LAVA CAVES IN KAMCHATKA

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ABSTRACT

The lava caves in Kamchatka are found in the region of the Klyuchevskaya Volcano Group (Central Kamchatka Basin) and in the region of Gorely volcano (South Kamchatka). All known caves there are in basaltic or basalt andesitic lavas (49-54% Silica) with large content of the big phenocrysts of plagioclase. Lava tubes and caves generation was observed in details during Tolbachik Eruption 1975-1976. It is supposed that the mechanism of lava tube generation is connected with the relatively high significance of the yield strength in the rheology of cave-bearing lava. The most complicated lava caves are connected with the temporary stops of lava flow motion when lava supply was constant.

The information about lava caves in Kamchatka is not abundant, because there were no special speleological investigations in this region. All the available direct information was obtained by the volcanologists, who deal with lava flows and lava fields formation. As a result we have a few known «registered» caves and only one mapped and described in some detail. But we studied the mechanisms of the lava caves formation, the types of lava caves, the role of lava tubes in the formation of lava fields. The connection of lava caves with the type and properties of lava flows was established. On this base we can say that there should be much more lava caves in Kamchatka than it is known now and the largest and the most interesting caves are waiting for the cavers.

GENERAL INFORMATION

Kamchatka is situated in the Northern part of the Kuril-Kamchatka Island Arc (Fig.1). There are 29 active and many hundreds of extinct volcanoes on it. Lava caves in Kamchatka are known only in the lavas of the active volcanoes. All the active volcanoes but one are situated in the East Volcanic Belt and in the Central Kamchatka Basin (Klyuchevskaya Volcanic Group). The mean eruptive productivity of the Klyuchevskaya Group per a time unit is as great as three quarters of total Kamchatka volcanic productivity. This mass and energy factor is believed to be connected with the peculiarity of the situation of these volcanoes in the place where the Aleutian Island Arc is abutting upon the Kuril-Kamchatka Island Arc. At the Klyuchevskaya Group the largest basaltic and basaltic-andesitic active volcanoes are gathered and most of the known lava caves are situated. The second place where lava caves are found is the region of Gorely volcano in the Southern Kamchatka not far from Petropavlovsk.

