

Sustainable development and exploration

Introduction

What is sustainable development? Everyone seems to have a slightly different view of sustainable development. The Brundtland report (United Nations, 1987) defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own.” Exploration for new materials is an integral part of sustainable development.

Mining is essential to maintain economic wealth because it is one of the ways that new wealth is created (fishing, farming and forestry are others). Without a continued supply of natural resources to manufacture and produce products that society demands, society cannot continue to improve and grow technologically. Recycling, re-use, less use, materials replacement and alternative product design are some ways to replace mined commodities, but exploration and mining of new resources is still required.

Mining began when prehistoric man first used a stone or rock as a tool for hunting, tanning or crushing to make life easier. Today, just about everything we use involves mining — even agriculture or the growing of crops depends on minerals for fertilizers to enhance growth, pesticides to ward off predators of plants and tools to plant and harvest the crops. Indeed, the use of raw materials in the United States and the world increased dramatically in the 20th century and is continuing to increase in the 21st century (Wagner, 2002).

However, mineral resources generally are not renewable. When mining occurs, the ore body being mined is depleted. One factor of sustainable development is to continue to supply society with the raw materials, metals, industrial minerals and energy minerals it requires. This requires exploring for new resources. However sustainable development is not about sustaining a particular mine. Instead, mines have a beginning and an end, which we refer to as the mine-life cycle (Fig. 1).

Mining companies realize that they must meet the mineral needs of our society, while protecting the health, safety and welfare of its workers, the surrounding community and the environment. Mining companies

V.T. MCLEMORE AND D. TURNER

V.T. McLemore, member SME, is senior economic geologist with New Mexico Bureau of Geology and Mineral Resources (NMBGMR), New Mexico Institute of Mining and Technology, Socorro, NM; D. Turner, member SME, is senior project coordinator with Arizona Department of Environmental Quality, Phoenix, AZ. Preprint number 04-170, presented at the SME Annual Meeting, Feb. 23-25, 2004, Denver, CO. Original manuscript accepted for publication April 2005. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to May 31, 2006.

operate an industrial enterprise with importance to local and national economies, generate tax revenues and provide sustenance to numerous individuals and families (Parr, 2001). Under sustainable development concepts, not only are mining companies expected to produce profits for the shareholders, but mining companies are also expected to provide resources to the local community that will sustain its growth during and after mining. In many rural areas, mining companies provide community

leadership and emergency medical personnel that the rural communities would not otherwise have. The company is sustainable only if it continues to develop new reserves. This is accomplished during the exploration stage of mining.

Definitions

A *mineral occurrence* is any locality where a useful mineral or material is found. A *mineral prospect* is any occurrence that has been developed by underground or aboveground techniques or by subsurface drilling to determine the extent of mineralization. These two terms do not have any resource or economic implications. A *mineral deposit* is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present or future favorable conditions. An *ore deposit* is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade and accessibility to be extracted (mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change.

Mineral deposits and especially ore deposits are not found just anywhere in the world. Instead they are relatively rare and depend on certain natural geologic conditions to form. The requirement that an ore deposit must be extracted at a profit makes them even more rare.

Industrial minerals are any rock, mineral or other naturally occurring material of economic value excluding metals and energy minerals. Examples of industrial minerals include perlite, pumice, gypsum, salt, mica,

Abstract

The mining industry is at a crossroad. To sustain our technology-based society, demands for commodities are increasing, and exploration for these commodities is a must. The debate is between sustainable development and the status quo. It begins with exploration, where it is determined if a mineralized area contains enough potential ore to be mined economically. Mineral deposits are relatively rare, depend on certain natural geologic conditions to form and may not always occur in locations that are most suitable to society. Exploration can be compatible with environmental protection and social responsibility. But difficult challenges face the industry to develop a property that is environmentally, economically and socially responsible.

aggregates (crushed stone, sand and gravel), zeolite, calcite, both silica and chemical limestone flux, mineral desiccants, feldspar, clay, humate, fillers and extenders, wollastonite and semiprecious gemstones (Barker and McLemore, 2004).

Stages of mining

One of the principles of sustainable development in mining is that every mining operation has a beginning and an end (Fig. 1; MMSD, 2002). The mine-life cycle can be divided into four stages: exploration, development, operations and closure/postclosure. Only the exploration stage is discussed here.

