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Geotectonics and Heat Flows

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ABSTRACT

Geotectonics is controlled by mechanical processes within Earth's crust. The role of Earth's heat is considered as secondary in comparison with geotectonic processes due to hidden character if its activity within ancient structures and absence of clear ideas about heat source and conditions of its transfer in the Earth's crust, mantle and core.

Hydrothermal-magmatic systems within regions of recent volcanism (controlled by heat flows with capacity on one-two orders higher than regional heat flows) transfer Earth's heat due to geothermal gradient. Heat transfer by convection within Earth's crust and mantle is determined by self-organization expressed by formation of geological structures conducting heat in these conditions.

Thus heat energy is transformed in structure-forming mechanical energy expressed in geotectonics.

These ideas make obvious priority of geothermal heat against tectonic processes. Such an approach toward geotectonic problems explain role of geothermal heat in evolution of crust of oceans, mobile belts and platforms.

It is noticed principal difference of regional heat flow, which is stable and associated with life of Earth's core, and pulses of volcanic and tectonic processes reflecting pulses of astrogenic and solar factors. Volcanic cycles show tendency toward global-scale synchroniety.

The meaning of anomalous heat flow is changing. This change reflects the existence of pulses of intense tectonic movements and flare-ups of volcanic activity divided by periods of relative quiet regime. Pulses are generated by the Earth's rotation, which generate centrifugal plate movement (fig. 1). Coincidence of such pulses with different astral and solar variables (Milankovich,1941, Shirokov, 2002, Zemtsov and Tron', 1985) confirms ties of anomalous heat flow generation with rotation processes.

1. INTRODUCTION

Antique civilization was born in the geologically-active Mediterranean. The voyages of ancient seafarers along the north shores of Sicily were lighted by of the frequent eruptions of Stromboli, and their medical problems were treated in geothermal waters. It is suggested that caldera eruption of Santorini volcano destroyed the Mycenaean civilization on Crete, and eruption of Vesuvius in 79 b.c. leveled the cities of Pompeii and Herculaneum. Structures with which were associated events of this type are called "volcanoes", by the name of the island named by the ancient God of the underworld. From this god's Latin name "Pluto" theory based on acceptance of prime role of Earth's internal energy has been named "plutonism". Its origin has been associated with names of such distinguished scientists of the ancient world as Heraclites, Empedocles, Aristotle and Pliny the Elder. This theory was the basis of ideas about Earth up to the Nineteenth Century.

People of antiquity worshipped Nature as part of polytheistic beliefs. As a result, every creek had its own nymph; every locality had its own God. The mightiest among them was God of the Sea Poseidon, and God of Fire and the Underground Hephaestus (Pluto in Roman mythology). Therefore, it is not surprising that Heraclites has considered Fire as one of main elements which create the World. It has been difficult to underestimate manifestations of underground might. So it is not by chances Heraclites considered fire as one of main elements which create the World.

According to the works of Heraclites, all matter originated from Fire. Fire is the most dynamic of all forces of Nature, constantly changing its form. Thus for Heraclites fire has considered as beginning of the Earth while Water was only one among the other forms of matter. Fire has been condensed into air which in turn has been transformed into solid Earth. Heraclites considered that the Earth on which we live had been a part of initial Fire, but afterword cooled. Other manifestations of the Underworld's power were catastrophic earthquakes quite usual in the Mediterranean. Ideas about the Underworld's energy playing a leading role persist through the history of earth sciences, being modified from time to time in accordance with the prevailing ideas of different generation. These include ideas of a contracting Earth, starting with the name of Eli de Bomon, and up to recent plate tectonic theories. However, a solid basis for modern ideas was formed in the late Nineteenth Century, through studies of Alexander Humboldt and Leopold von Buch, who had proved the volcanic origin of basalts and created a new theory named "plutonism".

The career of distinguished scientist Leopold von Buch illustrates the inspiration engendered by even superficial acquaintance with volcanic phenomena. He has been an ardent supporter of the neptunism theory (from the Roman name of the God of the Sea, Neptune) based on the primary role of marine sedimentation, until his brief visit to Canary Island volcanoes: Las Canadas on Tenerife, and de Taburiente on the island of Las Palmas. As a result, his notions were completely changed and he became a fierce advocate of plutonism. We owe to these two visits the introduction of the geological term "caldera".

According to his works everything had been originated from fire and remained in state of constant change. The fire is the most dynamic of all forces of Nature. Thus for Heraclites fire has considered as beginning of the Earth while water was only one among other forces. Fire has been condensed into air, air in turn transformed into earth. The Earth itself on which we live has been a part of hot fire but afterword cooled. Other underground manifestations might be considered catastrophic earthquakes quite usual in the Mediterranean. Changing of the superficial structure (in modern terminology tectonics) has been considered as a secondary manifestation in comparison with fire (heat). Ideas about underground energy's leading role come through the whole history of Earth's sciences being modified in accordance with prevailing ideas of certain times starting from ideas of Earth's contraction associated with the name of Eli de Bomon and up to recent plate tectonic theories. But final form they acquired in the end of XIX century in studies of A. Humboldt and Leopold von Buch, who had proved volcanic origin of basalts and created a new theory named "plutonism". History of distinguished scientist Leopold von Buch provides an idea about impression created by even superficial acquaintance with volcanic manifestations. He has been an ardent supporter of the "neptunism theory" (by the Roman name of the God of the sea Neptune) based on acceptance of marine sedimentaion's primary role until his brief visit to Canary Island's volcanoes Las Canadas on the Tenerife Island and de Taburiente on the island of Las Palmas. As a result his scientific ideas have been completely changed and he become fierce adept of plutonism theory. We owe to these two visits introduction of the term "caldera".

2. STRUCTURE FORMATION

Subject of this article is connections between Earth's structures (we consciously avoid term geotectonic associated primarily not with structures themselves but rather with ideas about ways of their formation) and one of main processes of Earth's internal life which lead to structure formation. Such an approach demands to have precise formulation which structures and processes are considered. Choice of main structures' types and dynamics of their formation is based on the acceptance of widely accepted ideas (Belousov, Khain and Lomize, 1995).

3. CONCEPTUAL MODEL OF STRUCTURE FORMATIOM AND HEAT FLOW OR THE GLOBAL GEODYNAMICS HYPOTHESIS.

It is established principal difference of stable heat flow manifestations associated with Earth's core life and pulsate nature of tectonic and volcanic processes reflecting pulsate nature of cosmogony factors. It is a reflection of the same order (practical equality) of heat flow density within Earth's first order structures – oceans and continents (Stein). In contrast to this tectonic and volcanic processes occurred as pulses of high activity interrupted by periods of tentative quiet regime. Acceptance of pulsate character of tectonic activity has been reflected in ideas about global epoch and phases of folding (Assintian, Caledonian, Hercynian, Kimmerian, Alpine). In accordance with accuracy of biostratigraphic method it has been suggested that such epochs' duration equal tens of millions of years. In the beginning of XX century acceptance of these ideas found confirmation in so-called Stille canon (Stille, 1924) completely confirmed by radiometric dating (Rubinstein, 1967, Gastil, 1960). In accordance with accuracy of analysis duration of pulses has been accepted in several millions of years.

