Late-Pleistocene Geology and Structural Control of the Karymsky Volcanic Center Geothermal Fields, Kamchatka: Evidence for Evolution of Magmatic System

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ABSTRACT

The Karymsky volcanic center - a group of volcanoes, calderas, and maars – are located in the central part of the Eastern Volcanic Belt of Kamchatka. It was constructed since the Pliocene, and a voluminous eruption of pyroclastic flows and ash-fall deposits were in Late Pleistocene. In 2003 works in area of the Karymsky geothermal system belonging to the Karymsky volcanic center have been completed. Works were carried out with the purpose of studying magmatic supply system of volcanoes, for reception of the new data on the magmatic chambers, their interrelation, and a role in a thermal feed of geothermal system. The lead works have allowed specifying essentially history of volcanic development in area for last 200 thousand years. The new geological map is made; volumes of pyroclastic deposits, connected with formation separate calderas are appreciated. Structural conditions of location Eastern Kamchatka's high-temperature hydrothermal systems and Karimskaya hydrothermal system are analysed. It is shown that the main structural elements determining the position of high-temperature hydrothermal systems are faults. Magma and hydrothermal fluids are constantly rising along them and complex volcanic structures on the surface are formed. Thermal manifestations are usually located within boundary of such structures and around them.

1. INTRODUCTION

The Karymsky volcanic center is located in the central part of Eastern Kamchatka. There are seven calderas formed in last 0.18-0.15 Ma in this center (Ivanov, 1970; Selyangin, 1974, 1977, 1987; Volcanic center, 1980). One of youngest calderas of Kamchatka - Karymskaya, formed 7,7 thousand years ago is located also in this center (Braitseva et al., 1994). Repeated catastrophic ignimbrite eruptions have been in this place in past. The tens cubic kilometers of magma were erupted and the extensive areas were devastated. These eruptions are connected to activity of upper crust magmatic chambers, which, apparently, continue to keep activity and now - there are active volcanoes (Karymsky and Maly Semyachic), hydrothermal systems, numerous pumice bombs erupted in Academy Nauk caldera in 1996 (Grib, 1998). Whether the renewal of upper crust magmatic chambers activity and new catastrophic caldera-forming eruptions is possible, or this process is completed and similar eruptions will cannot to be? In one of the previous works (Masurenkov, 1980) the conclusion was made, that the ignimbrite-forming processes in this area have been finished and new catastrophic eruptions here will not be, whether but so it?

How develop the magmatic chambers? Our knowledge about it is still very incomplete. Why in one cases they quickly freezen and after caldera-forming processes any activity connected with them are not observed, as, for example, in northern part of the Karymsky volcanic center, and at the same time the process of caldera-forming repeated again and again in other cases, how in a southern part of the same center? Why eruptions of basalts are beginning frequently after eruptions of large volumes a silicic pyroclastics and a caldera formation? Whether the representation is correct that the influx of basalt can be "trigger" and to cause eruption from crust magmatic chamber (Sparks, Sigurdsson, 1977)? Whether can the eruption of basalts in Karymsky volcanic center in 1996 provoke eruption of the silicic pyroclastics in the near future? On these questions while there are no unequivocal answers.

In 1996-2003 years we studied a geological structure and history of caldera formation in a southern part of the Karymsky volcanic center, where previous researchers allocated calderas: Polovinka (Krainiaya), Odnoboky volcano (Odnobokaya), Academy Nauk, Karimskaya. First three of named calderas are telescoped enclosed each other and represent a good example of repeated activity of caldera forming processes in the same place. We studied the sections of pyroclastic deposits connected to each of named calderas, mineralogy and geochemistry of erupted products in details. The purpose of researches was reception new data about a condition of magma chambers, probable depth of it, reasons of their periodic activity.

2. GEOLOGICAL STRUCTURE OF AREA

The Karymsky volcanic center (fig. 1, see end of the paper) - a group of volcanoes, calderas, and maars – are located in the central part of the Eastern Volcanic Belt of Kamchatka. It was constructed since the Pliocene, and a voluminous eruption of pyroclastic flows and ash-fall deposits were in Late Pleistocene (fig. 2). The many researchers were studied of Karymsky volcanic center geology, structure and history of volcanism (Vlodavets, 1947; Ivanov, 1969, 1970; Selyangin, 1974, 1977, 1987; Volcanic center, 1980; Leonov and Ivanov, 1994; etc.). Some researchers have allowed considering the center as a special structure - elementary cell of a volcanic belt (Volcanic center, 1980). The center has the sizes 55x65 km; it is a little extended in a northeast direction along the volcanic belt. The total amount of the volcanic material erupted in the center for 3 Ma of volcanic activities is estimated in 1700 км^3 (Masurenkov, 1991).

The system of calderas is forming extensive area of subsidence, extended along the axis of the Karymsky volcanic center – Karymsky-Semyachic caldera depression (Selyangin, 1974, 1977, 1987). The ages of calderas are 0.18-0.15 Ma (Volcanic center, 1980). The powerful eruptions of pyroclastic accompanied their formation, therefore the extensive fields on periphery of the center have appeared are covered by dacite and rhyodacite tuff and ignimbrites (fig. 1). The volume of erupted pyroclastic is 280 км^3 (Masurenkov, 1980) or about 100 км^3 of magma (Leonov et al., 2001).

The formation of calderas and tuff and ignimbrites connected to them occurred at the end of Middle Pleistocene. It was an appreciable boundary in a history of the volcanic center. Up to this boundary within more than 0.5 Ma volcanism in this area was mainly basaltic. In this period Zhupanovsky Vostryaky, Ditmara, Krayny, Razlaty, Soboliny, Stena, Pribrezhny Yuzhny, Pribrezhny Severny, Berezovy volcanoes were formed.

The volcanoes were dispersed on the extensive area and did not represent the uniform detached group (fig. 3, a). Total amount of lavas and pyroclastic, composing these volcanoes are estimated differently - from 150 км^3 (Kozhemiaka, 2001) up to 375 км^3 (Masurenkov, 1980).

