Hydrothermae and volcanoes of Kamchatka

Hydrothermae and volcanoes of Kamchatka

L A Vorozheykina, N P Asaulova, N V Obora
Joint Stock Company Heat of the Earth, Termalny village, Paratunskaya Str., Kamchatka Krai, Russia

Hydrothermae and volcanoes of Kamchatka are concentrated in the Mid-Kamchatka, East-Kamchatka volcanic belts oriented in NE~50º direction subparallel to the Kurile-Kamchatka Trench. A similar direction is also typical for modern open fault zones accompanying Planetary fault at the eastern coasts of Kamchatka [8]; it corresponds to the direction of the Thermal Rift and the zones of depressions controlling geothermal objects. Such coincidences are clearly not accidental. Having regard to the above, it became necessary to consider the features of the most studied Paratunka geothermal field relative to the existing volcanic belts of Kamchatka. Based on the actual data, the possibility of forming a standard Paratunka field as a result of post-caldera volcanism manifested at the boundary of volcano tectonic structure is shown. By analogy with the Paratunka field, the hypothesis of the peninsula formation as a result of the confluence of two super volcanoes with a common crater structure in the Klyuchevskoi group of volcanoes was suggested. The formation of the volcanic belts of Kamchatka is considered from the perspective of the manifestation of the post-caldera volcanism.

Key words: Kamchatka, hydrothermae, volcanoes, wells, field, rifts.

The main directions of the company's (Heat of the Earth) activities are the operation, monitoring, protection of natural heat carrier reserves of 10 geothermal fields in Kamchatka (Esso, Anavgay, Bystrinskoye, Puschinskoye, Paratunka, Verkhne-Paratunka, Ozernovskoye, Nizhne-Ozernovskoye, Pauzhetskoye) scattered on the peninsula. During the materials analyzing of carried out work, the question inevitably arises: what caused a compact and harmonious cooperation of hydrothermae and volcanoes within the subparallel linear zones of the East- and Mid-Kamchatka volcanic belts at the territory of the region?

28 active volcanoes, more than 150 groups of thermal manifestations are coincided to the volcano-tectonic belts of Kamchatka (Fig. 1). Along with the active volcanoes hydrothermae are considered to be a modern phenomenon closely connected with volcanism and accompanying geodynamic processes.

The Paratunka field is coincided to the graben-like depression of the valley of the Paratunka river oriented in the direction of NNE 20º - subparallel to the Planetarny fault near the eastern coasts of Kamchatka [8] (Fig. 2). The depression is filled with a thick mass (up to 250 m) of loose quaternary deposits.

In the valley of the Paratunka river Kamchatgeology company drilled ~ 135 wells, explored Paratunka and Verkhne-Paratunka fields of nitrogen thermae with total reserves of natural heat carrier 557 l/s, T=77ºC. In the basin of the Paratunka river 10 groups of thermal sources flow, there are three of them (Severny, Nizhny, Sredny) on the territory of the Paratunka field.

In the late orogenic structure of the region the long faults and lineaments of the NW, NNE, NE and EW trending are identified. All zones are living, diagonal and younger than sub-lateral zones [11].

Thermal manifestations of the region tend to faults intersection of sub-lateral and NE trending in tectonically weakened nodes. According to the work carried out, the most watered zones are the feathering fissure zones. Based on the results of the generalization of geophysical data and the analysis of location scheme of zones and nodes of increased permeability of the earth's crust for N-57-XXVII sheet, it was noted that the overwhelming number of nodes of increased permeability, despite of their different depth, group into extended zones of three main directions - NW, NE and EW.