It is widely accepted now that the main generator of tectonic movements' rotation is the Earth's rotation. Under the rotation's influence single primordial continent Pangea is moving toward equator and has been divided in two continents Laurasia and Gondwana, which were in turn divided onto series of blocks roughly corresponded to today's continents (fig. 1).

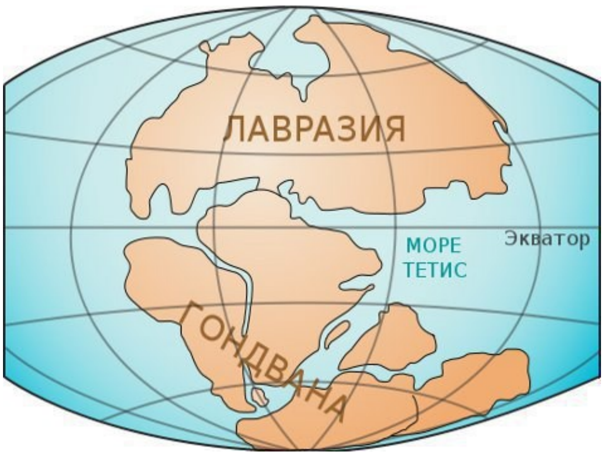

Figure 1: Splitting of original Pangea continent onto two constituents – Gondwana and Laurasia and following division these two onto plates of recent continents.

In this process within blocks north-south oriented stress has been created. Lesser in size blocks underwent rotation forming vortex structures (Lee Sy-guan, 1958). Recognition of the leading role of block's movement toward equator took place eliminate the main contradiction of plate tectonics demanding arrangements of mid-ocean ridges and island arcs as pairs generated tectonic movements due to spreading in mid-ocean ridges, compensated by subduction within island arcs' systems.

But the base for establishing character of connection between active volcanic processes and hydrothermal processes (Erlich, 1973). It is characteristic that heat flow in Urals is anomalously low in comparison with mountain systems of similar geological age (Salmanova, 2012). In her article one can find island arcs' cross-sections (fig.2).

On this figure is seen that the belt between deep-water trench and geanticlines' uplift of the outer arc or similar to it structures is characterized by decreased meanings of heat flow coinciding with a strip characterized by increased thickness of the crust.

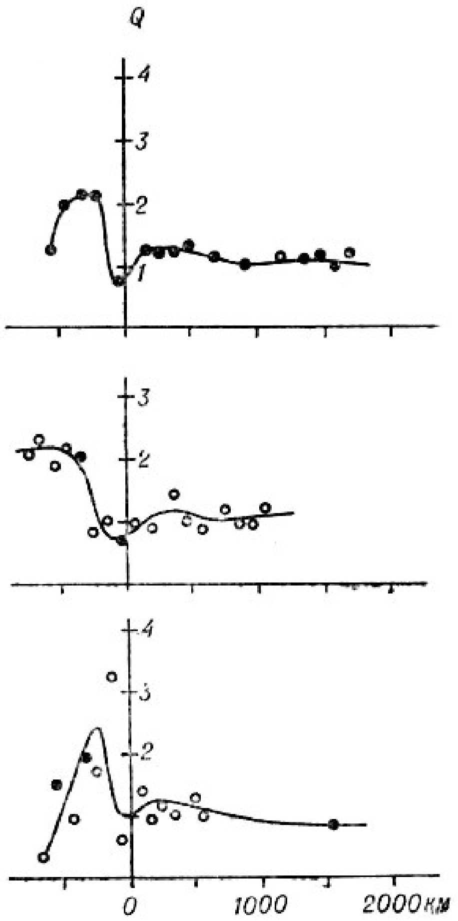

Figure 2: Distribution of heat flow within islands and similar to them tectonic systems. By [Hotta, 1970, cited from Erlich, 1973]; I -Kurile island arc, II – Japan, III – Bonin arc. Along horizontal axis are shown distances from deep-water trenches.

These data show that heat flow is determined by two sources – heat flow of volatiles going from the depth most probably from the Earth's core outer boundary and stress regime in the crust

Pressure applied by volcanic edifices on the ocean's bottom close to Hawaiian volcanoes resulted in lithosphere subsidence of lithosphere and Hawaiian ridge. Most volcanoes have been subsided for 2-4 km after their uplift over sea level and bottoms of volcanoes for 5-8 km[Moore, 1987]. The main part of subsidence occurred during about 1 mln. year after volcanism's started on the sea bottom and height of volcanoes has been decreased for about a half as a result of this process. Combination of weight of erupted material and evacuation of material from the depth for volcanoes' feeding generate lithosphere and volcanic islands' subsidence. Subsidence partly is generated by cooling and compression of lithosphere in process of its departure from mantle hot spot, which is a complete analog of anomalous heat flow.

Descending ridge influenced surrounding sea bottom at the distance more than 100 km from the ridge axis. Volcanic products of the ridge filled internal part of depression, but its external part remained lowered, and formed a trench on the sea bottom (Hawaiian trench). The axis of this trench is parallel to the ridge from each side and form an arc around southeastern end of the ridge with radius 140 km (fig. 3). The curvature's center is located on the island of Hawaii between summits of Mauna- Loa and Mauna-Kea Loa. Descending ridge influenced surrounding sea bottom at the distance more than 100 km from the ridge axis. Volcanic products of the ridge filled internal part of depression, but its external part remained lowered, and formed a trench on the sea bottom (Hawaiian trench). The axis of this trench is parallel to the ridge from each side and form an arc around southeastern end of the ridge with radius 140 km (fig. 3).

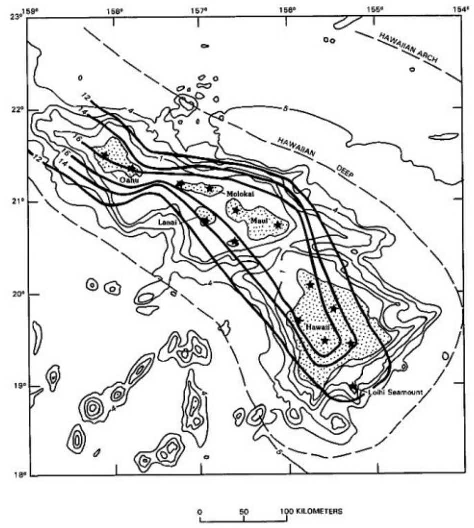

Figure 3: Location of Hawaiian volcanic ridge within linear structural depression [Moore, 1987]. Isolines indicate location of the Earth's crust bottom below sea level in km.

