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REGIONAL STRUCTURAL POSITIONS OF HIGH TEMPERATURE HYDROTHERMAL SYSTEMS OF KAMCHATKA

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ABSTRACT

Structural conditions of locations with high-temperature hydrothermal systems in Kamchatka are analyzed herein. It is shown that hydrothermal systems are located within the boundary of Pliocene-Quaternary volcanic belts and confined to areas where these belts are superimposed on deep troughs of the basement. The main structural elements determining the position of high-temperature hydrothermal systems are faults that bound such troughs. These faults are rarely exposed on the surface, they are usually overlapped with a powerful sedimentary -volcanogene cover, but systems of recent (mainly late Pleistocene-Holocene) fractures stretching along the abyssal boundary are formed above them in this cover. Hydrothermal systems are located in places where faults bounding troughs of the basement intersect complicating faults having transversal or intersecting position. Stable and long-existing zones of permeability are formed in these sites. Magma and hydrothermal fluids are constantly rising along them and complex volcanic structures differing in polyorifice volcanicity and presence of extrusive domes of dacite and rhyolite composition are formed on the surface. Thermal manifestations are usually located within and the boundary of such structures and around them. It is shown that lateral displacement of hydrothermal systems relative to these structures is connected with inclination of faults bounding troughs of the basement. Sometimes it is directed to the side of rise of fault planes.

1. INTRODUCTION

About 150 groups of thermal springs are known in Kamchatka but only a few of them have surface water temperatures reaching boiling point. Such springs, including geysers, are usually viewed as surface manifestations of high-temperature systems (Table 1). These systems are confined to volcanic belts composed by fused foots of volcanoes basically of Pliocene-Quaternary age (Figure 1). Two such belts are distinguished: Eastern and Middle (Central). They are elongated along the peninsula in a north-north-eastern direction, are about 700 km long each, and up to 100-130 km wide. Hydrothermal systems as well as active volcanoes of Kamchatka are mainly confined to the eastern volcanic belt.

Eight of eleven high-temperature hydrothermal systems are located within its boundary along with 28 of 29 active volcanoes. Two high-temperature hydrothermal systems and only one active volcano are located within the middle (Central) volcanic belt boundary. Hydrothermal systems are spread irregularly, united in groups located at a distance of 160-200 km from each other.

The geological structure of most hydrothermal systems in Kamchatka has been studied in detail. There are many works containing detailed geological maps, geothermal area sections, data on the deep structure received on the basis of geophysical and drilling works and the like. (Vakin et al., 1970; Volcanism, the Hydrothermal Process and Ore-formation, 1974; Hydrothermal Systems…, 1976; Belousov, 1978; Leonov, 1989; Kiryukhin et al., 1991; etc.).

From the very beginning of hydrothermal activity study a close connection with outcrops of rocks of acid composition has been noted: extrusions of dacites, rhyolites, fields with widespread pumices and ignimbrites. It was noted that many hydrothermal systems are located within the boundary of volcanic-tectonic depressions, calderas and grabens. The connection between high-temperature hydrothermal systems of Kamchatka and long-living volcanic centers was studied.

Nevertheless there is a great deal of uncertainly in the research of conditions of geological-structural localization of hydrothermal systems. Hydrothermal systems do not appear everywhere where calderas, acid volcanism manifestations and long-living volcanic centers are located. On the contrary, in many places they are found in areas where there are none of these phenomena. Determination of conditions of geological-structural localization of hydrothermal systems is important for developing a geothermal exploration strategy. The cost of this work can be considerably decreased if common regularities of geothermal area locations can be determined and conditions of deep geothermal fluid flow within them understood.

The author has studied the geological structure of Kamchatka hydrothermal systems for many years. He composed detailed geological maps for all areas where geysers, boiling springs or powerful jets of superheated and saturated steam are discharged to the surface (Leonov, 1981; 1989; 1991; et al.,). A conclusion of this body of work is that high-temperature hydrothermal systems of Kamchatka are connected not so much with local peculiarities of geological structure of this earth's crust areas but with processes taking place over large areas up to 200-250 km long in the volcanic belt. Hydrothermal activity focuses itself in the continuous processes of tectonic-magmatic activity which manifest themselves most brightly in the areas of large faults of north-eastern strike intersecting volcanic belts at the acute angle (Leonov, 1991).

