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Environmental Property of Mineralogy

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Abstract - Study of environmental property of mineralogy is closely associated with resource and environment, the two major subjects of the earth sciences, and is based on the resource property of the minerals. Environmental changes will leave imprints on minerals during the cycle of mineral evolution from their formation, development to decomposition, and this makes minerals become the information carrier of environmental changes. Adoption of appropriate measures to prevent the decomposition of minerals may help to prevent impact on human health and environment. Purification function of natural minerals reflects mainly the basic properties of the environmental mineral materials. Studies of functioning of minerals and living materials are the subject across between organic and inorganic world. The extraordinary chemical properties of minerals at nanometre levels are the key to participate nano-biological functions.

I Introduction

It can be said that human recognition and application of nature were derived from that of minerals from the earliest stage. Human beings began come into contact with non-metallic minerals in the Stone Age and then later with metallic minerals in the metallic ages [1][2]. The property of minerals being discovered and used has been therefore the resource property. With the emergence of mineralogy, people began to classify and study minerals with various characteristic applications and quantities. When Theophrastue described 16 minerals in his textbook "De Lapidibus" around 300 B. C., he laid the foundation for the science of mineralogy and provided the basis for understanding a panoply of natural phenomena. The minerals he described provided the raw materials that let to the discovery of many of the chemical elements, and their study was essential in establishing the disciplines of chemistry and physics [3]. For several centuries since the emergence of mineralogy, the resource property of mineralogy has been attached with great importance and utilised.

Sustaining Earth, in the face of both technology thrusts and population dynamics, depends on our ability to maintain a delicate balance between human-promoted planetary modification and decline thresholds for land (soil), water, atmosphere and biological systems. Mineralogy, as much as any other single science, will be central to this process [4]. The investigation of environmental property of minerals ie, environmental mineralogy emerges as the earth surface is faced with crisis of environmental pollution and ecological disasters. Environmental mineralogy is a new field. The term environmental has come to be employed to refer to those systems at or near the surface of the Earth where the geosphere comes into contact with the hydrosphere, atmosphere and biosphere. But it has no definite boundaries nor any established and accepted body of literature [5]. Some tentative definitions show as follow. Environmental mineralogy is the study of the occurrences of minerals in our environmental and their impacts on the environmental and human health [6]. Environmental mineralogy is emerging as a field that seeks to define the roles of minerals in all environmental systems, and to work towards the preservation and restoration of such systems [7]. Environmental mineralogy is a branch of science dealing with interactions between natural minerals and spheres of the earth surface as well as reflection of global changes, prevention of ecological destruction, remediation of environmental pollution and participation in bio-mineralogy [8]. We consider that environmental mineralogy deals with minerals as information carrier reflecting natural evolution and studies the nature of minerals in aspects affecting human health and environment. Environmental mineralogy also studies basic properties of minerals in remedying environmental pollution, and effect and mechanism of mineral interacting with biosphere at nanometre levels. Mineralogists have a central role to play in the relevant environmental sciences and technologies [9].

II. Information carrier of mineral reflecting natural evolution

Natural minerals, which were products of evolution of the earth, contain plentiful information reflecting environmental changes at different time and space during the life cycle of formation, development, alteration and consumption of the minerals. Natural minerals actually become information carriers recording global changes. The information is reflected in crystal form and structure, chemical composition and property, physical property, spectrum characteristics and genetic occurrences of the minerals. Both quality and quantity of environmental evolution information from the minerals will increase following advance of investigating methods and the research levels.

Glacier and loess formed during the Quaternary period are the key research objects in the field of global change studies. Mineral particles in glacier and mineral composition of loess recorded information about evolution of glacier and loess respectively [10][11][12]. It will be helpful to understand characteristics and principles of global environmental changes when features of these minerals as information carriers are investigated in more detail. Research on minerals from stalactite and stalagmite in karst area [13][14] will also reveal evolution characteristics of palaeo-climate and palaeo-environment at finer time scale.

A variety of pre-existing and epigenetic minerals from floating dust in the air, sediments in waters and in soils are the direct target of study when evaluating features of environmental changes at smaller space scale [15][16]. For example, characteristics of minerals from floating dusts should be taken into consideration when evaluating acid rain and smoke in the air. Characteristics of minerals in sediments at the bottom of lake should also be taken into consideration when evaluating the quality of water and sources of contaminants. Features of soil minerals such as clay and iron, manganese and aluminium oxides and hydroxides should be taken into consideration in more detail when investigating environmental capacity of soil. The contents of toxic and harmful elements in soil should not be the sole standard when evaluating the environmental quality and the ecological effect of the soil. The key issue is to reveal environmental balance between adsorption and desorption, fixation and release between minerals and contaminates in soil. Through the investigation of mineral composition in soil balance between minerals and contaminates can be revealed so as to establish and protect the mechanism of environmental harmony and to enhance remediation capacity of soil.

