Paper 6

Geoscience Information Management and Access: Evolution of a Key Enabler for Exploration Success

Broome, J. [1], Cox, S. [2]

1. ESS GeoInformatics, Earth Sciences Sector, Natural Resources Canada, Ottawa, Ontario, Canada
2. CSIRO Exploration & Mining

ABSTRACT

The last decade has seen exploration companies focusing increasing attention on access to digital data and their proper management. Reviewing technology, business and methodology evolution over this period reveals a number of factors that have caused a new recognition of the link between effective data management and exploration performance. In the 90's, computer technology was the focus of attention as hardware and software emerged that was capable of processing the large volumes of public and proprietary data utilized during integrated interpretation. During the same period, the Internet evolved from being an entertaining curiosity to a core component of routine information management and computing infrastructures. In addition, enormous technological change, mergers, and the shift away from internal capacity to outsourcing resulted in increased mobility for exploration staff. The frequent result of this mobility was that corporate knowledge about data assets was lost. New standards of corporate accountability, enforced through the Sarbanes-Oxley Act, but enabled by maturing technology and enterprise approaches to IM, led companies to improve their information management and lead to recognition of the need for terminology and other standards. (OGC, ISO, CGI, etc.) This paper will map the evolution of mineral exploration data management and associated technologies to the present and consider the future.

INTRODUCTION

The mineral exploration industry has seen rapid technological evolution in many areas during the last decade. Information management and information technology are two areas of profound change that have had a significant impact on the exploration business.

For the purpose of this paper, we will define "information management" to include: data management and access, data integration and analysis, geographic information systems (GIS), and the supporting networks, computers, and software.

This paper will map significant changes in data management and associated technology during the last decade, review current approaches, and present opinions on future developments, opportunities and risks.

EVOLUTION OF INFORMATION MANAGEMENT AND ANALYSIS – 1967-1997

Collection and expert analysis of a variety of types of information has always been a fundamental component of the mineral exploration process. To trace the evolution of information technology, management, and analysis, as applied to exploration during the last decade, it is informative to review papers in the proceedings volumes of the "Exploration" series of decennial conferences as these papers can be interpreted as "decade time capsules" of current thinking.

In the proceedings of Exploration '77, there were only two papers on the use of computers in exploration. These papers on "computer compilation and interpretation of geophysical and geochemical data" by Spector and Parker (1979) and Haworth and Martin (1979) discussed the application of various transforms to data and visualization methods utilizing line contours, symbols, and graphs. Another paper on "integrated exploration" by Coope and Davidson (1979) discussed how integrated exploration at that time was primarily a subjective process and proposed that improved exploration performance could result from a more objective approach that would integrate the data and knowledge of geochemists, geophysicists, and geologists.

The Exploration '87 volume provides evidence of the acceptance of Coope and Davidson's (1979) proposal for improved exploration performance through integration of the geoscience data by including five papers under the category "Integrated Case Histories". In these case histories, different data types were visualized and analysed in combination and while there was one reference to the use of a computerized workstation, there was no reference to data integration software or GIS.

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Computer integration and data management did not play a part in the case histories; however, there was a group of six papers grouped as "Modern Computer-based Methodologies: Their Coming Role in Exploration". These discussed, as emerging technologies, exploration data management and workstation-based data analysis and integration. In a prescient paper on database technology, Holroyd (1989) recommended that RDBMS technologies, originally developed for financial and business applications, could significantly benefit exploration and proposed that data be managed independently outside of the project context and documented using metadata. A complementary paper by Martin (1989) outlined how expert system software was already being used in the oil industry to analyse data managed in databases and suggested that this process was appropriate for mineral exploration as well. Another paper by Witherly and McLeod (1989) referred to the growing use of microcomputer hardware and software as a "micro revolution" and foresaw problems arising from the autonomy that can result from widespread ad-hoc microcomputer adoption.

During the 1980s, geophysical, geochemical, and remotely sensed data were routinely collected and managed in digital form. Data management and exchange standards were; however, typically unavailable hampering interoperability and integration. An "80/20 rule' arose for GIS work. This rule referred to the 80% of the time spent on data preparation and the remaining 20% applied to productive analysis. In many exploration companies, project-based data management was common and different projects often adopted different approaches, standards, and systems. GIS software was starting to be used to manage exploration data at the project level but data management was typically limited to backing up project data in a proprietary GIS format and putting it in a safe place. Some companies had become concerned about the risks and inefficiencies of this practice and were investing in the creation of centralized corporate data warehouses.