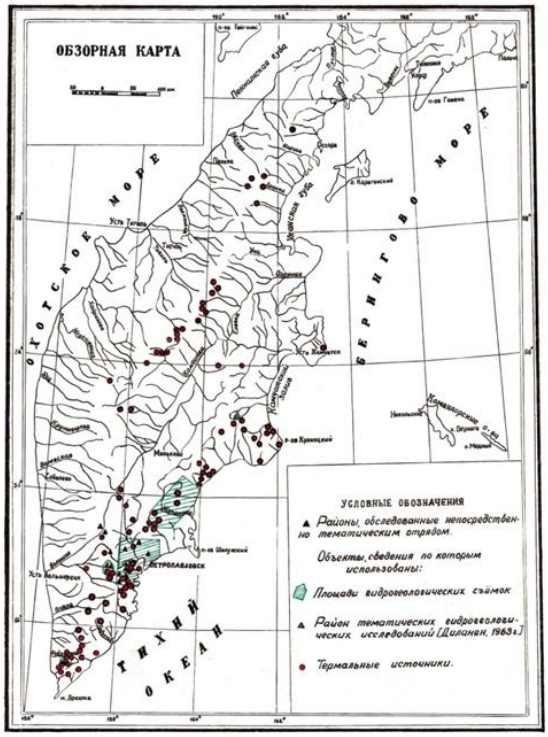


Fig. 1. The map of thermal manifestations of East-Kamchatka, Mid-Kamchatka volcanic belts.

In the southern part of the territory the NE orientation of these zones predominates. Three zones are traced the most clearly. They are related to Paratunka. The first zone extends from the head of the Left Bystraya river on the NW slopes of Topolovy ridge to the Mikijinsky Cape mountain, Sosnovka village, Khutor village. The second one is parallel to the first zone; it is traced from the head of the rivers Poperechnaya - Ovrajiya to the confluence of the Paratunka-Karymshina rivers, then to the Nikolaevka village. The third zone is traced from the eastern slope of the Poperechny ridge along the left bank of the Paratunka river, then to the region of the Seldevoy mountain and to the mouth of the Paratunka river [11].

Based on the results of geological-geodynamic analysis and interpretation of the aerial-surveys, the materials of the geological-structural map of N-57-XXVII sheet VA Sokolkov made the following conclusions [9f]:

- Depression zones of NNE trending is *thermo-controlling*.
- Kinematic structures coincided to the feet of the middle and low rheological levels are *thermo-containing*.
- NW systems of dislocations are *thermo-supplying*.

The most productive wells of the Paratunka field gravitate toward the bottom of the graben of the Paratunka river. There are fragments of graben with the break of its boundaries in the direction of open fractured zones of NE ~ 50º, they control the location of the most watered wells.

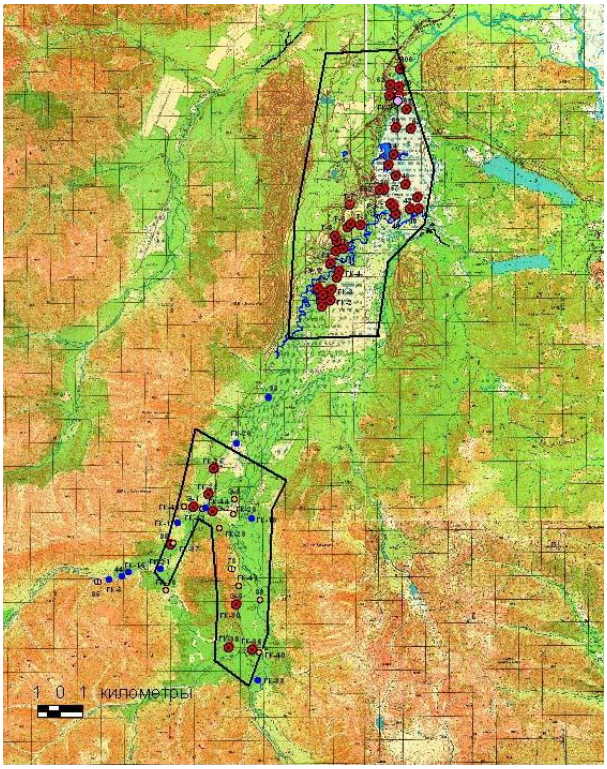


Fig. 2. The map of the Paratunka and Verkhne-Paratunka deposits in the valley of the Paratunka River

