Stage Analysis of Minerals that Witnessed Formation and Evolution Dynamics of Sedimentary Rocks – Perspective Scientific Direction of Lithology and Geology of Oil and Gas

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Abstract. The paper highlights methodology and techniques of the dynamic lithology – scientific direction developed by the author. It includes knowledge of historical and geological alternation of multistage epigenesist and genesis of sedimentary rocks, with estimates of tectonogenesis influence on these processes in different geostructural areas of the lithosphere. The author describes the scheme of lithogenesis systematization and its diagnostics by optical and electron microscopic observations of specific material and structural effects of the multistage sediment lithification (stage analysis of lithogenesis). The practical contribution of such studies is in their use in the development of theories concerning stratiform ore genesis and naftidogenesis.

Keywords: stage analysis, sedimentogenesis, lithogenesis, authigenic mineral genesis, process, fluid, dynamics, stratosphere, system

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Introduction

Current research in the lithology is based on three fundamental methodological principles: geneticity, historicism, and consistency. On this basis lithologist, who studies ancient (pre-Quaternary) sedimentary strata, has the ability to reconstruct and scientifically justify the dynamics of multistage and multirange rock formation processes, as well as to assess the likelihood of direct and indirect relationships with their tectonic genesis, ore genesis or naftidogenesis. Today in lithology two fundamental areas are clearly isolated: the doctrine of sedimentation and doctrine of postsedimentary-premetamorphic lithogenesis and its stages diagenesis, katagenesis (regional epigenesis) and metagenesis. Both directions are inherently intertwined by the unity of sedimentary process sensu lato, but so far our knowledge of planetary sedimentation regulations is way ahead of information about postsedimentary lithogenesis.

The reason is lack of access to lithogenetic processes by our direct observations because of their depth and duration, incomparable with the duration of human life. We extract information about such processes only indirectly – by microstructural features of destruction and renewal, or turnover of mineral components within the sedimentary rocks. This is the method of Lithogenesis Stage Analysis (SA), the principle of which was formulated by N.A. Strakhov in 1957: "stage analysis consists in the recognition of features in the rock, arising in epigenesis (or early metamorphism), sedimentation and diagenesis" (Methods of studying sedimentary rocks, 1957, p. 27). That is, the researcher by observing rock thin section under polarizing microscope (and now under scanning electron microscope) separates the mineral associations in retrospective order of their appearance – from the newest to the initial.

In English literature the term SA is not accepted, but the relevant research is carried out quite intensely, starting with Pettijohn F.J. (1975), Selli R.K. (1976), Feyerbridge R. (1967.), and others.

In the Soviet Union numerous works of A.G. Kossovskaya and V.D. Shutov (1955 et al.), A.V. Kopeliovich (1965), N.V. Logvinenko (1968), V.I. Muravyeva (1968), I.M. Simanovich (1964.1978), V.I. Koporulina et al. (Methods of studying sedimentary rocks, 1957) significantly contributed to the development of SA. However, at the turn of the century the number of publications on this subject in national journals began to decline. This topic is maintained by the student of G.F. Krasheninnikov and A.G. Kossovskaya (Yapaskurt, 1976, 1986, 1992, 1999, 2013 a, b). Today, SA is displayed on a new level: in addition to the inherent historism and geneticity, a systematic synthesis of evidence from different levels of matter organization is introduced, from the mineral component to a rock-layered, and then – facies and formational levels.

Informational content of Stage Analysis

The SA can diagnose the following features of the material at the micro- and nanoscale:

1 – authigenic mineral genesis and its phasing,

2 – corroded sedimentogene (terrigenous, edaphogenic, volcanic, biogenic) rock components,

3 – transformation of their crystal lattice,

4 – recrystallization blastesis,

5 – traces of migration in the fluid phase in the rock,

6 – signs of metasomatism (Yapaskurt, 2013 a, b).

Authigenic mineral new formations are different from allothigenic ones by euhedral-conformal crystallinity or colloformic isotropic nanostructure. At the different occurrence of authigenic minerals their age sequence is detected by analyzing the forms of contacts between them (Yapaskurt, 1999).

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Corrosive micro- and nanostructures of allothigenic components are accurately recorded by optical and scanning electron microscopy (SEM). Analysis of their combination with authigenic nodules (Fig. 1, 2) gives an indication of the source material for authigenesis. In some cases it is local (due to corrosion of intra-rock sedimentogene minerals), and in other cases it is introduced by groundwater from other layers or other formations. This analysis is very valuable for understanding the causes of different rock permeability due to connectivity of pores or by sealing with carbonate, siliceous, and other substances.

Fig. 1. Incorporation structures of gravitational corrosion on the contacts of clastic quartz grains in the sandstone. Photos of the section with crossed nicols of polarization microscope. K_1, Priverkhoyansky deflection.

Fig. 2. Border of regeneration quartz around quartzous sand grains (white on the left); between them – intermittent film of authigenic chlorite (dark gray). Photos of the thin section with crossed nicols. P_2 of Verkhoyansky complex.