Exploration stage of mining

The first stage of mining is the prospecting or reconnaissance stage, or the identification of areas that might contain mineral deposits (Hartman, 1992). Once a mineralized area is located, it is determined if the mineralized area contains enough potential ore to be mined economically. If a potential mineral deposit is located, then the company performs a feasibility study to determine if the deposit can be mined under future economic conditions. If a mine cannot afford the cost of environmental remediation, then the deposit probably should not be developed. Claim staking, road and trail building and helicopter transport typically occurs during the exploration stage and may continue into the advanced exploration and feasibility stages.

A variety of exploration techniques may be employed in both the exploration and development stages, including literature searches, geological mapping, geochemical exploration (rock, soil and water sampling and analysis), geobotanical surveys, geophysical surveys (surface, subsurface, airborne, satellite), aerial photography and drilling. Most exploration programs, however, never result in operational mines, making exploration a relatively high-risk investment.

The modern explorationist, typically a geologist, has more tools to choose from than his predecessors when locating ore deposits. Satellite images, remote sensing imagery, geologic maps, geophysical studies and geologic reports are examined to identify favorable areas for exploration. Technological development has made it possible to perform exploration with less physical disturbance to the land. This is an important contribution to the well being of the environment and a key to sustainable development. Mineral deposit models (tectonics, metallogenesis, environmental models) are useful in identifying targets. These same techniques can be used in environmental studies. Once the mineralized areas are identified, the explorationist conducts field examinations of the area. Surface sampling, stripping, drilling and trenching, bulk sampling and even panning are still used in the beginning phases of exploration today.

Outcrops are examined for favorable lithology and mineralogy, and samples are submitted to laboratories for chemical analyses. Most samples are solid (rocks, soils and stream sediments); other sample media can be collected and chemically analyzed (biological, water and air).

The explorationist also can use geophysical and geochemical techniques not available to the prospectors of the 1800s. Detailed geologic maps are prepared to help characterize the rocks at the surface and to predict the

Table 1

Information that should be identified and collected during exploration (National Academy of Science, 2002).

Data

Water quality (surface and ground water).
Chemical analyses of soils, especially metals.
Trace elements in ores, especially elements of environmental concern.
Presence of asbestos and asbestiform minerals.
Potential for acid rock drainage (ores, wastes and adjacent terrains).
Location of aquifers in relation to ore bodies and areas of mine development.
Identification of areas of sensitive environmental concern.
Climatic data, especially precipitation.
Social and community needs and environmental issues.
Presence of indigenous cultures and their needs and issues.

rocks in the subsurface. Despite the numerous exploration techniques available, ultimately the deposit must typically be drilled. Several drilling techniques are available that provide samples of the hidden potential deposit. In some cases, test (or exploration) pits, adits and drifts are excavated to provide enough material for metallurgical testing and other purposes.

New exploration techniques are essential in quickly defining areas of potential mineralized bodies as well as eliminating or reducing environmental impacts in the area to be explored. Ultimately, the minimum grade to be mined is determined by the market price of the mined commodity.

Some of the issues that could arise during exploration that apply to sustainable development concepts include:

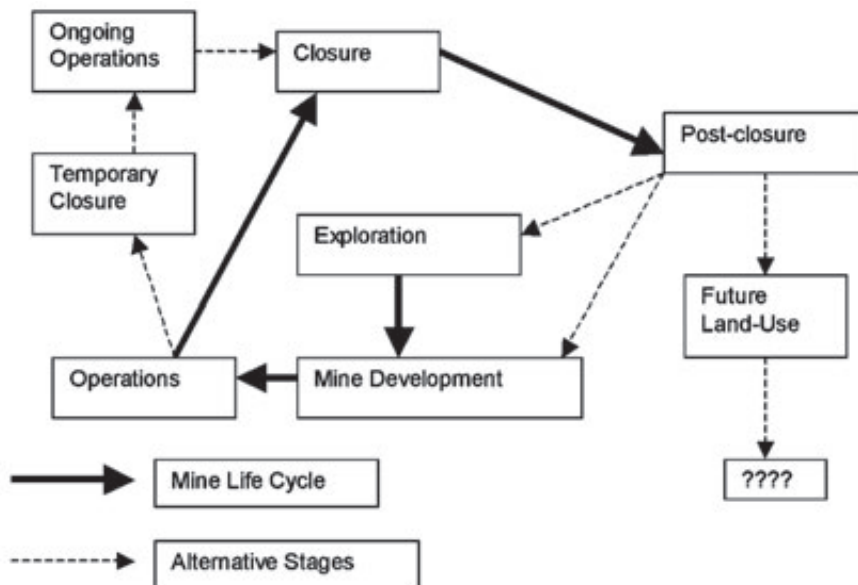
- land access;
- relations with the local community, especially indigenous peoples);
- environmental impacts;
- rare and endangered species; and
- health and safety of employees and the public.

