and dimensions. The major morphological lava types were scoriaceous-blocky and flat-blocky with smooth surfaces turning into rough hummocky. Festooned, ropy and filamented pahoehoe flows were less common (Figs. 11, 12).

Pyroclastic material was represented by crystal-vitroclastic ash, vesicular black scoria, scoriaceous spilled and cloddy bombs, more seldom fusiform bombs. Flat, more seldom cruciform and spherical growths of

FIG. 11 - Festooned lava is overflowing the borders of a lava channel after increase of its level. *Photo by Yu. SLEZIN.*

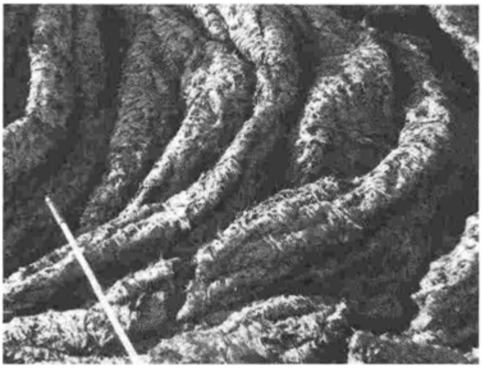

FIG. 12 - Filamented ropy lava effused in January 1976. A ski-stick gives the scale. *Photo by Yu. SLEZIN.*

plagioclase crystals were abundant in lapilli, particularly during the first months of eruption. At the same time minute fragments of white and light-gray pumice, probably fragments of molten basal rocks, occurred in ejecta in low abundances. Deepseated xenoliths were not observed.

As a result of a 450-day South vent activity, a scoria cone more than 150 m high and 0.01 km^3 in volume was formed. About 0.05 km^3 of ash and scoria was thrown outside the cone. The volume of pyroclastics amounted to 0.06 km^3. The volume of effused lavas was about 0.92 km^3. The total volume of erupted products amounted to 1 km^3. The average density of lava and pyroclastics was equal to 2.2 g/cm^3 and 1.2 g/cm^3, respectively; thus the total weight of solid products accounted for 2.1 10^9 ton. The total heat energy of eruption was equal to $3.1 \cdot 10^{18}$J. The index of explosiveness was 3.5 weight per cent. The average discharges of pyroclastic and lava was 2 ton/sec ($1.7 \cdot 10^5$ ton/day), and 53 ton/sec ($4.6 \cdot 10^6$ ton/day), respectively. Significantly the average lava discharge at North and South vents is equal.

COLLAPSE OF THE PLOSKY TOLBACHIK SUMMIT CRATER

The third important event occurring in the region of the Tolbachik eruption was collapse of the Plosky Tolbachik summit crater which was noticed during an aerial inspection made on August 25, 1975.

The flat top of Plosky Tolbachik volcano (altitude 3,085 m) represented a large caldera covered by ice with a diameter averaging 3.8 km. There was a small inner caldera cut into the large caldera in its southwestern part. The diameter of the small caldera was 1.8 km. The active pit crater was situated in the center of the small caldera. A lava lake was occasionally observed at its floor. In 1974 the active pit crater had the dimensions of 400 × 450 m, its depth and the volume accounted for 230 m and 0.02 km^3, respectively (Fig 13).

During the period from March to July 1975 there were observed repeated ash emissions from the crater. While climbing the top of Plosky Tolbachik no large collapses which occurred at that time could be seen. However, the floor of the crater was found to be broken by fresh fractures. By August 25, 1975, as a result of collapse, the crater increased to dimensions of 1,300 × 800 m. An elliptical cauldron with large diameter oriented to 310-315° occupied almost half of the small caldera. The depth and volume of the crater were nearly 400 m and 0.27 km^3, respectively.

The major collapse occurred in August-September, 1975. It coincided in time with

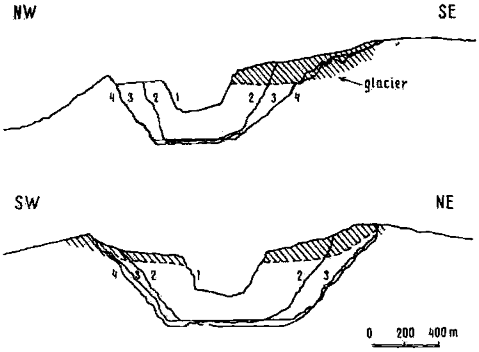

FIG. 13 - Evolution of Plosky Tolbachik summit crater. Cross sections and volume of collapsed crater have been determined at different time by stereophotogrammetric method from aerial survey data. 1 - 6.9.1974, 0.02 km^3; 2 - 25.8.1975, 0.27 km^3; 3 - 17.9.1976, 0.34 km^3; 4 - 26.9.1977, 0.35 km^3. Vertical and horizontal scales are equal. After GUSEV *et al.*, (1979).

strong North vents eruption. The collapse was not accompanied by the summit crater eruption. The collapse probably occurred into the peripheral chamber beneath the Plosky Tolbachik caldera due to pressure drop in a system of magma chambers and channels caused by the eruption.

The aerial inspection made on October 6-7, 1975 showed that the floor of the crater had been covered by porridge-like masses consisting of collapsed loose caldera deposits and glacier fragments.

By December 1975 the collapsed ice had melted and a lake had been formed in the cauldron. In September 1976 the volume of water in the lake (maximum at that time) was 0.6 km^3. The total volume of the cauldron was 0.34 km^3.

The caldera represents a telescoped structure. The composition of its walls suggests that collapses were repeated periodically in the geologic history of the volcano.

In September 1977 the floor of the cauldron crater was almost completely exposed. The depth and total volume of the crater amounted to more than 400 m and 0.35 km^3, respectively. In April 1978 no significant changes were noted in the crater, except an increase in fumarolic activity was noticed on the floor of the crater.

CONCLUSIONS

During the large Tolbachik fissure eruption, 1975-1976, four new big scoria cones have appeared and more than 2 km^3 of volcanic products with the total weight of $3.5 \cdot 10^9$ ton have been ejected. The weight of gases emitted during the eruption, according to MARKHININ's estimates, exceeded 30×10^6 ton. The total heat energy of eruption accounted for $5.2 \cdot 10^{18}$J. The eruption area extended for 30 km. The formation of monogenic scoria volcanoes, basalt plateaux and subsidence of the summit caldera were observed for the first time during the eruption in Kamchatka. This was the strongest basalt eruption which has taken place in the Kurile-Kamchatka volcanic belt in historic time.

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