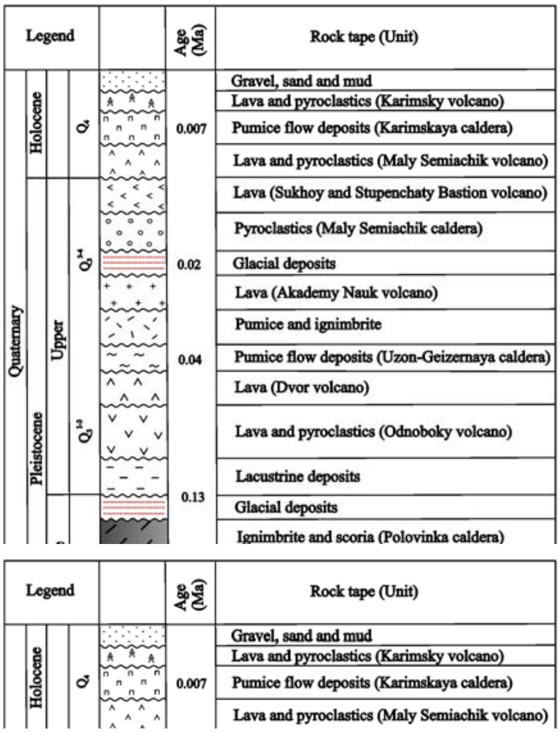

Figure 2. The stratigraphy column of rock units of the Karimsky volcanic centre

After formation of the calderas volcanic activities has concentrated extremely inside them. In this period, in the beginning of Upper Pleistocene, Odnoboky, Dvor, Pra-Semyachic, Pra-Karimsky volcanoes were formed. The lavas composing them is mainly andesites (average contents SiO_2 - 56,1 (Masurenkov, 1980), volume of lavas is 80 км^3 (Masurenkov, 1980). The further development of volcanic activities in area was connected to activity of these volcanoes. New calderas are formed on some of them (Odnobokaya, Maly Semyachic), and new volcanoes were formed in Late Pleistocene inside these calderas (Academy Nauk, Maly Semyachic), and then - again were formed calderas (Academy Nauk, Karimskaya). The Late Pleistocene – Holocene volcanism differs by the large variety of facial types. In the southern sector of structure main volume consist of pyroclastics - pumice, tuff and ignimbrites.

Thus, the Late Pleistocene – Holocene volcanism in the Karimsky volcanic center considerably differed from what developed here in earlier period (in Lower - Middle Pleistocene), both on structure, and on character of display. As it was marked in (Volcanic center, 1980), volcanism gradually reduced and has tendency located in two rather small on the size sites: near Maly Semyachic volcano in north and between Odnoboky and Dvor volcanoes in the south.

The objects of this paper are, mainly, calderas of southern sector of the Karimsky volcanic center. There are three main calderas in this sector (fig. 1). Polovinka caldera, other name – Krainiaya (Selyangin, 1974, 1977, 1987) is the most ancient caldera in the given area. The age of climactic eruption occur within this caldera is 0.18-0.15 Ma on one data (Volcanic center, 1980) and about 0.13 Ma on another's (Selyangin, 1987). Caldera had correct circle form and diameter about 10,5 km.

After Polovinka caldera formation the area was covered powerful glaciation (fig. 3, в). The moraines are found in considered area in many places - on the Pravaya Kedrovaya, Krestianskaya, Korneva and Polovinka rivers. The glaciers completely filled formed already to this time Karimsky-Semiachinsky caldera depression. The moraine lay down everywhere on tuffs and ignimbrites, connected with Polovinka caldera.

The Odnoboky volcano was formed inside Polovinka caldera after glaciation and almost completely has filled caldera by its lavas and pumice (fig. 1). The volcano has a complex history, in which repeatedly inflows of basaltic lavas were replaced by eruptions of pumice and pyroclastic flows. Detailed study of sections, including those numerous new cliffs, which were formed on the coast of Karimskoye lake after eruption of 1996, have allowed us to dismember the deposits of a volcano. The caldera of Odnoboky volcano is complex; it consists from several depressions (explosive funnels) located alone longitudinal fault zone.

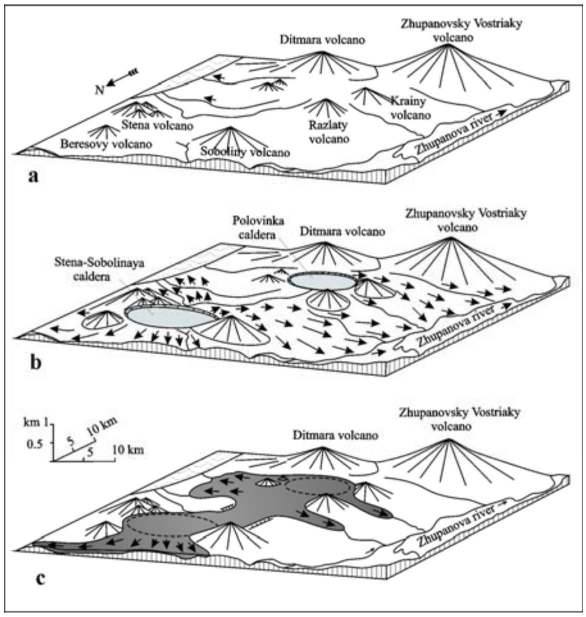

Figure 3. The basic stages of the Karymsky volcanic centre Middle Pleistocene development. a - precaldera stage; b - during formation of the Middle Pleistocene calderas (the arrows show a direction of movement pyroclastic flows connected to calderas formation); c – during the Middle Pleistocene glaciation (the grey colour shows glaciers; the dotted line marks calderas borders).

There are many layers of scoria (or phreatomagmatic deposits with pieces of scoria) among pumice deposits of a Odnoboky volcano and in more ancient deposits filling Polovinka caldera. The estimations have shown, that there were 15 eruptions of basaltic scoria for last 0.1 Ma. There was one eruption approximately of time in 7 thousand years (Fedotov et al., 2002). This estimation, certainly, very approximates, but is doubtless, that the inflow of deep basaltic magma occurred here repeatedly.