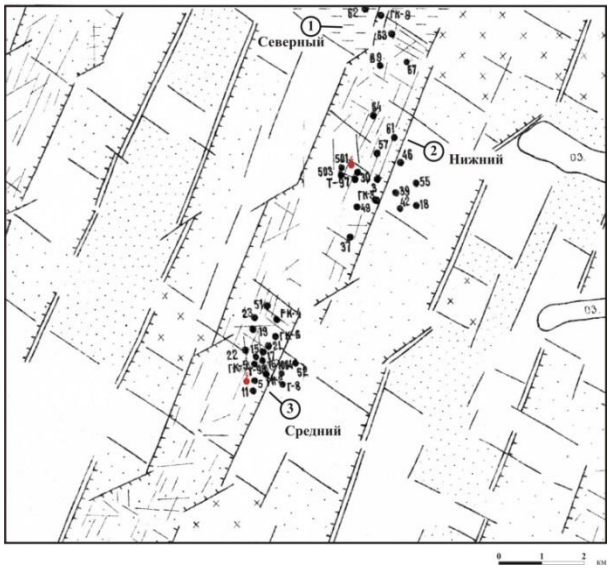


Fig. 3. The map of productive wells on the main sections of the Paratunka field (based on the interpretation of the aerial surveys – [11])

According to the results of a special structural-geomorphological analysis [11] the distinct confinedness of the Paratunka hydrothermae to the late orogenic structure was noted. It can be possible due to the connection with the current forming rift stretching zone. The unique position of the Paratunka-Banny zone of sub-lateral faults in the late orogenic structure of Kamchatka was noted. Being trans-

zonal and trans-island, the Paratunka-Banny lineament is traced far eastwards, identifying the position of shelf edge and continental slope, generally affecting the planned contours of Kamchatka. This zone is associated with a sudden width shorten of the southern peninsula part [11]. The earthquake centers deeper than 100 km form bands of sub-lateral trending, coinciding with latitudinal zones, which allows them to be interpreted as low crustal-upper mantle ones.

Immediately on the field area, sub-lateral zones control the boundaries of the main allotments and the territory of the Paratunka field. On the Nizhny allotment the sub-lateral zone is most expressed; it is traced along the Korkina stream and then to the east; the supposed chamber of hidden volcanism adjoins this zone at the north. Some features of hidden volcanism are brachyanticlinal structure of the allotment [7], geophysical anomalies [11], radial faults, maximum predicted temperatures (by silicate geothermometer), increased chlorine content, a wide range and maximum contents of microcomponents, maximum well temperatures (up to 106 ºC), etc. Hidden volcanism is also manifested on Sredny allotment, as a small crater funnel, discovered on drill-hole cores [5].

The rift zone of the submeridional orientation is a fragment of the Central-Kamchatka rift. At the field it is represented by the Central fault, which divides the field into the East (Nizhny and Severny allotments) and Western part (Sredny, Promezhutochny, Mikizha, Svetlyachok, fish-breeding farm). The eastern contour of the field borders with the South-coast geothermal area and in recent years it has been affected by underground waters, as well as the groundwater of the Paratunka-Avacha depression. Thermal waters of sulphate composition with mineralization up to 1.3 g/l predominate on the field, at the same time chloride-sulphate waters with an increased mineralization up to 3.4 g/l (well 101) are typical for the eastern flank of the territory.

Another rift zone is represented by the *Paratunka-Pinachevo seismogenic zone of decompression* determined by I K Rundquist [11] based on the results of interpretation of thermal space images [11] (Fig. 5). The fragment of this zone is the Zapadny fault; it combines thermal anomalies of Sredny and Promezhutochny allotments. Both rift zones control the submeridional zones of 80-degree thermal anomalies in the west and east of the field (760 m below sea level).

Not only rift zones but also ring structures control the productive allotments of the field; the Paratunka field is located in the zone of interference of two volcano tectonic structures of the second order - Avachinskaya and Bystrinskaya structures.

The ring structures allocated in the rank of the second order occupy a special position. Appearing of these structures is associated with the most active formation of volcano tectonic structures in a new, absolutely continental quality. In general plan they form chains of NNE and NE directions [11].

It is necessary to note that the general contour of the productive area of the Paratunka field has the form of a half-arch open to the west. The half-arc shape is also observed in the contours of the modern relief of this territory (Fig.6).

Based on the results of a special structural-geomorphological analysis made by the professor of the Moscow State University N P Kostenko [11], the paleostructure of the Paratunka-Bystrinskaya depression was shown. The paleostructure combines the lower reaches of the valleys of the Paratunka and Levaya Bystraya rivers. Later in the center of depression the ridge Topolovy and horst Topolovy have grown, and they continue to grow [11].