Additional factors that affect whether or not the deposit can be mined include:

- location and size (is the location, size and shape of the deposit amenable to available low cost mining and processing methods?);
- mining rate (high mining rate usually means lower unit costs);
- geochemistry of the deposit (specifically the presence of sulfides that may lead to acid drainage);
- ease of recoverability of the commodity by known processing techniques (mineralogy, grain size of the ore mineral, hardness, impurities);
- available land access for safe, long-term storage of mine wastes;

FIGURE 1

Mine-life cycle (van Zyl, written communication, 2002.)



- geotechnical characteristics (stability of underground openings, steepness of open pits, slope stability, etc.); and
- social setting of the deposit (what does the local community feel about a mine in their neighborhood).

These factors should be considered during the exploration phase.

Challenges facing the mining companies

Many of the challenges mining companies face today differ from the challenges the industry had faced in the past, including:

- It is a global market with global competition for resources, land access, money and markets.
- Many people have little if any understanding of where products they use everyday come from or where real wealth comes from.
- Local and national governments depend on the revenues generated by mining companies to be sustained far into the future. Yet these same governments are supposed to impose and enforce strict health, safety and environmental regulations.
- Local communities expect that the mining companies will provide employment, infrastructure and other benefits and that they will leave them better off than when the mine started.
- Communities expect mining companies to involve them in the decision-making process in all aspects of mining and closeout plans.
- Society expects mining companies to adhere to higher standards of performance and that the industry will avoid ecologically and culturally sensitive areas.
- Mining companies are expected to protect and enhance biodiversity. Many people believe that the benefits of mining are not enough to justify the impacts on biodiversity (Blench, 2001; <http://www.iiied.org/mmsd/activities/biodiversity.html>, accessed on Oct. 24, 2003).

- New mining and processing methods are needed that have a lower environmental impact than methods being currently used.
- An exploration company may need to transfer a grant of exploration rights to involve other entities with greater financial and technical capacities (Parr, 2001). In some situations, local regulations can prevent this type of transfer.
- Better ways of converting land that are liabilities into lands that are assets.
- Can companies establish specific targets based on long-term environmental and community well being?

Some of the traditional challenges for mining companies remain.

- To reduce the risk of successful exploration, areas with favorable geology and known mineral deposits are examined. However, these areas are limited.
- Mineral deposits are found in specific locations not always compatible with society's needs and wants (not in my backyard syndrome).
- Many of the largest, highest-grade mineral deposits closest to the surface and closest to the markets have been depleted or are currently in production or on standby.
- Financing a mine can be a moderate to high risk, and some commodities are perceived by investors to be politically incorrect (such as uranium). Investors expect higher returns and dividends.
- Generally accepted risks associated with a specific target still provide a challenge in mining (climate, sulfides, water, access, etc.).
- Securing a well-trained and educated workforce is a challenge.
- The workforce and the public demand significantly fewer work-related accidents and health effects from mining.
- Compared with other industries, the financial improvement in mining has not increased significantly to attract investors (Adams, 2002).

Exploration geologists are now being asked to collect environmental data as well as identify environmental concerns. Even industrial minerals operations, traditionally perceived as having few impacts on the environment, are under public and government pressure to identify and plan for environmental impacts (Barker and McLemore, 2004). Permitting typically begins during exploration in many areas of the world. Some of the additional information requested by the environmental departments of the mining companies, stakeholders and other interested parties is summarized in Table 1.

Land access

The most important aspect of exploration is access to mineralized areas, not only for actual exploration, but

also for continued mine development. "The absolute worst thing that can happen is denial of an opportunity to mine after extensive expenditures over long periods of time with little chance of success and major investments for site specific evaluations have finally identified an economically exploitable mineral deposit" (Parr, 2001).

Many countries, including the United States and Canada, have legislated areas that are off-limits to exploration and mining (wilderness areas and national parks) in an attempt to protect environmental and cultural sensitive areas. Decisions concerning land access tend to be made in the political arena without regard to the presence of important mineral resources. A better way (and more sustainable) is for a multi-stakeholder planning process to be implemented (as in Manitoba) to develop a land access policy and division that pays attention to environmental, social and mineral resource values.

