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Research Paper

Pulsating Electromagnetic Sounding Method as a basis for determining deep substance mobilization and migration

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***ABSTRACT**: The evolution of deep matter occurs when it rises to the surface of the planet. Deep matter, conventionally, can be divided into two interrelated components: magmatic melts and deep degassing products – fluids. In vast majority, the lithosphere fluids are most likely not solutions but gas mixtures, because the existence of aqueous solutions and H_2O vapors is possible only in the uppermost horizons of the Earth's crust. Typically, fluid heat and mass transfer across the lithosphere occurs mainly in gaseous state and can enter into geochemical processes with the environment through which it passes.*
The mechanisms of transportation of fluids and their interaction with rocks are determined by the depth, temperature and pressure in the direction from the interior to surface of the Earth.
The consequences of outside impact on an open system will be its tendency to adequately respond to external changes through the processes of self-organization of the system and possibility of its continuous development due to the influence of endogenous processes. Depending on the depth of fluid formation, the energy state of the fluid and its ability to contact with other rocks of the lithosphere are evolved, as well as the ability to fill volcanic and volcanic-sedimentary reservoirs. The method of pulsating electromagnetic sounding makes it possible to determine the zones of origin and migration of deep fluids at hydrocarbon deposits and in coal rock massifs.
***KEY WORDS:** pulsating electromagnetic sounding method, deep matter, fluids, lithosphere.*

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I. INTRODUCTION

An important direction of increasing the efficiency of geologo-geophysical investigations at search and exploration of minerals associated with migration of deep fluids is the development of new express technologies for detection and mapping of the latter. Such new experimental methods and unconventional technologies include the method of pulsating electromagnetic sounding (PEMS).

Before moving on to the analysis of endogenous processes and migration of fluids available for survey in the upper parts of the lithosphere, it is necessary to emphasize the uniqueness of geological development of the Earth which has being formed for more than 4 billion years by laws of self-organization, and this process is irreversible. The planet evolution is caused by endogenous and exogenous processes, in particular, tectono-plutonic and tectono-magmatic cycles. The cyclic development of endogenous processes is based on the mechanism of pulsating degassing and is expressed as periodic occurence of volcanism and magmatism manifestations under the influence of which specific basins are formed on the shields and in the sedimentary cover where mineral deposits are formed. In the course of the Earth degassing, during which the deep matter and fluids play a leading role, the lithosphere, atmosphere and hydrosphere undergo transformation. Mainly due to endogenous processes, the state of all shells of the planet changes during its development.

The evolution of the deep matter occurs when it rises to the surface of the planet. Conventionally, the deep substance can be divided into two interrelated components: magmatic melts and deep degassing products – fluids. In vast majority, the lithosphere fluids are most likely not solutions but gas mixtures, because the existence of aqueous solutions and H2O vapors is possible only in the uppermost horizons of the Earth's crust. Usually, the fluid heat and mass transfer through the lithosphere proceeds predominantly in gaseous state and can enter into geochemical processes with the environment through which it passes.

A great number of scientists were engaged in investigations of deep matter of the Earth, its age, changes and contacts with the environment. Researches of O.M. Ponomarenko determine the role of hydrogen in the modern gas migration at the planet. Summarizing works of V.M. Shestopalov support and develop the "gas respiration" direction and determine certain interrelations in the modern gas migration. E.F. Shniukov's studies are devoted to mud volcanoes of the Crimea and Black Sea and establish, in particular, the formation depth of modern emissions. F.A. Letnikov focuses his works on diverse studies of modern gas migration correlating them with the formation of ore deposits. F.A. Letnikov's views on the effect of fluids in the formation of ore deposits are shared by L.S. Galetsky. The works of A.Ya. Radziwill are aimed mainly at determination of influence of tectono-magmatic events on redistribution of matter and energy in the lithosphere. Chemical composition of fluids and their relationship with the lithosphere rocks were investigated by A.D. Bondar. G.N. Dolenko has substantiated the effect of inflows in the formation of oil and gas deposits of the Western oil and gas bearing region.

Their efforts have laid a conceptual basis for study of fluids in geological environments and, in particular, of fluid input in the formation of minerals. At the same time, many issues remain unresolved, and determination of depths of formations and migration zones of fluids is among them.

Goal

• to determine the depths of origin of fluid systems;

• to find out the mechanisms of transportation of fluids and their interaction with rocks at different depths, temperatures and pressures;

• to determine the processes of self-organization in fluid systems;

• to evaluate the connection of fluid formation and migration zones with volcanic and volcanic-sedimentary collectors.