The close spatial relationship with the zone of Central volcanism, the proximity to the eastern volcanism zone, the presence of hidden volcanism and rift zones, the presence of an anomalous thermal-supplying NW fault according to the predictive temperatures, controlling role of the edge of the crater of above-mentioned paleostructure of volcano tectonic structure, etc. permit to make a conclusion that the formation of the Paratunka field of thermal waters was caused by the process of post-caldera volcanism and it is associated with the last outbreak of volcanism in Kamchatka during the Holocene period.

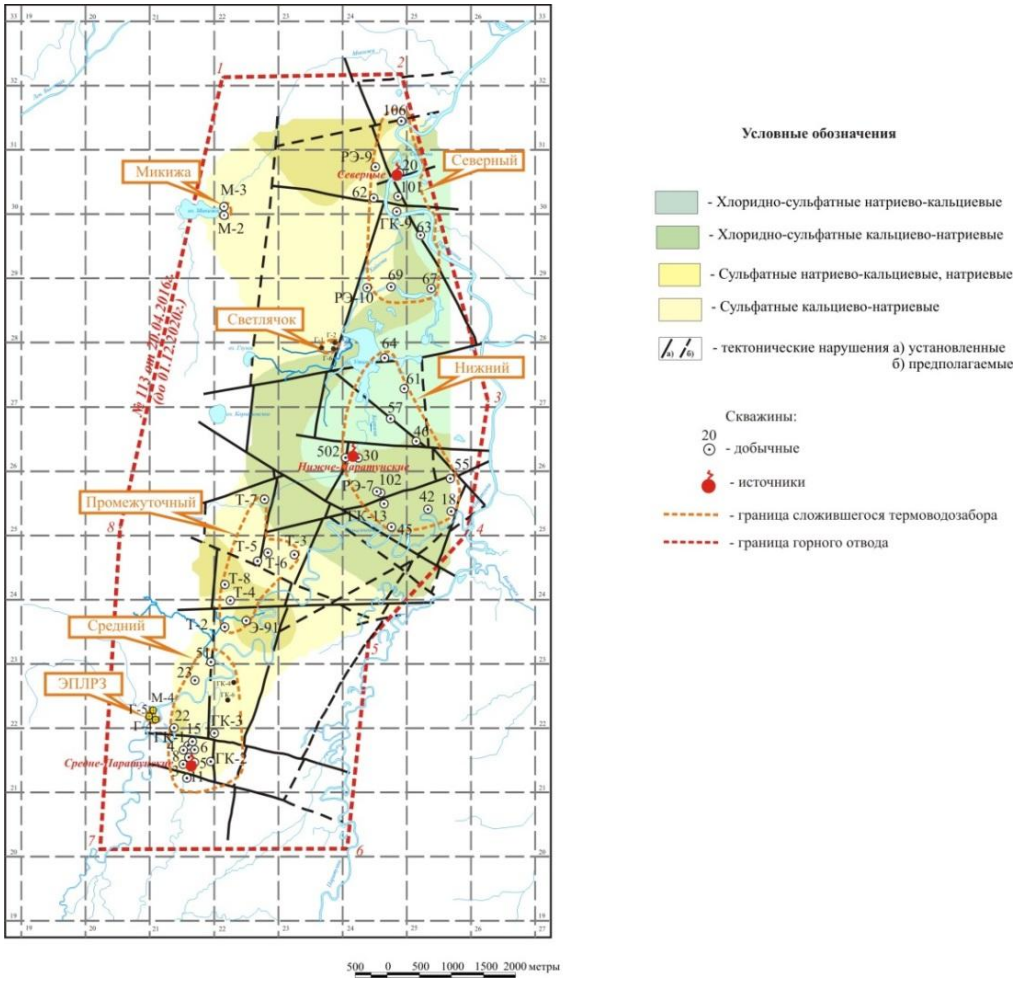


Fig. 4. Geological and hydrogeological scheme of the Paratunka field

The Paratunka field is modern and young. Geothermal situation of the field is characterized by an extreme degree of heterogeneity: high-gradient zones are replaced by low gradient ones, positive anomalies are replaced by negative, gradientless zones of crossflow – by areas of calorimetric mixing. Heat transfer is carried out mainly in a convective way.