Transformation (a term introduced in 1964 by the French explorer J. Millot) is a process of replacing the original (sedimentogene) mineral with other mineral, without phase transitions, by means of exchanging part of its own cations with others received by the crystal lattice from the aqueous medium. This lattice architecture is preserved unchanged, but formulaic composition and physical-mechanical properties of the component change fundamentally. Examples: transformation of sedimentogene smectite in the early stages of deep katagenesis (at T = 100°± 20°C) into illite and (or) chlorite when converting clay into non-swelling mudstone; transformation of terrigenous biotite sandstone into chlorite-illite packages at deep katagenesis and others. These phenomena are difficult to detect without the involvement of the SEM or electron diffraction method. Wonderful descriptions and illustrations of mineral transformations are given in the monographs of V.A. Drits and A.G. Kossovskaya with reference to their works in the author's publications (Yapaskurt, 2008).

Crystalloblastesis of quartz and other minerals (Fig. 3) that worsen the reservoir properties (sandstones lose their permeability) is described in detail in the works of I.M. Simanovich (1978) and the author (Yapaskurt, 1999). Signs of this process show thermal activation of metagenesis stage (apokatagenesis, anchimetamorphism).

Joints of fluid abruption (Fig. 4) indicate of matter outflow together with interbedding fluids that overcome lithostatic pressure. The source of these fluids is transformation of own clay and organic matters. These signs are hardly noticeable and often ignored in petrographic thin sections description. For the diagnosis of fluid compositions the analysis is required by using SEM of nanocomponents filling the joints.

Signs of metasomatosis require particularly careful reasoning. Often, researchers postulate "metasomatism" based on the detection of regenerative nodules of authigenic quartz on terrigenous quartz or discovery of well crystallized carbonate minerals in the pore space of sandstones. However, in cases where minerals were crystallized in the open, filled with aqueous fluid cavities, we are dealing with ordinary authigenesis. The classic definition of metasomatism by D.S. Korzhinsky is the dissolution of pre-existing mineral, followed by crystallization of new minerals to replace the old. Consequently, metasomatic nature of the specific mineral component can be reliably determined only with detection of residual relics of former mineral component. Undissolved nanoparticles of former mineral can only be detected using SEM and other precision equipment.

All of the above postsedimentary processes substantially correct (improve or worsen) reservoir properties encountered in sediments at the stages of sedimentation and early diagenesis. These changes are recorded by the SA. Experienced researcher can describe the history of multi-stage material and structural sediment changes, as well as rock formed from it for all time of its existence in the earth, up to the moment of its extraction from the well or from a natural outcrop. The significance of the research to explain reservoir or fluid-resistant properties of sedimentary rocks is quite obvious (Yapaskurt et al., 1997).

Above rock levels of the SA are reduced to graphic images in intensity of intralayer matter transformations on lithofacies and paleotectonic profiles of the studied geological formation.

The so-obtained data are used for theoretical conclusions regarding the methods and features of influence on lithogenesis by various exogenous and endogenous factors,

Fig. 3. Microstructure of recrystallized-granulation blastesis on the periphery of quartzous sand grains, near its conformal borders with adjacent grains. Photos of the thin section with crossed nicols. P_1 of Verkhoyansky complex.

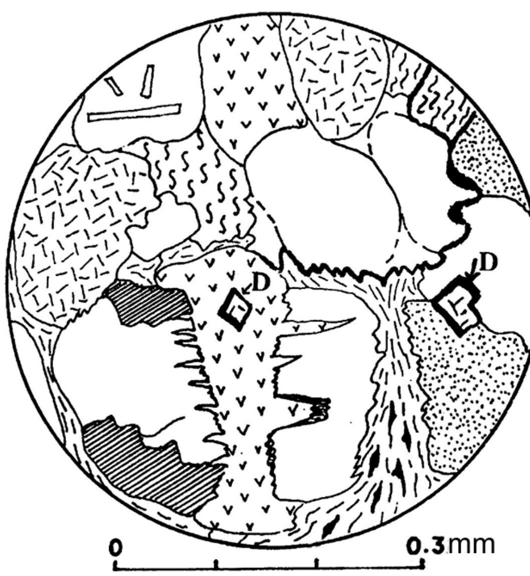

Fig. 4. Seam of fluid abruption (black, twisting) in combination with conformal incorporation structures of gravitational corrosion of quartz detrital grains (white) and lithoclasts (indicated by specks) and with later inclusions of rhombic dolomite crystals (D) of metasomatic nature. Sketch of sandstone section T_3 of Tyumen well SG-6, at depth 5.5 km.

subject to certain tectonic conditions of sedimentary basin formation. In this way, the signs are specified depending on the mineral and structural changes of sediments and rocks formed from them, on the speed and paleo-depth of tectonic immersion (ensuring the consistent occurrence of rocks in increasing temperature and lithostatic pressure); degree of stress influence on lithification near specific disjunctive tectonic disturbances of the basin; former rock belonging to the paleo water-bearing horizon or confining bed and so on. (Yapaskurt 1992, 2013, b., etc).

