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ABOUT INTERRELATION OF STRUCTURE OF AN ANOMALOUS GEOCHEMICAL FIELD WITH THE MECHANISM OF FORMATION OF HYDROTHERMAL SYSTEM

V.G. Voroshilov

Tomsk polytechnic university.
E-mail: voroshilovvg@ign.tpu.ru

The model of formation of anomalous structures of geochemical fields during formation of thermo-fluidic ore-forming system is proposed. The morphology of these fields is caused by the combination of diverged mineral zonation in relation to a power source and converging zonation in relation to the centers of an ore deposition. Influence of tectonic conditions of functioning of hydrothermal system on an internal structure of anomalous geochemical fields is shown. Connection of efficiency of hydrothermal deposits with structure of a geochemical field containing them is grounded.

In modern concepts of ore formation endogenous hydrothermal systems are considered as complex magma – fluid, as superfluous heat flow in zones of tectonic -magmatic activization cannot be explained only by influence of flying components. It is confirmed by high correlation of ratios $^3He/^4He$ and $^{87}Sr/^{86}Sr$ in the hydroterms, testifying about fluidic -silicate nature of deep heat mass flow [1].

Appearance of fluidic-magmatic ore-forming systems usually is bound with influence of deep plums on the mantle and overlying lithosphere in this connection the area of functioning of such systems is divided on the mantle, asthenosphere and high crust zones. There are only hypothetical ideas about a state of fluids in the bottom and middle mantle, and the more certain opinion is formed about asthenosphere, as the zone of origin of the magmatic centers and fluidic – magmatic columns [2-4]. The top part of arising fluidic-magmatic columns represents the area of mantle metasomatism above the centers of restite basite melt which are replaced with depth by hyperbasite melt, and deeper are underlaid by the softened substance of asthenosphere [5]. Taking root into the bottom crust, these columns form the centers of basite magmas which are conductors of the mantle fluids in the top crust.

The melting centers of rocks are simultaneously generators of huge mass of flying components (H_2O, CO_2, H_2 etc.). As melting of rocks is preceded by their transition in plastic and viscous – plastic state, fluid-stops with poor permeability for flying components are formed above zones of initial heating [6]. It promotes accumulation of fluids and their regular emission in overlying horizons after achievement in the chamber of the pressure exceeding strength of the screen. According to the geophysical researches data, similar fluid saturated centers and plastic screens are fixed as a zone of the lowered speeds and increased electroconductivity on depths up to 100 km [3, 7, 8].

Under influence of high heated fluids progressive metamorphism of rocks takes place with forming of huge additional masses of water and carbonic acid in overintrusive space. The acidic melts with viscous plastic screen, regulating fusion of rocks and penetration of fluids in overlying thicknesses, are produced in the zones, where the temperature reaches the level of 640...720 °C at pressure of water vapors 100...400 MPa. Obviously, that and the cooling down melts themselves become at the moment of crystallization, for certain time the screen for entering from below intratelluric fluids. As a whole, accumulation of fluid mass within the limits of the considered interval of depths with temperatures 640...370 °C is controlled by capacitor properties of medium and strength characteristics of screening thicknesses. Catastrophic breaks of isolating covers are not the sole mechanism of stabilization of escalating pressure. The significant part of a fluid, as the high pressure gas, is removed through numerous drainage channels that provides it area dispersion before penetration into overlying horizons [6].

The hydrosphere begins from cut levels where the medium temperature falls below boiling temperature of fluid and its condensation takes place. On the bottom boundary of the hydrosphere, in sites of its intensive drainage, the root zones of hydrothermal systems themselves are formed. From here solutions migrate in the beginning vertically upwards, and with increase of permeability of rocks form fanlikely diverging figures of spilling.

The major feature of functioning of hydrothermal systems in a subcritical range of temperatures is ability to form inside them steam (steam dominating) zones [9]. Such areas arise at passage of a liquid hydrothermal solution of tectonically weakened zones where the solution temperature, as a result of pressure fall, exceeds the boiling point. As show observation of the Kamchatka modern hydrothermal systems, intensive acid metasomatism takes place within the limits of steam zones, and in the zone of liquids – vapor transition the complex geochemical barrier is formed and sulphidic minerals and gold are deposited [10].