The author hereby shows that large troughs of the earth's crust, which are determined according to regional geophysical data (Zubin, 1980; Moroz, 1991), play a definite part in localization of high-temperature hydrothermal systems of Kamchatka.

2. STRUCTURES OF THE BASEMENT AND CONDITIONS OF LOCATION OF HIGH-TEMPERATURE HIDROTHERMAL SYSTEMS IN GEOTHERMAL AREAS OF KAMCHATKA

Volcanic belts of Kamchatka are superimposed on the heterogeneous basement. Basic elements of this structure can be seen in the Figure 2 where surface relief identified with Pre-Cenozoic (Upper Cretaceous) complex.

T South Eastern-Kamchatsky volcanic belt is superimposed on the South-Kamchatsky anticlinorium and troughs complicating it. Further north-eastwards it intersects Eastern-Kamchatsky trough and Eastern-Kamchatsky anticlinorium and ends with volcanoes located within the Central-Kamchatsky trough boundary. The Middle (Central) volcanic belt is superimposed on Kamchatsko-Koryaksky anticlinorium and in its central part – on Palansky trough. Volcanism is weakly manifested in places where volcanic belts are superimposed on raised areas of the basement compared to places where they are superimposed on troughs. All the largest and most complex volcanoes and volcanic centers of Kamchatka are located in the basement troughs. High-temperature hydrothermal systems are also confined mainly to such areas where volcanic belts intersect troughs and are concentrated on their bounds (See Fig.2).

The positions of further hydrothermal systems are viewed according to the areas of their manifestations, separately in South, Eastern and Middle Kamchatka.

2.1 South Kamchatka

The trough located here is 30-40 km wide and approximately 220-240 km long. Two distinct areas are determined within the boundary of the trough: the south area where the trough has north-eastern strike and the northern area where the trough strike is close to meridional. Both areas are about 100 km long. Within the boundary of this trough the Cretaceous basement roof is submerged to a depth of 3-3,5 km while the crystalline basement roof occurs at a depth of more than 6 km (Zubin, 1980).

Figure 3 shows in more detail the position volcanoes and thermal manifestations occupy with regard to the extreme southern Kamchatka trough. In this area two high-temperature hydrothermal systems – Pauzhetskaya and Koshelevskaya are located. Numerous thermal manifestations relating to these hydrothermal systems are confined to two complex volcanic structures – the Kambalny and Koshelevsky ridges. Each of these ridges consists of several large and many small volcanoes and volcanic domes that are closely spaced and stretched along definite directions: meridional on the Kambalny ridge and latitudinal on the Koshelevsky ridge. Thermal manifestations are confined to apical parts of the ridges, where steam jets are most common, as well as to the foot of the ridges, where different thermal springs are located. The greatest thermal manifestations on the above ridges are located near their western or north-western foot.

Also there are two groups of young fractures: of north-eastern strike (mainly of middle-Pleistocene age) and of north-north-eastern strike (mainly late Pleistocene-Holocene age). Both these groups of fractures were described in detail previously (Leonov, 1989). The youngest fractures, which are of late Pleistocene-Holocene age, form the extended belt traced through the Koshelevsky and Kambalny ridges occupying positions close to the north-western boundary of the trough.

The section of another district confined to the northern part of the Southern Kamchatka is given in the Figure 4. Two high-temperature hydrothermal systems: Mutnovskaya and Bolshe-Bannaya are located here (See Table 1). Numerous small volcanoes and extrusive domes composed of lavas of dacite and rhyolite composition were formed here in the knots of intersection of the trough boundaries and the fractures crossing it. Near the Mutnovsky volcano they form a meridional series stretching 20 km northwards (Kirsanov, 1976). Young (mainly late Pleistocene-Holocene) fractures of north-north-eastern strike are widely developed within the boundary of this zone. The network of these fractures forms the wide graben-like structure. This structure is about 5 km wide and 25 km long (Leonov, 1989). In the area under study most of the thermal manifestations are concentrated within the boundary of this meridional zone but some thermal manifestations are located far away from it, in river valleys located in the east and north-east. All these thermal manifestations are considered as parts of the integrated large high-temperature hydrothermal system – Mutnovskaya.