II. METHOD

This publication is based on the production reports, geophysical researches, scientific publications and field and analytical studies conducted by the author.

For comprehensive electrical survey (PEMS), the «Phoenix 10-01» instrumentation was used having inductance measuring sensors made in the form of coaxial coils with the effective length of receiving circuit of 200 meters and the four-meter generator circuit, as well as a GPS-GLONASS positioning system Trimble GEO-7x with RTK support.

Researches using the PEMS method allow to do the following:

- to conduct multicomponent measurements permitting to create the 3D (and more) information systems;
- to allocate zones of formation and migration of fluids.

The method can be used for researches on land and in marine waters.

Presentation of basic research material

The PEMS method permits to record the flows of fluids which rise from deep horizons lining a sedimentary complex or from deep intrusions (postvolcanic processes) and can accumulate in traps (collectors) of both sedimentary or sedimentary-volcanic and volcanic nature. We consider fluid as a gas, steam, liquid-gas or liquid substance that is stored in and/or transferred through the masses of rocks of the lithosphere. The fluid components combine with the lithosphere elements and accumulate in the points of contact or are transferred higher up to the place of accumulation. A fluid system is a set of fluid components that form a stationary system with boundary physico-chemical parameters determined by the fluid regime and processes of self-organization of the environment. A fluid mode is a set of physico-chemical parameters that characterize the state of the fluid system. If any component or parameter changes, an irrevocable change in the environment takes place due to self-organization, which is well fixed by the PEMS method.

In oil and gas collectors and carbohydrate arrays there are hydrogen-hydrocarbon or hydrocarbon-hydrogen fluids, which are determined by the composition of gas mixtures. In oil and gas and coal-hydrocarbon fields, the content of homologues of methane and hydrogen increases with increasing depth. Hydrocarbon deposits are characterized by changes with depth: first, they are of pure gas which gradually turns into gas condensate and then into gas and oil condensate with light oil. Along with change in depth and component composition, the isotope composition of hydrocarbon gases also changes.

In the Earth interior, streams of convective-diffusion hydrocarbon gases are observed at the degassing of rocks and gas-containing deposits which are controlled by the cessation or significant decrease in the inflow of hydrocarbons. Therefore, the most likely model of formation of clusters of hydrocarbon gases in gas, gas condensate oil and coal deposits is the one in which there is a continuous feeding of deposits with hydrocarbon gases of deep genesis, which are probably formed due to decay of hydrides of various elements in the deep interior of the Earth. Although it is possible that hydrocarbon gases at these depths can be of juvenile nature. The inflow of deep hydrocarbon-hydrogen gases into all sorts of deposits not only affects the isotope composition of carbon of these deposits, but also contributes to chemical interaction between the components of the hydrocarbon-hydrogen flow and condensed organics of sedimentary rocks, primarily due to mechano-chemical processes [1].

At the same time, the secondary calcite veins of 0.1 mm or calcite cores with a capacity of up to 10 cm were recorded in coal layers and excavations of the Krasnoarmiisk Coal Industry Region (Ukraine) indicating on a liquid state of fluid with low temperatures. The modern migration of fluids in coal-producing massifs is evidenced by new carbonate-calcite formations observed on sandstones in temporarily closed down coal excavations prepared for development (Fig. 1a, 1b). The isotope composition of hydrocarbons found in them correlates with characteristics of carbonates that line these excavations. The revealed manifestations of fluid migration may be defined as periodic or interruptive-continuous in character depending on the initial and final stages of the new formation in the coal-producing massif and changes in the component (fluid) composition in the hydrocarbon deposits.

Fig. 1a

Fig. 1b

Figure 1 a, b: Modern new formations in prepared for excavation drifts of mine "Pioner" of colliery group Bilozirske of DTEK "Dobropilliavugillia" (1 year without mining)

III. RESULTS AND DISCUSSION

1. Fluid migration from depths

As confirmed by the PEMS method for the Donbas and Dnieper-Don depression (DDD) structures, all the variety of endogenous processes in the lithosphere is associated with transfer of fluids.

The role of deep faults as active conductors of high-energy fluids initiating the processes of formation of mineral deposits has become apparent long ago [1-9].