III. Essence of minerals affecting human health and ecological environment

Minerals formed in nature are in equilibrium with its environment where they were formed and thus are stable ie, there is a coherent relationship between natural minerals and their environments. However, mining activities bring minerals to the Earth's surface and reduce stability of the minerals due to decrease in temperature and pressure of their environment. It is the alteration and decomposition of minerals that release the heavy metals and anions, which in turn contaminate the surface water and soil and directly impact the environment. Some metallic minerals, especially those containing elements of changeable valence, are particularly prominent in this regard [17]. A typical example is acid mine drainage (AMD) which seriously damages the ecological environment, derives from oxidation and decomposition of metallic sulphides from the mine's tailings. It has become one of the most important research subjects how to prevent effectively oxidation of metallic sulphides under surface conditions [18].

Mining activities also bring some radioactive minerals to the Earth's surface and lead to grave consequences to human health. Minerals' chemical barrier [19] nature, one of the environmental properties of mineralogy, plays an important role in dealing with the treatment of nuclear waste. Clay minerals tend to be able to play a crucial role. Processing and utilisation of minerals can also threat human health, like dust from the processing and asbestos minerals [20]. One of the pernicious effects of long-term exposure to asbestos fibre is an interstitial lung fibrosis called asbestosis [21]. It is well known that thermal decomposition of minerals during usage of energy resource lead to harmful health effect and air pollution.

Weathering of minerals in the rocks directly affects environmental capacity of local soils and environmental quality of local waters, and tends to give rise to problems of local disease and ecological destruction [22]. It is crucial to study mineral composition and their alteration characteristics for the protection of historical relics and ancient sculptures; the study plays an active role in preventing decaying of the ancient sculptures [23].

There is a negative effect to environment by destruction and decomposition of minerals due to production and other human activities. Environmental properties of minerals related to prevention of decomposition can be used to decrease or avoid the negative effect. Prevention is better than remediation.

IV. Characteristics of minerals relating to remediation of environmental pollution

Pollutant treatment by natural minerals reflects natural self-purification function in the inorganic world, similar to that in the organic world – biological treatment. The purification function of natural minerals to pollutants reflects mainly in the basic properties of environmental mineralogical materials. Environmental mineralogical materials related to environmental mineralogy generally consist of natural minerals or their modified products with good coherence with environment and direct function to purify environmental pollution. The basic properties of this function include surface adsorption, modified porous filtration, defects of crystal structure, ionic exchange, chemical activation, physical effect as well as mineralogical-biological interactions [24][25][26][27].

Studies of surface adsorption of minerals have been fastened following advancement of experimental technology and theoretical analysis. They have now gone deep into molecular level in terms of surface interaction, expression and characteristics, and quantitative description, modelling and prediction of the process [28]. Relatively high specific surface area and variable charges on mineral surface can be used to treat cation and anion contaminates. Porous filtration and ion exchange of minerals can be used to dispose pigment, organic pollutants, ammonia, nitrogen, oil and pathogenic bacteria in water. To modify minerals which have certain adsorption, filtration and ion exchange functions is a better way to improve basic properties of environmental mineralogical materials. For example, natural clays have strong hydrophilicity that is favourable to adsorbing inorganic pollutants. Hydrophobic organic clays can be formed by using cation surfactants to modify natural clay surfaces that are capable of adsorbing organic pollutants [29]. We use this property of organic clays modified from natural clays to build chemical barrier in sanitation landfill in order to prevent organic pollutants contaminating ground water.

Metallic minerals containing elements with changeable valence, such as Fe, Mn and S, can be used as good reductants or oxidants to react with pollutants. A striking example is natural mineral of iron-bearing sulphides used for treating Cr (VI)-bearing wastewater developed by us. Cr(VI) can be reduced into Cr(III) by pyrrhotite FeS and then is precipitated in the form of Cr2S3 or Cr3S4, effectively removing Cr(VI) from water. Traditionally chemical reductant Na2SO3 commonly used for reducing Cr(VI) is produced from pyrrhotite. When they are applied to reduce the pollutant of Cr from 6+ to 3+ and form SO42-, one molecule of Na2SO3 can only provide 2e from 4+ to 6+, while one molecule of FeS can provide 8e from 2- to 6+. It means that FeS is 4 times as effective as Na2SO3 [17][30][31][32].

Fe, Mn and Al oxides and hydroxides together with clay minerals are effective in adsorbing heavy metals and anions in soil systems. Our research shows that specific surface area and charge density of iron and manganese oxides and hydroxides are fairly high and good for chemical adsorption. Features of redox of these minerals are also remarkable due to compositions of changeable valence of Fe and Mn, which are minor but common in nature. Especially manganese oxides and hydroxides have perfect porous property that is beneficial to filtration [33].

Heat effect of natural minerals used to remove sulphur dioxide and filtrate fine particles of carbon during coal burning involves two aspects, one is the property of decomposition and the other is the stability under high temperature [17]. The products of decomposition of these minerals are so active as to react with sulphur oxides and form new phases under high temperature. Minerals having stable pores or expansion voids under high temperature can be used as porous materials to filtrate particles of carbon.