Bolshe-Bannaya hydrothermal system is also located on the edge of the trough distinguished according to geophysical data (Figure 1,2). It is also connected with young fractures of north-north-eastern strike manifested in the vicinity. It can be seen that structural position of all high-temperature hydrothermal systems is monotypic in this area.

2.2 Eastern Kamchatka

In Eastern Kamchatka a Pliocene-Quaternary volcanic belt is also superimposed on a large trough of the earth’s crust (Fig.2,5). The trough is elongated almost 300 km north-eastwards, varying in width from 30 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 north-western boundary of the trough is distinctly expressed in relief – simultaneously this is the south-eastern boundary of the Eastern ridge of Kamchatka within the range of which rocks of Pre-Cenozoic basement are outcropped. The south-eastern boundary of the trough is not manifested in the relief. It is overlapped with volcanogene rocks mainly of late Quaternary age widely developed in the central section of Eastern Kamchatka. Within the field of development of these rocks only young late Pleistocene-Holocene fractures are distinctly manifested. Here, as well as in South Kamchatka, these fractures have north-north-eastern strike and form several groups located echelon-like with respect to each other and in the whole are elongated into the line of north-eastern strike. This line approximately coincides with the south-eastern boundary of the trough. The largest volcanic centers, with associated connected caldera complexes and wide pumice and ignimbrite fields, are located within this line. High-temperature hydrothermal systems (Karymskaya, Semyachikskaya, Geysernaya and Uzon – See the Table) are connected with three of these centers.

The location of thermal manifestations within the bounds of hydrothermal systems here as well as in South Kamchatka is influenced by large structures occupying intersecting positions toward fractures bounding the trough. In Karymsky center this is the fracture of meridional strike. In Bolshe-Semyachiksky center it is of north-western strike and in Uzon-Geyserny center it is the sublatitudinal fracture. Sites of intersection of these fractures with abyssal permeable zones of north-eastern strike are the places where the most intensive volcanic and hydrothermal activity is concentrated. Thermal manifestations of known hydrothermal systems located in these sites are in most cases elongated lengthwise, intersecting fractures.

2.3 Middle Kamchatka

The middle (Central) volcanic belt, as well as the Eastern belt, stretches along the peninsula in a north-north-eastwards direction and is superimposed on different structures of the basement. The main structures distinguished here are Kamchatsko-Koryaksky anticlinorium and Palansky trough (See Fig.2). The latter disintegrates into two parts and the volcanic belt is superimposed on the southern part of the trough. This part is 200-250 km long and between 70 and 100 km wide. The Cretaceous basement roof is submerged to 2-3 km within the bounds of the trough (Moroz, 1991).

Two high-temperature hydrothermal systems: Apapelskaya and Kireunskaya are distinguished in Middle Kamchatka. Their power is considerably less than those of hydrothermal systems in the Eastern volcanic belt (See Table 1). They are located not far from each other, in the center of the area where the volcanic belt intersects the south-eastern boundary of the Palansky trough. The location of Quaternary volcanoes and young fractures in this area is shown in the Figures 1, 6. The largest and most differentiated volcanoes are confined to the south-eastern boundary of Palansky trough. The extended zone of newest fractures is located along this very boundary. This zone is 20-25 km wide and totally strikes north-eastward. Fractures are mainly of late Quaternary age and chains of scoria cones of late Pleistocene-Holocene age are located along some of them.