The evolution of Hawaiian volcanoes is shown in fig. 4. It shows that volcanic process occurred on the back of general subsidence reflected in the formation of a linear tectonic depression. The accumulation of volcanic material resulted in the formation of a accumulative ridge. As a result these processes formed a structure which in cross-section has the form of a two-fold lens, the lower part of which reflect tectonic subsidence and the upper the accumulation of volcanic products.

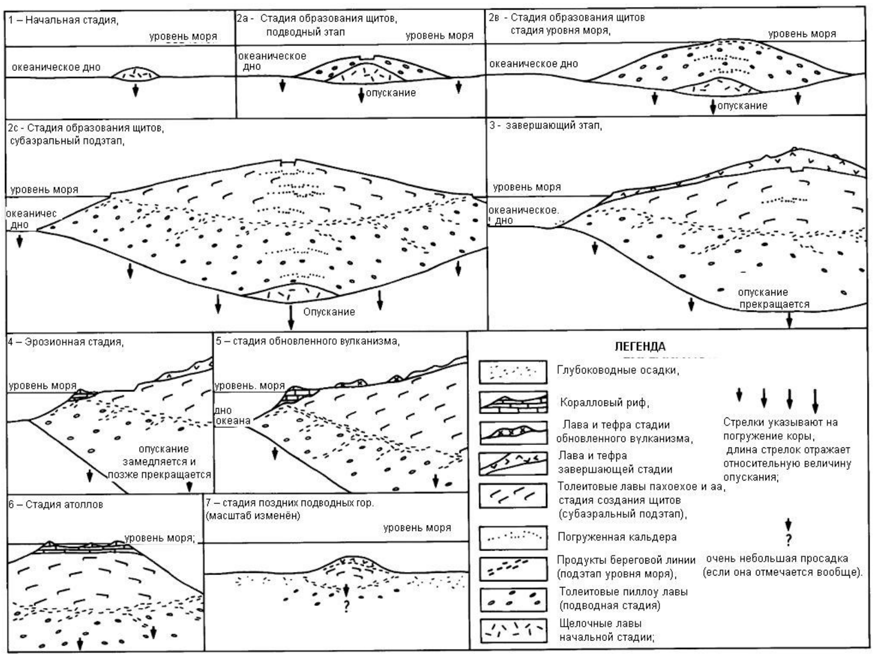

Figure 4: Diagrams of consequent stages of Hawaiian volcanoes evolution by [Peterson and Moor, 1987].

Due to the fact that in anomalous heat flows dominated convective heat transfer originated by the movement of Earth's matter in which such currents are active mobilized part of this matter to generate mechanical work. Joel established equivalency between heat and mechanical work equal quantitative ratio 1 kcal to 426.9 kgm. This suggested that conversion of 1 kcal of heat energy in tectonic movement resulted in elevation of 1 kg of rock on the height of about 400 m. In another words 1 kg of basaltic melt with heat content 400 kcal/kg as a result of conversion of heat into mechanical work resulted in elevation of about 400 kg of any rock to the same elevation. So emplacement of even small intrusive body under certain condition can produce great-scale deformation. Differentiated movements of Earth's crust in volcanic regions confirm such relationship of heat and tectonic processes. As has been shown above dominating forms of mobile belts' deformation are represented by subsidence of Earth's crust in the Upper Mantle interconnected with subsequent inversions.

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4. REGIONAL HEAT FLOWS

Regional heat flow from Earth's depth flows continuously toward Earth's surface. Its meaning is calculated by formula:

$$Q = -\lambda \cdot \text{grad}\, T,$$

where Q is heat flow, λ is the heat conductivity coefficient, and grad T is the temperature gradient. The heat meanings of the conductivity coefficient vary from n•10-3 cal/cm·c•°C, in average to 5·10-3 сал/cm·c•°C and vary for most the widespread types of rocks within narrow limits. Measurements of regional heat flows shows a conductivity coefficient of /1.5•10-6 кал см2s (a single unit of regional heat flow equals 10-6 cal/cm2 or 41.8 Wt/m•K).

Such regional heat flows were measured within regions of active volcanic activity. Average regional heat flows of continents (0,059 Wт/м2) and oceans (0,063 Wт/м2) were almost equal.

These data lead to the conclusion that regional heat flow is Earth's thermal parameter, as part of the Solar system. The Earth formed from solar-obtained potential heat energy including [Shklovsky, 1987]. The primary sources of Earth's energy obtained even in process of planet formation belong part of energy of gravitational accretion (energy of planetezimales' sedimentation onto Earth's surface) and energy of Earth's interior compression [Sorokhtin, Ushakov, 2002].

Regional heat flows have stable meanings heat transfer is conducted directly by heat conductivity. Formation of anomalous heat flows is probably associated with increased flow of volatiles from the outer core's border, which created the ability for gas flow migration in connection with the plate's centrifugal movements. This in turn created conditions for convective heat transfer.

5. ANOMALOUS HEAT FLOWS

Earth's anomalous heat flows are characteristic for the regions of recent volcanism, where magmatic, hydrothermal and seismotectonic processes are active. These events take place during the whole Earth's history. F.Pirajno (Pirajno, 2009) calls them 'thermal-tectonic' stressing connections of terrestrial heat and tectonic processes.

5.1. Heat Flows of the Hydrothermal Systems, Andesitic Volcanoes and Areas of the Mantle Volcanism

The scale of recent hydrothermal activity can be assessed by heat capacity of hydrothermal systems in the natural conditions. At the present time, the heat capacity of hydrothermal systems and thermal fields is determined as the total amount of heat evacuation by springs, vapor jets and fumaroles, heat evacuation from the areas of dispersed vapor outcrops ("steaming earth"), heat evacuation from the surface of hot rocks, conductive heat-transfer within areas of thermal fields and heat evacuation from the surface of warm lakes and boiling chambers. Table 1 shows data on heat capacity of thermal fields and hydrothermal systems in which all its constituents including hidden evacuation of high-temperature waters are taken into account to some degree (Averiev, 1967). Table 2 shows data of specific removal of heat, feeding of the hydrothermal systems (Kovalev, 1971).

Table 1. Heat capacity and specific heat evacuation (heat flow) of some hydrothermal systems and thermal fields in volcanic areas (Averiev, 1967).