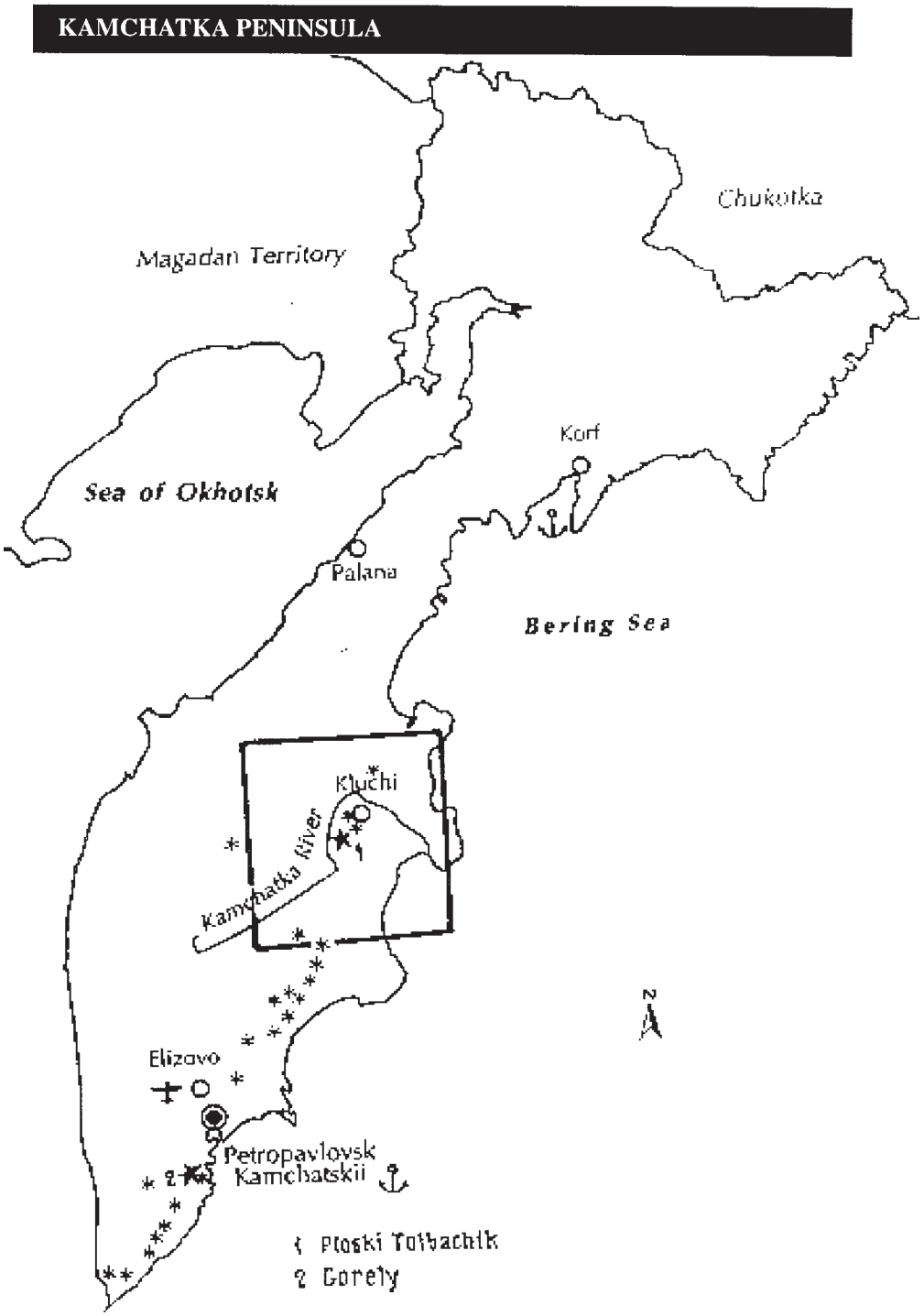

Fig.1.- Kamchatka peninsula. Stars - active volcanoes. In a square frame there is the territory shown on Fig.2.