According to our conceptions, zonation of structures of regional scale, up to ore fields inclusive, is caused by character of migration of fluids at the high-temperature vapor-gas mixes level, under hydrosphere borders. As a whole, conditions of synchronous growth of pressure and temperatures with depth provide the liquid state of water with density about 1,0 g/sm^3 practically on all the interval of the earth crust [11]. Therefore vapor-gas mixes can arise only on sites of sharp increase of temperature, or so sharp pressure fall. Similar situations are characteristic for the contact halos of magmatic bodies and zones of tectonic breaches, that and causes the constant coinciding of hydrothermal deposits to such geological structures. Lateral migration of fluids is provided at this stage by their springing by poor permeable covers which can be presented by thicknesses of rocks with corresponding physical mechanical parameters, overthrust planes, viscous – plastic overintrusive zones and bases of the crystallizing magmatic centers. If such surfaces have slight inclined character, it promotes the directed migration of gaseous fluids and formation of their lateral temperature zonation on which background local hydrothermal systems of ore deposits are formed in following.

Zonation of the rank of deposits and ore columns is caused by the acid-basic evolution of streams of the condensed fluids breaking in the hydrosphere on zones of increased permeability. During formation of high-temperature preore metasomatites fluids sufficiently uniformly percolate through weakened zones, forming temperature anomalies of a simple structure with a direct zonation (fig. 1, *A*). Self-organizing of a hydrothermal flow, on a background of focusing influence of breaking infringements [12, 13] and involving in it of convective flows of colder vadose waters, results in division of a general thermal anomaly into system of competing convective cells. As result, the high-temperature central (nuclear) zone of system is formed in the most permeable part of structure, the zone of the frontal temperature anomalies separated from the center by area of lowered temperatures (fig. 1, *B*) is formed on periphery.

Thus contact of juvenile and local fluids and their gradual mixing with formation of the interspersed mineralization takes place along ascending branches of convective system. At appearance of an open fissure in the central zone mixing of solutions is added by their sharp cooling, owing to pressure fall (down to appearance of steam dominating zones), and deposition of vain mineralization (fig. 1, *C*). In horizontal section such system is presented by several temperature anomalies, central which has the local temperature minimum bound to the underpressure zone, and face-to-frontal ones fix the centers of secondary convective cells (fig. 1, *D*). It is obviously, that zonation of a temperature field influences

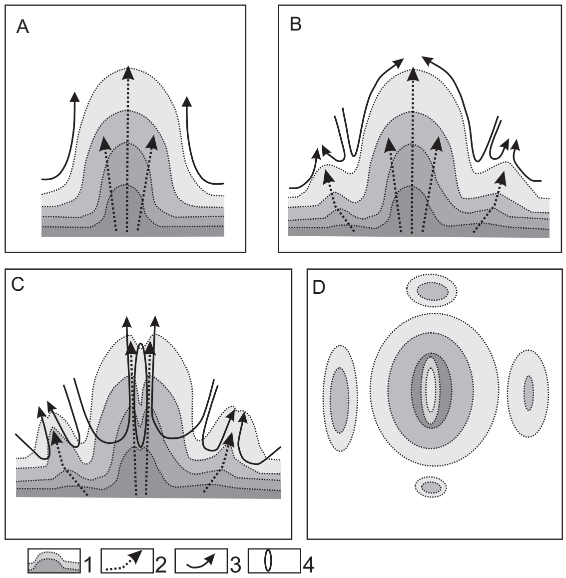

Fig. 1. *Model of temperature evolution of endogenous thermofluidic systems: 1) isolines of fluid temperature distributions; 2) directions of movement of a endogenous fluid; 3) ways of convective currents of local solutions; 4) areas of temperature and pressure fall, including steam zones; A, B, C) stages of temperature evolution of hydrothermal system (cuts in a vertical plane); D) horizontal section of system at a final stage of ore deposition*