Both hydrothermal systems located here are connected with the above-described zone of fractures striking north-eastwards. Apapelskaya system is confined to fractures bounding this zone in the south-east and here distribution of thermal manifestations is controlled by sites of intersection of north-eastern and latitudinal fractures. The latter form a graben. The Kireunskaya system is located in the same zone 60 km further north-eastwards near the foot of the complex volcanic massive Alney-Chashakondzha. This massive in many ways resembles long-living volcanic centers of South and Eastern Kamchatka. Its formation took place mainly in middle-upper-Quaternary period. Intrusion of large extrusive domes of dacite and rhyolite composition occurred on its slopes in late Pleistocene. Thermal manifestations confined to Kireunskaya hydrothermal system are located east of the Alney-Chashakondzha massive in grabens laid lengthwise in large intersecting fractures with latitudinal and north-western strike.

3. COMMON REGULARITIES OF STRUCTURAL LOCALIZATION OF HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN KAMCHATKA

The analysis conducted has shown that large troughs of the basement and faults bounding them are the important factors which in almost all cases determine 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 to those areas where the belts are superimposed on basement troughs. The troughs in most cases have north-eastern strike and are intersected by volcanic belts at an acute angle. Hydrothermal systems are arranged in groups and mainly confined to zones of faults bounding troughs in the east and south-east. In the extreme south of the peninsula they bound troughs in the north-west. A generalized view of structural conditions that result in forming high-temperature hydrothermal systems in Kamchatka is given in the Figure 7.

Apparently deep fractures bounding the basement troughs determine not only total localization of hydrothermal systems but also some regularities of the range of thermal manifestations related to these systems. As was shown above, most high-temperature hydrothermal systems of Kamchatka are connected with complex volcanic structures formed in the middle-upper-Quaternary period, and differ in polyorifice volcanicity and presence of extrusive domes of dacite and rhyolite composition. Thermal manifestations are usually disclosed within the boundary of these structures as well as near the foot. Most often 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 positions towards abyssal bounds. In such cases thermal manifestations are located along intersecting faults and can occur at considerable distance from volcanic structures. In the extreme south of the peninsula where hydrothermal systems are connected with faults bounding the trough in the north-west, thermal manifestations are displaced relatively near volcanic structures westwards and north-westwards. In other territories, where hydrothermal systems are located on faults bounding troughs in the east and south-east, thermal manifestations are displaced eastwards. Apparently such peculiarity of distribution of thermal manifestations is connected with inclination of faults bounding troughs. After ascending inclined zones of faults hydrothermal solutions are displaced in the direction of their rise (See Fig.7).

Generalizing the above data we can make the conclusion that in all cases the position of high-temperature hydrothermal systems of 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 along zones of faults bounding troughs). The position of each discrete hydrothermal system is determined by sites of intersection of faults bounding troughs and minor faults occupying intersecting positions (thermal manifestations disclosed within the boundary of hydrothermal systems are usually located along intersecting faults). 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.

In the conclusion we would like to pay attention to the fact that the conditions under which high-temperature hydrothermal systems of Kamchatka are disclosed do not suggest connections between hydrothermal systems and calderas. Seven calderas formed in upper Pleistocene and Holocene are distinguished in Southern Kamchatka (Kurilskaya, Ilyinskaya, Zheltovskaya, Prizrak, Ksudach, Gorelaya and Opala) and none of them are connected with large hydrothermal systems. Moderate thermal manifestations are found only in Ksudach and Ilyinskaya calderas. Ten middle-upper Pleistocene and Holocene calderas are located in Eastern Kamchatka. Hydrothermal systems are connected only with Akademii Nauk and Karymskaya calderas and Uzon-Geysernaya depression. In the Bolshe-Semyachiksky centre thermal manifestations are located near the caldera but beyond its border-line. Inside this caldera as well as within Stena, Soboliny and Krasheninnikov calderas thermal manifestations are absent. Nine calderas that are connected mainly with basalt volcanoes are located in the Middle Kamchatka. Hydrothermal systems are also absent in them.

Another frequently used thesis that hydrothermal activity is connected with near-surface acid magmatic chambers should be specified. From the above examples it can already be seen that the formation of calderas, which is apparently always connected with near-surface chambers, is far from always accompanied by formation of large hydrothermal systems. Another demonstrative example is Dikiy Greben volcano located in South Kamchatka. This is the largest volcano composed by acid volcanites in the Kuril-Kamchatka insular arch. The volcano is of late Holocene age and there are many reasons to consider that an acid magmatic chamber is located, not too deeply, in its bowels (Bindeman, 1992). At the same time there are no thermal manifestations on this volcano or in its vicinity.