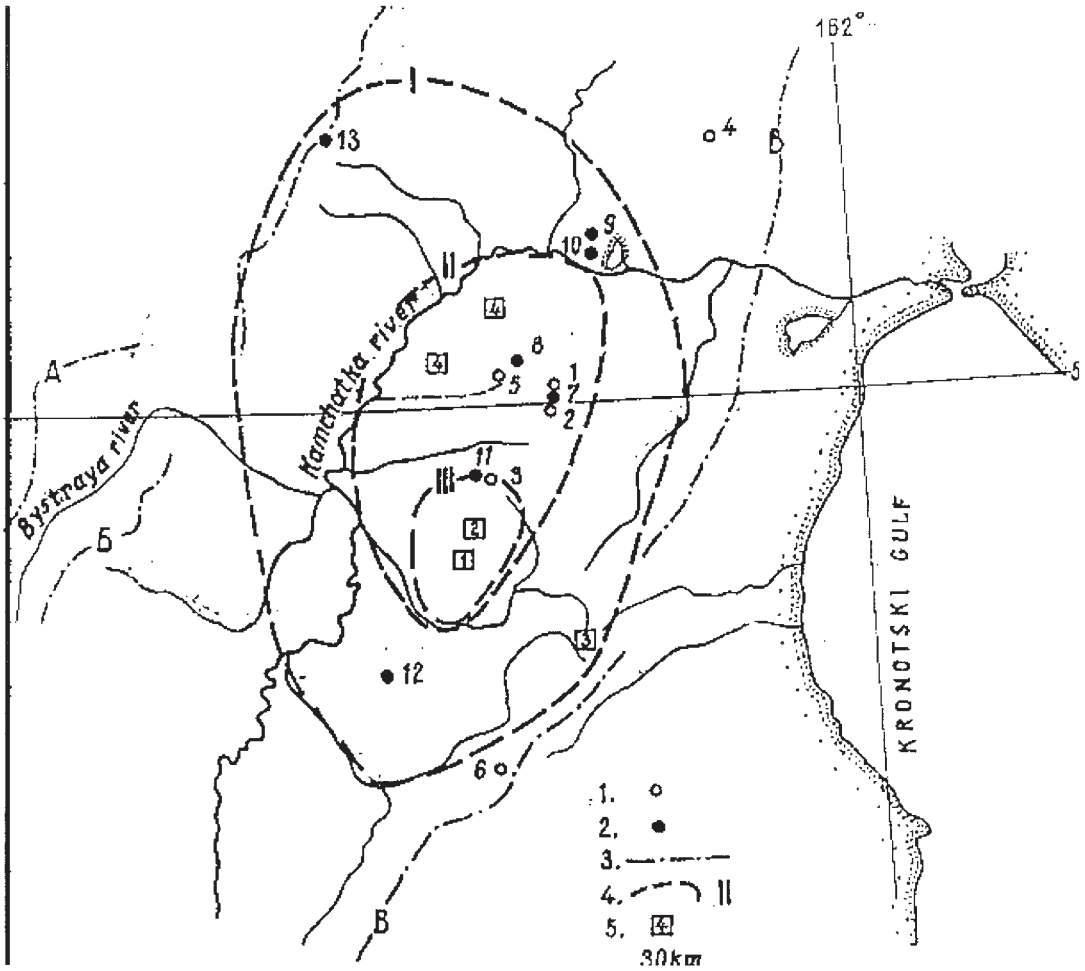

Fig. 2.- Areals of megaplagiophiyric basalts around the Klyuchevskaya Volcano Group at: 1 - Late Pliocene; II - Pleistocene; III - Holocene AA-Central Kamchatka and BB-Eastern Kamchatka Ridges; small circles, numbered by Arabic figures - volcanoes, active when open, extinct when solid. Small square numbered by Arabic figures - sites of petrological sampling made by the authors: 1 - Tolbachik Southern Breakthrough, 2 - «Zvezda».

The basement of the entire Klyuchevskaya Volcano Group is represented by some giant shield volcanoes for which the so-called megaplagiophyric basalt (containing the quantities of big disk-like labrador phenocrysts) is characteristic (Shantser, Kraevaya,1980). All the known lava caves in the Klyuchevskaya Volcano Group are connected with this type of lava and we need to give some sketch of its geographical and geostructural position.

The initial areal of the megaplagiophyric basalt was much wider, having included ajacent to Central Basin parts of Central Kamchatka and Eastern Kamchatka Mountain Ridges. Some 40 thousand years ago this areal shrinked to the limits of the Klyuchevskaya Volcano Group basement. Now only Tolbachik volcano produces megaplagiophyriclavas and only here one can observe lava caves in process or immediately after (in geological sense) their origination (Fig.2).

The cave-bearing lavas of the Gorely volcano also contain large amount of the plagioclase phenocrysts, though of less dimensions. Physical and petrological properties of such lavas and their connection with the generation of the caves is an actual problem and in this paper we'll touch only one (mechanical) aspect of it.

LAVA CAVE MORPHOLOGY AND FIELD OCCURENCES

The area of Tolbachic volcano appears to be most informative in regardsof lava caves undoubtedly. The Tolbachic Eruption of 1975-1976 made it possible to watch the process of lava caves origination (Large Tolbachik ..., 1984). The preceding similar lava extrusion happend here in 1739. In the lavas of that historic eruption several lava caves are found and one of them (seen and reported by Sergey Fedotov) was described and mapped by one of the authors of this article (Fedotov, Markhinin, *et al*, 1977) (Fig.3).