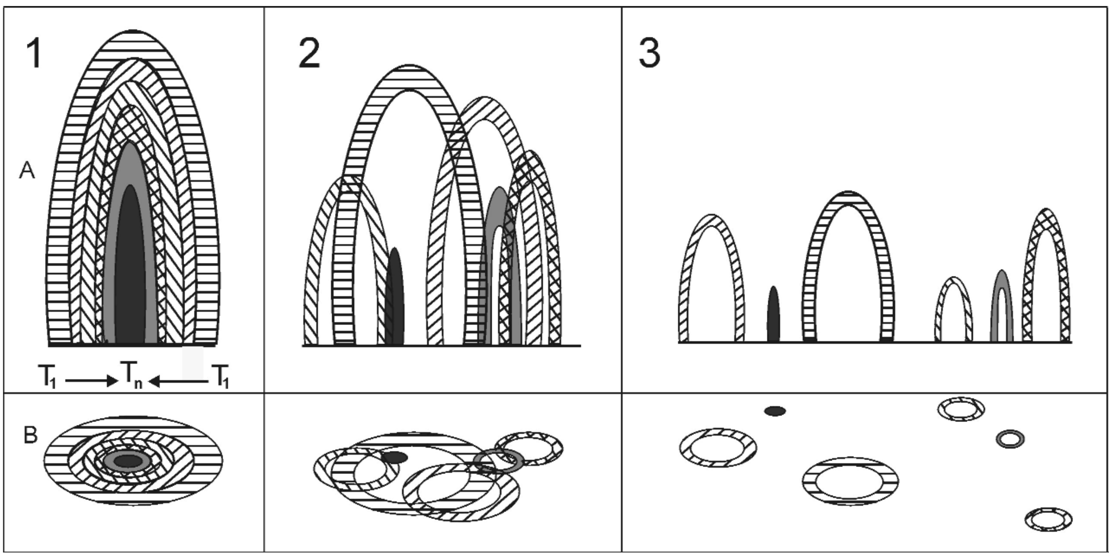

Fig. 2. *The diagram of formation of the ASGP nuclear zones in hydrothermal systems with a various level of stationarity: A) the diagram of the ASGP structure in a cut; B) the same in plan; shadings and filling in show areas of mixture of juvenile and local solutions at the moment of time T_i (sites of accumulation of mineral associations occurring at different times); figures designate systems with a different level of stationarity: 1) stationary, 2) intermediate, 3) non-stationary*

on character of hydrothermal mineralization placing by deciding way and is reflected in structure of the anomalous geochemical field where the central zone of accumulation of elements and the frontal anomalies of their introducing surrounding it, separated from the center by region of the relatively lowered concentration of ore elements have to appeared. Curious consequence of offered model also is that, in view of primary development of open cracks in the central zone, the mineralization here can be more low temperature one, than on periphery.

One of principal causes of deposition of hydrothermal minerals is mixing of hot juvenile and relatively cold «local» solutions. The pulsing mode of entering of endogenous fluid provides sliding character of contact border of these solutions. Accordingly, the sizes of an ore deposition area and character of change of depositing mineral structure depend on a tectonic mode of functioning of hydrothermal system. It is known, that large and unique deposits of gold are polychronal and, frequently, polygenic formations. In the context of the stated concept it means, that accumulation scales of a productive mineralization are defined by stationarity of the ore-forming system. Under stationarity we in this case understand systems not only consistency in time of metal bearing fluid streams, but also space time stationarity of structures controlling fluids. From these positions one can derive three limiting cases in the ASGP (fig. 2).

1) The concentric ASGP with the well defined central (nuclear) zone of accumulation of the ore elements, surrounded by spacious zone of relative decrease of their concentration and further – by the zone of external (frontal) enrichment by ore elements are most perspective. Such fields arising at long and stable development of hydrothermal system, usually accompany large and unique deposits with concentrated ore formation.

2) Complex polyelement halos without well defined symmetry of monoelement anomalies placing in relation to ore controlling structures are less favorable for detection of industrial mineralization. Such fields are formed at numerous changes of the deformation plan in process of ore formation and accompany small deposits and nonindustrial ore manifestation.

