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Innovations on Assembled Techniques of Geochemical Lithofacies and Their Applications in Basin Analysis and Exploration for Minerals in Basins

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1 Introduction

Research and development on assembled techniques of geochemical lithofacies is to be oriented, at the firstly, by technological issues or conundrum in methodology, and to be subsidiary directed by applications of theoretic basis in sedimentary basin analysis and explorations for minerals in the ore-hosting basin. However these are to be steered by integrated knowledge and cross-sectional study while they are focused on the core value and innovative technology. Issues include geochemical rock-ore lithofacies, lithofacies of mineral geochemistry, innovative techniques and theory for intergrowths of the mineral commodity, combinations of screening classifications of tectonic deformations and precise dating of isotope geochemistry, reconstructions of diagenesis-mineralization evolution, and geochemical restoration engineering in the damaged ecologically environment system. Reviews on the previously research of geochemical lithofacies and its applications (Fang, 2012a, 2012b, 2016,2017), assembled techniques of geochemical lithofacies and their applications in basin analysis and exploration for minerals in basins were summarized.

2 Assembled Techniques

Based on geochemical dynamics of fluids and rock associations, geochemical lithofacies were classified into oxidizing-reducing facies, heterochemical potential facies, acidity-alkalinity facies, temperature facies, pressure facies, chemical potential facies, salinity facies, and heterochronous heterochemical potential facies. Methodology for technical techniques of geochemical lithofacies may be exemplified by the following formula.

Geochemical lithofacies =(X-Y-Z-T-M-t)

Variable assignment in the above formula comprise X and Y =horizontal direction, Z=vertical direction, X-Y-Z for space domain, T=temperature domain, t=time domain, and M=material domain.

And therefore, technical techniques consist of the above mentioned eight kinds of geochemical lithofacies, combined with mapping of tectonic lithofacies, deep mapping of tectonic lithofacies using geophysical data.

3. Applications in Basin Analysis and Exploration for Minerals in Basin

3.1 Glutenite-type Cu deposits in hinterland basin and Glutenite-type Pb-Zn-U deposits foreland basin

In volcanic sedimentary basin and sedimentary basin analysis, geochemical lithofacies may be applied to study on lithofacies of sedimentary rocks and volcanic rocks in the formation and evolution of the basin. It may help us to restoration for fluid field, migration rules of fluid field, mechanism and dynamics of fluid migrations at the large-scale, and relationships of hydrothermal fluid superimposing during the basin deformation in order to predication for minerals at the depth.

Co-enrichment of copper-lead-zinc-uranium and coal-oil-gas deposits in the same basin exhibited in the Mesozoic to Cenozoic continental redbed basin in the northwestern Tarim. Basin fluids may be classified into gas-type, oil-gas-type, brine-type, hydrothermal sedimentary type, HBFER-type (hydrocarbon-rich basin fluid with extensive reductibility). The brine, the hydrothermal, the Fe-Mn-riching-CO_2-gas, magmatic hydrothermal type, and HBFER-type, had underwent extensive physical coupling among tectonics-lithofacies-lithology during the late cataclastic lithofacies and basin deformations, at the same time, the chemical coupling reactions were taken place. “Black-first, White-second, Discolored-third” was named for extensive alterations of the basin fluid in the mechanism of the geochemical lithofacies, resulting in most of Fe^{3+} into Fe^{2+} ions for the discolored alterations of aranthine irony conglomerate. Mechanism of the geochemical lithofacies could be

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assumed that large-scale discolored alterations not only for maranthine irony conglomerates-sandstones, but also for glutenite- Cu-Pb-Zn-U and sandstone-type Cu metallogenic belt, at the he Mesozoic to Cenozoic continental redbed basin in the northwestern Tarim.