Another significant change in papers in the '87 volume was the appearance of computer-generated images created from data interpolated onto a grid as a visualization tool to support data interpretation. A number of different visualization techniques were used including grey-tone and colour imagery, artificial illumination and shading, and composite colour images of co-registered remote sensing and geophysical data.

Microcomputer-based software for visualizing data becoming available in the mid-1980s and colour imagery became a popular exploration tool. Geological map information was being integrating with imagery using image analysis and GIS software but typically as line overlays and labels. Algorithms were available for more sophisticated data integration and analysis of data in vector form but these could only be effectively utilized in purpose-built workstations due to the limited software, computing power, and storage capacity available in standard computers at the time.

The most recent decennial conference in '97 coincided with the peak of a mining boom and this fact was reflected in the optimism about the future expressed in the papers. A number of papers were presented that focused on specific aspects of information management and technology. In the keynote presentation on the use of GIS for data integration and analysis in the geosciences and mineral exploration, Graeme Bonham–Carter (1997) identified 1987-1997 as the decade when commercial GIS was introduced to the geosciences. He attributed the growing use of GIS to the availability of adequate computing power, microcomputers, and geophysical, geochemical and remote sensing data in digital form. He also identified geological map data as the most complex and difficult type of data to incorporate in integrated studies because of the lack of a fully-developed data model and standards. He attributed this problem not to technological limitations but to the difficulty in obtaining agreement among geologists on a standard data structure and terminology for geological map data.

The growing use of GIS and other computer tools for exploration was exemplified at Exploration '97 by the 20 poster papers in a session titled "Integrated Exploration Information Management". These papers dealt with a range of topics including: GIS techniques, data integration, the Internet, portable field systems, data and mapping systems, and 3-D visualization. In addition to these specialized papers, the majority of the case histories and discipline papers referred to routine use of digital data, GIS and image processing.

A number of presentations at Exploration '97 focused on specific aspects of information management and technology with eight papers on GIS and data management. Simon Cox (1997) delivered a paper that discussed the emerging potential of the Internet for delivering exploration information. At that time, Internet applications were predominantly point-to-point and data access was primarily file-based. (ftp, etc.) The merits of a networked approach to data access rather than point-to-point were recognized, but the technology was not mature enough to support implementation.

In 1997, the Internet was being used as a communications tool and government agencies were permitting public access to some of their data. The access method was typically a hypertext client interface to structured data on a single server. The concept of integrated networks of geoscience data that would allow seamless access to multiple servers, data discovery through querying standard metadata, and online visualization of data were being prototyped in the Canadian Geoscience Knowledge Network (http://cgkn.net) and other similar national initiatives.

During the decade, the growing performance and affordability of personal computers had further stimulated the development of corporate geodatabases and companies invested in the development of proprietary software for exploration data visualization and analysis. Lack of appropriate commercial software forced this investment which was perceived to confer a significant competitive advantage. In this era, many government geoscience agencies were focused on research and the management of national data and supporting their discovery and access were of secondary importance.

Perhaps in response to this government attitude, a number of companies invested heavily in the construction of regional, and even global, exploration geodatabases to support their exploration and feed in-house interpretation systems. Companies built their own data warehouses by harvesting government and their own in-house data and integrating them in large computer databases. These data repositories combined with specialized company experts were expected to return a long-term competitive exploration advantage. These investments reflected the long-term business view prevalent in the major mining companies of the era which focused on the growth of corporate assets and expertise.

Some Corporate Trends

In the '60s and 70's information lived in a "paper world" with the exception of some large company's financial records. In the 80's and 90's, computer technology was the principal focus of attention as hardware and software emerged that was capable of processing the large volumes of data required for geospatial data integration, and interpretation. The concept of the digital office appeared but was not realized due to cultural issues rather than technological ones.

Companies that chose to manage data corporately typically built centralized systems consisting of file-based data warehouses. These warehouses were built up incrementally project by project. Undocumented data were delivered to the warehouse in diverse formats resulting in a warehouse containing data that could be neither easily discovered nor used.