Indigenous cultures

The mining community recognizes indigenous cultures as a major stakeholder in exploring for and developing potential mine sites in and adjacent to native lands (Downing et al., 2002; Warden-Fernandez, 2002). Yet many challenges still face the mining industry in gaining access to these lands. In many areas, mining is not compatible with religion and culture.

For example, the Navajo Nation in New Mexico and Arizona is experiencing a dilemma brought on by mining and oil and gas exploration. The Nation profits from oil, gas and coal production. However, many tribal members are opposed to mineral development of any kind and are opposed to any exploration within and adjacent to their reservation.

To compound problems between mining companies and indigenous peoples, in some areas, coal and gas resources are being developed, even though nearby residents do not enjoy the benefits of coal or gas heat (Romero, 2003). In another example, Teck Cominco Co. has established favorable relationships with the Native Americans in the area and formed a partnership to develop the Red Dog deposit in Alaska (Horswill and Sandvik, 2000).

Exploration technologies

Exploration is traditionally geology driven. But today and in the future, exploration will be technology driven as well. The search for new reserves depends on favorable geologic settings. So it is important to have current geological models that include the origins of the ore body, the geologic history, the genesis of the deposit, and mineral deposit grades and tonnages. These criteria determine the technically and economically feasible mining method.

For example, low-grade, disseminated ore bodies usually cannot be mined economically by underground methods. Openpit mining is the most efficient way of developing such ore bodies. The National Academy of Sciences (2002) has identified needed research and technology methods for exploration of mineral deposits, summarized below and in Table 2.

During the 1980s, mineral deposit models that incorporated tectonic setting and physical and chemical characteristics of the deposits became popular (Cox and

Singer, 1986; Roberts and Sheahan, 1988; Sheahan and Cherry, 1993). In the 1990s, U.S. Geological Survey's geoenvironmental mineral deposit models (du Bray, 1995) were developed. They provide geologic information that can be used to better understand, predict, minimize and remediate potential environmental effects of mineral resources. Geoenvironmental models provide one method of developing site conceptual models and identifying potential environmental impacts based on characteristics of the mineral deposit.

A geoenvironmental model is a compilation of geologic, geochemical, geophysical, hydrologic and engineering information pertaining to environmental behavior of geologically similar mineral deposits prior to mining and resulting from mining, mineral processing, smelting and refining (Plumlee and Nash, 1995). Today, geoenvironmental models are receiving international support

Table 2

Needed research methods and technologies for exploration of ore deposits (National Academy of Sciences, 2002).

Geologic methods

- Robust thermodynamic and kinetic geochemical data and models.
- New ore deposit models, especially for deposits with minimal impact on the environment.
- More sophisticated three-dimensional geological and ore-reserve models.
- Better geohydrologic models relating to mineral deposits, including industrial minerals deposits.
- Geologic maps of mineralized areas.
- Databases of mineral deposits and mineralized areas.

Geochemical and geophysical methods

- Hand-held and down-hole analytical instruments.
- Improved cross-bore hole correlation methods and characterization.
- Better understanding of element mobility in soils and water.
- Drones (unmanned aircraft) for airborne geophysical methods (for example Magsurvey's UAV, www.magsurvey.co.uk, accessed on November 5, 2003).
- Low-cost, seismic methods.
- Better interpretation of remote sensing and hyperspectral data (Livo and Knepper, 2004).
- More sophisticated three-dimensional geochemical, hydrological, and geophysical models.

Drilling technologies

- Application of existing petroleum and geothermal techniques to mineral exploration.
- Improvements in drilling methods.

Changes in corporate policy

- Diversification into other commodities, especially industrial minerals.
- Developing and maintaining expertise in exploration.

in the exploration industry. And the industry is demanding improved, more sophisticated geoenvironmental models. Models of industrial minerals deposits are needed as well (Barker and McLemore, 2004).

Despite these advances in mineral deposit models, data is still needed about the processes of ore formation (Table 2; National Academy of Sciences, 2002). Some of the data are company proprietary information and not readily available to others. Much of the data that is available (maps, production data, reserves) is in paper form and would be costly to convert to digital form.

Geophysical techniques reduce the physical impact of initial exploration, and research in these techniques has been ongoing since the 1950s. Ground-based techniques such as gravity and seismic surveys are costly and are being replaced by quicker, less expensive aircraft and satellite surveys, such as magnetic, remote sensing (Livo and Knepper, 2004) and hyperspectral surveys (National Academy of Science, 2002). Better implementation and interpretation of these methods is needed (Table 2).