Foreland basin, hinterland basin, and intermountain basin around the West-south Tianshan orogenic belt, has different controls on sediment-hosted Cu, Pb-Zn, and U deposit. First, the Sarekebayi intermontane basin, a secondary basin attached to the Tuoyun hinterland basin, is located at the northern part of the orogenic belt. The Sareke sediment-hosted copper deposit was hosted amaranthine irony conglomerate in the upper part of the Upper Jurassic Kuzigongsu Group. Second, the Wulagen sediment-hosted lead-zinc deposit is hosted between the upper part of the Cretaceous Kezilesu Group and the lower part of the Palaeogene Aertashi Group, located at the Wulagen foreland basin in the south part of the orogenic belt. However, Bashibulake sediment-hosted uranium deposit was hosted in the lower part of the Cretaceous Kezilesu Group at the Jiashi foreland basin. Final, The Palaeogene-Neogene sediment-hosted copper deposits were located in the migrating foreland basin system. Indices of tectonic lithofacies for the HBFER includes bituminization and discolorous alterations, multiple coupling pattern between cataclastic lithofacies and bituminization lithofacies. Nevertheless, indices of geochemical lithofacies included TOC, hydrocarbon-bearing salt-water, hydrocarbon, oil, and asphalt inclusions, low to middle salinity of mineralizing fluids, orebody of Cu-Ag-Mo intergrowth, Cu oxidized facies, Cu-Mo sulphide facies. Therefore, mechanism of the sediment-hosted Cu, Pb-Zn, and U deposits consists of the followings: source rock of hydrocarbon had given off the hydrocarbon feeders by the sny-faults after tectonic inversion from the strike-slip sag to compressional deformation. Tectonic channels of HBFER migration included tectonic inversion zone, regional divergent unconformity, detachment faulting zone, rocks with high porosity-permeability, which were ready for their migration at the large-scale. Moreover, rocks with high porosity-permeability between the muddy siltstones and gypsum-bearing argillites with lower porosity-permeability might have been the traps of tectonic lithofacies. Finally, mechanism of sediment-hosed copper deposit might have been produced by the mixing of the HBFER and the amaranthine irony conglomerate with oxidized facies copper, however, mechanism of sediment-hosted lead-zinc deposit and uranium deposit the mixing of oil-field brine and the hydrocarbon-rich basin fluid at multiple stages.

3.2 IOCG deposits in arc-basin and rifted basins

Superimposed diagenesis and mineralization of hydrothermal tourmaline-breccia system in IOCG of Moon hill in Chile was revealed (Fang, 2012b). Vertical zonation of altered lithofacies consist of calyization-sericitization- hematitization lithofacies at the top oxidizing acidic facies, and potassic altered lithofacies with tourmalinization in the middle high acidic facies from oxydic to reductive environment, Fe-rich alteration lithofacies and breccia lithofacies of hydrothermal fluid at the bottom alkaline facies with reduced environment. However, tourmalinization lithofacies may be the center of pneumatolytic hydrothermal fluid around the tongue-shaped intrusion of ivernite and monzodiorite, indicated the center with high acidic facies. Tectonic lithofacies and breccia lithofacies of hydrothermal fluid were hosted in the syn-magmatic brittle-ductile shear zone in Fe-rich picrate, Fe-rich andesite, and monzonite to ivernite intrusion during arc-back deformation.

Horizontal alteration lithofacies from the center to the outer for Baixila IOCG deposit in Dongchuan, Yunnan, China, were made up of alteration lithofacies of potassic silicate minerals at the center alkaline facies with oxydic environment, ore-hosted breccia lithofacies of hydrothermal fluid from oxidizing to reducing facies at the transition, and ankeritization-silicification lithofacies of copper- bearing fractured marble at the outer alkaline facies with reduced environment. They exposed around Ti-Fe-rich gabbro and Ti-Fe-rich diorite intrusion in the Dongchuan rifted basin.

All of these altered lithofacies are supposed to be the ore-hosted lithofacies for iron-oxide copper gold deposits (IOCG). Large-superlarge iron-oxide copper gold deposits (IOCG) are of multistage alteration lithofacies system superimposed by breccia lithofacies of hydrothermal fluid in different origins. Multistage of alteration lithofacies superimposed by heterochronous heterochemical potential lithofacies at the same place and excellent altered lithofacies of pneumatolytic hydrothermal fluid are exploration and prediction indicators for large-superlarge size iron-oxide copper gold deposits.