The driving forces of the transfer are huge pressure gradients (at spans of tens or even hundreds kilometres between the interior and surface of the Earth). The variety of models of fluid transfer through the lithosphere may, in general, be reduced to two:

1. migration of fluids in fracture zones through cracks and pores. With depth, the cracking disappears;
2. small-amplitude deformations are replaced by plastic ones, and the stratum goes into a state of viscous-plastic flow.

Experiments conducted with high-pressure plants have led to discovery of intensive movement of fluids through fissile metamorphic strongly fragmented rocks - tectonites - which form a deep fault zone. It turned out that, in the mass amount, this mechanism by several orders surpasses the volumetric fluid transfer by fractured zones and consists in the slipping of fluid films along fissile areas almost at a submolecular level. It is obvious that tectonite zones are the path of universal and intensive mass transfer of rock-forming fluid components through the lithosphere. The higher is the maturity of tectonites (the degree of their fissilization), the greater is their "mass conductivity ", that is, the more fissile areas are contained in rock, the higher is its ability to transfer the substance. Such approach has made it possible to explain the leading role of deep faults in the transit transfer of fluid and other components from mantle to the upper horizons of the Earth's crust. This mechanism is universal and takes place throughout the cross-section of the lithosphere. Only in the upper parts of faults where plastic deformations turn into fragile ones, the fluids change in character from film-like to voluminous formations and migrate through the system of large pores and cracks. Accordingly, their interaction with rocks and the pattern of mineral formation also change [5].

Zones of tectonite fissilization may be re-formed at tectonic and tectono-magmatic (plutonic) processes. The processes have different stages of activity and may be defined as interruptive-continuous ones. The most active processes of migration of fluids are noted during tectono-magmatic activations while at tectono-plutonic ones the fluid migration proceeds at a much slower rate but is longer in time. Accordingly, during the period of tectonic and tectono-magmatic (plutonic) activations, new systems of weakened zones are created, which are recorded as certain anomalies by the PEMS method.

The emergence of a tectonically weakened zone and penetration of fluidized melt in the lithosphere are associated with decrease of solubility of fluids in melts resulting in the emergence of independent fluid systems genetically related to a certain magmatic or plutonic system. Such a scheme may well be implemented in the upper horizons of the Earth's crust. However, numerous geological facts indicate that the scale of the fluid processing of rocks is not always comparable to the size of the magmatic (plutonic) body with which these fluid systems are genetically related.

Thus, the most universal ways of fluid mass transfer across the lithosphere are zones of deep faults and, to a lesser extent, extensive vertical magmatic columns or degassing pipes as given by [2, 3] and confirmed by the PEMS data.

A deep fault zone is a self-organized geological system of periodic action. Each antecedent stage prepares the manifestation of the following one. So, the fissilization creates a united fluid conductive system which causes a significant spread of metasomatic processes that even out the compositions of rocks and prepare them to the birth of magmatic foci. Depending on the combination of various factors, all three stages of a fault development may reveal themselves to different extent or may not appear at all [6, 7]. In some cases in crystalline arrays fissile zones undergo changes at all stages of the fault formation and create hydrocarbon collectors such as the White Tiger oil field (the Vietnamese shelf of the South China Sea) for example.

According to earlier studies of F.A. Letnikov and V.M. Shestopalov [4, 5, 9], with rise in temperature and pressure, the solubility of large quantities of rock-forming components in fluids increases. The depth of origin of fluid systems, on the one hand, causes their high energy intensity, and on the other - abnormal mass content. As a result, high-temperature massive fluid systems are formed, on the basis of which melting cells, zones of regional metamorphism, autonomous systems of individual minerals are formed in the upper horizons of the lithosphere as it was fixed by the PEMS method in the DDD and Donbas areas.

The role of deep fluid systems in the formation of regional geological structures is extremely important. Any tectonic zone of increased fluid conductivity is self-organized. While at the first stage the role of the tectonic factor is decisive, then in the next stages of life of such structures the main role belongs to fluid systems. Exactly they are the forces that destruct the lithosphere after the action of the tectonic impulse has ceased or lost leading importance. An analogy can be drawn between the influence of magmatic melts and postmagmatic processes. Thermodynamics transmitted by a pulse to fluids undergoes changes during their migration and interaction with the lithosphere environment, which allows the PEMS method to distinguish the corresponding anomalies and their change in the lithosphere with depth.