Hydrothermal systems and thermal fields	Temperature in the system (in°C)	Heat capacity in thousands of kcal/sec	Density of flow feeding the system (kcal/sec per sq. km)
Iceland			
Torfaakul	230	500	
New Zealand			
Waotapu	up to 300	130	
Wairakei (befor drilling)	245	100	1200 for an area of 125 sq. km and 240 for an area of 1100 sq.km
Kamchatka			
Geyser Valley, includinng Uzon	ab. 250	90	2000-2500 for an area of 50 sq. km
Pauzhetka with Kambalny Mountain range (befor drilling)	up to 205	20	1300 for an area of 15 sq. km
Fumarolic fields of volcanoes			
Kamchatka and Kurile Islands			
Mutnovsky volcano	up to 600	60	
Avachisky volcano	>>	20	
Ebeko volcano	up to 140	24	

Table 2. Specific heat evacuation (heat flow) of the hydrothermal systems (Kovalev, 1971).

Hydrothermal systems	Heat capacity in thousands of kcal/sec	Square of heat feeding of system km^2	Heat flow of system kcal/km^{2}sec
Bolshoi Semjachik, Kamchatka	75	(80-160)	470-940
Uzon,	64	160	870
Valley of the Geyzer, Kamchatka	75		2000-2500
Mendeleev volcano, island Kunashir, Kuril islands	5-6	6	830-1000
Golovnin caldera, island Kunashir, Kuril islands	10-13	7	840-1100
Beppu, Japan	19	(25)	760
Hakone, Japan	11	50	220
Torfaäkull	500	(700)	720
Hengill, Island	55-80	80	690-1000
Ahuachapan, Salvador	80	80	1000
Taupo Volcanic zone, New Zealand	770	(1100-1600)	480-700
Taupo Volcanic zone with volcano White island	940	(1600)	590

Specific heat evacuation (ratio of the hydrothermal systems heat capacity to the area of their formation) permits to compare intensity of hydrothermal activities in different regions. It is characteristic that in hydrothermal systems the specific heat evacuation is of the same order, and it exceeds average planetary conductive heat losses in tens or hundreds of times. Some discrepancies in the values of specific heat evacuation in different hydrothermal systems occurred probably due to different approaches of the researchers to the determination of the borders of heat generation areas and due to the difficulties in precise delineation of the heat generation areas.

Kovalev G.N. (1971) estimated the specific heat evacuation of some andesitic volcanoes, which is the ratio of the average power of the volcano to the area of heat supply. The area of thermal power corresponds to the size of volcano-tectonic depression, particularly calderas, and of the anomalous depth zones identified by geophysical methods. It was assumed that the heat flow at depth is uniform across the horizontal cross section of this region due to the convection in the magma chamber, and is 300-1600 kcal/km^{2}sec.

Thus, in terms of energy, the hydrothermal system and andesitic volcanoes are equivalent.

The volcanic zone in the central part of Sredinny ridge in Kamchatka (Ogorodov et al., 1972) is the most appropriate for the evaluation of anomalous heat flow in the region of the mantle-basaltic volcanism. It is characterized by mosaic-block tectonics formed in the Quaternary Period. The eruption of great amount of basalts within grabens located on the crest of uplift (Erlich, 1965) was the most intense tectonic event of this period. Grabens have a telescopic structure. Second-order grabens are divided by elevated blocks and were not formed simultaneously. First-order grabens were the most penetrable for basaltic melts which is another indication of the close interconnection between volcanism and tectonic processes.

Products of the Quaternary volcanism of the Sredinny ridge belong to two complexes: the Lower Quaternary complex which corresponds to the first stage of volcanic activity and the Upper Quaternary Holocene complex which corresponds to the second stage. The total area of lava of the first stage is about 10,000 km^2 and its volume is about 3,000 km^3. The volume of basaltic lava of the second stage is about 1,700 km^3 and the most part of it was erupted over the area of 8,500 km^2 during the last 10,000 -12,000 years. In the volcanic region of the Sredinny ridge in Kamchatka, the heat transfer was controlled by the magmatic system from the upper mantle to the outpouring on the Earth's surface. The predominance of olivine basalt melts and their weak differentiation in the absence of contamination by the crustal rocks indicates their mantle nature.

Calculations show that the anomalous heat flow that accompanied this event was about 7,000-8,000 Kcal/km^{2}sec and exceeded by approximately 4-10 times the heat flux of hydrothermal systems (see tables 1, 2). The difference in the values of anomalous heat flows either between hydrothermal systems or between hydrothermal and magmatic systems occured because the anomalous heat flow assessment didn’t consider heat losses in volcanic and metamorphism processes and also by hidden evacuation of thermal waters. Also, these values are the result of the various estimates of heat generation areas. In addition, the difference of heat flows of areas of basaltic (mantle) volcanism and areas of development of hydrothermal activity and central (andesitic) volcanoes may be due to the accumulation of heat in the Earth's crust and geological processes such as the general heating of the Earth's crust, partial melting, granitization *in situ* (Chen G-N Grapes, 2007), deformation of host rocks, etc.

5.2. Anomalous Heat Flows, the Nature of the Earth’s Heat and Geological Structure of Hydrothermal-Magmatic Systems

The regime of anomalous heat flows (AHF) is controlled by their internal energy, heat nature and geological structure of the regions of heat-transfer channels (hydrothermal-magmatic systems). AHF internal energy is determined by the energy of heat-transfer agents and their interactions along the way of migration. Magmatic melts, water and gases are the main heat-transfer agents. Energy of magmatic melts is controlled by their composition.

Basaltic melt is characterized by high heat content (about 400 kcal/kg) and high temperatures (1,000-1,200°C). In accordance with this, water, gases and alkaline metals in basaltic magma have a greater dynamic ability in comparison to silicic melts (boiling temperatures Na – 883°C, K – 759°C, H_2O - 100°C; heat of vaporization Na ~ 920 kcal/kg, K ~ 500 kcal/kg, H_2O ~ 540 kcal/kg). They comprise the base of a high-energy trans-magmatic transfer agent contained in the basaltic melt in the condition of a low temperature plasma (Belousov, Erlich, 2012, Belousov, Belousova, 2016).

Basaltic magma migration starts from magmatic reservoirs located in the upper mantle (fig. 5). The melt is transported through the Earth's crust toward surface through flat channels with a large cooling surface. This process is associated with high heat losses which result in magma temperature drop. As a result, the high gradient of temperature occurs within the magmatic channel. Its value determines the velocity of magma movement.