For many companies, attempts to preserve short-term profitability and survive in hard times meant reducing costs by abandoning their in-house technical centres and also downsizing or eliminating their data warehouses. Often, these data warehouses were viewed as not meeting the company's exploration data access requirements – users could not easily find data, data were not available in usable formats, and accessing data took too long. In retrospect, these problems were a consequence of a lack of defined data management policies combined with adoption of a centralized file-based architecture. This architecture was necessitated by the inadequate technical infrastructure, network capability, and data standards. However, even during difficult financial times, some companies did continue to support and improve their data warehouses.

Through at least the mid '90s, many companies created proprietary applications and standards for exploration data management and analysis. These systems were typically stand-alone and were designed to perform a particular task without consideration of external data access and use requirements. This made sharing data within and between companies very difficult.

With increasing availability of commercial-off-the-shelf (COTS) GIS software with the functionality to integrate and visualize mineral exploration data, companies moved away from in-house development to standardize on one of these commercial GIS software packages. These systems typically manage data at the project level using their own file formats and standards. Using these software to manage data met short-term, project-level data management requirements but was inadequate for long-term management of data. In addition, data sharing and interoperability between companies during partnership activities remained problematic since different companies often standardized on different systems that utilized different proprietary standards.

During the 90's, the Internet evolved into a core element of communication, data management, and the computing infrastructure. Network bandwidths and standards were available that allow geospatial data and high-resolution imagery to be moved rapidly from office to office and user to user. Service Oriented Architectures are emerging as the pattern for future corporate system deployments. Sun Microsystems longstanding mantra that "the network is the computer" is being realized through almost ubiquitous reliance on networked storage, and increasingly on networked applications, many of them browser-based. To those with long memories, modern corporate infrastructure shows more than a hint of a return to the mainframe/terminal based arrangements that existed prior to the microcomputer revolution, though these days the "terminals" are far from "dumb".

1997-2007: DEVELOPMENTS DURING THE PAST DECADE

The Exploration Business and Culture - General Trends

Mineral exploration activity is driven by commodity prices. The "Exploration" conference in '97 coincided with a peak in commodity prices and mineral exploration activity but that peak was short-lived and the conference also marked the beginning of a downslide that bottomed out in 2002/2003. The period following the downturn was characterized by companies downsizing, numerous mergers, and a shift from using internal expertise to outsourcing. These changes resulted in increased mobility for exploration experts with the frequent result that corporate knowledge of data assets was diminished. This loss of knowledge and a reduction in data warehousing activities has resulted in some dramatic losses of corporate data. The strategic problem of how to ensure data are managed properly and made accessible was recognized but not solved.

More recently exploration has returned to record high levels. Figure 1 shows the dramatic growth of mineral exploration, deposit appraisal, and mine complex development expenditures in Canada by junior and senior companies from 2003-2006. Juniors are responsible for an increasing percentage of exploration expenditures and, after having surpassed majors in 2004, are now responsible for more than 60% of total Canadian exploration and deposit appraisal expenditures (NRCan, 2007).