The cave consist of one big chamber up to 40 m across and 4.5 m high and of tubes of variable dimensions: from less than 1 m to 7-8 m across and from a few scores of cm to more than 2 m high. All tubes and chambers have nearly flat slightly sloping floors, covered mainly with ropy lava, and arched (in some places sagging), glazed ceilings ornamented with numerous lava «icicles» (stalactites) up to 15 cm long. The floor of some backside tunnels is terraced with vertical precipices of about 1.5 m high. Some vertical wells (lava drains) sealed with lava at the depth of 1 m indicate the presence of another horizon of lava tubes which was connected with the described cave in active state.

We have found two more caves in the vicinity of the mapped one. They are of similar dimensions and one can guess that all three of them in active state were connected with each other and formed a large system of lava chambers and channels. Besides these rather large and complicated caves there were fragments of simple straight lava tubes.

In the older lava fields nearby (a few thousand years old) one cave of about 100 m in length was found by geodesists, who used the cave as inclinometer chambers during Tolbachik eruption 1975-1976. Some years later the ceiling nearby the entrance of this «geodetic» cave partly collapsed and the entrance was blocked. No more open accessible caves in the lavas of this age are known, but we can see a lot of collapse structures (ground subsidences), in some places arranged lineally as if marking the caves with blocked entrances.

In January 1976 Yu. Slezin measured the characteristics of the warm air flow through the loose lava blocks in a subsidence crater. The air flow had a volume rate of about 3 cubic meters per second at temperature of +2 degrees Centigrade , when the temperature of the outer air was -25 degrees. The underground air was clean and humid. The air flow must have been the result of the ventilation of a cave. The mass rate and the temperature of the warm air flow remained constant for more than a month. That might be interpreted as an evidence of the great size of the ventilated cave.

In the oldest lavas (more than ten thousand years old) only a small number of caves have been found now. We can list one found by Alexandr Belousov in the forest near the town of Klyuchi and a few small grottos on the river bank, at the west flank of the Klyuchevskaya a known only one cave which was found by A. Belousov in the forest near town Klyuchi and a few small grottos on the river bank on the west flank of the Klyuchevskaya Volcano Group. The latters were found by a writer and amateur-archeologist Leonid Pasenyuk. He found bonfire coals, animal bones and stone tools there, but no professional archeological (as well as no speleological) researchers have been undertaken.

The presence of other, probably numerous lava caves in the Klyuchevskaya Volcano Group basement is indirectly shown by deformations and collapses of the overlapping pyroclastic layers and by the character of the drainage of this territory.

There are many funnellike hollows near and within the town of Klyuchi. The ground subsidence has continued in the present time and has caused the collapse of houses and has even damaged the newly built ranway of the local airfield. New hollows and gaps in the town appeared generally when builders disturbed the old caves and activated the transportation of loose ground through them. In some cases, when the builders try to fill up some gaps, hundreds of cubic meters of ground ought to be spilt into them. This phenomenon is analogous to one of the ways of the karst hollow origination, i. e. that one which happens due to spilling of loose ground through cave windows or even small fissures in their seilings. Sometimes builders used to discoverthe entrances into lava caves, nearly totally folled up with debris, sand and silt.

The Klyuchevskaya Volcano Group is very poor in surface water flows, but it is surrounded by a ring of voluminous water springs, many of them of Vauclusian type (e.g., so-called «Domashnee Ozero» in the village of Kosyrevsk). These springs have given name to the town Klyuchi and the volcano group Klyuchevskaya («klyuchi» is the Russian for water springs). The radial lava cave systems in this undergruond drainage serves as the main water supplier to all the nearby rivers, creeks and lakes.