2.1 Pyroclastic Deposits associated with the Calderas

2.1.1 *Polovinka caldera.* The section of deposits connected with Polovinka caldera is unusual. It is divided on two parts sharply distinguished on structure and on color. The bottom part (the first portion) is so-called "Belesie" tuff (Volcanic center, 1980), which is widely distributed to west from caldera. Most powerful pyroclastic flows are come down on a southwest side of volcanic center between Zhupanovsky Vostriaky and Krainy volcanoes. The "Belesie" tuff has in this place up to 200 m thick. The top part of pyroclastic deposits connected with Polovinka caldera - black scoria tuff and ignimbrite. These deposits are distributed only near to boards of caldera and alternate with phreato-magmatic deposits showing that the eruptions upper scoria tuff occurred already from filled of water caldera.

The main volume (by our estimations - about 42 km^3) Polovinka caldera pyroclastic deposits make rhyodacite tuff ("Belesie"). The color of them is white and light gray. Xenolithic fragments by the size up to 2-3 cm are submitted lavas and make 10-15 %. Pumice-flattened fragments form the fiamme by the size up to 15 cm. Two types of this tuff, distinguished on structure are allocated. First were erupted tuff with quartz and biotite - P1, second – tuff without quartz and biotite - P2. The products of a final stage of caldera formation are tuff and ignimbrite with black tape-shape fiamme - P3. We estimate their volume approximately in 8 km^3.

2.1.2. Odnobokaya Caldera. There are two stages of caldera forming on this volcano, which are divided by the period of effusive activity. The deposits of first stage (O1) are submitted on two parts: pyroclastic flows (O1-1) and air-fall pumice (O1-2), 15-25 m thick. The deposits of a pyroclastic flow (O1-1) have local distribution. The second stage of caldera forming on Odnoboky volcano (O2) was beginning in Upper Pleistocene after a series of basaltic lava flows are erupted. These deposits can be divided into two phases. The products of the first phase O2-1 are advanced basically in northeast sector of the volcano. These deposits consist of yellow-brown dacite pumice tuff with microinclusions (from shares of millimeter up to 3-5 mm) and thin andesitic fiamme of dark gray color. There are dark gray and black-red color dacite ignimbrite in upper part of sections. The products of the second phase of caldera-forming O2-2 are poorly condensed pumice tuff advanced only in northern sector of the caldera. In a northeast part of a slope they lay directly on tuff O2-1, being separated from them low power (up to 1,5 m), layer andesitic-basaltic tephra.

2.1.3. Academy Nauk Caldera. The pyroclastic deposits connected with climactic eruption on Academy Nauk volcano are submitted by agglomerates pumice tuff, which distributed on southern slopes of the volcano. Their color is white; size of fragments does not exceed 5-10 cm. In the bottom part of a slope they are densely packed and form a layer up to 2,5-3 m thick. In the pumice deposits of upper part, up to 25-30 m thick, there is rough lineation.

2.1.4. The Deposit of Phreatomagmatic Eruptions. In January 1996 has taken place phreatomagmatic eruption at northern coast of Karimskoye Lake in Academy Nauk caldera (Fedotov, 1998). Among products of eruption prevailed basaltic tephra (BT), up to 5-6 m thick, submitted by volcanic bombs and lapilli size up to 10-50 cm. The rhyodacite pumice bombs were erupted on a final stage of eruption January 1996 (Grib, 1998). At detailed study of sections of pyroclastic deposits it was revealed, that the layers of basaltic tephra (sometimes in association with poorly condensed basaltic tuff) meet in them rather frequently, since the end of Middle Pleistocene (Fedotov, 1998). The thick of them changes within the limits of 1,5-3 m, less often than 10 m.

Basaltic tephra of Holocene eruptions, up to 1,5-3,0 m thick, forms low terraces along northern board of Karimskoye Lake. The scoria in the basis of the bottom terrace in the central part of northern slope are submitted by basalts, on composition close to products of eruption of 1996. Tephrochronology study has shown, that age of tuff is about 4800 yr (Belousov et al., 1997).

2.2 Evolution of Upper Crust Magmatic Chambers

The work reported in this paper has been primarily a field study of the Karimsky volcanic center. Detailed petrologic and geochemical studies have been reported elsewere (Grib and Leonov, 2001a,b; 2004a,b). Here only general descriptions are given, along with some observations and interpretations that bear on hypotheses of magmotectonic evolution.

2.2.1 Polovinka Caldera. The process of caldera forming in the southern sector of Karimsky volcanic center began by eruption of rhyolite pyroclastic flows with high content of silica (P1). The occurrence of high evolution melt testifies large break in tectono-magmatic activity of the given area in the Lower - Middle Pleistocene. The gradationally zoned magma chamber is supposed are presence in interior of Karimsky volcanic center on precaldera stage (fig. 4, *A*, *B*). In upper part of this magmatic chamber was highly evolution melt with water-saturated conditions. By insignificant distribution quartz–biotite tuff, the capacity of this zone was insignificant. With depth the contents of volatile component decreased, and acidity of melt was gradually reduced up to dacite, which make basic volume of Polovinka caldera pyroclastics. The final stage of caldera forming in the Middle Pleistocene (P3) has taken place after some break in explosive activity: in uppercrust chamber again was generated week zoning (fig. 4, *C*). The composition of pyroclastics has changed from andesite (ignimbrite and tuff) up to andesitic basalt (agglutinate and bomb tuff), at obvious prevalence last. Characteristics of agglutinate - very low (3-4 %) contents in them of a crystal phase. The bimodal distribution of plagioclase phenocrists, pyrocsene, residual glasses in ignimbrites are shown on zoning in upper part of magmatic chamber (Grib and Leonov, 2004 b).

2.2.2. Odnobokaya Caldera. The formation of Polovinka caldera was finished by eruption of andesitic-basaltic tephra. It meant, that basaltic melt filling up of upper-crust magmatic chamber by the end of Middle Pleistocene, practically have superseded of silicic melt, and created by it barrier has ceased to exist. After powerful Middle Pleistocene glaciation the new cycle of tectono-magmatic activity began. The basaltic melt from lower-crust intermediate magmatic chamber began to inflow in upper-crust magmatic chamber and Odnoboky volcano was generated. The lavas of it have filled of Polovinka caldera practically completely (fig. 4, *D*).