3) The anomalous fields presented by separated monoelement halos are least perspective. Such fields arise at nonstable functioning of ore-forming system, on the background of tectonic situation being adverse for ore formation and accompany, as a rule, sites with dispersed (nonindustrial) mineralization.

Material expression of the stated concept can be tracked on an example of plutonogenous Central gold ore fields (Kuznetsk Ala Tau) (Fig. 3).

Here ore formation is presented by quartz-gold-sulphidic veins with beresites, located within the limits of large granitoid pluton of laccolithic-shape forms. Lateral zonation of metasomatites and the ores expressing in decrease of mineral formation temperature (on 80...100 °) from the south on the north with removal from a deep break with change of the following mineralogical zones (on characteristic minerals): tourmaline, scheelite, chalcopyrite – molybdenite, galenite – sphalerite, arsenopyrite is distinctly shown in scales of an ore field [14].

In the same direction the quantity of sulfides in veins increases (from 5...8 % up to 50...80 %), are grade of gold decreased (from 930 down to 650), quartz-muscovite beresites are changed by quartz-carbonate-cericite ones, type of conductivity in pyrites is changed from electron one on hole one, typomorphic properties of vain quartz and kalispar of space metasomatites are changed by law way. Boundaries between mineralogical zones are sharp, and vertical zonation in their limits is shown vaguely, therefore it is possible to speak about multiroot character of development of ore formation.

As one can see on Fig. 3, increase of a role of high-temperature associations from the north on the south of the ore field, as approaching to channel of entering of fluids, is combined with the concentric converging zonation caused by accumulation of late gold-bearing mineral associations in veins of northern part of the ore field. Area of ore deposition, thus, corresponds to those part of hydrothermal system where local decrease of pressure and temperatures occurs as the result of tectonic motions.

The similar structure of mineral and geochemical zonation is shown and in larger scale, at a level of deposits and separate ore bodies. All investigated veins of the ore field morphologically represents cone-shaped figures with structure of vein mineralization being well sustained on a vertical. The vertical zonation bound with movement of a fluid stream from below upwards, is the diverging straight line and consists in insignificant increase of temperature of decripitation and homogenization of gas-liquid inclusions in quartz, shares of pyrites with electron type of conductivity, decrease of natural thermo luminescence intensity of vein quartz, decrease of concentration of Pb, Zn, Cu in beresites and increase of Cr, Ti, V contents in them with depth. The centripetal zonation caused by repeated tectonic motions, is shown much more contrastly and consists in concentric change of mineralization structure and above-named typomorphic properties of minerals in relation to the centers of maximal ore formation [15].

Obviously, on the initial stage of crystallization of intrusive its base on the significant extent represented an original trap, poor permeable for the gaseous intratelluric fluids which have been accumulated under the cooling down magmatic body (fig. 4).

Migration of fluids in the sides from the feeding channel has provided their essential temperature and acid-basic differentiation that was, in our opinion, the basis for formation in following of zonation of the ore field hydrothermal formations. The curious evidence of the real presence of under-intrusive hydrothermal «sill» is intensive change of preore dikes of spessartite: all of them are transformed in chlorite and a carbonate-chlorite metasomatites while containing granodiorites on contacts to them frequently are not changed at all. Apparently, cooling down dikes were thermal fluid conductors for beresiting solutions.