3.3 Breccia System during basin deformations

Diagenetic and metallogenic mechanism of breccias with ore-bearing or barren is important issue, and developed in sedimentary basin and in volcanic sedimentary basin. Their individual mapping units and mapping of tectonic lithofacies are conundrums for geologists all the time. In the diagenetic-metallogenic system of hydrothermal breccias, hydrothermal breccias are not only coupling and superimposing of hot-fluids and rocks in stages, physical-chemical reaction library on the extensive hot-fluid metasomatism and coupling, but also material records of tectonic lithofacies for these superimposing of different geological process.

Breccias may be classified into sedimentary breccia, karst breccia, hydrothermal breccia, tectonic breccia, volcanic breccia, magmatic breccia, metamorphic breccia, hydraulic fractured breccia, and multiple genetic breccia. These are nine individual mapping units for basin analysis and exploration for mineral deposits in the basin in the basis of their mechanism. Different kinds of breccias may dissected by geochemistry in order to define individual geochemical lithofacies. Associations of breccias may be used to do restoration on system of hydrothermal breccias established by tectonic lithofacies at large-scale of 1:500 to 1:5000 in deposits or mines.

There may have several geological settings which are constructive environments for the tectonic system of hydrothermal breccias. Therefore, these targets should be paid more attentions to map on tectonic lithofacies while the other may be elementary in the project. Firstly, there are several special geological conditions in the compound magmatic intrusion which are favorable for the tectonic system of hydrothermal breccias, including magma immiscibility and immiscible crystallization, coupling between cooling magma and pre-existing tectonics, syn-magmatic intrusion brittle-ductile shear zone and magmatic intrusive process, and magmatic intrusion superimposed by late tectonic fluids. For example, breccias lithofacies of tourmalinization may be the center of pneumatolytic hydrothermal fluid around the tongue-shaped intrusion of biotite diorite in Fengshou exploration rights in Hainan province, China, indicated the center high acidic facies and of magmatic metallogenic fluids. Targets defined by the tourmaline breccias lithofacies could be indicated for W-Sn-Cs-Rb mineralized center of the tourmaline breccias.

Secondly, the early stage subvolcanic intrusion, the latter stage of subvolcanic intrusion, and later magmatic intrusion in the district of volcanic lithofacies are favorable to produce the tectonic system of hydrothermal breccias. Tectonic system of hydrothermal breccias at the surface and at the depth of Wandaoshan in Yinmin Fe-Cu deposit, China, were delineated by ground high-precision magnetic survey, surface mapping of tectonic lithofacies and underground tunnels. Furthermore, we had arranged the examination tunnel for the IOCG metallogenic system, and the thick Fe-Cu orebodies with high grade were discovered in gabbro-diabase intrusions. Bornite-chalcocite magnetite ores in the potassic altered lithofacies of Fe-rich gabbro intrusion are indicated for low-sulfur, high-copper environment with the oxydic-reduced transition facies. Copper-bearing hydrothermal breccia and biotite hydrothermal breccia developed on sides of gabbro intrusions.

Thirdly, Tectonic system of superimposed hydrothermal breccias may be generated by later basin fluids, hot-fluid intrusion, and complex magmatic intrusions during the deformation stage of the sedimentary basin, if there are pre-existing lithofacies system of volcanic breccias, karst breccias, and sedimentary breccias in sedimentary basin.

Finally, the tectonic system of hydrothermal breccias may be more easily formed in composite intrusions of tectonics-magmatic-breccia complex.

In summary, the main formation mechanism for the tectonic system of hydrothermal breccias cover complex magmatic intrusions，volcanic and subvolcanic intrusion, basin fluid, and composite magmatic intrusions during the later deformation of sedimentary basin. All of them are one of the ore-field tectonic types, and are accounting for diagenetic-metallogenic mechanism of many mineral commodities associations. Using these techniques of tectonic lithofacies mapping is very help to reconstruct diagenetic-metallogenic center for the different system of hydrothermal breccias in order to find concealed tectonic type and blind ore deposits at the depth.

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