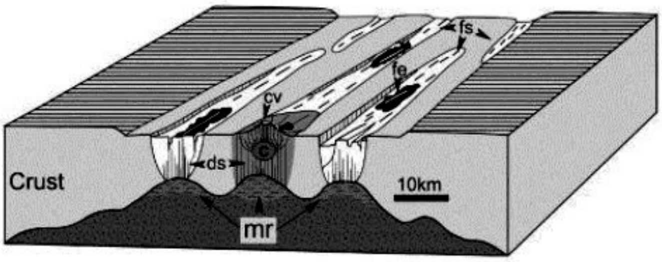

Figure 5: Schematic structure of magmatic system in Iceland (Thordarson, Larsen, 2007). Mr – magmatic reservoir; c – magma chamber in the crust; ds – dike swarm; cv- central volcano; fs – fissures swarm, fe –fissure eruption.

The formation of the mantle reservoir under the Earth's crust can be explained by magma heat transfer under shields of the partial melting magma pockets. CO_2 is the most common volatile component in the basalts of volcanic islands and mid-ocean ridges (Bottinga, Javoy, 1990). This is predetermined by the relatively high surface energy of basaltic melts. Formation of CO_2 requires its saturation excess in 1.5-7 times, which depends on the pressure. Under P>100 bars, in bubbles of such basalts CO_2 is prevailed. Within wide range of geological structures, gases-transporters (CO_2 и CH_4) can be considered as dominated. They control transfer and redistribution of the track gases and other volatile components migrating toward the Earth's surface (Etiope, Martinelli, 2002). It is suggested that separation of CO_2 has place within depths from 25 to 40 km (Lowenstern, 2001). This can stimulate increasing of heat losses. Basalts of the mid-ocean ridge contain bubbles with increased quantities of CO_2 (about 6% of total amount of water initially dissolved in magma). Due to the fact that water in the gas form is characterized by increased enthalpy (under the temperature 1000°C – higher than 1,000 kcal/kg) its separation from the melt leads to decrease in temperature and solidification of the melt. The result is the formation of a horizon completely formed by dikes above the basaltic magma reservoir (fig. 6).

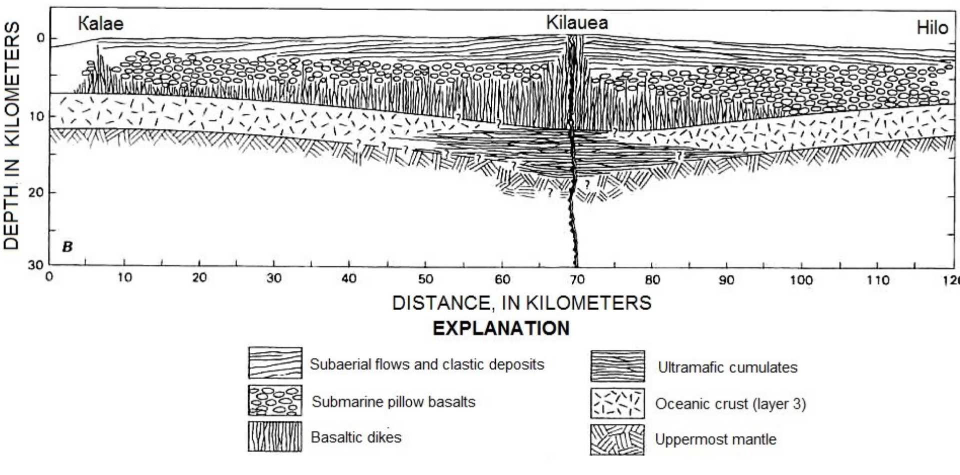

Figure 6: Schematic cross-section of Kilauea volcano, Hawaii geological structure (Hill, Zucca, 1987).

The structure of this horizon and character of dikes emplacement indicate high internal energy of basaltic magma in the mantle reservoir because it intrudes without any mechanical deformation of host rocks and doesn't use any fissures and faults.

It is suggested that under the shield of the dikes horizon (heat isolator) which is constantly renewing and serves as an accumulator of heat energy, magma determines the formation of a high-energy transmagmatic fluid. When thermodynamic parameters of the fluid reach their critical values corresponding to the thermophysical properties of the shield, fluids transform into the low-temperature plasma. Concentrating within apical parts of the magmatic reservoir, transmagmatic fluids burn the overlapping solid basalts without any significant deformation of host rocks (Belousov, 1978; Belousov, Belousova, 2016).

In the course of uprising, melt emits the gas phase of transmagmatic fluids, transforms into the two-phase condition and thus increases the velocity of flowing due to the uplift of gas bubbles (gaslift). Such process of eruption in mantle basaltic reservoirs and the pressure onto the surface of volcanic edifices on the background of general uplift can explain the rift formation within volcanic regions.

Central volcanoes associated with calderas and high-temperature hydrothermal systems erupt andesitic and silicic magma from shallow magma chambers. These melts are characterized by lower heat content (~250-300 kcal/kg) and decreased temperatures (800-1,000°C) which determine their physical conditions. A.T. Anderson (Anderson, 1976) thinks that these magmas are formed within the Earth's crust saturated by volatile components. Immediately before eruptions the most part of such magmas is mixed with basaltic magma that intruded from mantle reservoirs. Mixed magmas rise along the cylindrical channels in a plastic state. It emerges into the surface accompanied with blasts. The upper part of such melts interacts with underground meteor waters. Their boiling generates hydrothermal and hydrothermal-magmatic eruptions characterized by the evacuation of the great amount of heat. In the magmatic system the high temperature gradient is generated which stimulates the migration of transmagmatic fluids upward (Belousov, Belousova, 2016). Such forced heat convection moves "solid melts" toward the areas with lower temperatures. The result of the acid magmas migration is the deformation of hot rocks.

Crustal magma chambers became traps of basaltic magmas. According to A. Gudmundsson's model (Gudmundsson, 1995), the part of space needed for such chambers is being formed in the process of anatexis, melting of rocks with appropriate composition and evacuation of host rocks in the process of the eruption. These processes affect the melts ability to flow, their plasticity and migration in the form of diapirs, domes and volcanic ridges. Such chambers are one of the forms of heat accumulation and its dissipation within the underground hydrosphere. For a long time they sustain high temperatures in the upper parts of hydrothermal-magmatic systems which supports the heat transfer in regime of self-organizations from the magma-generation areas to the surface.

There are easily melted rocks - the products of underwater hydrothermal-magmatic systems – in the thick rocks which fill subsidence structures. They contain volcanogenic-silicic formations with biogenetic carbon and sulfides, massive sulfides and Kuroko-type deposits, hydrocarbons etc. Sometimes they can be subject to reduction-oxidation reactions associated with the evacuation of high amount of heat. Probability of such reactions is confirmed by the composition of fumaroles gases such as CO_2, SO_2 etc. within central volcanoes which suggest burning of sulfides and carbonaceous compounds within the depths of hydrothermal-magmatic systems.