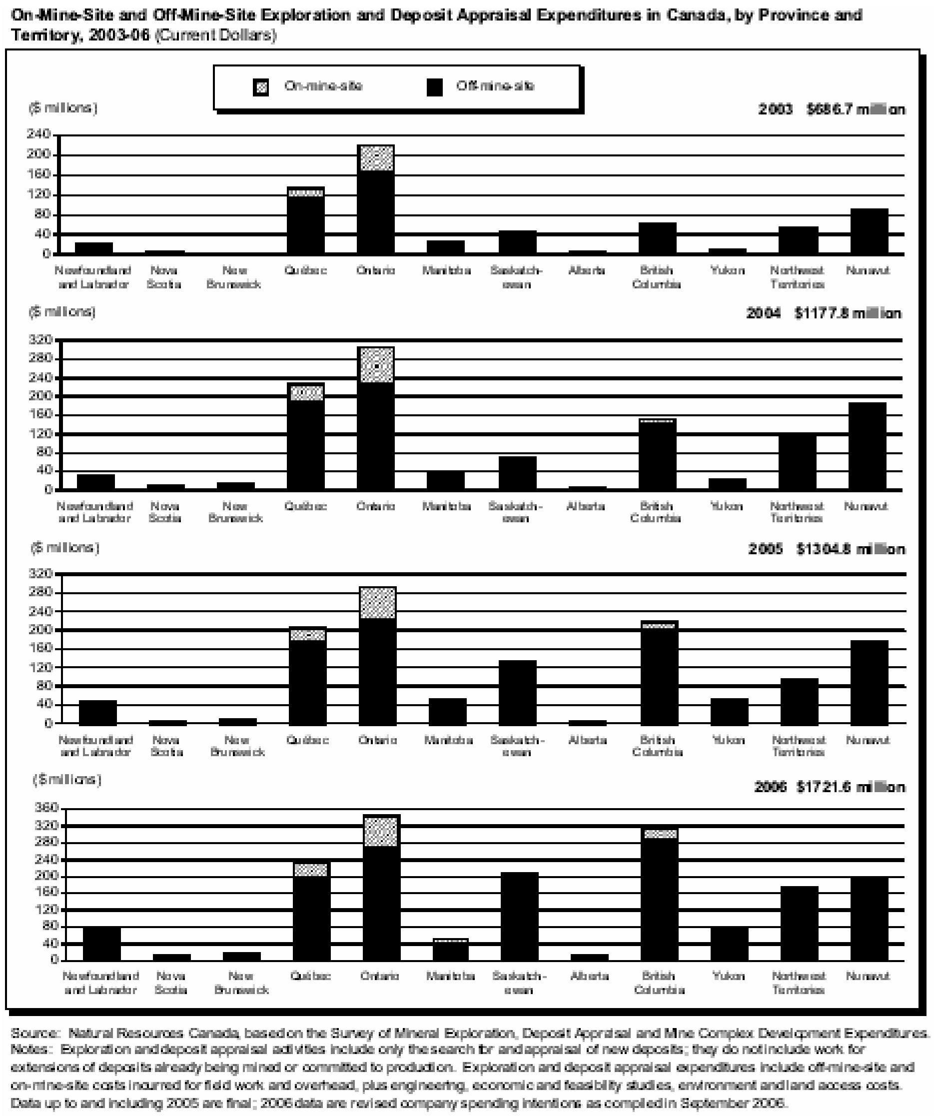

Figure 1: Statistics on mineral exploration, deposit appraisal, and mine complex development expenditures in Canada by junior and senior/major companies from 2003-2006 (Source: Natural Resources Canada)

The current pattern is typical of the cyclical nature of exploration activity. When market conditions are favourable, junior companies, who are often just exploration groups having no mining activity, start to have a large presence. When there is a slump in the industry, the juniors almost disappear. The majors, on the other hand, tend to maintain activity throughout market cycles. As a result, majors and juniors typically look at data management from a fundamentally different perspective. Majors typically have long-term investments in producing mining camps to protect while juniors tend to be are more agile, moving rapidly from project to project. This difference in perspective means that majors are more likely to place importance on long-term management and preservation of data. Majors are also often the ultimate destination of exploration data originally collected by juniors.

Increasing corporate accountabilities driven through legislation such as the 2002 Sarbanes-Oxley Act in the United States have also focussed attention on data management. Sarbanes-Oxley was intended to renew public trust in business and demanded improved accuracy and availability of corporate records. Since most corporate record keeping is IT-based the Act increased requirements for corporate information management and has driven investments in this area.

Given these requirements and trends, a number of major mining companies have, or are currently, re-assessing their data management requirements and most are concluding that upgrading and investment in data management are essential. In recognition of some failures during previous attempts to manage data corporately, a more rigorous approach is being adopted for designing data management systems to ensure that all requirements were identified and met. In some cases, formalized analysis tools and procedures, such as the Zachman framework for Enterprise Architecture (Zachman, 1987) were used to provide an understanding of the requirements. These procedures define a process starting with requirements analysis and proceeding through to business, logical, and system model development that guide the final implementation phase. The resulting enterprise data architecture provides a framework to guide the design and implementation of systems with capabilities that match the requirements of the business. Figure 2 shows a generic representation of a data architecture embedded in the enterprise technology architecture.

