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Conference Report

Economic Geology: New Directions and Sound Practice

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INTRODUCTION

The Mineral Deposit Research Unit (MDRU) is a collaborative industry-university initiative based in the Department of Geological Sciences at the University of British Columbia (UBC). The unit was formed in late 1989 in response to industry interest, principally in western Canada, and has grown rapidly in the last two years. The major function of the unit is to carry out applied research related to mineral deposits and mineral exploration, particularly in the Circum-Pacific region. In April 1992, MDRU organized a two-day workshop to assist the unit in defining a research focus for the next five to ten years. The first day of the workshop involved a series of invited presentations on a general theme, *The Future of Research in Economic Geology*. On the second day, participants divided into a series of discussion groups working on individual themes which included exploration philosophy, ore deposit models, exploration techniques, exploitation and environment, education, collaboration, and company support. The meeting involved more than one hundred participants from industry, government and academia and produced a consensus on a number of issues, and thought-provoking discussion on others.

Although the primary purpose of the meeting was to generate ideas and direction for MDRU, several conclusions emerged that are relevant to economic geology and mineral exploration in general. These conclusions are reported in this discussion. The themes, which have been synthesized by the author, are built largely on the contributions from many of the participants at the MDRU meeting, and particularly the invited speakers and session chairmen. These included D.W. Strangway (President, UBC), E. Gonzalez-Urien (Vice President of Exploration, Placer Dome), B.R. Berger (United States Geological Survey (USGS), Denver), H. Wynne-Edwards (President, Terracy), S.E. Kesler (University of Michigan), J. Guha (U. du Québec à Chicoutimi), R.N. Henley (Etheridge and Henley Geoscience Consultants, Canberra), P.M.D. Bradshaw (Vice President, Orvana and Chairman of the MDRU Board of Advisers), W.K. Fletcher (Head, Department of Geological Sciences, UBC) and J.M. Franklin (Geological Survey of Canada (GSC), Ottawa). The following does not necessarily reflect the views of any one of these individuals.

Five themes are developed in the following discussion: data integration and modelling, improvements in the database, collaborative research, environmental earth science, and education. These are, in part, related, but also stand out as separate trends often championed by individuals. The themes apply equally to research and exploration and, although most are recognized, all need emphasizing as their development will influence the science of economic geology and the future of the mining industry.

DATA INTEGRATION AND MODELLING

Computers have been a feature of the mining industry for many years, particularly in ore reserve estimation, production and plant operation. In the last five years, however, there has been an explosive increase in accessible computer power. The simultaneous development of new software, which in general is becoming increasingly user friendly, allows all geoscientists to use an amazing array of tools for analyzing and/or modelling data of different types. Geographic information systems (GIS) are a product of these developments and present multiple opportunities for all of earth science. Although the use of computers in exploration has been relatively limited compared to other areas of the industry, the prospect of easy and rapid data integration may change this.

Data integration is not a new concept. Most exploration companies and geologists have always assembled data (geological, geochemical and geophysical) for a region or property at the same scale on mylar sheets and overlaid them in the search for coincident anomalies or supporting information. What is new is the speed with which this can be done, the ability to simultaneously interrogate the data, and the opportunity to combine or invert data (*e.g.*, the production of three-dimensional earth structure models from multiple geophysical data sets). In exploration, the opportunity to routinely utilize and visualize all data (digital terrain models, remote sensing, geological mapping; rock, soil or other geochemistry for >30 elements; and airborne, ground and down-hole geophysical surveys) should improve target selection, and will certainly allow exploration management to more rapidly review results and proposals.

In the future, these complex data sets will be integrated directly with ore deposit models, based on critical empirical features, and supported, where possible, by genetic or process concepts. In many cases, this will still be done by the individual explorationist, based on his/her instinct and experience, but this integration may then be tested against diagnostic expert systems during the computer-oriented data analysis. Database-expert systems are more likely to be used routinely than were the early generation of expert systems that attempted to provide artificial intelligence based on the inductive powers of a few individuals. Although there are no guarantees, more effective use of data should increase exploration efficiency, given that many discoveries result from a single new interpretation after multiple exploration phases. Many explorationists conclude that the next major breakthrough in exploration technology will come from new methods of data analysis and data integration — that is, better use of existing data —

rather than a new geophysical or geochemical method. This is obviously a challenge to the geophysicists and geochemists.

Although there is considerable interest in GIS and data integration in the exploration industry, there is a virtual stampede in government agencies. This is partly practical, since it provides an easy means of assembling and publishing large regional data sets, but it is also driven by potential applications in resource assessment and land use management. The technology is available for outlining mineral potential by combining regional data and ore deposit models. Ultimately, a quantitative estimate of mineral potential may be attempted: a goal which is politically desirable but fraught with potential pitfalls.