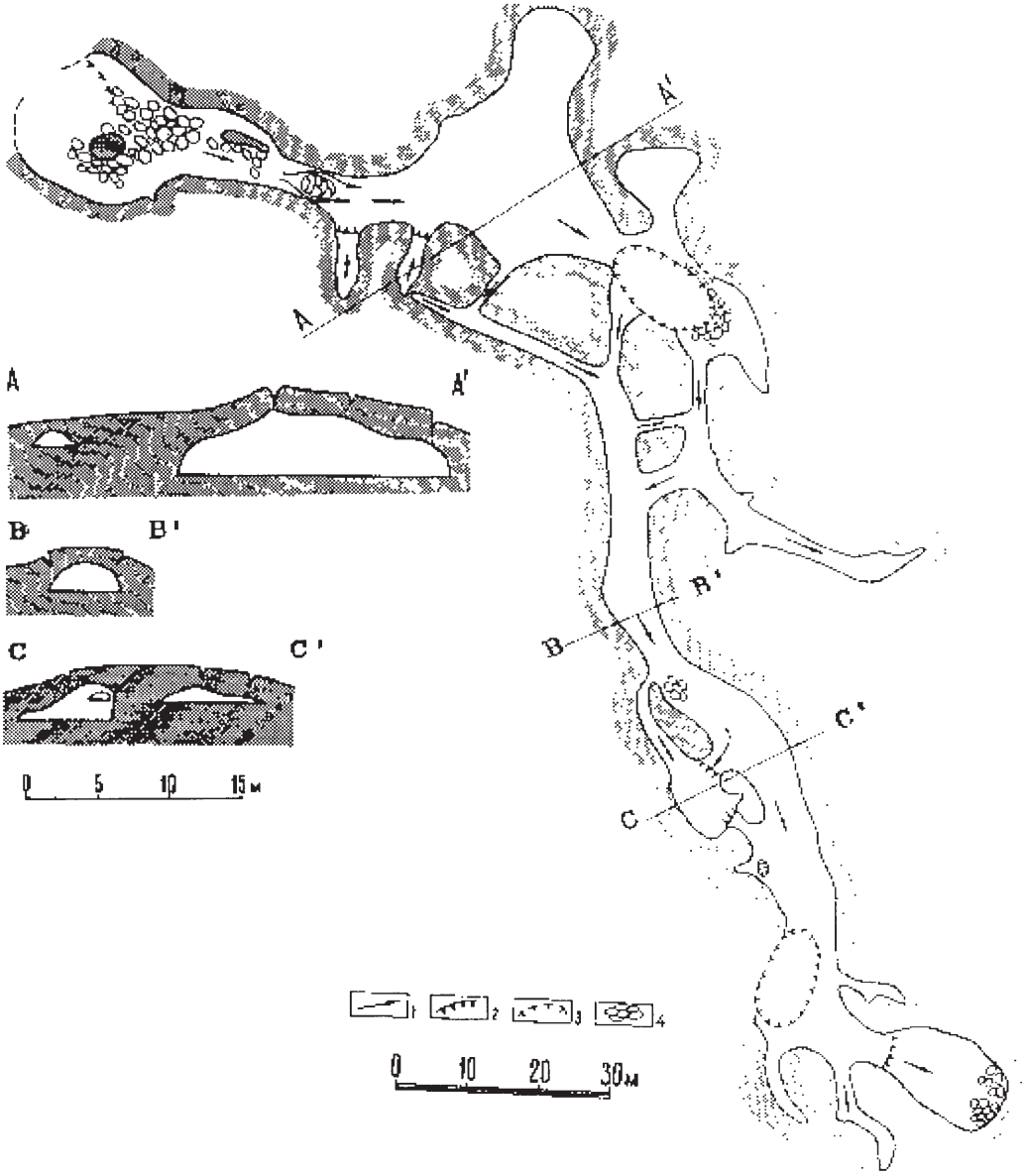

Fig.3 Map of the cave in the lavas of Zvezda cone in Tolbachic Dol, erupted in 1739. 1 - arrows indicate the lava flow directions determined by the curvature of the «ropes» on the ropy surface of the cave floor; 2 - vertical steps on the cave floor; 3 - contours of the collapsed parts of the cave roof; 4 - lava blocks heaped on the floor. The scale of the vertical cross sections is doubled relative to the scale of the map.