The first stage of development of a volcano, when were flowed the large volumes of basaltic lavas, by us is not considered. The age of the first caldera-forming stage on Odnoboky volcano (O1) is estimated in 0.11-0.08 Ma (Volcanic canter, 1980), after some break in volcanic activity. The consecutive change of composition of pyroclastic deposits from rhyolitic dacite up to dacite testifies to formation on a precaldera stage of compositional zoning in the top part of upper-crust magmatic chamber (fig. 4, *E*).

The first stage of caldera forming on Odnoboky volcano was replaced by inflow of basalts and andesite-basalts (as well as in a case of Polovinka caldera), specifying thus with rhythmical character of tectono-magmatic activity in the given area on the Middle-Upper Pleistocene. Subsequent lava flows of Odnoboky volcano has andesite and dacite composition testify about presence more silicic melt in magmatic chamber under a volcano. The evolution of basaltic melt was finished by second (O2) stage of explosive caldera-forming eruption (fig. 4, *F*). The pumice tuff of stage O2 has mainly dacite composition. On the basis of the geological data two episodes of eruption of pyroclastic material are allocated which on time follow one after another, though there are no data on a time interval between them.

2.2.3. Academy Nauk Caldera. It was formed near the southern border of Odnobokaya caldera in Upper Pleystocene (fig. 4, *G*). Andesite and dacite lavas compose the volcano. Pumice tuff connected with explosive eruption on this volcano and meeting only on its southern slope. The tuff has rather homogeneous rhyodacite composition.

Concerning an origin of the Academy Nauk caldera is not present unequivocal opinion, as the significant volumes of pyroclastic deposits connected to its formation are not found out. It was marked by previous researchers that collaps of caldera has taken place as a result of outflow of melts from upper-crust magmatic chamber (Volcanic canter, 1980). A new geological material and its judgement from positions of event of 1996 allow us to offer other variant. We assume, that the eruption of pumice tuff O2-2 in a zone of latitudinal fault has taken place in later time, when the Academy Nauk volcano was already generated. The inflow of high-temperature melt in upper-crust magmatic chamber could cause synchronous eruption on a volcano, its subsequent destruction and collapse of caldera (fig. 4, *H*). The all eruptions of basaltic tephra since Upper Pleistocene were occured in the northern sector of caldera in a zone of latitudinal fault (Leonov, 1998). They could provoke the explosion of silicic pyroclastics (Sparks and Sigurdsson, 1977). So, the eruption of basaltic tephra anticipated formation of pumice tuff O2-2. The silicic melt in upper crust magmatic chamber to this time was, probably, sufficiently freesen, as promoted of inflow of basalts on a surface.

The phisico-chemical conditions of melt crystallization are designed recently (Grib and Leonov, 2004b). It is shown, that the melt in upper crust chamber on preeruption stage was sufficiently evolutionary with formation of gradients on structure, temperature and contents of volatile for each caldera. Disequilibrium assemblage of catastrophic eruptions products mineral phases, occurrence in pumice tuff sections of basaltic scoria layers, feature of 1996 eruption in Karimskoye Lake, specify existence in interior of structure cooperation magmatic chambers located on different depth. We are made an estimation of the minimal depth of an upper crust chamber roof (or system of the chambers) - 5-7 km (1.2-2.2 kbar). The presence of high-aluminum hornblende (pargasite) in silicic pyroclastics specifies existence in the basis of upper crust magmatic system on depth of 11-12 km (3.6 kbar) of gabbro-diorite layer or sill. Similarity of isotope labels Sr and Nd in volcanic rocks from basalts up to rhyodacite, linear trends in composition of minerals testify to genetic connection of these melts. The presence in pyroclastics of whole crystalline clusters (cumulates) is a parameter of a conducting role of crystal fractionation in occurrence of a wide spectrum of this area rocks. The telescoped structure of Karimsky volcanic center southern sector calderas, inherited of magma-pass systems and cyclic character of volcanic activity are connected with tectono-magmatic activization in a latitudinal fault zone.

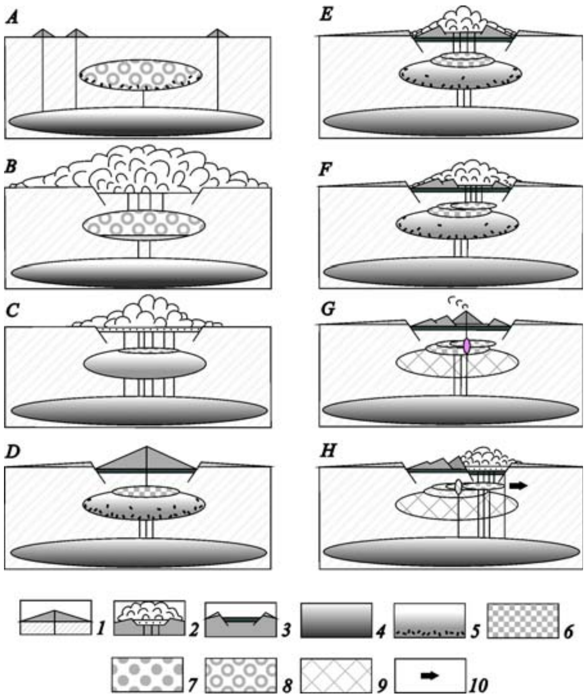

Figure 4. Schematic diagram showing the pattern of magma withdrawal from magma chambers of southern part of the Karymsky volcanic centre as the eruption progressed. The periods: *A* - precaldera (~200 thousand years ago), *B* - formation of the Polovinka caldera and tuffs P1 and P2 (~180-150 thousand years ago), *C* – formation of the upper part of cinder agglomerates, connected with Polovinka caldera (P3), *D* - formation of the Odnoboky volcano (~110 thousand years ago), *E* - formation of the first caldera on the Odnoboky volcano and tuffs O1 (~80 thousand years ago), *F* – formation of the second caldera on the Odnoboky volcano and tuffs O2 (~60 thousand years ago), *G* - formation of the Academia Nauk volcano (~40 thousand years ago), *H* - formation of the Academia Nauk caldera (~30 thousand years ago). *1* - volcano and its conduit; *2* - caldera during its formation, lake, filling it and eruptions occurring from lake are shown; *3* - caldera after its formation, the lacustrine deposits, filling it, and tuffs and ignimbrites on boards are shown; *4-8* – magma chambers of different structure: *4* - basaltic (lowercrast chambers), *5* - basaltic with

fractionation of crystals (uppercrust chambers), *6* - andesitic, *7* - dacitic, *8* - rhyolitic; *9* - cooled chambers; *10* - direction of supposed lateral displacement of the chambers.