Ultimately, the deposit must be drilled to evaluate the economic potential below the surface. The minerals exploration industry would benefit greatly by using newer drilling technologies currently employed by the petroleum and geothermal industries, such as directional drilling, horizontal drilling and drilling tools. "Sumppless" drilling, although more costly, reduces the risk of surface contamination by drill products. It is currently used by the petroleum industry and could be used in exploration for metals and industrial minerals deposits (Richards, 2002). Borehole geophysical logging is a standard technique in the petroleum, geothermal and coal industries, but is rarely used in other mineral exploration. These surveys measure the physical characteristics and differentiate rock types and could be used in many exploration projects.

Where to spend the exploration dollar?

As exploration budgets continue to shrink, new exploration technologies will be used. Most exploration companies continue to focus on known mineralized areas with a proven track record for land access and mineral development. The larger companies are diversifying into other commodities such as industrial minerals (Barker and McLemore, 2004).

New mining and processing technologies provide for new exploration targets. Development of better methods of bulk mining underground will enable less expensive mining with minimal impact to the surface. Optimizing slopes (steeper, stable and safer) in openpits result in less waste rock, less land disturbance, and less mining costs.

In optimization during operations, companies must be careful to prevent ongoing instabilities on closure. Advanced processing technologies, some based on biological processes and solvent extraction-electrowinning (SX-EW), are improving recovery rates and reducing the costs of mitigating environmental impacts. For example, the advent of heap leaching and SX-EW has cut out whole sections of processing flow sheets and reduced the costs of producing copper. Placer Dome's Zaldívar Mine in Chile is an example of a highly efficient and low-impact SX-EW plant and how things can be done correctly (Richards, 2002). However, environmental problems with

other SX-EW plants need to be worked out, especially in finding ways to close the heaps without ongoing treatment of effluent.

The increase use of in situ leaching and addition of new in situ techniques would eliminate the need for moving tons of ore and waste to recover small quantities of marketable metals. But, once again, proven technologies need to be improved with development of more environmental friendly lixiviants. Better techniques of recycling mine wastes can open up new exploration opportunities (Struther, 2000). The development of automated mining techniques should allow access to new sources of underground ore.

Indicators

Indicators are used to measure performance towards sustainable development. Some of the suggested indicators for exploration towards sustainable development are summarized below. These, and others, have been identified by the Sustainable Minerals Roundtable (Shields et al., 2003; www.unr.edu/mines/smr).

- the amount of land available for exploration and development,
- the number of exploration projects,
- annual drilling footage or active drill rig count,
- annual mineral leases,
- the amount of dollars spent on exploration,
- the number of new mines being developed,
- reserves/resources of specific commodities,
- area reclaimed after exploration,
- number of abandoned mines reclaimed during exploration and
- the number of mines with production of materials as byproducts that might otherwise be considered waste (especially industrial minerals such as clay deposits in coal fields or porphyry deposits).

Lessons learned

Some lessons learned by exploration companies are as follows:

- the recognition of the role of stakeholders, including indigenous cultures, in the decision-making process (Eggert, 2001) (this requires the development and implementation of effective and open means of communication and regular engagement with the stakeholders (for example, Molycorp's Questa Mine providing reports online, www.molycorp.com));
- a smaller, better-trained and efficient workforce;
- the recognition of the needs of local communities (some local people may value the land for its cultural and aesthetics and may be uncomfortable with any mining, even if there is compensation (Richards, 2002));
- recognition that some areas are not acceptable for mining (the New World deposit near Yellowstone National Park);
- changes in mining methods to optimize and minimize cost of mineral development; and
- mistakes made during the exploration period in not setting up positive engagement with communities can result in long-term problems in the development of new deposits.

Summary

Mining is essential to meeting the needs of present society, while contributing to a sustainable future. The challenge of exploration and mining in the future is to develop superior exploration and resource characterization methods and to develop better technologies to find and define larger high-grade reserves with minimal environmental disturbance.

New mining and processing techniques also can provide for additional exploration targets in the future. Exploration can be compatible with environmental protection and social responsibility, but difficult challenges face the industry to develop a property that is environmentally, economically and socially responsible. ■

Acknowledgments

Comments by James Barker and Dirk van Zyl on an earlier version of this manuscript are appreciated.