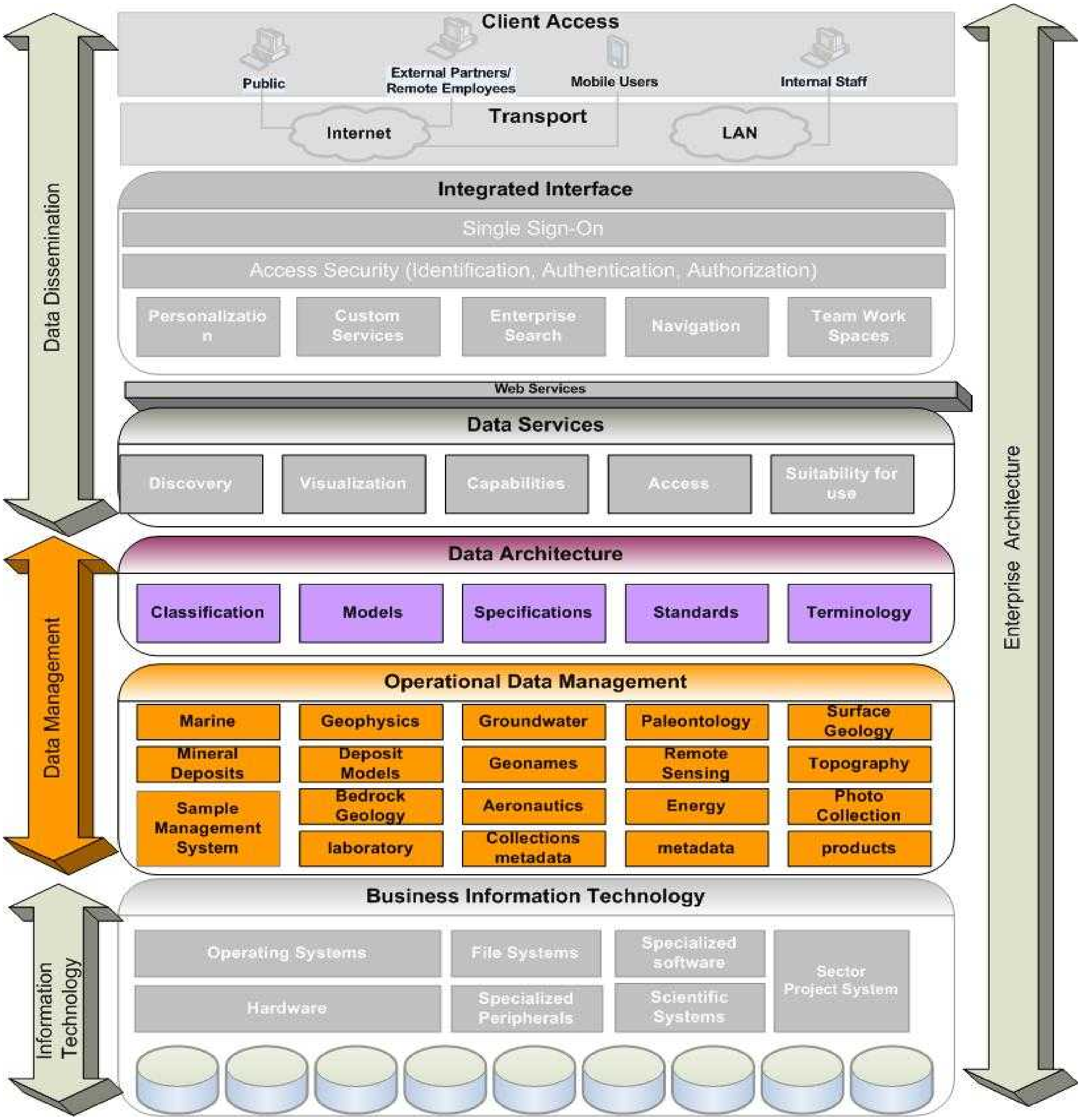

Figure 2: A generic representation of a data management architecture embedded in the enterprise technology architecture.

Information Technology Evolution: 1997-2007

Hardware

The accelerating evolution of data management and analysis technology during the previous three decades has continued since 1997. This was at least partly driven by general information technology advances. For example, computer power has continued to advance following the oft-quoted Moore's Law, and perhaps more significantly, Internet trunk speed doubles approximately every 22 months. Advances in personal computer performance and sophistication, such as graphical user interfaces (GUI) and compact and inexpensive storage technologies such as writeable CD and flash-RAM "memory sticks" appeared and evolved to the point that many data handling, interpretation, and imaging challenges could be performed by non-specialists using personal computers. Other information technology advances included the emergence of the Internet as the dominant communication media and increasingly powerful handheld devices with positioning and GIS capability.

Security

IT and network security have emerged as a major issue. Old approaches that allowed direct web access to internal servers were dropped and organizations increasingly implemented firewalls and replication of data into "demilitarized zones" (DMZ) to ensure internal systems were protected from unauthorized external access.