Research on mineral deposits has traditionally involved the combination of multiple types of data. It has been anchored on field work, but has probably included every available branch of earth science, depending on the deposit type or problem. It could be argued that economic geology is the home of the generalist (not necessarily regarded as a complimentary term) or in current parlance, the multi-disciplinary scientist (much more complimentary). Increased computing power has improved our ability to statistically analyze multiple data sets and model processes applicable to ore deposit formation. In addition, complex programs have been written to simulate natural ore-forming processes: fractional crystallization and volatile/sulphide saturation, with associated metal partitioning from magmas; chemical-mineralogical alteration and metal precipitation; boiling-mixing fluid models and metal transport; and quantitative evaluation of supergene processes. Not only do these models explain natural assemblages or processes, but they are also becoming predictive, suggesting new metal associations or environments. The programs for these models are becoming routinely available and this type of analysis will become commonplace in ore deposit studies.

The trend to use greater computing power in all areas of economic geology is absolutely inevitable. In addition to routine use, this field represents a challenging area of research for those who can combine a knowledge of mineral deposits with computing skills, and experiment with theories such as chaos, fractals and non-linear dynamics. It is not, however, a panacea. As with any advanced tool, there are many opportunities for abuse. There is a tendency to use computer power as a magic black box without necessarily understanding the data or the functions that the computer is performing. A lack of attention to detail, no calculation or propagation of errors, and over-interpretation of results appear to be common problems in research that relies heavily on computer analysis.

In view of the rapid developments in the computing field and applications to economic geology, it is particularly appropriate that a conference devoted to data integration has been jointly organized for April 1993 by the Society of Economic Geologists (SEG), the Society of Exploration Geophysicists, the Association of Exploration Geochemists (AEG) and the USGS. This conference will provide an excellent opportunity for professionals and researchers from the various geoscience disciplines to review and discuss current developments.

IMPROVEMENTS IN THE DATABASE

The availability of computer power is exciting for both mineral exploration and research related to mineral deposits. The danger, however, is that the ability to analyze and model will exceed the quality of the data. If the computing tools are to be put to the maximum and best use, the best primary data must be acquired, whether for exploration, research or a combination of uses, such as the development of ore deposit models.

There have been remarkable advances in analytical tools applicable to ore deposit research during the last ten years. New geochronometric techniques at the forefront are, for example, single crystal and ion probe U-Pb, and $^{40}Ar/^{39}Ar$, Rb-Sr and Nd-Sm on a range of previously untried minerals. There is wide support from government surveys, granting agencies and industry for geochronology; few things are more fundamental to exploration than the age of mineralization. Other significant advances have occurred in fluid inclusion technology, particularly fluid and gas analyses and work in opaque minerals; in stable isotope analyses by ion probe and other selective techniques, in analytical chemistry such as the ICP-MS, and in selective analytical techniques such as ion (SIMS) or laser (LIMS) probes. These are powerful or potentially powerful (some are still in the development stage) tools that are providing remarkable data and new constraints on ore-forming processes. Although extremely important, they produce a secondary database because their application is entirely dependent on the quality of the primary database — field relations. Furthermore, research using these tools can suffer from the same problem as computers (*e.g.*, a lack of error analysis). Precision and accuracy are not always reported or discussed, and analytical errors are rarely propagated (*e.g.*, in calculated water-rock ratios or mixing models based on isotopic measurements).

The support for analytical developments is intrinsic to the system that funds science. New equipment has tremendous appeal, not only because it may provide a new way to answer unresolved fundamental questions, but because it offers (when working) high productivity, and hence data for numerous publications. Unfortunately, similar support is not generally available for the primary database. Field-based research is slow and laborious, it does not usually produce immediate results, and it can be expensive in remote areas. Other areas of long-term or basic research critical to the primary database, such as experimental studies, have also suffered to some extent in the last few years. Experimental studies are also slow and have an even greater chance of failure. They remain absolutely necessary, however, if we wish to better constrain models for ore-forming processes, particularly the computer simulations.

Although the importance of field work has been played down in the last ten years, there are signs that its relevance has not been overlooked. New national mapping programs — partly justified by the necessity for realistic resource assessment — have been or are being initiated in Australia, Canada and the United States, and large collaborative grants have been awarded for research projects with a significant field component. Recent recipients of the SEG Lindgren award and the Duncan Derry Medal of the Mineral Deposits Division of the Geological Association of Canada (GAC) have included researchers whose science is largely field based. Finally, the inclusion of more field-based papers in *Economic Geology*, the SEG newsletter, and the new journal, *Exploration and Mining Geology*, suggests that there is wide support for this fundamental aspect of economic geology. A continued emphasis on sound field work is absolutely necessary if we are to discover new mineral deposits, carry out reliable resource assessment, and make the most of the exciting developments in computing and analytical tools.