The main feature of the longitudinal thermal section of the field is a stepped immersion of high temperatures from the Sredny allotment to Severny. Negative gradients carry information about the direction of thermal waters movement in spreading zones. Similar allotments were used by VN Neprimerov et al to determine the age of the field by the geothermal method, it was ~ 6500 years. The lack of thermal equilibrium in the system, the presence of cracks in the water column indicate that the thermo-outputting cracks appeared after the formation of quaternary deposits, and the calculated age value is a quite real approximation [6].

Water nutrition of the field is made due to meteoric waters forming, mainly, far beyond the basin of the Paratunka River at the height of ~ 1500 m above sea level. It is supposed that the transit of meteoric waters to the field is carried out along the current zones of the fault of NE 50°C, mainly from the Gorely volcano and Tolmachev Lake. From the Vilyuchinsky volcano water supply is provided to the South-coast area along the cleft zones of the submeridional orientation (see space images) and, in part, the eastern flank of the Paratunka field. The zones of the cleft are poorly expressed in the relief (dashed), but they are young and open to the depth; they form an original drainage system that allows the underground waters of Kamchatka to move for hundreds of kilometers and form upward, down-

ward currents or accumulate in depressive structures, depending on the structural features of the territory; freely change the circulation mode, depending on the specific situation on the site.

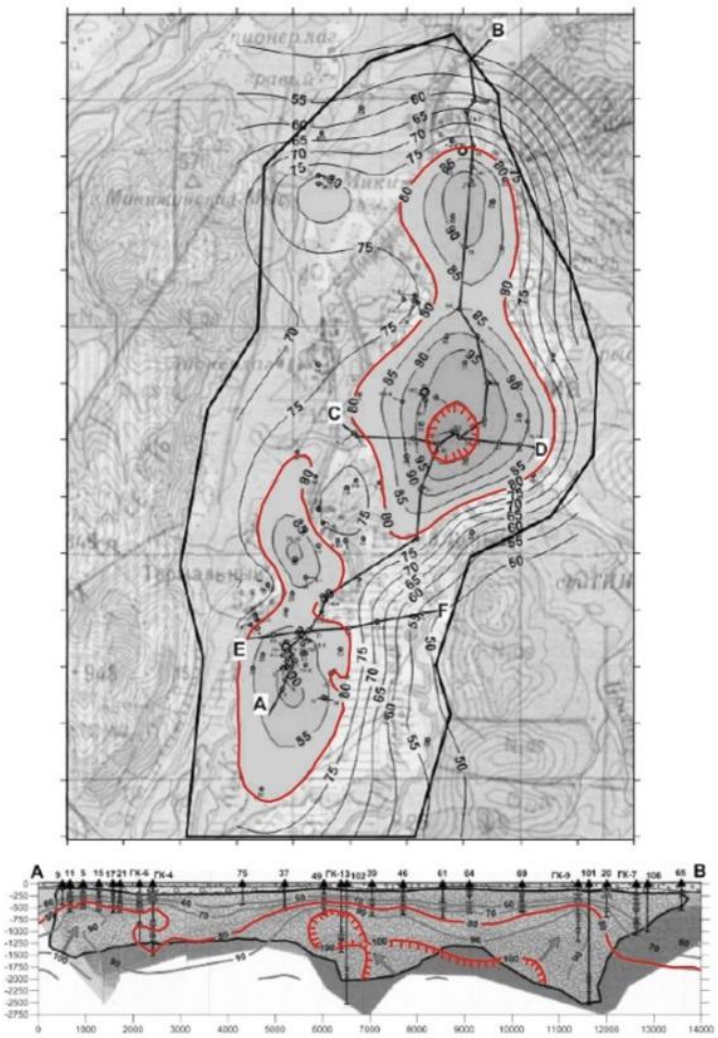


Fig. 5. Geothermal anomalies of the Paratunka field to the depth of 760 m below sea level. Western and eastern contours of the 80-degree thermal anomaly

Having paid attention to the presence of geodynamic activity in the area of the Paratunka field, it should not go unspoken about the tectonic features of the Avacha Bay, bordering on the Paratunka field. The complex contour of the Avacha Bay boundaries "models" the tectonic features of the adjacent territory (Fig. 7).