3. STRUCTURES OF THE BASEMENT AND CONDITIONS OF LOCATION OF HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN GEOTHERMAL AREAS OF EASTERN KAMCHATKA

In eastern Kamchatka Pliocene-Quaternary volcanic belt is superimposed on a large trough of earth's crust (fig. 5).

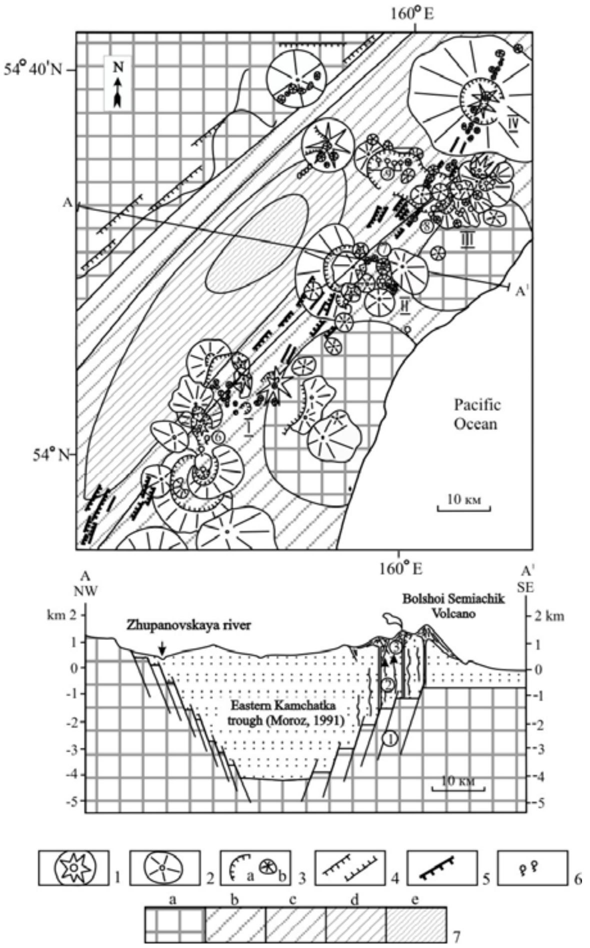

Figure 5. Map and section showing of the volcanoes, high-temperature hydrothermal systems and basement troughs in the central part of Eastern Kamchatka. 1 - Late-Pleistocene volcanoes; 2 – Middle-Upper-Pleistocene volcanoes; 3 - calderas (a), scoria cones (b); 4 - main north-east faults; 5 – Late-Pleistocene –Holocene fissures and normal faults; 6 - thermal springs; 7 – depth of the basement rock complex, km (Moroz, 1991): a - <1; b – 1-2; c – 2-3; d – 3-4; e - >4. Numbers – volcanic centers: I – Karimsky, II – Bolshoi-Semiachic, III – Uzon-Geyzerny, IV – Krasheninnikov. Numbers in the circles marks the high-temperature hydrothermal systems: Karymskaya (6), Semyachikskaya (7), Geysernaya (8) and Uzon (9) (Leonov, 2000). A-A′ - the line of the cross-section. The lower portion of the figure shows the schematic cross-section along the line A-A′. Hatched area is basement rock complex. Numbers in the circles mark the zones: 1 - troughs boundary faults - deep structural traps for the magma and hydrothermal fluids, 2 - ascent magma and hydrothermal fluids, 3 - Late-Pleistocene - Holocene fissures and normal faults near the surface.

The trough is elongated almost to 300 km northeastwards; its width varies from 30 up to 50 km. Within the boundary of this trough the roof of Cretaceous basement is submerged to 3-4 km and the roof of crystalline basement - to 6-7 km (Moroz, 1991). The northwestern boundary of the trough is distinctly expressed in relief – simultaneously this is the southeastern boundary of the Eastern ridge of Kamchatka within the range of which rocks of Pre-Cenozoic basement are outcropped.

Southeastern boundary of the trough is not manifested in the relief. It is overlapped with volcanic-sedimentary rocks mainly of late Quaternary age widely developed in the central section of eastern Kamchatka. The largest volcanic centers with which connected caldera's complexes and wide pumice and ignimbrite fields are located within this line. High-temperature hydrothermal systems (Karymskaya, Semyachikskaya, Geysernaya and Uzon) are connected with three of these centers.

Location of thermal manifestations within the bounds of hydrothermal systems here is influenced by large structures occupying intersecting position toward fractures bounding the trough. In the Karymsky center – this is the fracture of longitudinal strike. In the Bolshoy-Semyachik center – one of northwestern strike and in the Uzon-Geyserny center – the sub latitudinal fracture. Sites of intersection of these fractures with abyssal permeable zones of northeastern strike are the places where the most intensive volcanic and hydrothermal activity is concentrated. Thermal manifestations of known hydrothermal systems located in these sites in most cases are elongated lengthwise intersecting fractures.

The conducted analysis (Leonov, 2000) has shown that large troughs of the basement and faults bounding them are the important factor, which almost in all cases determines the position of high-temperature hydrothermal systems in Kamchatka. Being located within volcanic belts having common north-north-eastern strike high-temperature hydrothermal systems are confined only to such areas where these belts are superimposed to the basement troughs. The last ones in most cases have northeastern strike and are intersected by volcanic belts at acute angle. Hydrothermal systems are arranged in groups and mainly confined to zones of faults bounding troughs in the east and southeast. Generalized views of structural conditions, which result in forming high-temperature hydrothermal systems in Eastern Kamchatka, are given in the fig. 6.