Let us formulate specific goals and possibilities of using this method. Traditionally the SA is used for the following tasks.

1. The statement of formation phasing of mineral rock components.

2. Connection of the above steps to a certain stage of the sedimentary process: sedimentogenesis, early and late diagenesis, weak, moderate and deep katagenesis (regional epigenesis), metagenesis; correlation of these stages with historical and geological events.

3. Assessment of distortion degree of the original material composition as a result of sediment lithification.

Solving such problems is necessary for reliable paleogeographic reconstructions. There are many instances of complete replacement of sedimentogene minerals by newly formed minerals at katagenesis or metagenesis. For example, full dolomitization of limestone, its sideritization, silicification; cementation of quartzous sand material by carbonates of postsedimentary origin; transformation of smectite clay components into chlorite-illite mudstone and so on. The Stage Analysis techniques can detect residual relics in the origina matter of the rock or intermediate categories between layers of weak and entirely altered rocks (dolomitization, sulfation, silicification). Thus, the results are verified of genetic litho-facies analysis for sedimentary strata structure.

New challenges and opportunities of the SA are generated in (Yapaskurt, 2013 a, b). They include evaluation of fluid factors influence on lithogenesis.

This role is dual:

1 – interbedding aqueous fluid as the condition required to implement authigenic mineralogenesis due to redistribution and transformation of local material from the intial sediment;

2 – fluid as a carrier of third-party agents for authigenesis. Both methods of the fluid impact on the lithification are reflected in certain signs of authigenic minerals and their similarity or difference with allothigenic minerals.

It follows by a fundamentally important conclusion: at the Stage Analysis of diagenesis, katagenesis and metagenesis two genetically different groups of authigenic minerals should be diagnosed – one that emerged from the local sources, the other – from the alien material sources. Such a proposal was made a long time ago (Kholodov, 1970). Its author has formulated the relevant terms: the first group of the above authigenic minerals he called auto-genetic, the second authigenic he named allo-genetic. These names were not recognized, and, in fact, were not noticed. We consider it is necessary to revive them, replacing a more linguistically comfortable authigenic own (A_1) and authigenic alien or superimposed (A_2).

The main features of the A_2:

1) authigenic mineral does not have counterparts among allothigenic components (such as calcite in quartz and quartz-feldspar sandstone);

2) the area of new formations in thin section of mineral is much higher than the total size of cross-sectional area of its potential donors and the size of their corrosive cavities;

3) Authigenic mineral of the same composition forms two or more generations (in this case for re-generation, donor reserves of primary substances are likely exhausted). To this we must add that in some cases the same heterochronous mineral at different stages of geological time could belong alternately to different generations – A_1 and A_2.

Diagnosis of the above two categories of authigenesis helps clarifying the problem solved differently by geologists from different schools: whether the substance of ores and hydrocarbons was brought from endosphere, or the very formation generated fluid under the influence of certain pressure and temperature factors. To solve this problem it is advisable to combine the SA with the study of oxygen isotopes, carbon and other elements in the authigenic components.

Another inexhaustible possibility of the SA is to calculate its data in correlation of lithogenesis dynamics with the evolution phasing of geodynamic processes in stratisphere.

We consider stratisphere as a self-organizing and dynamically developing organogenic-mineral-rock-water-fluidic system, which under certain circumstances actively influences on postsedimentary rock formation and, in particular, ore genesis. It constantly seeks to achieve a state of physical and chemical equilibrium with the periodically updated environment, while constantly fueled by the energy and matter both from the above and below, and it also gives its energy to the phase differentiation of own materials on many systematic micro and macro levels.

In contradiction "the system – updated environment" driving forces are laid for most mechanisms of postsedimentary rock changes, including stratiform ore genesis and naftidogenesis. However, the system itself is internally inconsistent. It was originally formed as a non-equilibrium formation in sedimentation stage. Therefore, in most of its structure there is a possibility of multiple mineral-fluidic chemical reactions. Environmental factors stimulate accelerate them (for example, a known rate doubling of chemical reaction at every temperature increase by 10 °C).

The processes of the system are ranked according to the following levels of its organization:

1 – mineral-component (corrosion, regeneration, transformation of the crystal lattice of the mineral particles, etc.),

2 – rock-layered (redistribution of substances in solutions and diffusion),

3 – interlayer (removal of H_2O, SiO_2 and various cations from smectite clays, transformed into illite mudstones, and addition of these components in the intergranular cavities of adjacent sand layers). These processes leave a memory of themselves, structural traces of which are available by the SA diagnosis.

The following are categories of processes on a larger scale:

4 – intraformational,

5 – interformational (intra-stratispheric),

and (probably)

6 – juvenile (when fluid is introduced from the lower geospheres).

Conclusion

The development of the above areas of research will undoubtedly contribute to the establishment of a new branch of science of the Earth sedimentary formations – Dynamic Lithology, studying the dynamics of historical and geological development of genesis and epigenesis of sedimentary rocks in the aspect of tectonic genesis impact. The practical efficiency of the development of this scientific field is to contribute to the theory of stratiform ore genesis and naftidogenesis.

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