COLLABORATIVE RESEARCH

The breakdown of barriers between traditional science disciplines is a recognized phenomenon witnessed by the rash of new inter-disciplinary centres and institutes within universities. Although obviously in vogue, multi-disciplinary science has an important role to play in Canada, and is now defined as a special grant category by the Canadian Natural Science and Engineering Research Council (NSERC).

As stated previously, economic geology is, by its very nature, multi-disciplinary, although it is interesting to note that authors of several recent ore deposit papers have felt it necessary to use the term to describe field and laboratory studies. It is also clear that economic geologists have much to learn by being truly multi-disciplinary and working with specialists in other areas, including those outside earth science. This is especially important in applied or exploration-related research, where one job of the researcher is to devise innovative applications from theoretical research in other fields.

Large collaborative projects provide a platform for multi-disciplinary science. Examples where economic geologists have contributed to mega-projects include the Ocean

Drilling Project (ODP), other sea-floor programs such as PACMANUS and PACLARK, the LITHOPROBE program in Canada, and a variety of International Geological Correlation Program (IGCP) projects during the last 20 years. At a more deposit-directed level, projects have been initiated at Sullivan and Kidd Creek involving Canadian federal and provincial surveys and, in the case of Sullivan, the USGS. Finally, relatively large grants have been awarded by NSERC and other agencies (*e.g.*, Science Council of British Columbia) to metallogenic or thematic projects of the type pursued by MDRU.

Although the mining industry in North America has always supported universities and individual research projects, there have been few attempts to organize multi-company collaborative research. These programs have existed in South Africa (EGRU at Witswatersrand), in Australia (AMIRA), and, to a lesser extent, in the UK (MIRO) for many years. Australia has recently reorganized most of its economic geology research into three universities — the Key Centres at the universities of James Cook, Tasmania and Western Australia — partly to facilitate continued collaborative research with the industry. In Canada, collaborative programs have been initiated by Memorial University (CERR), École Polytechnique-McGill-Montréal (IREM-MERI), Queen's University, and most recently UBC (MDRU). In the latter case, a mechanism has been devised to multiply collective company funds by up to four times in order to provide large budgets for applied research projects. The necessity of this approach has been underlined further by the formation of a new Exploration Technology Division within the Mining Industry Technology Council of Canada (MITEC). This initiative is already supported by 14 companies which hope to see increased collaborative research in exploration technology and mineral deposits. Finally, the Geological Survey of Canada is offering a matching fund collaborative research program with industry as part of a broader cost recovery philosophy which is influencing many surveys around the world.

The premises behind collaborative multi-company research are: a) individual companies no longer have research divisions of any magnitude, b) Canadian or North American mining companies are competing as much with overseas companies as each other, and c) most research does not produce an immediate competitive advantage to a single company. Competitive advantage is more likely to be achieved by intelligent application and speed of reaction rather than a new idea, new data, or even a new tool. The latter are necessary, however, if exploration is to continue to advance and new discoveries are to be made to replace the dwindling reserves in North America. Collaborative research with companies has another important and less stated aspect: it provides a mechanism for tapping the considerable experience and expertise of company geoscientists in research which, under the normal pressures of work, is difficult to achieve.

The increase in collaborative research will continue, although there are some clouds on the horizon. Academic pressure does not encourage scientists to be involved in areas outside of their expertise, where they may not receive full credit for their efforts. Furthermore, it is difficult and time consuming to learn the new skills that may be necessary. This can be resolved on mega-projects, where scientists are involved because of their interest and specialist knowledge, but is more difficult to achieve at a smaller scale. Companies can create multi-disciplinary teams with greater ease, although ensuring an effective team performance is no less challenging.

Company support for research is vital, but it may be jeopardized by the sheer number of collaborative proposals bombarding busy personnel. Personal contact and involvement of industry from the outset is necessary if this is to be avoided. Finally, many companies are suffering financially and/or are merging with other companies, hence limiting the funds available to support research. It is reasonable to anticipate, however, that company prosperity will return and that a component of research can assist in this process.

ENVIRONMENTAL EARTH SCIENCE

The rising importance of the environment has major implications for the mining industry that do not need to be stated here. Most companies are fully aware of the issue and have moved to a proactive stance on many aspects of environmental control and regulation. Although environmental issues are recognized by the industry as vital, academic economic geologists have been reluctant to enter the environmental field, at least until recently.