In the Avacha Bay Dmitriev V D, Yezhov B V [4] identified two fractured zones of NE and NW orientation. They are also fixed by geophysical anomalies. A *seismogenic node* is associated with the intersection of these zones; the axes of the node are of sub-lateral and submeridional orientations (Fig. 7).

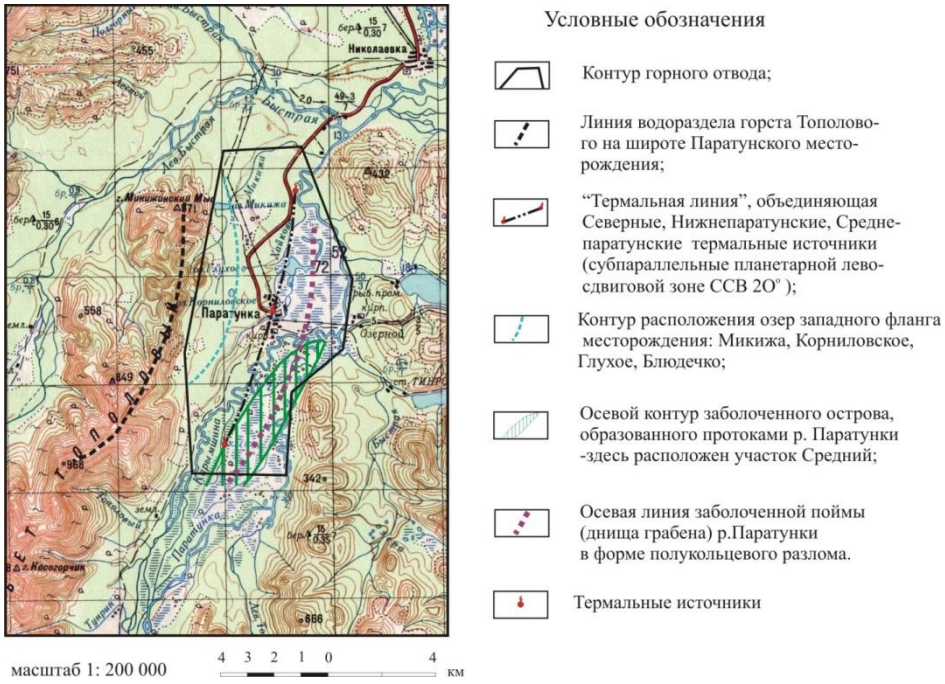


Fig. 6. Some elements of the structural control of the Paratunka field

It is supposed that the orientation of the axes of the seismogenic node reflects the submeridional, sub-lateral directions of active structure-forming faults. This is evidenced by the submeridional direction of the Central-Kamchatka rift; the direction of isolines of heat flow [1]; submeridional structure-forming faults of Kamchatka identified by Yu P Masurenkov [1] when studying active volcanoes in dynamic systems of volcanic centres (Fig. 8), etc. The sub-lateral aseismic zones of Kamchatka have already been mentioned. At the intersection node of the sub-lateral and submeridional regional zones the NW direction is formed, which is reflected in the orientation of the Koryak-Avacha depression open to the ocean in the Avacha Bay area.

Perhaps, the allotments of concentration of the sub-lateral zones control the location of the eastern coast bays, which are associated with the "slipping" of the continental part of the peninsula into the ocean [11]. This refers both to Avacha Bay and other bays of the eastern coast of Kamchatka.