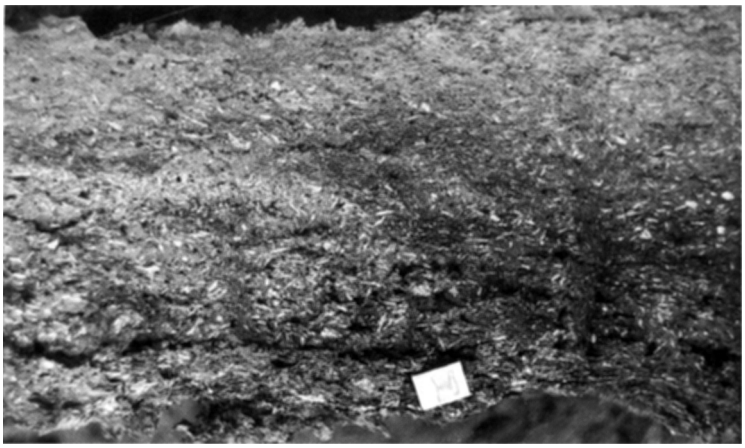

Fig. 4 The cross section of a lava tube roof. The white cross sections of the disk-like crystals of plagioclase are seen. Hydrodinamic forces arranged nearly all «disks» parallel to the direction of the lava flow (perpendicular to the picture plane). See a matchbox as a scale. (Photo: Yu.B.Slezin).

In the second area in the vicinity of Gorely volcano lava caves were found in the big (15 km long) lava flow that resembles the lava flows of Tolbachic region both in surface features and in inner structure. The lava is of basalt-andesiyic composition with a little more silica content than of Tolbachik - about 54%. It also containsplagioclase phenocrysts, though of smaller size. The age of this lava flow is about 2000 years (radiocarbone dating, personal communication of V. Ponomareva).
Gorely volcano lava caves are no longer, than 60 m, but their cross sections of some of them are rather impressive - up to 40 m wide and 8 m high. There is a lake with an ice bottom in one of these caves. Most of the grottos are indeed the fragments of former large cave systems.

THE MECHANISM AND THE CONDITIONS OF LAVA CAVES FORMATION

All the lava caves known in Kamchatka were formed in the fluid lavas that flowed over the slightly inclined surface (a few degrees). Such lavas in such conditions formed the vast lava fields composed of individual flows. The length and width of the individual flow depended on the lava mass rate and could be of more than 10 km and up to 1 km respectively. The mean thickness of an individual flow was small - less than 10 m. All the lava flow surface as a rule is complicated with local swells, bulges and ridges elevated several meters above the mean level. Under these swells in many cases there were the largest and the most complicated caves. The relative dimensions and the main features of a lava flow is a result of lava transportation through the tubes.

To form a lava tube, there is to be a solid, stable, immovable crust over fluid moving lava. To form a cave, the fluid lava contents of a tube must be finally evacuated from under the crust.To form a large cave with a complicated structure, there must be also the mechanism of building and evacuation of the local swells on the lava flow.

The cooling, degassing and solidification of lava begin at the surface and provide the formation of the solid crust but in most cases this crust is deformed and destroyed by the moving lava at the first stages of solidification. To make the crust not only solid but stable there must be very sharp transition between the fluid melt with low viscosity and solid matter of the crust. Such a sharp transition is the property of a Bingham Body with a rather low plastic viscosity and relatively large yield strength. In this case very small changes in the shear stress or yield strength can change fluid to solid and vice versa. Basalt lavas with crystals possess these properties, and thus we can explain the origin of the lava caves with the presence of the lavas of a certain type. In Fig.4 you can see the typical megaplagiophyric lava in the cross section of the lava tube roof in the lavas of the Tolbachik eruption of 1975-76 years.