References

- Adams, R.G., 2002, "Value-Based Management: Reality Based Management: Reality or Public Relations? or Public Relations?" Mineral Economics and Management Society Economics and Management Society, 11th Annual Conference Annual Conference Montreal, Quebec Montreal, Quebec, April 11, 2002.
- Barker, J.M., and McLemore, V.T., 2004, "Sustainable development and Industrial minerals," SME Preprint No. 04-171 (CD-ROM), 10 pp.
- Blench, R., 2001, "Biodiversity Issues: The Enabling Environment and Mining," MMSD No. 60, IIED, 26 pp.
- Cox, D.P., and Singer, D.A., eds., 1986, "Mineral Deposit Models," U.S. Geological Survey, Bulletin 1693, 379 pp.
- Downing, T.E., Moles, J., McIntosh, I., and Garcia-Downing, C., 2002, "Indigenous Peoples and Mining Encounters: Strategies and Tactics," MMSD No. 57, IIED, 41 pp.
- Du Bray, E.A., ed., 1995, "Preliminary Compilation of Descriptive Geoenvironmental Mineral Deposit Models," U.S. Geological Survey, Open-file Report 95-831, 272 pp.
- Eggert, R.G., 2001, "Mining and Economic Sustainability: National Economics and Local Communities," MMSD No. 19, IIED, 84 pp.
- Hartman, H.L., 1992, "Introduction to mining," in *Mining Engineering Handbook*, Hartman, H. L., ed., SME, Littleton CO, pp. 3-42.
- Horswill, D.H., and Sandvik, H., 2000, "Mining and sustainable development at Red Dog," *Mining Engineering*, Vol. 52, No. 11, pp. 25-31.
- Livo, K., and Knepper, D., 2004, "Non-invasive exploration in an environmentally sensitive world," SME Preprint No. 04-172 (CD-ROM), 8 pp.
- McLemore, V.T., Russell, C.C., Smith, K.S., and the Sampling and Monitoring Committee of the Acid Drainage Technology Initiative—Metals Mining Sector (ADTI—MMS), 2004, "Sampling and Monitoring for Closure," SME Preprint No. 04-062 (CD-ROM), 10 pp.
- MMSD, 2002, "Industry in Transition, A Profile of the North American Mining Sector," International Institute for Sustainable Development and Alistair MacDonald, 147 pp. (www.iisd.org).
- National Academy of Sciences, 2002, "Evolutionary and Revolutionary Technologies for Mining," National Academies Press, 86 pp. <http://www.nap.edu/openbook/0309073405/html/19.html>
- Parr, C.J., 2001, Operational Needs and Realities in the Search for and Development of a Mine," Mining, minerals and sustainable development, Report No. 49, 18 pp.
- Plumlee, G.S., and Nash, J.T., 1995, "Geoenvironmental Models of Mineral Deposits — Fundamentals and Application," U.S. Geological Survey, Open-File Report 95-831, pp. 1-9.
- Richards, J.P., 2002, "Sustainable development and the minerals industry," Society of Economic Geologists, *SEG Newsletter*, No. 48, pp. 1-12.
- Roberts, R.G., and Sheahan, P.A., eds., 1988, "Ore Deposit Models," Geological Society of Canada, Geoscience Canada, Reprint Series 3, 194 pp.
- Romero, S., 2003, It's gas vs. heritage in Navajo Country," *New York Times*, October 14, 2003, www.NYTimes.com
- Sheahan, P.A., and Cherry, M.E., eds., 1993, *Ore Deposit Models*, Vol. II, Geological Society of Canada, Geoscience Canada, Reprint Series 6, 154 pp.
- Shields, D.J., Wagner, L.A., and Van Zyl, D., 2003, "Indicators of mineral systems contributions to sustainability in the USA," *Proceedings*, International Conference on Sustainable Development Indicators in the Mineral Industries, Z. Agioutantis, ed., Milos Conference Center, pp. 35-41.
- Struther, S., 2000, "Recycling – the key to sustainable mining," Fifth International Symposium on Environmental Geotechnology and Global Sustainable Development, Belo Horizonte, Brazil, Aug. 17-23, 2000.
- United Nations, 1987, *Our Common Future, Report of the World Commission on Environment and Development (the Brundtland Commission)*, Oxford, Oxford University Press, 383 pp.
- Wagner, L.A., 2002, "Materials in the Economy — Material Flows, Scarcity, and the Environment," U.S. Geological Survey, Circular 1221, 29 pp.
- Warden-Fernandez, J., 2002, "Indigenous Communities and Mineral Development," MMSD No. 59, IIED, 30 p.