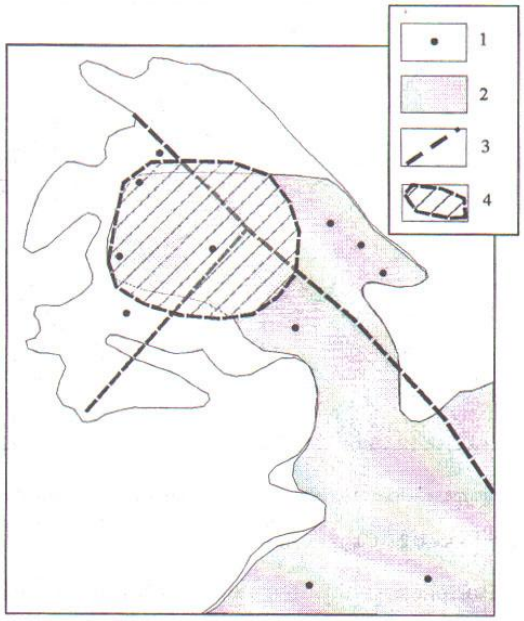
The Central-Kamchatka zone of volcanism, to which the territory of the Paratunka field refers, is distinctly presented on the space image (SI). The central point of this zone is the largest Eurasia volcano – Klyuchevskoi (4800 m). The value of heat steam here is maximum, up to 95 mW/ m^2 [1].

East-Kamchatka, Mid-Kamchatka volcanic belts surround the Central-Kamchatka volcanoes zone and its southern structural extension: a thermal rift, volcanic structures located to the east from the Central-Kamchatka deep fault.

By analogy with the Paratunka field, the concept about the formation of the modern Kamchatka territory due to the confluence of two super volcanoes with a common center of volcanism in the Klyuchevskoi group of volcanoes appeared:

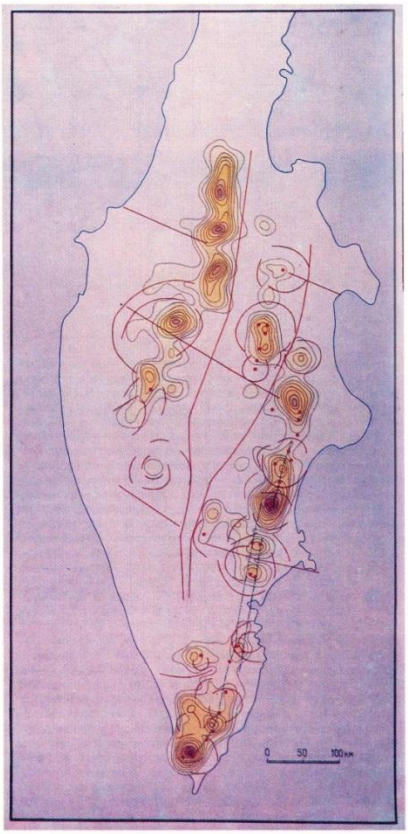
Paleovolcano **1** is the whole territory of Kamchatka. The modern volcano **2** is located in the center of the paleovolcano **1** and it is framed by famous volcanic belts, due to the manifestation of post-caldera volcanism at the boundary of the caldera structure of volcano **2**.

The hypothetical model is in good agreement with the generally accepted tectonic map of G M Vlasov et al. (Fig. 10), with the orientation of current open zones of faults of 50 ° NE, coinciding with the direction of volcanic belts (Fig. 1).



Legend:
1 – sampling point
2 – $Cd_{weighted}$ > 0,01 μg/d;
3 – disjunctive break;
4 – seismogenic node.

Fig. 7. Tectonic map of the Avacha Bay.



Legend:
Volcanic centres and ring structures of Kamchatka
isolines of volcanoes density (quantity for 625 km^2) (brown);
external faults of ring structures (rounded, red);
main structure-forming faults of Kamchatka, submeridional (red lines);
active volcanoes (red circles)

Fig. 8. Predominant structure-forming faults of Kamchatka noted during the studying active volcanoes in dynamic systems of volcano centres by Yu P Masurenkov [1]

Volcano 1. Its western boundary coincides with the western outline of the peninsula. The eastern boundary is along the ocean coast. The bays of the eastern coast, presumably, control the zones of slipping of the continental part of the territory into the ocean, i.e. the part of the paleovolcano1 is hidden in the depths of the ocean.

The volcano 2. The western boundary is supposed to be along the Central-Kamchatka rift. There are no active volcanoes except solfatara of Ichinsky volcano here, but there are a number of thermal manifestations. The eastern boundary of volcano 2 is framed by the East-Kamchatka volcanic belt with its many active volcanoes and hydrothermae manifestations observed along the eastern coast of Kamchatka.