Thermodynamic properties of gases and their mixtures can be calculated with the aid of modern equations of state. However, direct comparison of thermodynamic properties at specified temperatures and pressures is possible only for elementary gases, whereas for complex ones such a comparison is not correct and is permissible only in case of reactions of synthesis or decomposition. In addition, it is advisable to take into account that when comparing the energy of gases in the crust and mantle of the Earth, it is necessary to allow for continuous change of thermodynamic parameters (temperature, pressure, aggregate state of the fluid) which depend on the depth and composition of the lithosphere.

The main components of the lithosphere fluid are gases of the C-N-O system while acid compounds F, Cl and S with involvement of nitrogen and noble gases play a smaller role. A system C-H-F-Cl-S-N-Ar-O complemented by volatile silicon compounds (SiF_4, $SiCl_4$) was considered. All calculations were carried out with the help of special procedures realizing equations of state for various gases and data included in the TERMINEOS database. As follows from a comparative analysis of 19 gases at the level of 170 km on continental geotherm, the most energy intensive are recovered H_2, C_2H_6, HCl, CH_4 and NH_3, CO, which account for almost 55% of the released energy. Immediately bordering them are oxidated H_2O, Cl_2, H_2S, N_2 followed by SO_2, SO_3, HF, CO_2, F_2, and low-energy Ar, O_2, SiF_4, $SiCl_4$ close the series [4, 5].

All fluid components were divided by their ability to transfer thermal energy into several groups: low-energy - $SiCl_4$, SiF_4, O_2, Ar, F_2, CO_2, HF, SO_3 (1-5 kJ / g), medium-energy - SO_2, N_2, H_2S, Cl_2, H_2O, CO (5-10 kJ / g), high-energy - NH_3, HCl, CH_4 (10-15 kJ / g), and ultra-high energy - H_2 (35-45 kJ / g).

So, hydrogen as a deep heat carrier is out of competition. Considering that reactions of its interaction with minerals of rocks are exothermic, the role of hydrogen as a main "fuel" for endogenous processes in the lithosphere may be recognizes as universal.

2. Characteristic features of fluid systems

As a result of generalization of rock samples taken from different depths, it became possible to create a scheme of location of fluid facies in the continental lithosphere. The most ancient and deeply buried under archaean plates in the astenospheric layer are fluid systems with a high carbon content (C> H) – C-systems (Fig. 2). The youngest systems lie at relatively shallow depths (H> C) – H-systems. It is interesting that, even by fragmentary data, the same behaviour is observed for the oceanic lithosphere [4, 5].

Standing out among the C and H fluid systems singled out in the lithosphere are the C and H deep zones of increased conductivity sometimes related to faults. A high fluid conductivity of such zones is doubtless, and their drainage role with respect to the asthenosphere is obvious. The C-structures are characterized by a wide spread occurrence of carbonaceous minerals (carbonates, carbides, graphite, diamond) and gases. They correspond to zones containing arrays of kimberlites, carbonates, alkaline ultrabasic rocks with well developed processes of carbonation, graphitization and bituminization. Usually, such structures attract formation of deposits of diamonds and of rare, noble and non-ferrous metals.

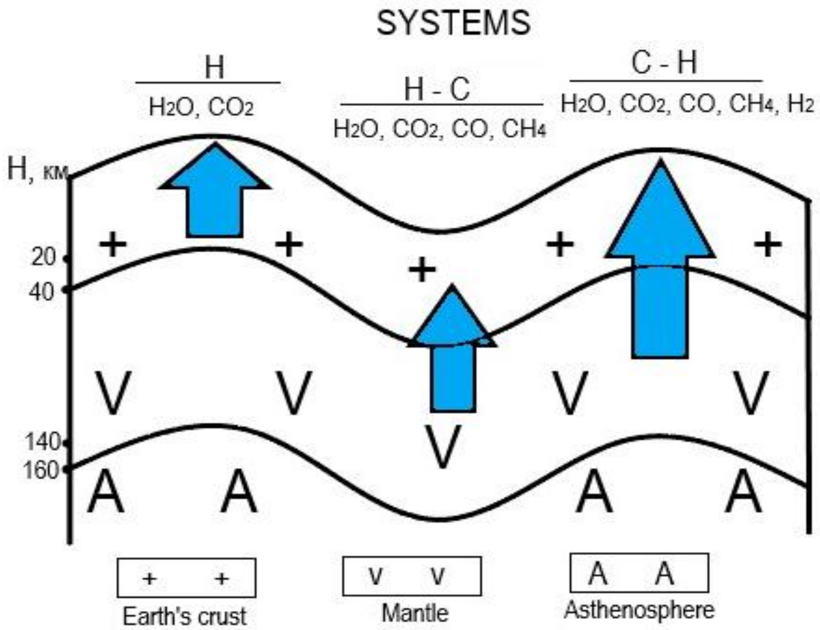

Figure 2: Physico-chemical parameters of deep CH-systems in lithosphere (*after F.A. Letnikov with the author's modifications)*