Software and Systems

In the late 1990s, a stratified or layered approach to software and systems supported by modular structures and non-proprietary standards gathered momentum. This approach led to reduced software complexity, improved interoperability, and; ultimately, increased innovation and more choice for the user. Operating systems also become much more generic and independent of hardware platforms. As the middleware layer evolved, allowing greater cost-effectiveness and greater innovation at the client layer, application vendors were freed from having to worry about delivering broad functionality and could focus on specific niche areas. These developments facilitated increased standardization, essential to the exploitation of networking technology and the Internet. For computers to communicate with each other and for great stores of information to be virtualized, simple and standardized communication protocols and data standards must be available.

Many large corporations have embraced the service oriented architecture (SOA) concept. Service orientation is a paradigm which, in the data domain, provides a means for organizing and utilizing distributed capabilities that may be under different ownership by replacing tightly-coupled systems with "loose coupling" and dynamic system composition, through adherence to interface standards. The technological architecture shown in Figure 2 is an example of an SOA that used standard interfaces and services to connect the different technology and functional layers.

Commercial software and hardware are now available that can efficiently meet all but the most esoteric data integration and analysis requirements. This largely eliminates the requirement for companies to develop their own software. At the extreme, this makes it possible for companies, in particular smaller ones without internal experts, to contract out the design, and even the operation, of their data management system.

Data Management and Access

In 2007, it can fairly be stated that all exploration data are acquired and analyzed digitally. However, while mining companies routinely spend millions of dollars on exploration, their investment in managing the resulting data is often inadequate. The result is that few companies can reliably locate data collected five years ago and, if they can find them, they often know nothing about the data attributes such as the original source, processing, and quality, which makes using these data effectively very difficult.

The 1990's were the "lost decade" for archiving. There was widespread adoption of 2D GIS as a standard tool for data integration and analysis and disk drives with increasingly high capacity were used to locally store both new and highly-processed data. Data were often managed if they were "personal" property rather than a valuable corporate asset and, in the absence of corporate information management policies, were not catalogued or replicated. Staff were increasingly mobile and moved from company to company, and project to project. Without proper data management procedures, when key staff departed the result was often that "data knowledge" also walked out the door. Critical information about the collection, location, parameters, specifications, and processing of valuable 'legacy' data can be lost with the result that the data must be acquired again or reprocessed. Attempts to find and reuse data often failed or were complicated because the data were stored in a myriad of diverse standards necessitating error-prone translation to the current standard before re-use.

Recognizing the problem, major mining companies have a renewed commitment to corporate data management, with the goal of making data accessible and interoperable across the organization. Once the decision to invest in a corporate data management system is made, the next step is to decide upon the approach. Many companies that implemented corporate data management in the 80's abandoned the practice because the results did not meet the requirements and expectations. Fortunately, data management knowledge and the supporting technologies, standards, and expertise have advanced dramatically. In particular, there is renewed interest in cataloguing data and one large mining company created metadata for 2 million data files in 2006. Creation of a comprehensive metadata catalogue describing all corporate data is widely seen as the logical first step in data management improvement.

A decade ago, the only feasible approach for corporate data management was to implement a warehouse approach where all data was managed in one location. This approach was effective for data preservation, but off-site data access was slow forcing regional and project offices to run duplicate data systems. Although improvements in Internet bandwidth through much of the world now support access to centralized systems, the problem with this approach is that it is completely network dependent and, in remote locations where the network can slow or unavailable, data access is inadequate.

Distributed data storage is another alternative. Managing data in local or regional warehouses can reduce some of the negative effects of Internet limitations. In cases where the Internet is inadequate or not dependable, many companies reduce risk by installing their own dedicated links between mines and regional centers, thus bypassing the Internet.

For many large distributed companies, a hybrid solution is best. A hybrid architecture may establish multiple networked regional data centres to serve a region. A process of replication can be used to ensure that key data sets, such as metadata catalogues, are copied to all data centres. Since each region has its own complete copy of the data, network dependency is reduced and data security is increased.

Data must also be discoverable and interoperable which is achieved through adoption of standards and consistent data practices. In the past, it was common for companies to establish their own standards for data to enhance internal interoperability; however, this approach does not facilitate use of data managed outside the company.

The importance of metadata catalogues has also sparked the need for suitable metadata standards to support their data discovery requirements. In addition to metadata standards, exploration companies require a range of other data standards and work has been initiated in conjunction with government and international agencies to establish these standards. As was pointed out earlier, development of standards is increasingly an international activity involving a range of stakeholders aimed at developing open non-proprietary standards.