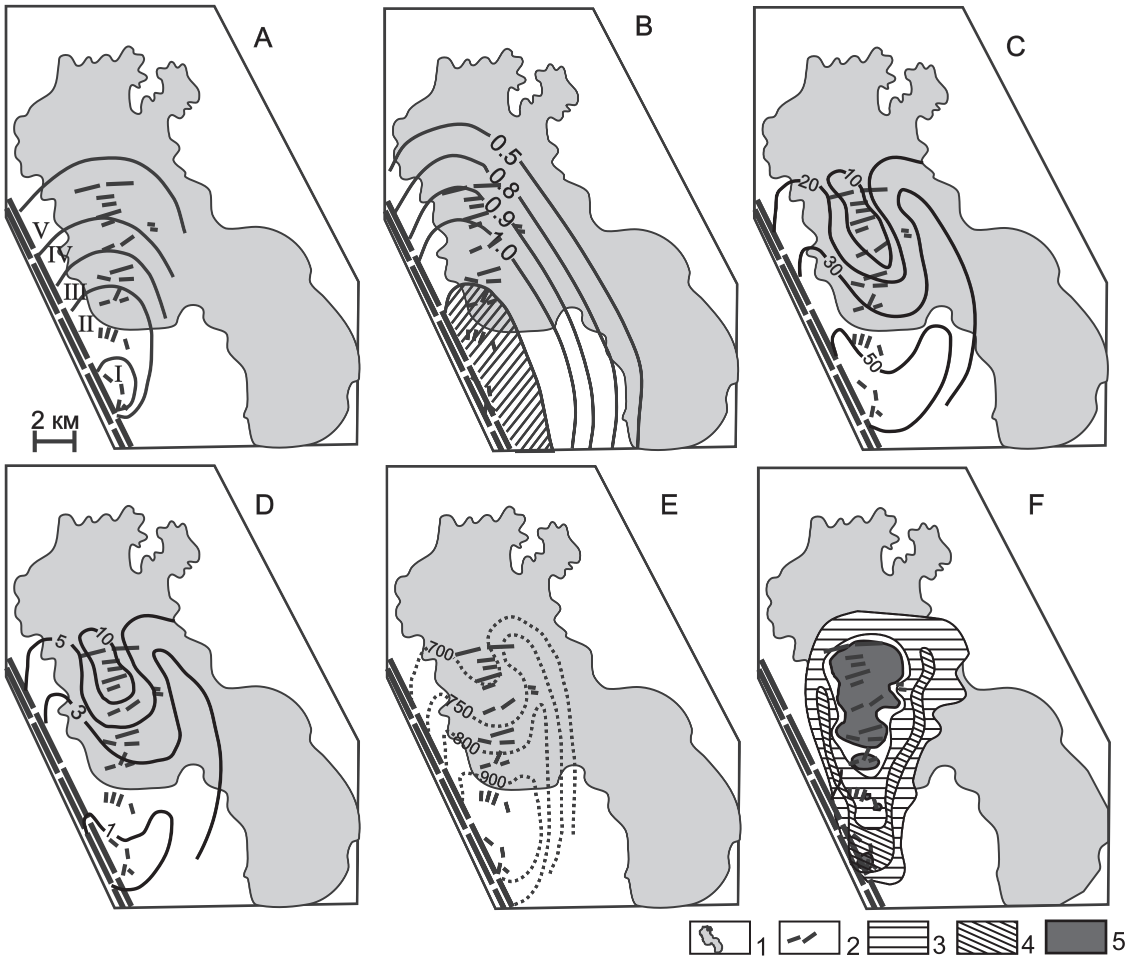

Fig. 3. *The lateral zonation of the Central ore field (Kuznetsk Ala Tau): 1) the contour of granodiorite massif; 2) the basic gold-bearing veins; A) mineral zones of the ore field (on typomorfing minerals): I) tourmaline; II) scheelite; III) molybdenite – chalcopyrite; IV) galenite – sphalerite; V) arsenopyrite; B) degree of triclinicity of kalispar from zones of kalispar-epidote – chlorite metasomatites (the development area of a latticed microcline is shaded); C) the share of pyrites with electron type of conductivity (in %) in gold-bearing quartz-sulphidic veins; D) intensity of natural thermo luminescence of vain quartz (in standard units); E) grade of native gold in quartz-sulphidic veins; F) storage sites of geochemical associations: 3) V, Ti, Ba, Zr, Sr; 4) Ni, Co, Cr; 5) Au, Cu, Zn, Pb, Ag, As*

