The Environmental Effect of Mine

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***Abstract*—**with all of the news reports of global warming and other environmental troubles facing society today, one might wonder if mineral science has any role to play in solving these problems. It certainly does! Traditionally, the major application of minerals and mineral science has been in the understanding of how rocks form (petrogenesis) and behave. This is essentially the study of the solid part of the earth, or petrology.

Environmental mineralogy is by no means new, but it is certainly seeing an impressive rise in scope and activity. Monographs review the immense literature and diverse applications of environmental mineralogy. Recently, the Mineralogist published special "green" issues that focus on environmental mineralogy. The important role of minerals in many interesting environmental problems makes today a very exciting time for mineralogy .Environmental mineralogical topics as the effects of minerals on human health, minerals that form in surficial acidic environments, and microbe–mineral interactions.

Mineral resources are an important source of wealth for a nation but before they are harnessed, they have to pass through the stages of exploration, mining and processing. Different types of environmental damage and hazards inevitably accompany the three stages of mineral development. The negative effect on the environment of the activities involved in harnessing the minerals. An attempt will also be made to examine the possible precautions and remedies that can be applied in order to mitigate the effect of adverse environmental impact of mining activities.

Clearly, the major goal of this special issue is to highlight some of the important research that is occurring in the new, multidisciplinary field of environmental mineralogy. Another goal is to reveal to the members and officers of the mineralogical societies an indication of the range of mineralogical research that can be considered pertinent to the environmental sciences. Lastly, the society officers and the journal editors want to encourage the submission of more manuscripts on this challenging topic.

Environmental mineralogy is by no means new, but it is certainly seeing an impressive rise in scope and activity. One indication of this is the number of recent books and monographs that review the immense literature and diverse applications of environmental mineralogy. The sidebar lists numerous examples of such review volumes.

***Keywords*—** economics**,** environmental damage, mineralogy, minerals.

I. Introduction

Mineralogy is the study of chemistry, crystal structure, and physical (including optical) properties of minerals. Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.

History of mineralogy early writing on mineralogy, especially on gemstones, comes from ancient Babylonia, the ancient Greco- Roman world, ancient and medieval China, and Sanskrit texts from ancient India and the ancient Islamic World. Systematic scientific studies of minerals and rocks developed in post- Renaissance Europe. The modern study of mineralogy was founded on the principles of crystallography and microscopic study of rock sections with the invention of the microscope in the 17th century (Needham, 1986).

In any urban development it is important that land use decisions be made with full recognition of the natural resources of the area. Depending on the region, these natural resources can include geologic deposits of moderate to high value minerals used in manufacturing processes and in the production of construction materials. Aggregate (crushed rock) and limestone used in concrete production are examples of common extractable mineral resources. The past several decades of urban expansion in Southern California have reduced or restricted access to significant mineral resources, resulting in a net loss of potential resources.

More recently, driven by advances in experimental technique (such as neutron diffraction) and available computational power, the latter of which has enabled extremely accurate atomic-scale simulations of the behavior of crystals, the science has branched out to consider more general problems in the fields of inorganic chemistry and solid-state physics.

It, however, retains a focus on the crystal structures commonly encountered in rock-forming minerals. In particular, the field has made great advances in the understanding of the relationship between the atomic-scale structure of minerals and their function; in nature, prominent examples would be accurate measurement and prediction of the elastic properties of minerals, which has led to new insight into seismological behaviour of rocks and depth-related discontinuities in seismograms of the Earth's mantle. To this end, in their focus on the connection between atomic-scale phenomena and macroscopic properties, the **mineral sciences** (as they are now commonly known) display perhaps more of an overlap with materials science than any other discipline.

II. Types of Mineralogy

Mineralogy is an interdisciplinary science, as is geology, in which the principles of physics and chemistry are applied to Earth materials. There are numerous other applications of minerals outside the realm of petrology or even geology, and the importance of minerals extends into many areas of scientific and technological pursuit including materials science, environmental science, medicine, biology, and engineering (Ramsdell, Lewis, 1963).