Apparently deep fractures bounding the basement troughs determine not only total localization of hydrothermal systems but also some regularities of range of thermal manifestations related to these systems. As it was shown above most high-temperature hydrothermal systems of Eastern Kamchatka are connected with complex volcanic structures formed in Middle-Upper-Quaternary period. There are many different volcanic edifices, extrusive domes of dacite and rhyolite composition belonging to these volcanic structures. Thermal manifestations are usually disclosed within the boundary of these structures as well as near there foots. Such structures are elongated in some direction and a zone of weakness (a zone of increased permeability) along which magma and hydrothermal fluids rise up can be determined according to location of eruption centers. Usually these zones are located along deep faults bounding troughs, but sometimes they trace minor faults occupying intersecting position towards abyssal bounds. In such cases thermal manifestations are located along intersecting faults and they can be disclosed at considerable distance from volcanic structures (Leonov, 2000).

Generalizing the above data we can make the conclusion that in all cases the position of high-temperature hydrothermal systems of Eastern Kamchatka is determined by sites of intersection. Geothermal areas (groups of hydrothermal systems) are located at sites of intersection of volcanic belts and deep troughs of the basement (hydrothermal systems are elongated in chains lengthwise zones of faults bounding troughs). The sites of faults intersection, which bounding troughs, and minor faults occupying intersecting position (thermal manifestations disclosed within the boundary of hydrothermal systems are usually located along intersecting faults) are determined the positions of hydrothermal systems (fig. 6). Inclination of faults bounding troughs determines the direction of lateral displacement of therms, which can disclose themselves at considerable distance aside volcanic structures with which they are connected.

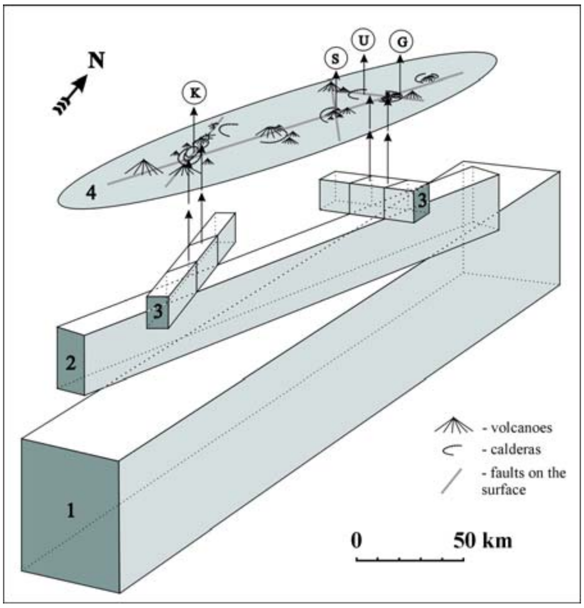

Figure 6. Simplified model of the structural levels where fluid-magma flows in the earth crust of Kamchatka are located. 1-3 – fault zones (the pass for magma and fluids) located in the lower part of the earth crust (1), in the middle part ones (2) and in the upper part ones (3); 4 – surface expression of crustal structures – volcanic zone where located volcanoes, calderas and high-temperature hydrothermal systems: K-Karimskaya, S- Semyachinskaya, U– Uzon and G - Geysernaya (Sugrobov and Yanovsky, 1991). The arrows are places of magma and fluids uplift.

4. CONCLUSION

The system of calderas is forming extensive area of subsidence, extended along the axis of the Karymsky volcanic center – Karymsky-Semyachic caldera depression. The ages of calderas are 0.18-0.15 Ma. The powerful eruptions of pyroclastic accompanied their formation, therefore the extensive fields on periphery of the center have appeared are covered by dacite and rhyodacite tuff and ignimbrites. The volume of erupted pyroclastic is 280 km^3 or about 100 $км^3$ of magma.

The objects of this paper are, mainly, calderas of southern sector of the Karimsky volcanic center. There are three main calderas in this sector: Polovinka, Odnobokaya, Akademy Nauk. It is shown, that the melt in upper crust chambers on preeruption stage was sufficiently evolutionary with formation of gradients on structure, temperature and contents of volatile for each caldera. Disequilibrium assemblage of catastrophic eruptions products mineral phases, occurrence in pumice tuff sections of basaltic scoria layers, feature of 1996 eruption in Karimskoye Lake, specify existence in interior of structure cooperation magmatic chambers located on different depth.

Structural conditions of location Eastern Kamchatka's high-temperature hydrothermal systems and Karimskaya hydrothermal system are analysed. It is shown that the last ones are located within the boundary of Pliocene-Quaternary volcanic belt and confined to areas where this belt are superimposed on deep troughs of the basement. The main structural elements determining the position of high-temperature hydrothermal systems are faults, which bounds such troughs. Hydrothermal systems are located in such places where faults bounding troughs of the basement intersect complicating faults having transversal or intersecting position. Usually in such sites stable and long-existing zones of earth's crust penetrativeness are formed. Magma and hydrothermal fluids are constantly rising along them and complex volcanic structures are formed on the surface.

The data given in this work allow to suppose that only long-existing zones of earth's crust permeability occurring at knots of intersection of deep and surface fault zones can make conditions for formation of powerful hydrothermal systems. Large and complexly constructed volcanoes can be formed in such zones and calderas can occur but they also can be absent. The main condition is presence of the permeable zone: a stable, continuously developing and penetrating to great depth. Apparently faults bounding basement troughs described herein are related to these very structures.

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REFERENCES

Belousov, A.B., Belousova, M.G., and Muravyov, Y.D.: Holocene Eruption in the Academii Nauk caldera and Age of Karymsky Volcano (Kamchatka), *Doklady* of Russian Academy of Nauk, **354**, (1997), 648-652 (in Russian).

Braitseva, O.A., Melekestsev, I.V., Ponomareva, V.V., Sulerzhitsky, L.D., and Litasova, S.N.: Age of Active Volcanos of the Kurile-Kamchatka Region, *Volcanology and Seismology*, **4/5**, (1994), 5-32.

Fedotov, S.A.: Study and Mechanism of the Simultaneous 1996 Karymsky Volcano and Academii Nauk Caldera Eruptions in Kamchatka, *Volcanology and Seismology*, **19**, (1998), 525-566.