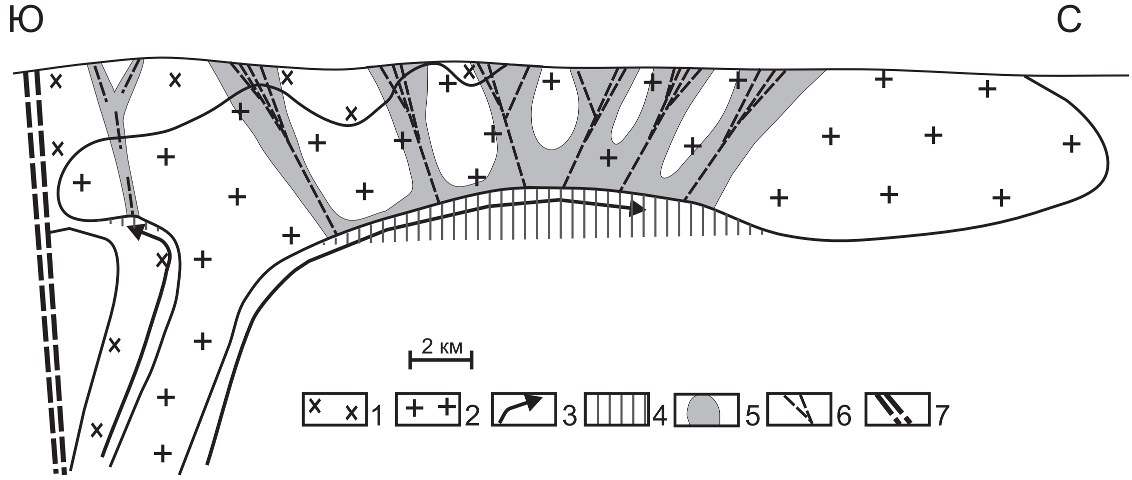

Fig. 4. *The schematic cut of the Central ore field (Kuznetsk Ala Tau): 1) horned and uralitized gabro-diorites (metadiorites); 2) granodiorites, tonalites, quartzitic diorites; 3) stream of a deep fluid; 4) storage field of a gaseous fluid under a cover of cooling down intrusive; 5) area preore metasomatites; 6) the cracks controlling and containing of ores; 7) the Kuznetsk Ala Tau deep break*

Preore metasomatites are presented in an ore field by spacious zones of kalisparing with thicknes in tens-hundreds meters on which periphery the raised concentration of biotite and magnetite are established. All quartz – vein gold ore bodies spatially gravitate to zones of development of area preore metasomatites. At the same time, in the most permeable parts of these zones the veins are presented by clampings and conductors, and quartz -sulphidic lenses and ore columns are located in weak fissured biotitiezed granodiorites. All this testifies that aria potassic metasomatism in zones of the heightened permeability was carried out under action of high-temperature (450...350 °C) fluids, mainly residual, without appreciable their mixing with waters of containing rocks.

In process of decrease of fluids temperature, their stream more and more concentrated in the most permeable central parts of zones, where at temperatures 350...300 °C epidote and chlorite were deposited, including, as small veins. The following decrease of temperature and occurrence of open cracks was accompanied by introduction of dykes, penetration along them and on zones of fissuring of solutions of the heightened acidity and formation of near fissure beresites. The solution enriched by leached bases migrated in a near fissure space, and at decrease of general permeability of medium, was pulled together in open fissures, causing display of the mechanism of automixture of solutions with all following consequences, with the following involving of these fissure fluids in the convective system being joint with vadose solutions.

As applied to the structure of anomalous geochemical fields obtained conclusions mean, that from the initial stages of formation of hydrothermal systems to final ones the centrifugal mineral-geochemical zonation is changed by concentric centripetal one. At it is very important, that ASGP of different hierarchical levels are figures of similarity. On this background, occurrence in geochemical fields of spatially mating high gradient zones of intensive bringing of elements and areas of relative decrease of their concentration, is the indicator of completeness of formation processes of mineral and concentrated ores.

Conclusion

The model of formation of anomalous structures of geochemical fields during formation of thermofluidic ore-forming system, is presented. According it:

1. The concentric zone structure of an anomalous geochemical field with localization of central and frontal zones, is caused by disintegration of hydrothermal system on a number of competing convective cells in process of its self-organizing.
2. The internal structure of anomalous geochemical fields is connected with stationarity of hydrothermal ore-forming systems and reflects the scales of ore formation connected with them .
3. The structure of anomalous geochemical fields is caused by combination of diverging mineral zonation in relative to a power source and zonation in relative the centers of an ore deposition.

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