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

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Table 1. High temperature hydrothermal systems of Kamchatka (after Sugrobov,V.M. and Yanovsky,F.A.,1991; Sugrobov,V.M.,1995)

Nos. in fig.1	Hydrothermal systems	Natural heat capacity, Mwt of heat	State of heat carrier at the surface
1	Koshelevskaya	314	Overheated and saturated steam
2	Pauzhetka	104,6	Saturated steam, water (boiling)
3	Khodutkinskaya	42	Springs 88°C
4	Mutnovskaya	129 (522)*	Overheated and saturated steam
5	Bolshe-Bannaya	79	Water (boiling)
6	Karymskaya	146	Water (boiling)
7	Semyachikskaya	314	Saturated steam
8	Geysernaya	321,5	Saturated steam, water (boiling)
9	Uzon	268	Saturated steam, water (boiling)
10	Apapelskaya	16	Water (boiling)
11	Kireunskaya	21,8	Water (boiling)

Note: * With attracting of the heat capacity of the Mutnovsky volcano North crater.

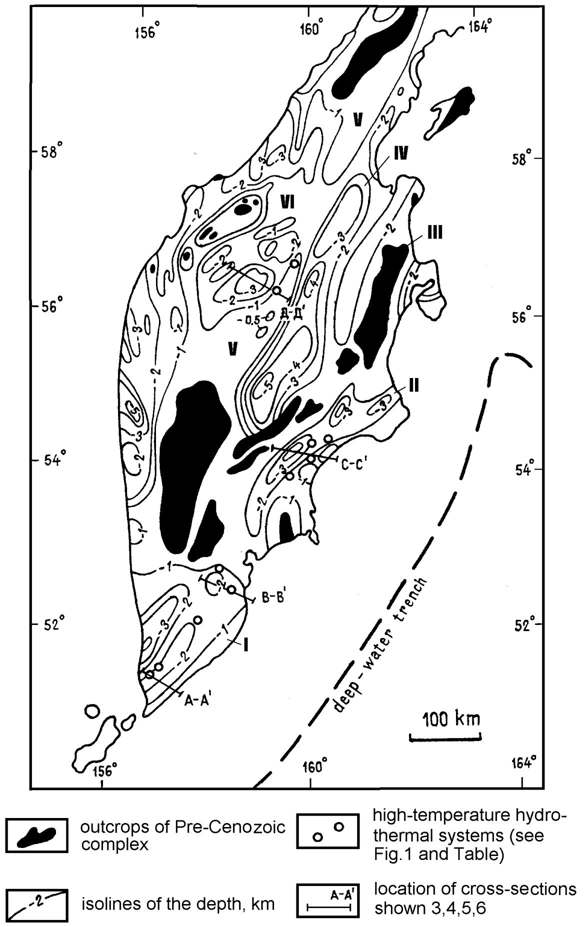

Figure 2. Structure of the basement rock complex (Pre-Cenozoic) that underlies the sedimentary cover (determined by electrical prospecting methods, after Moroz, 1991).
I - Southern - Kamchatsky anticlinorium, II - Eastern - Kamchatsky trough, III - Eastern - Kamchatsky anticlinorium, IV - Central - Kamchatsky trough, V - Kamchatsko - Koryaksky anticlinorium, VI - Palansky trough.