6. INFLUENCE OF HEAT FLOWS ON THE EVOLUTION OF EARTH'S CRUST OF VOLCANIC REGIONS

The Earth's crust of the volcanic regions is slowly descending in the upper mantle partly melted up to the depth of several hundreds kilometers (Gudmundsson, 1995; Decker, 1987). The melt in the mantle migrates upward and accumulates in the areas with elevated bottom of the crust forming a magmatic reservoir. The process of its accumulation is accompanied by the increase in the concentration of highly energetic transmagmatic fluids. From time to time the Earth's crust becomes penetrable for these fluids with critical concentrations. Intrusion of such fluids and basaltic melts are determined by heat accumulation and increasing capacity of rising heat flows with self-organization behavior. The Earth's crust thickness grew by differentiated rocks in which long-living heat-conducting systems are forming. Such systems support the active heat transfer and generate heat by chemical reactions.

As a result of further evolution of hydrothermal-magmatic systems the increasing growth of heat-isolating horizon completely formed by solid dikes takes place as well as the expansion of newly formed thermal field under this horizon. Transmagmatic fluids migrate faster and accumulate within dome-like uplifts of the dikes layer base. This horizon becomes thicker and its heat-isolating properties grow. The Earth's crust thickness grows downward and magmatic melts are displaced into uplifts. The rising magmatic flow can be divided by the root of the belt of active hydrothermal-magmatic systems. Superficial erosion, evacuation of disintegrated material of volcanic edifices and its deposition in the adjacent depressions result in the formation of sedimentary masses on both sides of the belt of hydrothermal-magmatic systems. The thickest sedimentary masses are being formed in the enclosed depressions. They also become heat-isolators for one of branches of the rising mantle current under which the heat accumulation takes place. As the heat flow within side currents is weaker than in the main current, the velocity of heat accumulation under sedimentary sequence is lower than in the main current. Thermal activity in this belt in a form of hydrothermal-magmatic systems may occur later. Thick sedimentary masses deposited directly on descending oceanic crust hide heat discharge. The most part of heat energy is consumed for their transformation expressed in metamorphism and formation of great magma chambers with granitic melts.

At a later stage of the evolution of this part of the mobile belt due to the infusion of melts and fluids from the mantle reservoirs, the expansion of the earth's crust and the elevation of its upper part against the general lowering of the movable belt (inversion).

As in the case of magmatic-hydrothermal systems, the lower part of the oceanic crust becomes thicker, its heat-isolation increases and permeability decreases. Transformation of the sedimentary masses which thickness can reach tens of kilometers results in the general uplift of this part of the mobile belt.

The second branch of the mantle current looks toward ocean. Sedimentation decreases, and its capacity is insufficient for the accumulation of the heat amount required for the formation of hydrothermal-magmatic systems. However, it is possible that heat accumulation continues close to the crust's bottom which is accompanied by formation of small anatexis magmatic chambers, their rise to the surface and the Earth's crust mechanical deformations. Thus, the discharge of this heat flow results in seismotectonic processes.

7. HYPOTHESIS ON SOURCES OF EARTH'S HEAT

Dominating concepts of planet thermal evolution associate it with the process of gravitational energy release connected with primordial planet contraction (compression). It is also suggested that the source of energy is disintegration of long-living radioactive elements. Planetary differentiation is also the reason of elevation (advection) of hot mantle currents generated within different depths of the Earth's interior. Evaluations of endogenous processes' moving forces are only of qualitative character (Antonov, 2007).

On the base of data obtained as a result of study of hydrothermal-magmatic systems within active volcanic regions it has been made a conclusion that energy of anomalous heat flows is the main endogenous force of geological processes.

Anomalous heat flow value within regions of recent volcanic activity is in average in two orders of magnitude higher than the values of regional heat flows. Due to this fact anomalous heat flows in the regions of recent volcanic activity can be originated from other sources. The most known among them are exothermal chemical reactions. Such reactions within hydrothermal-magmatic systems are determined by the products of their degassing. The good example of this is represented by Hawaiian volcanoes which energy comes from the upper mantle. For gases of the Kilauea volcano the fraction of sulfur combinations (SO_2, H_2S) is almost equal to the H_2O content and that indicates the great role of sulfur in chemical reactions within the upper mantle. Some scientists think that the upper mantle is characterized by chalcogenic composition and can contain silica sulfides (Osipov, 1996). The most widespread there probably is silica disulfides (SiS_2). It is not known at the Earth's surface because it is decomposed by water onto SiO_2 and H_2S. It is formed under 1,300°C in the course of reaction ($2H_2S + Si = SiS_2 + 2H_2$). The H_2S presence in volcanic gases confirms probability of such processes. It is suggested that periodic infusion of marine waters in the upper mantle resulted in transformation of disulfide into silica oxide. As a result of this process heat is generated. Besides of silica disulfide, in the upper mantle and the lower part of the Earth's crust metal sulfides among which pyrite is prevailed can be found. It is well known that oceanic water is saturated with oxygen. Within northern polar regions at the depths 1,500-2,000 m saturation with oxygen reach 88-97%, close to the equator - 30-40% and within southern polar regions - 60—70%. Fast infusion of such waters can generate the following reaction:

$$4FeS_2 + 11O_2 = 2Fe_2O_3 + 8\ SO_2 + 790\ \text{kcal}$$

Such reaction can take place under the temperature 800°C and more.

All andesitic, dacitic and rhyolitic eruptions within island arcs are characterized by exceeding S content which is not typical for basaltic volcanoes of hot spots. Some basaltic volcanoes of island arcs are not characterized by high sulfur exceedance, and the constant degassing of volcanoes is characterized by a high excess of sulfur caused by the generation and dissolution of gas from the melt at the shallow depths (Wallace, 2005). Wallace concluded that due to the increased sulfur dissolution in low-temperature silicic magmas sulfur can be presented in the form of bubbles dispersed in magmas at shallow depths. High amounts of volatile components participating in eruptions lead to suggestion that they are concentrated within apical parts of magmatic bodies during the periods of rest between eruptions and can be incorporated by hydrothermal traps located above the magma chambers. The presence of outgoing vapor phase within crystallizing magmatic bodies can play an important role in volcanic eruptions stimulation. Besides, the presence of S and CO_2 in the vapor phase can be a result of mafic magma injections.