A. Physical mineralogy

Physical mineralogy is the specific focus on physical attributes of minerals. Description of physical attributes is the simplest way to identify, classify, and categorize minerals, and they include:

- crystal structure
- crystal habit
- twinning
- cleavage
- luster
- color
- streak
- hardness
- specific gravity

B. *Chemical mineralogy*

Chemical mineralogy focuses on the chemical composition of minerals in order to identify, classify, and categorize them, as well as a means to find beneficial uses from them. There are a few minerals which are classified as whole elements, including sulfur, copper, silver, and gold, yet the vast majority of minerals are chemical compounds, some more complex than others. In terms of major chemical divisions of minerals, most are placed within the isomorphism groups, which are based on analogous chemical position and similar crystal forms.

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III. Environmental Mineralogy

International Mineralogical Association (IMA) Working Group on Environmental Mineralogy and Geochemistry definition: Environmental mineralogy [and geochemistry] is an interdisciplinary field dealing with systems at, or near, the surface of the Earth where the geo sphere comes into contact with the hydrosphere, atmosphere and biosphere. This is the ‘environment’ on which plants and animals (including humans) depend for survival and which can be disrupted by human activity, particularly that associated with exploitation and utilization of Earth’s resources.

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Environmental mineralogy is obviously a very diverse sub discipline of mineralogy, and a comprehensive review of its many aspects is far beyond the scope of these column two applications of environmental mineralogy (Rakovan, 2008):

(1) Remediation of heavy-metal contaminates that are currently in the environment.
(2) The design of solid forms of radioactive waste for stable disposal.

One significant class of environmental pollutants is heavy metals such as Pb, As, Cd, Cr, and Hg, which are toxic, even at low concentrations, and may act as carcinogens. These may be naturally present, but human activity has greatly increased the flux of biologically available forms of heavy metals in the environment.

If the metals are present in a form that cannot get into plants and animals or is nonreactive (i.e., cannot be metabolized), they are not bio available and pose a much lower health risk. This leads to one possible strategy for contaminant remediation. Instead of removing the metals from the environment, the idea is to change their speciation to a stable, non bio available form, such as being incorporated into the crystal structure of a mineral with low solubility (Bostick et al. 2000).

Mineralogists and other scientists (Wajima et al. 2006, 2007) are investigating the potential of converting paper sludge into usable minerals such as zealots. Once converted, these materials may ultimately find use in other environmental applications such as sorbents for water purification

The type of mineral and its physical and chemical properties are used as time keepers (absolute ages), as markers of specific geological events (impacts), as biomarkers (magnetite, calcite),and as indicators of particular physiochemical conditions (acidic, icehouse, greenhouse) past and present. The question often asked in identifying and studying near surface mineralogy (minerals that dominate the regolith), is what is their significance to the environment?

The mineralogical diversity in the near surface is being used to infer paleo and recent disturbed or pure environments and to study, monitor and remediate important contaminated environmental issues. Central to any study of mineral based investigation and monitoring of environmental problem is the accurate identification (often including identifying an aspect of the mineral such as disorder, compositional variation and quantification) of the mineral or minerals associated or linked with the problem and knowledge of their likely formative conditions.

Particular areas where minerals are playing important roles either as markers of specific environment or as indicators of spatial and temporal extents of environmental change produced by human activity are: metalliferous and mine wastes, acid sulfate soils and dusts arising from natural, mining and urban activities. Besides these human induced problems, near surface mineralogy has been used to infer particular aspects of the natural environment. Although 'environment' in geosciences is mostly associated with geochemistry, it is worth noting a quote by a geochemist: "when attempting to interpret most forms of geochemical data, three rules should always be applied: mineralogy, mineralogy, mineralogy. produced and ultimately their resting place.

Minerals as indicators of specific environment conditions (chemical and physical).The environment parameters that can be inferred from the presence of a specific mineral are: (Irwin, 1997).