The H-structures are characterized by high activity of H_2O and include a wide set of hydrogenous minerals – amphiboles, micas and other hydrosilicates. These structures are associated with zones of granitization, amphibization, mica formation and of other types of metasomatosis. They house a vast majority of ore hydrothermal or metamorphogenic-metasomatic deposits.

In a generalized form, the aforesaid is shown in Fig. 3 indicative of the following tendency: the deeper the H-structures of fluid systems are located, the more they are enriched with elements having a high affinity with oxygen and fluorine.

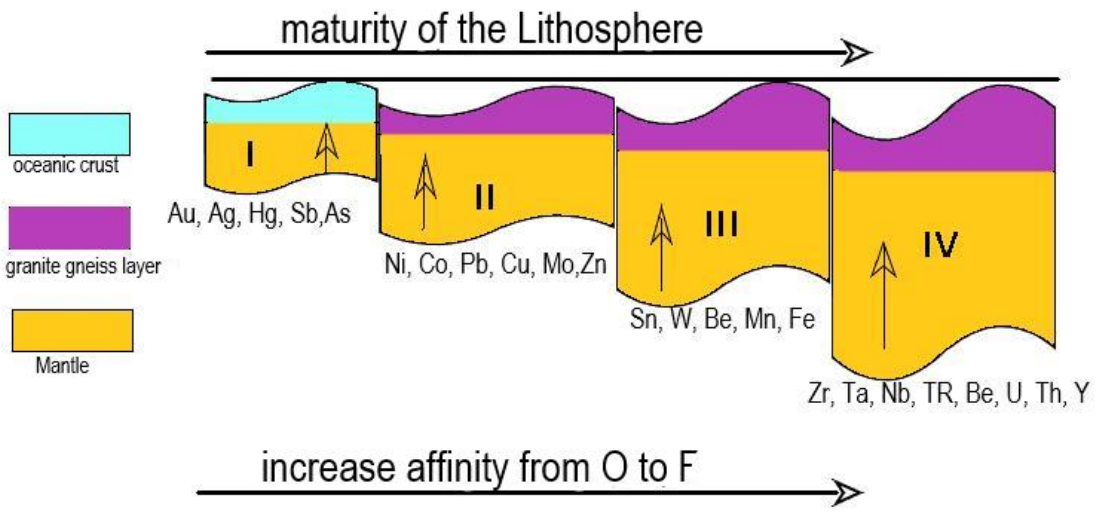

Figure 2: Fluid enrichment with mineral components depending on depth of fluid origin (*after F.A. Letnikov with the author's modifications)*

That is, as temperature and pressure increase and partial pressure of oxygen decreases, elements having a growing affinity with oxygen and fluorine will move from the main (base) or ultra-basic matrix into the fluid. Certainly, the scheme may alter depending on specific conditions, especially for seam zones when fluids from astenosphere of two adjacent blocks are involved in the formation of systems. This tendency gets broken to even greater extent if, under the action of fluids, melting foci occur in crust and, in turn, give rise to new fluid systems with their own characteristics.

New approaches to analysis of natural fluids lead to fundamentally different way of study allowing for the whole set of factors affecting their development. One of the methods that make it possible to explore the zones of fluido-dynamic systems is the PEMS method. It permits to track changes in the character of these systems at different depths.

IV. CONCLUSION

The main routes of fluid migration in the lithosphere are fault systems created by tectonic, tectono-magmatic and tectono-plutonic processes, as it was confirmed by the PEMS method for various tectonic structures in the Ukraine. The ways of transportation of fluids and their interaction with rocks depend on depths, temperatures and pressure in the direction from the interior to surface of the Earth and are fixed as certain anomalies at construction of the 3-D models by method of PEMS.

A deep fault zone is a self-organized geological system of periodic action. The C-N fluid systems correlate with deep zones of hyperconductivity.

The energy state of a fluid and its ability to contact with other rocks of the lithosphere as well as to fill volcanic and volcanic-sedimentary collectors depend on the depth of that fluid origin.

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