Fig. 9. Space image of Kamchatka and formal boundaries of the volcano 2

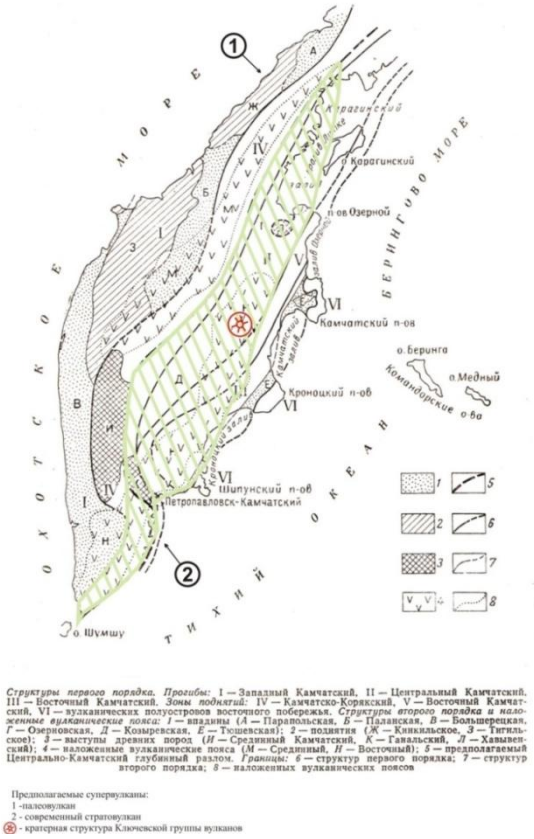


Fig. 10. The tectonic map of Kamchatka and conditional volcano 2 boundaries (G M Vlasov at el., 1992)

Conclusions

- The territory of Kamchatka is formed by two different age super volcanoes (1-2) with a common center of volcanism in the region of the Klyuchevskoi group of volcanoes,
- The formation of the East- and Mid-Kamchatka volcanic belts is caused by the process of post-caldera volcanism, manifested at the boundary of the crater structure of the volcano 2,
- The NE orientation of the volcanic belts of Kamchatka is subordinated to the direction of the modern crack zones of NE 50º accompanying the planetary fault near its eastern coasts and the orientation of the Kurile-Kamchatka Trench. The coherence of the planetary and regional tectonic zones is obvious.

References

[1] *Active volcanoes of Kamchatka* 1991 (Moscow, Nauka) vol 1-2
[2] Averiev V V 1966 *Hydrothermal process in volcanic areas and its connection with magmatic activity* (Current Volcanism, Moscow, Nauka)
[3] Chudaev O V and et al 2000 *Geochemistry of waters of basic geothermal areas of Kamchatka* (Dalnauka)
[4] Dmitriev V D, Ezhov B V 1977 *Towards the origin of Avacha Bay* (The questions of Kamchatka geography, Petropavlovsk-Kamchatsky) Issue 7
[5] *Hydro-thermal systems and thermal fields of Kamchatka* 1976 (AS USSR FESC)
[6] Neprimerov N N, Shtanin A V 1970 *Research work on the theme: Hydrodynamic and thermal studies of the Paratunka thermal water field* (Kazan University)
[7] Pashchenko L G at al 1968 *Report on the results of detailed exploration of the Severny, Nizhny and Sredny allotments of the Paratunka thermal water field (with the calculation of operational reserves on November 25, 1968* (Yelizovo, Funds of FSI PFI)
[8] Utkin V P 1989 *Shift dislocations, magmatism and mineralization* (Moscow, Nedra)
[9] Vakin Ye A, Kutyev F Sh 1979 *Depths of generation of fluid constituent recent of modern hydro-terms* (Study and using of geothermal recourses in volcanic areas, Moscow, Nauka)
[10] Vorozheykina L A, Asaulova N P, Obora N V 2017 *Hydrogeothermal features of Paratunka field of thermal waters* (Petropavlovsk-Kamchatsky)
[11] Vorozheykina L A, Sokolkov V A, Sidorov M D at al 1995 *Field trials on the application of geological, hydrogeological, geophysical and remote criteria to search thermal waters on enclosed areas* (Termalny village, Funds of FSI PFI)