- pH
- Radix conditions
- Presence of specific anions
- Drainage with landscape position and
- Temperature & climb sequences
- Transported versus in situ regolith

Minerals can be used as indicators of specific environmental parameters on a variety of scales ranging from the micro (thin section) to macro (hand specimen) to profile (vertical differences) to landscape (hydrology, topography) to even continental scale.

pH – Acid or Alkaline with dominant anion

The pH is the master variable and pH of surface and ground waters (shallow and deep) have a direct effect on the precipitation and stability or persistence of secondary minerals in the regolith. Often, the corollary is also true: presence of specific mineral or mineral assemblage is an indicator of pH and dominant anion present in the present or past environment. The main limitation in this inference is that the minerals indicative of the pH may dissolve or transform to another mineral on change of the pH conditions and thereby not be distinctive markers of previous pH's. It is possible to also add an extra variable in the form of dominant anion in the surrounding environment (vadose and groundwaters) to pH and infer both these variables from the minerals present.

Redox Conditions

Specific minerals in the regolith are indicators of redox state of the environment under which they formed. They form and persist in a restricted EhpH range of oxidation potential.. Pyrite (black) and mono-sulphides ("black ooze") are indicators of reducing environments, where sulphur reducing bacteria catalyze oxidation of organic matter and link it to reduction of Fe^{3+}. However, if high CO_3^{2-} ion is present in pore waters as is the case in alkaline reducing environments, siderite ($FeCO_3$) will be the dominant mineral present. Oxidizing acid conditions favour the formation and persistence of iron-sulfate minerals -jarosite and schwertmannite. Jarosite is stable over a longer period while schwertmannite is met stable and transforms to goethite with time (months to a year). Therefore, the presence of jarosite and schwertmannite is used as an indicator of acid conditions ($pH < 4$) and this pH – mineral stability linkage has been used to spatially and temporally map surface acid conditions via hyperspectral remote sensing. Goethite and kaolinite are indicative of wide oxidizing pH range from mildly acidic to neutral to alkaline conditions.

The chemistry of individual minerals can also provide information on pH conditions during time of formation. The presence of Al-substituted goethite (15-30% Al) suggests acid conditions because Al goes into solution phase only at low pH's. Al-poor goethite will imply neutral pH.

Drainage or water activity

The rate of flow of groundwater vertically and laterally (landscape) through a profile, sediments or sedimentary rock can affect the nature of the minerals that form, and the presence of resulting minerals can be used as indicators of the rate of flow of water or in thermodynamic terms the water activity.

Slow rate of water movement through a regolith profile allows the water to become saturated with the ionic components being released due to the weathering of minerals, and therefore potentially achieve equilibrium with specific secondary minerals. In a vertical profile, the weathering of a mafic rock results in the release of Ca, Mg, Si, Fe, Al to varying degrees due to the weathering of primary minerals and slow water flow or impeded drainage can result in high ionic concentrations of all or some of the released components in the groundwater, leading to the formation of calcite-smectite-goethite assemblage. A similar profile under rapid flow or free drainage conditions is likely to attain saturation in Al, Si and Fe resulting in the kaolinitegoethite and/or hematite association.

Landscape or Catenaries' Position

Regolith minerals can be used as indicators of past landscape position, but interpretation is a combination of drainage and pale landscape evolution or substrate type. The iron oxides, especially hematite and goethite, having their genetic pathways controlled significantly by Water activity or saturation, provide the best indicators of drainage linked to centenary position.

This sequence is interpreted as drier or freely draining edges favour hematite while inwards, slower drainage favours goethite. On convex slopes without incision, hill crests have better drainage while valley bottoms are poorly drained and accordingly the drier hill crests will be richer in hematite and therefore have redder soils, while the valley bottom soils are dominated by goethite and therefore are coloured brown-yellow.

Temperature & Climate
Generally, there are few reliable mineral indicators of current and past temperatures. The main indicators are the iron oxides and hydroxides. Magnetite, commonly found in globules (nodules, mottles) within soil and on the surface as ferruginous lag, is a likely indicator of forest-fires. Iron oxides (goethite, hematite) present in soil matrix and in globules when heated to temperatures above 3000C in the presence of organic matter (top soil organics), transform to magnetite. Therefore, the presence of magnetite is used as an indicator of forest fires.