Fedotov, S.A., Ozerov, A. Yu., Maguskin, M.A., Ivanov, V.V., Karpov, G.A., Leonov, V.L., Dvigalo, V.N., Grib, Ye.N., Andreev, V.I., Lupikina, Ye.G., Ovsyannikov, A.A., Bydnikov, V.A., Bakhtiarov, V.F., and Levin, V.Ye.: Eruption of the Karymsky Volcano in 1998-2000, Connected with it Seismic, Geodynamic and Postvolcanic Processes, their Influence on an Environment, *Catastrophic Processes and their Influence on Natural Environment*, Regional Public Organization of the Scientists on Problems of Applied Geophysics, Moskow, (2002) (in Russian).

Grib, Ye.N.: Petrology of Ejecta Produced by the Academii Nauk Caldera Eruption of January 2-3, 1996, *Volcanology and Seismology*, **19**, (1998), 605-635.

Grib, Ye.N., and Leonov, V.L.: Various Ways of Evolution Uppercrast Magma Chambers of the Calderas Complexes of East Kamchatka. Part I. A Structure of the Pyroclastic Flows, Comparative Mineralogy, *Volcanology and Seismology*, **4**, (2001a), 3-17 (in Russian).

Grib, Ye.N., and Leonov, V.L.: Various Ways of Evolution Uppercrast Magma Chambers of the Calderas Complexes of East Kamchatka. Part II. Physics-Chemical Conditions of Crystallisation of Ignimbrite-Forming Melts, *Volcanology and Seismology*, **4**, (2001b), 18-28 (in Russian).

Grib, Ye.N., and Leonov, V.L.: Evolution of the Southern Sector Karymsky Volcanic Center Calderas Magmatic Chambers. Part 1. Geologic Setting, Structure and Composition of Pyroclastic Flows, *Volcanology and Seismology*, **4**, (2004a), 18-28 (in Russian).

Grib, Ye.N., and Leonov, V.L.: Evolution of the Southern Sector Karymsky Volcanic Center Calderas Magmatic Chambers. Part II. Physics-Chemical Conditions of Crystallisation of Ignimbrite-Forming Melts, *Volcanology and Seismology*, **4**, (2004b), 29-45 (in Russian).

Ivanov, B.V.: Ignimbrites of Area of Karymsky Group Volcanos, *Volcanic facies of Kamchatka*, Science, Moscow (1969) (in Russian).

Ivanov, B.V.: Eruption of the Karymsky volcano in 1962-1965 гг. and Volcanos of the Karymsky Group, Science, Moscow (1970) (in Russian).

Kozhemyaka, N.N.: Quaternary Polygenic Volcanos of Kamchatka: Scales of the Volcanism, Balance of Products, Dynamics of Intensity and Efficiency in Separate Types of Constructions, Volcanic Zones and on Region as a Whole, *Volcanology and Seismology*, **5**, (2001), 3-21.

Leonov, V.L.: Ground Surface Breaks Produced by an Earthquake and Volcanic Eruptions in the Karymsky Volcanic Centre on January 1-2, 1996, *Volcanology and Seismology*, **19**, (1998), 655-674.

Leonov, V.L.: Regional Structural Position of High Temperature Hydrothermal Systems of Kamchatka, *Proceedings*, World Geothermal Congress, Japan (2000).

Leonov, V.L., Grib Ye.N., and Kartasheva L.A.: Ignimbrite Differentiation and Estimation of the Volume of Magma Ejected during Ignimbrite Forming Eruptions in East Kamchatka, *Volcanology and Seismology*, **22**, (2001), 469-491.

Leonov, V.L., and Ivanov, V.V.: Earthquakes at the Karymskiy Volcanic Center and their Relation to Tectonics, *Volcanology and Seismology*, **16**, (1994), 115-131.

Masurenkov, Yu.P.: The Volcanic Centre, as a Projection of Endogenic Dynamic System, *The Volcanic centre: a structure, dynamics, properties (the Karymsky structure)*, Science, Moskow (1980) (in Russian).

Masurenkov, Yu.P.: Tectonic Position and General History and Evolution of Eastern Kamchatka Volcanos, *Active Volcanos of Kamchatka*, **2,** (1991), 8-13 (in Russian).

Moroz, Yu.F.: Structure of the Sedimentary-Volcanic Cover of the Kamchatka according to Geophysical Data, *Pacific Geology*, 1, (1991) 59-67 (in Russian).

Selyangin, O.B.: The Karymsky Group of Volcanos. Volcanos Karymsky and Maly Semyachik, *Volcanos and geothermal systems of Kamchatka* (Materials of IV USSR Volcanol. Conference), Petropavlovsk-Kamchatsky (1974) (in Russian).

Selyangin, O.B.: Evolution of the Caldera Complex, Rhythm and Orientation of Volcanic Process in Karymsky Group of Volcanos, Kamchatka, *Volcanism and Geodynamics*, Science, Moskow (1977) (in Russian).

Selyangin, O.B.: Petrogenesis of Basalt - Dacitic Series in Connection with Evolution of Volcano-Structures, Science, Moskow (1987) (in Russian).

Sugrobov, V.M., and Yanovsky, F.A.: Geothermal Field of Kamchatka, Heat Losses by Volcanoes and Hydrotherms, *Active Volcanoes of Kamchatka*, (1991).

Sparks, S.R., and Sigurdsson H.: Magma mixing: a mechanism for triggering acid explosive eruption, *Nature*, **267**, (1977), 315-318.

Vlodavets, V.I.: Volcanos of the Karymsky Group, *Works of the Kamchatka Volcanostation,* **3**, (1947), 3-48.

Volcanic Centre: a Structure, Dynamics, Properties (Karymsky Structure), Ed. Masurenkov, Yu.P. Science, Moskow (1980) (in Russian).