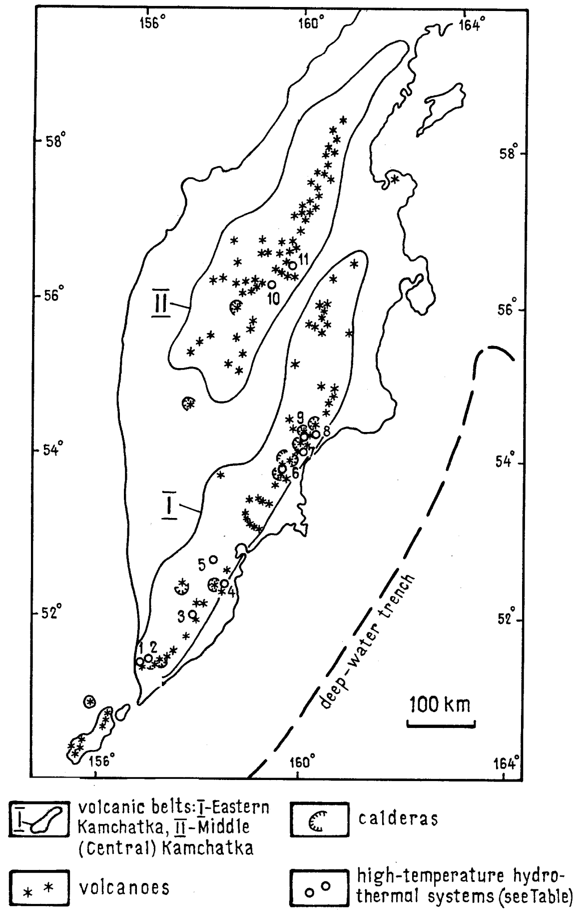

Figure 1. Scheme showing the location of the volcanic belts, main volcanoes and high-temperature hydrothermal systems on Kamchatka.

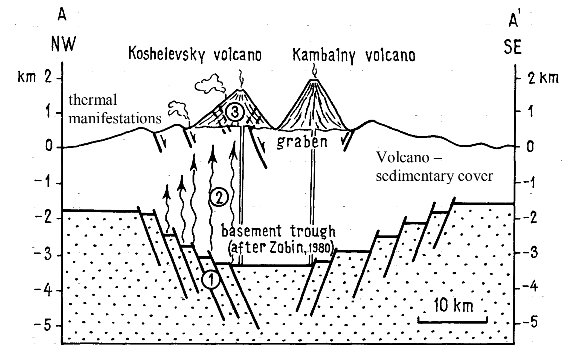

Figure 3. Section showing the location of the volcanoes, thermal manifestations (high-temperature hydrothermal systems) and the position of the basement trough on the extreme Southern Kamchatka.
Dotted field is basement (Pre - Cenozoic complex), number in the circles mark the zones: 1 - trough boundary 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.

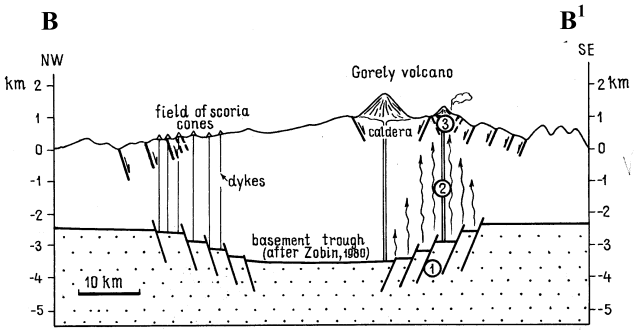

Figure 4. Section showing the location of the volcanoes, thermal manifestations (high-temperature hydrothermal systems) and the position of the basement trough on the north of Southern Kamchatka. Legend same as Figure 3.

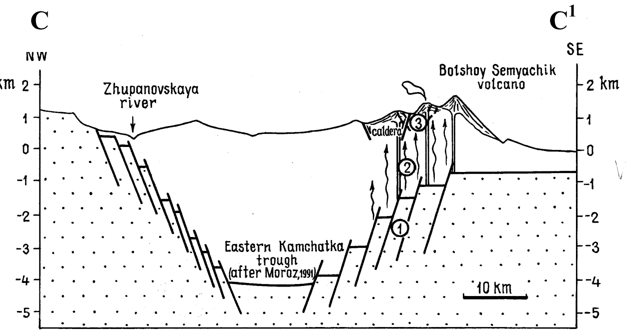

Figure 5. Section showing the location of the volcanoes, thermal manifestations (high-temperature hydrothermal systems) and the position of the basement trough on the Eastern Kamchatka. Legend same as Figure 3.