Since 1980s, experimental research on synthetic cryptomelane [34], especially a competitive aim with the new research work after the zeolite-type tetragonal molecular sieve that has been developed and utilized on large scale since the 20 century, has brought considerable attention over the world. Because a better tunnel constructed by active Mn-O octahedron in cryptomelane crystals is similar to that of tetragonal molecular sieve in zeolite, cryptomelane has the function of active octahedral molecular sieve. As compared with natural zeolite, the aperture of cryptomelane (0.46 nm) is close to that of zeolite (mostly 0.23-0.52 nm); and the K+ in tunnels of cryptomelane that has the feature of ion exchange is similar to Na+ and Ca2+ in the tunnel of zeolite. However, the more pronounced feature for cryptomelane is that it has the manganese element of variable valences and can release oxygen. Thus cryptomelane has become the real mineral of active octahedral molecular sieve [35].

Obviously, natural minerals play a unique role in treating contamination and remedying environment, and have advantages in terms of scale, costs, technology, facilities, operation and non-secondary pollution. It will help to widen the area of application of environmental mineralogy to investigate thoroughly and systematically basic properties of environmental minerals, to reveal purification mechanism and to exploit purification function of environmental mineralogy. Mineralogical and biological methods are both working effectively in pollutants treatment and jointly constitute the natural system of self-purification.

V. Micro-effect of minerals interacting with biological materials

Mineral-microbe interaction is a broad, rather poorly understood field of science [7]. Research on interaction of bio-mineralisation [36][37], especially on mechanisms of the interaction at nanoscopic scale transects the boundary between inorganic and organic world. The boundary between inorganic and organic world is increasingly indistinct because of formation and alteration of minerals participated by bacteria, and activities of bacteria participated by minerals. It is biologically precipitated minerals and organic-inorganic interactions relevant to the origin of life that have considerably broadened the purview of mineralogical science [3]. Chemists and biologists are exploring the mechanism of interaction between bacteria and molecules, atoms and electrons. It will be necessary for mineralogists to participate the research from the point of view of nano minerals due to extraordinary chemical properties of nano minerals that may play important role in bacteria activities.

Investigation on bio-mineralisation shows that kidney stone, tooth plaque and various tissue mineralisation of pathogenic diseases may be likely related to the nano organisms which have been isolated from mammalian blood and even detected in human blood and their antigens found in kidney stones. The chemical composition and morphological features of mineralised nano organisms resemble mineral particles found in calcified tissue cells and kidney stones. These nano organisms will play a significant role in understanding the mechanisms of pathogenic mineralisation and may provide insight into bio-mineralisation processes in bone and dentin [38]. The investigation on strong adsorption of metal cations by nano-scale aqueous polymeric silica also shows that adsorbed metals remain stable for billions of years, unlike clays, which will release bound metals during the transition. It is the special chemical properties of nano-scale silica polymers that play a role for the strong adsorption occurring as inner-sphere bonding [39].

The surfaces of bacteria are highly interactive with their environment. Most of the surfaces are charged at neutral pH because of the ionisation of the reactive chemical materials. Many bacteria can concentrate dilute metals in environment or adsorb toxic heavy metals on their surfaces and initiate the development of fine-grained minerals [40]. It is possible that this ability of bacteria to concentrate dispersed metals into minerals can be used as a bio-remediation process to detoxify heavy metal contaminated environment [41]. A bacterial consortium, which produces a bio-film, controls Eh and pH in the aqueous environment. This consortium has been shown actively involved in various dissolution, precipitation and alteration reactions of iron oxides and hydroxides. The consortium can remove grains of magnetite from thin sections of granite and the magnetite being incubated with the consortium was converted to hematite. The iron minerals precipitate directly onto the cell wall and being disseminated throughout the bio-film [42].

V. Conclusion

In summary, research on resource property of minerals relates to a process of production of environmental pollution and ecological destruction; whereas research on environmental property of minerals relates to a process of prevention of environmental pollution and ecological destruction. If we take into the consideration of the review presented above, it is reasonable to propose that research on environmental property of minerals is a further development of resource property of the minerals.

Mineralogy has been the foundation to geology and made a due contribution during the process of human recognition and utilisation of the Earth resources. Today in the 21st century when geology is facing two fundamental tasks: resources and environment, mineralogy as a very old branch of science is expected to play a new role for the development of geosciences, and more importantly lay a new foundation for geology. It will be a great and rare chance for development of mineralogy to change mineralogical research from resource property to environmental property. Because of special role of mineralogy played in geology, research of environmental geology needs investigation of both mineralogy and environmental sciences. In fact, research of environmental property of minerals can provide theoretical basis and technological support for geological method to harness contamination and remedy environment. There is no shirking the responsibility for environmental mineralogy to lay the foundation for environmental geology. Environmental mineralogy is a new growing point of earth science serving social development and human progress, and therefore shall shoulder heavy responsibilities.

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