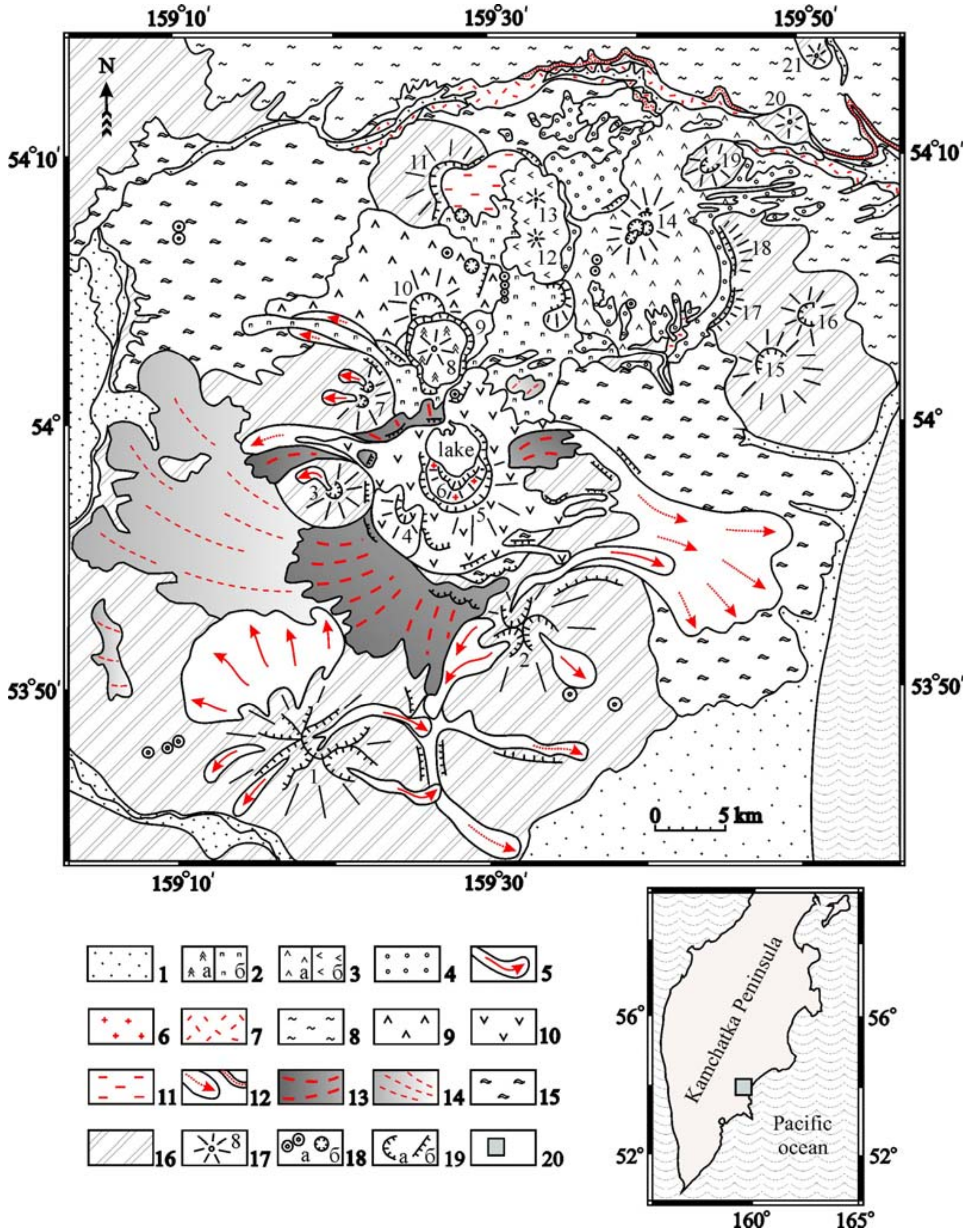

Figure 1: A schematic geological map of the Karymsky volcanic centre. 1 - alluvial, sea and lacustrine deposits (Q_4); 2 - (a) andesitic lavas and pyroclastic, Karymsky volcano (Q_4); (б) - pumice and pyroclastic connected with Karymsky caldera (Q_4); 3 - (a) - basalts, andesite-basalts, them tuffs and tuff-breccias, Maly Semiachik volcano (Q_4); (б) - andesitic lavas, Sukhoy and Stupenchaty Bastion volcanoes (Q_3^4-Q_4); 4 - agglomerates, tuffs, tuff-breccias, connected with a Maly Semiachik caldera (Q_3^4); 5 – glacial deposits (Q_3^4); 6 – andesitic and dacitic lavas, Academy Nauk volcano (Q_3^4); 7 – pumice tuffs and ignimbrites, source is not established (Q_3^4); 8 - ignimbrites connected with Uson-Geysernaya depression (Q_3^4); 9 – andesite-basaltic and andesitic lavas, Dvor volcano (Q_3); 10 – basaltic, andesite-basaltic and andesitic lavas, pumice deposits, Odnoboky volcano (Q_3); 11 - complex innercalderas volcano-sedimentary and lacustrine deposits (Q_3^1); 12 - glacial deposits (Q_2^3); 13 -scoria, dacitic and andesic ignimbrites connected with Polovinka caldera (Q_2^3); 14 – pumice tuffs and rhyolitic ignimbrites connected with Polovinka caldera (Q_2^3); 15 – dacitic ignimbrites connected with Stena-Soboliny calderas (Q_2^3); 16 - lava, pyroclastic, volcano-sedimentary deposits generated on a precaldera stage (N_2-Q_1); 17 - volcanos (1 – Zhupanovsky Vostriaky, 2 – Ditmara, 3 - Krayny, 4 - Belyankina, 5 - Odnoboky, 6 – Academy Nauk, 7 - Razlaty, 8 - Karymsky, 9 – Pra-Karymsky, 10 -Dvor, 11 - Sobolyny, 12 - Sykhoy, 13 – Stupenchaty Bastion, 14 – Maly Semiachic, 15 – Pribrezhny Uzhny, 16 – Pribrezhny Severny, 17 -Stena, 18 - Massivny, 19 - Berezovy, 20 - Dvukhgorby, 21 - Nezametny); 18 - (a) - cinder cones, extrusive domes; (б) - maars; 19 - (a) - erosive circuses, craters of volcanoes, calderas; (б) - scarps of large breakages; 20 - area shown on a map (on a fragment).