However, this concept is questionable, since the concentration of sulfur in acidic magmas does not allow the emergence of such "excess" flows of sulfur. In addition, such sulfur flows often precede the eruptions of magmatic melts, which can be explained by the discharge of additional heat. Such heat flow is possible not only due to the influx of basaltic magma from the mantle reservoir, as it would, on the contrary, reduce the concentration of sulfur in the crust hearth. Our preferred concept is that the excess fraction of sulfur in the composition of the volatile phase of the central volcanoes is formed as a result of the expansion of magma chambers due to the melting of the surrounding rocks of the volcanogenic-siliceous formations containing sulfides (black shales), deposits of massive sulfides and Kuroko type sulfides. The combustion of sulfides and carbon of these entities generates an additional heat flow, which also supports the "operating status" of the hydrothermal-magmatic system.

The discovery of hydrothermal rocks within Rainbow and Lost City hydrothermal systems provided a possibility to study chemical and heat-generating processes associated with serpentinization (Allen, Seyfried, 2004). The heat balance models showed that heat generation during serpentinization is insignificant. But it has been shown that such a process of the heat formation by chemical reactions exists and is widespread.

Heat generation as a result of radioactive isotopes break-up is suggested by many scientists. It has been considered that this source of heat provided all the thermal activity of the Earth. But the recent researches show that this source of the heat can not be the source of regional heat flows and much less the anomalous heat flows of active volcanic regions.

The high concentrations of ^4He (0.5–6.9%) were determined within some regions of India. It is suggested that such concentrations of He are caused by the break-up of U and Thorium within Precambrian basement. It has been confirmed for this region by heat flow values of 145–200 MW/m^2 which are twice higher than the values of the global heat flow and are equal to the heat flow of mid-ocean ridges (Gettings et al., 1986). Such heat flows here can be caused by the heat generation as a result of break-up of long-living radioactive elements.

The comparative analysis of anomalous heat flow sources shows that almost all of them are of the chemical nature. Exothermic chemical reactions within the upper mantle and Earth's crust take place in liquid water receiving energy from the Sun. Thermo-nuclear synthesis of light isotopes generates the heat which is transferred to the Earth by electromagnetic radiation and warms up its surface to the sufficient degree in order to sustain water in liquid condition. Liquid water produces mechanical work and chemical reactions resulted in the formation of products participating in exothermal reactions (sources of heat), anomalous heat flows accompanied by appropriate tectonic processes. On the final stage of such circulation the heat energy is dissipated in the Space, come to the zone of Sun's influence. Such cyclic processes of the solar-terrestrial energy relations are in accordance with the law of conservation of energy.

8. CONCLUSION

The title of this page contains names of two processes – tectonics and heat flows but any review of heat-transfer can't be consider complete without consideration of role of volcanism in this process.

Mass manifestations of volcanism are of global character. Moreover when we worked on stratigraphy of Quaternary volcanic sequences of Kamchatka [Erlich, 1973, Melekestsev, Braitseva et al., 1974] we to our surprise discovered that absolutely independent researchers of different countries (Japan, New Zealand, USA) drew identical picture of Quaternary volcanism evolution. Thus were established global cycles of volcanic processes in the scale of thousand years. In ideologically-charged Soviet environment we have been charged in Ultrastilleanism.

Each cycle started by basaltic eruptions and completed by silicic volcanism. Masses of volcanic products conduct process of heat dissipation conducted from the depth in the form of lavas (in the course of basaltic volcanism) or pyroclastic flows in particular thick covers of ignimbrites associated with caldera-forming eruptions. Thus cycles of volcanic activity observed at the surface reflect deep-seated processes of heat- and mass-transfer. It looks similar to formula pronounced at the time of burials: "Earth to earth, ashes to ashes''.

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REFERENCES

Allen, D. E. and Seyfried, W. E. Jr.: Serpentinization and heat generation: Constraints from Lost City and Rainbow hydrothermal systems, Geochimica et Cosmochimica Acta, Vol. 68, No. 6, (2004), 1347-1354.

Anderson, A.T.: Magma mixing: petrological process and volcanological tool, Journal of Volcanology and Geothermal Research, Volume 1, Issue 1, June 1976, 3-33.

Antonov, A. Yu.: Critical review of views on the main geodynamic areas of modern geological science in the context of informative advertising the main scientific publications of Russia (part two), Herald kraunts. Earth science. №2. vol. No. 10, (2007), 118-128.

Aver'ev, V. V.: Hydrothermal process in volcanic areas and its relations to magmatic activity. Bulletin of Volcanology, Vol. 30, Issue 1, (1967), 51-62.

Belousov, V. V.: Fundamentals of geotectonics. M., "Nedra", (1975).

Belousov, V.I.: Role of geologic-structural factors in formation and activity of hydrothermal systems within recent volcanic regions. Autoreferat of candidate dissertation of geologic-mineralogical science Petropavlovsk-Kamchatsky, (1967) (in Russian).

Belousov, V.I., Belousova, I.V. Heat Transfer in Hydrothermal-Magmatic Systems//Proceedings, Fourtieth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 22-24, 2016SGP-TR-209

Belousov, V. I.: Geology of geothermal fields in the areas of modern volcanism. M.: Nauka, (1978).

Belousov, V.I., Erlich, E. N.: The heat of the Earth /https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnx2dWxrYW5pY2Vza2fhz2vvbg9nawf8z3g6mzdlntczzjdjmgjhmjyxng/

Belousov, V.I., Belousov, A. B., Belousova, M. G.: Deposits and sequence of events of the eruption of Bezymyanny volcano (Kamchatka) on the March 30,1956: deposits of fragmental avalanche, Volcanology and seismology, №1, (1998), 25-40, (in Russian).

Bottinga, Y. and Javoy, M.: MORB degassing: Bubble growth and ascent. Chem. Geol., 81, (1990), 255-270.

Chandrasekharam, D.: Geothermal energy resources of India: country update, Proceedings World Geothermal Congress, (2000), 133-145.

Chen, G-N., Grapes, R.: Granite genesis: in situ melting and crustal evolution, Springer, (2007).

Clifford, T. N.: Tectonomagmatic units and metallogenic provinces in Africa, Earth and Planetary Science Lett. 1, (1966), 321-436.

Davies, G. F.: Dynamic earth: plates, plumes, and mantle convection, Cambridge University Press, (1999).

Decker, R. W.: Dynamica of Hawaiian volcanoes: an overview, Chapter 42, Volcanism in Hawaii, (1987), 997-1118.

Demidov P.G.: Burning and properties of inflammable matters, M., (1962), 264, (in Russian).

Erlich, E. N.: Geodynamics and magmatism of platforms. Saints Petersburg, Publishing house "Napisano perom", (2016).

Erlich, E. N.: Recent structure and Quaternary volcanism of the Western part of the Circum-Pacific, Novosibirsk, Nauka, (1973).

Erlich, E. N.: On the structural position of Quaternary volcanism in Kamchatka, Geotectonics, № 1, (1965), 93-105, (in Russian).