On a continental scale, hematite shows dominance over goethite in the warmer, humid northern parts of southern hemisphere continents as compared to the temperate, but cooler south, where goethite predominates. Although other factors affect hematite versus goethite formation (water activity, organic matter), general observations suggest that warmer climates are favourable for hematite formation and preservation. Other studies indicate an altitude-climate relationship between hematite and goethite. The yellow soils dominant in goethite occur under cooler wet climates at higher altitudes, while the redder hematite dominates in lower altitudes where warmer temperatures and drier conditions prevail.

Transported vs. in situ regolith
Regolith is broadly classified into that produced as a result of weathering of the basement rocks in situ) and that produced due to the transportation processes, which is essence is surficial sediments.

One method proposed to identify the in situ – transported boundary is to measure the “crystallinity” of kaolinite throughout the regolith profile. Kaolinite is the most common layer silicate in the regolith and occurs in most parts of the regolith profiles and therefore lends itself as a good marker to estimate specific environment parameters. Well “crystalline” kaolinite as estimated via hk0 d-values from XRD or via the depth of separation in the 2160 and 2177 nm doublet absorption features in reflectance spectra is suggested to be an indicator of in situ regolith because the slow formation allows it to crystallize without many defects.

IV. Types of Environmental Damage

“Environment” as used in this paper has three components, namely, the sum total of external conditions in which organisms exist; the organisms themselves including the floral and faunal community; and the physical surroundings such as landforms. All these three aspects, which include various entities such as air, water, land, vegetation, animals including human, landscape and geomorphologic features, historical heritage etc. are adversely affected one way or the other during the course of mineral development (Aigbedion ,2007).

Air, land and water pollution
Varying degrees of pollution of air, water and land occur in the course of mineral development depending on the stage and scale of activities attained. While only minor pollution occurs during mineral exploration, more intense air and water pollution emanates from the exploitation stages, particularly if carried out on a large scale. In the oil-producing areas of the country oil spillage of differing intensity resulting from burst pipelines, tanks, tankers, drilling operations, etc. is a common phenomenon.

Damage of vegetation
Vegetation in form of natural forest or crop plantation is usually the first casualty to suffer total or partial destruction or degradation during the exploration and exploitation of minerals in a locality. The vegetation damage is more extensive at the time of mine development and mining operations and is more expensive when crop plantation is affected.

Ecological disturbance
Another adverse effect of mineral extraction and processing activities, which may not be immediately felt, is the disturbance of the ecosystem with possible adverse consequences on the floral and faunal community in general.
Oil spillage produces a devastating ecological disturbance in the oil-producing states as well as in areas where leakage occur due to natural breakage of oil pipe line or illegal bunkering .The plants, animals, soils and water are affected.

Degradation of natural landscape
A common negative effect of mining minerals from the earth’s surface is the destruction of its natural landscape, creating open space in the ground and generating heaps of rock wastes that cannot be easily disposed off. These phenomena are amply demonstrated in several parts of Nigeria, where commercial mining or quarrying had occurred in the past or is currently taking place.

In the Younger Granite Province, especially the Jos Plateau, tin and columbite mining has resulted in the destruction in places of the scenic landscape which is replaced by unsightly large irregular holes and heaps of debris produced by the opencast method of mining (Brooks, 1974).

Geological hazards

Mining operations normally upset the equilibrium in the geological environment, which may trigger off certain geological hazards such as landslide, subsidence, flooding, erosion and tremors together with their secondary effects.

Minor earth tremors are generated due to blasting of rocks in various quarries. Villages and settlements in the neighborhood of the quarries have experience unpleasant earth movements when the rocks are blasted (Ajakaiye, 1985). Some buildings are damaged by developing cracks due to minor tremors occasioned by the incessant blasting of the rocks.

V. Mine Development: Exploration, Planning, Approval and Construction

Mine development consists of a sequence of activities:

- Prospecting and exploration work to locate and delineate the ore resource.
- Economic, environmental and technical feasibility assessment of the ore body
- Planning and design of the mine layout, site infrastructure and the mining sequence
- Obtaining relevant government permits and approvals.
- Construction and commissioning of the operation.