The effective evacuation of the lava tubes can take place under certain conditions. There has to be fast diminishing of the lava mass rate in the source when lava flow remain in active movement and the

active flow must be long enough to provide the hydraulic head necessary for the drainage of the most part of the tube. The fulfilling of both conditions needs the large duration of the lava flowing with high mass rate. The first of them as usual is the result of the new lava breakthrough near the source which in its turn is the result of the rise of the hydraulic head in the original source because of the rise of the flow resistance in a long tube. The lava transport through tubes helps to the fulfilling of the second condition.

There is one more factor that helps lava to flow over great distances in rather small tubes and to drain the tubes after the lava supply has stopped. This factor consists of exothermic reactions of the magmatic gases with air, which help to maintain the lava's high temperature and low viscosity under the tube roof. We've measured the temperatures of gas jets in the fissures in the roofs of lava tubes, and found that it was, in many cases, several tens of degrees Centigrade above the temperature of the lava. In one case , the difference in temperature was more than two hundred degrees. The glazed surfaces in tubes and long thin lava icicles must be the result of the contact with hot gas. The gas that reacted with the oxygen under the tube roof most probably was the hydrogen. The measured hydrogen content in magmatic gas (without condenced fraction) was in some samples up to 34 volume percent (Markhinin, 1980).

The mechanism of the creation of the largest and most complicated caves was more specific and connected with the interruptions of lava flow motion whereas the lava supply continued the same way. When the lava flow front stopped, the internal lava motion continued through a few narrow active channels, and in the motionless front parts of the flow lava created some local swells - tumuli and elongated cupolas. Rather fast swelling of these structures increased the static pressure of the liquid lava, and eventually the latter broke through at the base of the front rampart of the flow and thus opened one or two secondary lava sourses. These secondary sources are similar to the initial source save enlarged mass rate during short period of time at the beginning and a little more viscous lava. If they acted enough time, they formed the second step of the lava flow similar to the first.This procedure as usual was repeated several times, making up to four or five steps each about 1-3 km long (Andreev, Gusev, *et al*, 1978). The end of each step was marked with a rampart 3 to 6 meters high. The intense outflow of magma through these secondary sources effectively evacuated chambers under the swellungs and so formed the big caves.

Interruptions in lava flow motion are connected with its rheology and the inclination of the ground surface. In their gentle slopes the front parts of the lava flows have fanlike form and cracked crust, the fragments of which are partly mixed with the melt that influence the rheology and the motion of the flow as a whole (lava channels and tubes appear some distance up the flow). Lava flow acquires the so-salled «bulk yield strength» (the term was proposed in (Pinkerton, Sparks, 1978)), the rise of which stops the motion.

It is significant that lava flow of such type and geometry cannot resume its motion if the swelling proceeds over the good part of its surfase, but as the lava continues to flow in a few narrow tubes, the localisation of the swelling process in a few rather small areas helps in the fast rise of the hydrostatic head and lava breakthrough.

We saw that the largest systems of lava caves are connected with the swells near the front parts of the steps in the lava flows. This connection with the general lava flow topography could be used for searching the caves in old megaplagiophyric lavas covered with ash and soil. We recommended this morphological criterium to building engineers (Slezin, Tsyurupa, Tarakanov, 1981).

SHORT CONCLUSIONS

1. There are lava caves in Kamchatka, and we are convinced that most part of them and the largest of them are not found yet because there were no special efforts for that.

2. All known lava caves are connected with the basaltic and basaltic-andesitic lavas of low viscosity with megaplagiophyric structure, which flowed over slightly inclined ground.

3. There are two types of the lava caves: simple lava tubes, situated in all parts of the lava flow, and rather complicated lava chambers, situated under big swells near the front parts of lava steps.

4. The generation of the caves is connected with the Bingham rheology of the lava of low plastic viscosity and relatively large yield strength.

5. The generation of the largest complicated caves is connected with occasional stops and subsequent resumes (by the way of lava breakthrough) of lava flow motion as a result of the Bingham rheology of the lava flow as a whole.

6. Lava caves are not very stable and the probability of finding big accessible caves in the lavas much older than a few thousand years is little.

Special investigation of the conditions of the preservation and prospecting of lava caves should be made.

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