Etiope, G. and G. Martinelli.: Migration of carrier and trace gases in the geosphere: an overview // Physics of the Earth and Planetary Interiors 129 (2002), 185-204.

Gardens, N. In. Kozhemyaka N. N., Ageevskaya O. A., Ogorodova, A. S.: Volcanoes and Quaternary volcanism of the Sredinny ridge of Kamchatka. Iz-vo "Nauka", M, (1972).

Gastil, G.: The distribution of mineral dates in time and space, Amer. Jour. Sci., V. 258, (1960), 1-35.

Gettings, M. E., H. R. Blank, W. D. Mooney, and Healey, J. H.: Crustal structure of southwestern Saudi Arabia. Jnl. Geophy. Res. Vol. 91, (1986), 6491-6512.

Greenland, L.P.: Hawaiian eruptive gases. Volcanism in Hawaii, chapter 28, (1977), 759-770.

Gudmundsson, A.: Infrastructure and mechanics of volcanic systems in Iceland/Journal of Volcanology and Geothermal Research 64, (1995), l-22.

Gunnarsson, B., B. D. Marsh, and H. P. Taylor, Jr.: Geology and petrology of postglacial silicic lavas from the SW part of the Torfajökull central volcano, Iceland. J. Volcanology and Geotherm. Res. 83, (1998), 1-45.

Hotta, H.: A crustal section across the Izu-Ogasawara Arc and Trench. J. Phys. Earth, 18, (1970), 125-141.

Khain, V. E., Lomize, M. G.: Geotectonics with bases of geodynamics//Tutorial. For students of geological specialties. M: Izd-vo MGU (1995).

Kovalev, G. P.: Method of measurement of dissipated evacuation of heat within thermal fields, Bulletin of volcanoloical stations, № 42, (1966).

Kovalev, G. N.: Some quantitative ratios in modern volcanic process// abstract dis. (1971).

Lee Sy-guan: Vortex structures of North-western China. M., State publishing house of scientific-technical literature in geology and environmental protection, (1958), (in Russian).

Lowenstern, J. B.: Carbon dioxide in magmas and implications for hydrothermal systems //Mineralium deposita is 36, (2001), 490-502.

Melekestsev, I.V., Braitseva, O.A., Erlich, E.N., Shantser, A.E., Chelebaeva, A.I., Lupikina, Ye.G., Yegorova, I.A., Kozhemyaka, N.N.: Kamchatka, Kurile and Kommandor islands// The history of relief development of Siberia and Far East. /I. V. Luvchitsky, ed., M. Nauka, 1974, (in Russian).

Milankovich, M.: Kanon der Erdlestruhlung und seine Anwendung auf des Enzeien problem. Acad. Roy.Serbe, ed. Sp. 1, CXXXI, sec. De Sci. Math et Nat., 383, Belgrade, (1941).

Moore, J. G.: Subsidence of the Hawaiian Ridge, Chapter 2, Volcanism in Hawaii, (1987), 85-100.

Ogorodov, N. V. Kozhemyaka, N. N., Vageevskaya, O. A., Ogorodova, A. S.: Volcanoes and Quaternary volcanism of the Sredinny ridge of Kamchatka. Iz-vo "Nauka", M. (1972).

Osipov, V. P.: Self-organization in the evolution of galaxies, stars and planets (1996).

Papers to Commemorate the 75th Anniversary of the Founding of the Hawaiian Volcano Observatory, *by* Robert W. Decker, Thomas L. Wright, and Peter H. Stauffe, eds.

Peterson, D. W. and Moore: Life Stages of Hawaiian Volcanoes. In: Volcanism in Hawaii, (1987).

Pirajno, F.: Hydrothermal Processes and Mineral Systems, Chapter 4, Springer, Geological Survey of Western Australia, (2009), 205-354.

Righter, K., Chesley, J. T., Ruiz, J.: Genesis of primitive arc basalt: constraints from Re, Os and Cl on the depth of melting and role of fluids. Geology 30, (2002), 619-622.

Rubinstein, M. M.: Orogenic phases and periods of folding in he light of data of absolute geochronology. Geotectonics, №2, (19367), 35-49, (in Russian).

Sal'manova, R. Yu.: Structure of heat flow of Southern Urals with paleoclimate conideration. Scientific library of dissertations and authoreferats http://www.dissercat.com/content/struktura-teplovogo-potoka-yuzhnogo-urala-s-uchetom-vliyaniya-paleoklimata#ixzz4Q4xXxhnO , (2012), (in Russian).

Schapov, V.A.: Geothermic studies in Urals, Autoreferat of dissertation http://earthpapers.net/geotermicheskie-issledovaniya-urala#ixzz4Q4yWiqY2 , (2012), (in Russian).

Sharp, R. P., Dzurisin D.& Malin, M. C.: An early 19th century reticulite pumice from Kilauea Volcano Volcanism in Hawaii, (1987), 395-405.

Shirokov, V. A.: Working out new methods of long-term forecast of volcanic eruptions by studying of astral factors influence onto them.//Materials of annual conference devoted to the Day of Volcanologist, March 27-29, (2008), city of Petropavlovsk-Kamchatsky: IV&S Far East division of RAN, 315-322, (in Russian).

Shklovsky, I.S.: The universe, life, mind (1987).

Sidorov, A. A., Thomson I. N.: Ore-bearing black-shale sequences: convergence of alternative concepts, Herald of the Russian Academy of Sciences, volume 70, No. 8, (2000), 719-724.

Sorokhtin, O. G., Ushakov, S.A.: Development of the Earth, Publishing house of Moscow state University, (2002), (in Russian).

Stille, H.: Geoteconische Gliderung der Erdesgeschifte. Berlin, Gebruden und Berntraeger, (1924), 459, (in German).

Svatlovsky, A. Ye.: Structural volcanology, M., «Nedra», (1971), 232, (in Russian).

Teplow, W., Marsh, B., Hulen, J., Spielman, P., M., Kaleikini, D. Fitch, and W. Rickard.: Dacite Melt at the Puna Geothermal Venture Wellfield, Big Island of Hawaii// GRC Transactions, Vol. 33, (2009), 989-994.

Thordarson, T., Larsen G.: Volcanism in Iceland in historical time: Volcano types, eruption styles and eruptive history//Journal of Geodynamics, 43, (2007) 118-152.

Wallace, P. J.: Volatiles in subduction zone magmas: concentrations and fluxes based on melt inclusion and volcanic gas data, Journal of Volcanology and Geothermal Research 140, (2005), 217-240.

Zemtsov, A. N., Tron' A. A.: Statistical treatment of catalogues of volcanoes of the World, Doklady Academy of Science USSR, (1985), 583-585, (in Russian).