Most environmental impacts during this stage of the mining life cycle are typically associated with planning, exploration and construction.

Planning

Planning is important to avoid or reduce adverse environmental impacts over the life of the mine and after closure. Planning is most effective when the entire life of mine is encompassed. Defining the final objectives of mine closure from the outset allows an optimum balance between operational, rehabilitation and closure goals to be selected, thus minimizing the cost of these activities.

Planning takes account of factors such as air and water quality, land surface disturbance, noise and vibration, surrounding and post-mining land uses, wildlife and biodiversity and cultural and historic site locations.

Exploration

Exploration activities have some environmental impacts. These are largely related to land disturbances from the clearing of vegetation, construction of camps, access roads, drilling sites and sumps for drilling fluids and fines. Noise and vibration from seismic surveys and drilling operations may also be of concern.

Effective planning of the exploration activities reduces potential impacts by using existing infrastructure where possible, taking appropriate care during the construction of access tracks and containing any drilling fluids and fines in sumps. On completion of exploration, rehabilitation of disturbed areas is enhanced by the capping or grouting of drill holes, the filling of sumps, the ripping of compacted areas, and the replacement of removed topsoil and revegetation.

Modern remote sensing exploration techniques reduce the area disturbed by exploration activities. The use of gravity and geomagnetic surveys allows wide areas to be covered with little or no impact, reducing the need for more intrusive exploration techniques.

Construction

Construction activities have significant potential to have adverse environmental impacts. During this phase, often a large transient workforce is employed, workforce numbers tend to peak and material and equipment movements tend to be large. Impacts are typically related to land disturbance caused by earthworks, air emissions from dust, noise from equipment and construction activities and heavy volumes of traffic on access roads. In many cases, specialized third party companies and consultants conduct mine construction activities.

Other potential impacts

A variety of other impacts may occur because of extraction activities, including noise and vibration due to blasting and the operation of equipment.

In some places, unsightly landscapes have been improved by maintaining buffer zones, planting greenbelts or the constructing barrier fences.

VI. Socio-Environment Problems

Some socio-environmental problems are sometimes created as a result of certain peculiarity of the mineral industry. Since minerals are exhaustible and irremovable commodities, the life of a mine and, consequently, the mining activities in a place have a limited time. The stoppage of mining activities imposed by depletion of the available reserves often leads to migration of people from the mining areas to other places. This may result in the formation of “ghost towns”, which are abandoned towns and previous bubbling mining communities.

Since some damage to the environment is inevitable in the course of mineral exploitation, usually, the only option left is to apply some remedy to the damage. The remedy or compensation should depend on the type, extent and magnitude of damage, which can be permanent or redeemable in which case the damage effect fades away as the causative factor is withdraw. The environmental impact of mining and processing activities can extend for many kilometers from the operation site.

VII. Environmental Management

Environmental management is an activity that is ongoing throughout the entire mining life cycle, from initial exploration to the final closure of the operation and handing over of the site. It encompasses and influences all the different activities of the mining life cycle and is most effective when integrated with the day-today management and planning of the operation. Environmental management consists of systems, procedures, practices and technologies that vary depending on the specific characteristics of the surroundings ecosystem, the legal framework and the mining methods and beneficiation processes employed.

As appreciation of the complexity of environmental considerations has grown, a variety of management tools have been developed to assist company's better control the effects of their operations and provide a higher level of environment protection. These tools include: environmental management systems (EMS); environmental impact assessment (EIA); environmental technology assessment (EnTA); environmental auditing; life cycle assessment (LCA); cleaner production and environmental reporting (United Nations Environment).

A. Environmental Management Systems

The ISO 14000 Environmental Management system and the European Union Eco-management and Audit Scheme (EMAS) standards provide widely recognized frameworks and guidelines that companies can use to develop their own environmental management systems. These are third-party certified, providing a means by which the company can demonstrate its commitment to improved environmental performance. Many phosphate rock and potash mining companies are looking at the ISO 14000 standards to guide the development of systems that are specific to their needs.