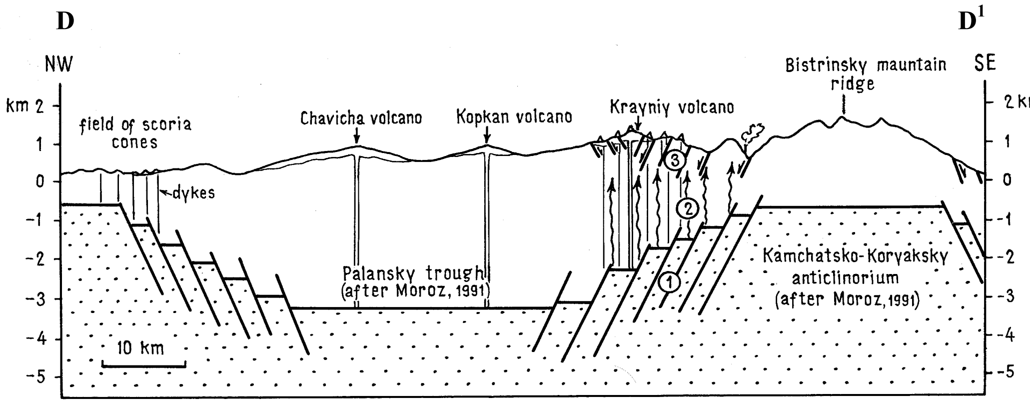

Figure 6. Section showing the location of the volcanoes, thermal manifestations (high-temperature hydrothermal systems) and the position of the basement trough in the centre of Middle (Central) Kamchatka volcanic belt. Legend same as Figure 3.

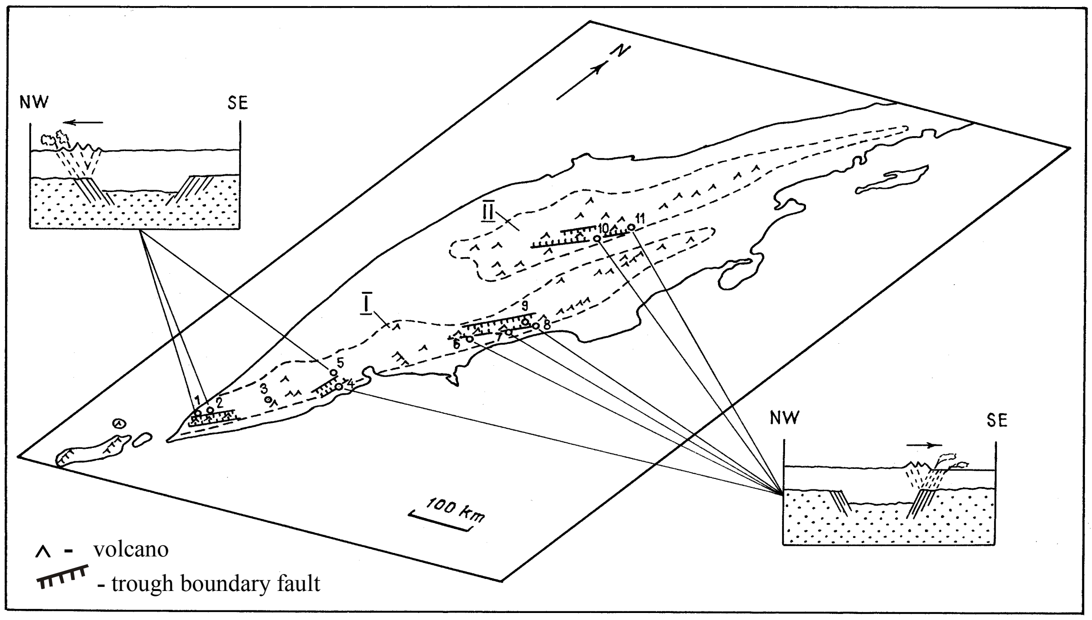

Figure 7. A schematic illustration of the location of high-temperature hydrothermal systems on Kamchatka. Arrows are displacement direction of the thermal manifestation. Other legend same as Figure 1,3.