Apart from the importance to the mining industry, there are other reasons for economic geologists to take an active role in environmental research. As with economic geology, environmental earth science is naturally multi-disciplinary. It involves hydrology, geochemistry, geology (particularly Quaternary geology), biochemistry and geophysics. Much of the research, however, is being carried out by engineers, chemists, biologists, environmental scientists, and hydrologists. In subjects such as acid rock drainage, tailings disposal and waste disposal, economic geologists, geochemists and geophysicists have much to offer. Furthermore, research on acid rock drainage problems has potential implications for the understanding of weathering, supergene enrichment and exploration geochemistry, which are directly relevant to economic geology and exploration. As stated during the MDRU meeting, an explorationist's dispersion train is equivalent to an environmentalist's pollution plume. This has been recognized by the GAC and the AEG, which recently organized workshops or conference sessions on acid rock drainage.

Future research in problems such as acid rock drainage, which directly effect the mining industry, must involve the economic geology community and should be integrated with regional geology, deposit studies, and natural processes. Attempts have been made to do this (*e.g.*, the EXTECH project of the GSC and Manitoba Department of Energy and Mines in the Snow Lake area) and more are likely in the future. There are obvious opportunities to utilize GIS and related computer modelling in regional and deposit-scale studies of acid rock drainage.

At the larger research scale, economic geologists may make significant contributions to research on problems related to global change. Economic geologists have a fundamental interest in the changing composition of the oceans and atmosphere through time, and the related distribution of metals. It is important that economic geologists continue to be involved in this research and the ensuing debates.

EDUCATION

The professional in the exploration industry requires an extensive range of knowledge and skills to be successful. This includes all aspects of geology and an understanding of geophysics, geochemistry, environmental science, law, politics and sociology. This situation is likely to get increasingly complex while, at the same time, the task of discovering new ore bodies will become increasingly difficult, particularly in mature mining camps and covered areas. These challenges should provoke the interest of many good students, but instead, interest in economic geology is declining and it is becoming difficult to find high-quality students for research. The decline reflects the limited job opportunities and the virtual lack of career development and job security in the industry. Lack of these are not, however, unique or new to the exploration and mining industry. They are a feature of North American business, which distinguishes it from Japan and Europe, exacerbated by the historic boom and bust cycle within the mining industry. The current situation is especially bad in Canada, and it is slightly ironic that the potential reward from the investment in collaborative research, currently being made by the industry in North America, may be limited by the lack of capable people to take advantage of the results.

There are two partial solutions to this problem that are already evident as emerging trends. The first is that companies must continue to invest in training for their personnel. This includes supporting attendance at short courses, field trips and conferences, but also involves in-house training. Computer-aided education offers a new and rapid means of learning, although this must be supported by ongoing field training using senior company personnel or consultants. The use of mentors was common in many large successful exploration companies in the past, but has virtually disappeared in the chaotic rush for short-term success, rapid changes of emphasis or commodity, and the rule of the accountant over the explorationist. The second approach is to broaden the appeal of economic geology by relating it more directly to other areas of earth science, such as the environment, within undergraduate curricula. To some extent, this requires that economic geology be divorced from its traditional vocational label. In future, researchers in economic geology and even explorationists may enter the subject through an interest in the environment, only to find that their real interest lies with ore deposits. Co-operative programs may provide a formal mechanism for combining a broader education with professional training. These programs are becoming more common in a number of areas and are popular with students.

Although there is a trend toward broader earth science curricula in universities, which could be beneficial to economic geology, there is a significant problem emerging in the lack of emphasis on field work. Increasing numbers of faculty in earth science carry out non-field research and are, therefore, reluctant or incapable of teaching field work. Furthermore, field schools are expensive and time consuming. The survival of field skills is vital to our profession, and economic geologists must work to preserve this aspect of the science. In addition, many students enjoy field work and enter earth science for that reason. Economic geology can take advantage of this interest by emphasizing its basic relationship to the field, combined with a broadening of the opportunities available to the multi-disciplinary economic geologist.

CONCLUSIONS

Many sciences and related professions are in a state of change. Economic geology is no exception and is under considerable pressure. The science is focussed on a resource industry that is vital to economic well-being, but is also subject to scrutiny. The science and profession must adapt if they are to remain effective. There are many indications that this is happening, assisted, in part, by the new generation of computers.

Although technological developments are exciting, it is also critical that economic geologists remember the nature of the primary database on which all further work is built. The most advanced analytical results and the most sophisticated models will have limited application if field relations are incorrect or if practitioners fail to understand the limitations of the data. Field work and the collection of other basic data must be supported as part of the traditional sound practice of economic geology.

The profession and the science need talented people. Broadening of economic geology through collaborative research and applications in environmental science provide a means of attracting new people to the benefit of the science and, eventually, the profession and society at large.

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