Quality management systems are more prevalent than environmental management systems. Adoption of these has been assisted by perceived greater benefits in terms of improved product quality and consistency and greater recognition in the market place. Even though not specifically orientated to environmental performance, systems such as the ISO 9000 Quality Management series tend to produce environmental benefits from an improvement in the overall performance of the operation. In many cases companies have found such systems to be an excellent foundation upon which to build an environmental management system.

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Recognition of the growing importance of environmental management systems is evident in a number of countries including many developing countries, where producers understand the competitive advantage of meeting the increasing demands of consumer markets such as the European Union and Japan. As community awareness has grown, demands on industry have increased accordingly. In many countries, both industry and governments are becoming more accountable for the decisions and actions they take. This is partly because of the increased availability of information concerning their actions and more stakeholder involvement in the decision-making process.

In future, community concerns may shift away from a focus on environmental damage at the mine site to the need to balance competing demands for limited natural resources such as fresh water and agricultural land. The mining industry, as a consumer of natural resources, will not be isolated from these pressures. Foresight and the adoption of adequate and effective solutions to arising issues will assist the industry's response.

Governments are responding to community pressure through new legislation. The European Union's Integrated Product policy is one such response. Policy implementation will lead to increasing producer responsibility for their products. It will also increase the use of market instruments to internalize the external environmental costs of products over their entire life cycle. This responsibility will concern not only companies' own activities but also those of their suppliers, transporters and service providers Mining firms with good reputations to keep and healthy financial resources are more likely although not certain) to engage in socially responsible mining. Such firms are typically international or they are domestic firms with ties to reputable international firms. In the short run, socially responsible mining costs more and requires considerable financial resources but this is the sine qua non of long-term viability.

There remains a need to create positive demonstration effects to promote sustainable mining through tangible examples of successful, modestly sized operations that practice responsible mining. Rushing to expand the mining sector may increase the likelihood of further accidents that are almost certain to undermine the sector's growth potential. A strategy of mining expansion focused more on the quality than the quantity of mining operations will pay higher dividends over the medium to long term.

The costs of environmental irresponsibility and bad social practices on the part of one mining company are borne by all companies in the region, and peer pressure should reduce the likelihood of major accidents and improve the credibility of the industry. Therefore, the private sector in developing countries should seek to institute mechanisms for collective self-evaluation and self policing with regard to member companies' environmental performance and contributions to community development.

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VIII. Conclusion

The production and the depletion of mineral resources, and especially oil and fossil fuels, has been an object of extensive predictive. Any environmental problem, there is need to assess or measure the magnitude of the problem. This can be done by direct measurements such as calculating the value of economic trees removed and changes in farm produce due to pollution; land, road and property reparation cost; water treatment cost; and the costs of treating diseases directly traceable to the environmental damage. However, direct measurements of environmental damage are not always possible because the damage may be intangible, subtle or even slow to appear. Under such a situation the cost of providing an alternative environment or renewable resources elsewhere, if possible, can be considered.

A major issue concerning the remedy or compensation for environmental damage resulting from mining and processing activities is that those who bear the costs of the environmental damage are the people who live in the environment and not the producing companies. The problem requires the intervention of government through appropriate legislation that can compel the mining/processing companies to internalize the reparation or replacement costs, which are so far borne by the people who live in the environment. Safe disposal of unavoidable waste in stable and aesthetically acceptable structure must be enforced through legislation. Thus, withdrawing the area from mining would have economic impacts on the local communities and may have social and economic effects that are regional or national.

Extraction and processing of mineral resources is the backbone of the national economy in many developed and developing countries of the world. However, the great danger poised by mineral exploitation such as abandoned sites, biodiversity damage, use of hazardous use of chemicals with potential health risk to mine workers and neighborhood communities deserved urgent attention. Emphasis should shift from waste disposal to waste minimization through sorting; recycling of regents and water. Safe disposal of unavoidable waste in stable and aesthetically acceptable structure must be enforced through legislation.

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