There was also a growing expectation that governments would manage and provide access to data in standards forms. A number of countries, including Canada and Australia, still distribute geoscience data in proprietary GIS file formats but these countries, and others, have initiated the development of National Spatial Data Infrastructures. These initiatives are characterized by use of the Internet and standard web services to provide free and open access to data and provision of comprehensive metadata.

STANDARDS

The Geoscience and Geospatial Context

Enabled by maturing technology and increasingly enterprise-level approaches to information management, companies invested recognize the need for broader geospatial and geoscience data standards.

The development and adoption of data and exchange standards is motivated by two arguments:

1. Standardization of data models and formats facilitates sharing and understanding of information between agencies.
2. Standardization supports economies of scale in software development.

For some geoscience data, such as geophysical data, workable standards had existed for some time. However, geological data management was primarily designed to support the creation of analogue map products and were inadequate for GIS work. In 1996, development of a data model for digital geological data was initiated in North America (Canada, US, Mexico) under the title of the 'North American Data Model' (North American Geologic Map Data Model Steering Committee, 2004).

This initiative was part of a broader trend to develop free and open access to spatial data through national and international spatial data through national initiatives such as GeoConnections (http://geoconnections.org) and INSPIRE (http ://www.ec-gis.org/inspire/). Other national initiatives followed closely that were focussed more specifically on geoscience data coordination initiatives such as the Canadian Geoscience Knowledge Network (CGKN) (http://CGKN.org) and the Australian Government Geoscience Information Policy Advisory Committee (GGIPAC).

The CGKN initiative focussed on development of an on-line data catalogue for Canadian government geoscience data and associated metadata standards. Efforts to promote standardization on the North American Data Model were met with some resistance by agencies that had invested heavily in their own standards and systems and could not see a compelling justification for re-engineering their systems.

Standards for Service-Oriented Geospatial Architectures

While proprietary standards still tend to dominate data storage and application layers, open standard interfaces are increasingly being used to allow the construction of complex systems involving the integration of a number of vendor's products. This approach permits the development of both open and proprietary applications and the implementation of specialized processing capabilities and graphics which interoperate with other applications.

The general argument is that open standards increase the usefulness of software and allow greater specialization by growing the overall market. Data suppliers, consultants, and labs support increased standardization because it reduces the number of formats they must support.

Particularly notable initiatives in this area are the complementary activities of the ISO Technical Committee 211 (Geographic Information, http://www.isotc211.org) and the Open Geospatial Consortium (OGC, http://www.opengeospatial. org/standards). Both organizations were formed in the mid 1990's.

The OGC emerged from the open-source GRASS GIS project to become a large vendor- and research and development-based consortium, focussing on development of interface specifications though an iterative and experimental "bottom-up" approach featuring collaborative "interoperability projects". ISO/TC 211 is backed primarily by national cartographic agencies, including the defence sector, and takes a more measured approach, initially developing consensus on conceptual models in support of distributed geographic information systems, using a more "top-down" methodology based on the principles of Model Driven Architecture® (MDA). The MDA and the Unified Modeling Language™® (UML®) are modeling standards supported by the Object Management

Group (OMG, http://www.omg.org) OMG has been an international, open membership, not-for-profit computer industry consortium since 1989. OMG's tools enable powerful visual design, execution and maintenance of software and other processes, including IT Systems Modeling and Business Process Management. OMG's middleware standards and profiles, are based on the Common Object Request Broker Architecture (CORBA®), and support a wide variety of industries. The ISO and OMG cooperate closely, with many documents co-branded.

Through the OGC, a number of http-based service interfaces have been standardized (http://www.opengeospatial.org/standards), most notably the Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) and Catalogue Service (CS/W). Many data custodians (including geological surveys) now provide access to a pictorial view of their data using WMS. Data downloads using WFS have become available more slowly due to the fact that, while pictorial representations can use existing cartographic conventions, data transfer requires development of a data model (represented as an XML Schema) which is a much more demanding task. Software support for WFS has also been limited.

The OGC and ISO/TC 211 standards are concerned generically with "Geographic Information", but their reference model explicitly emphasizes the key consideration that information sharing occurs within a domain of discourse, or community of practice. They go on to provide a methodology for formalisation, implemented in XML file formats based on the Geography Markup Language (GML). In practice, this creates a forum for consensus within domains, such as geoscience, to develop community agreement on specialized formats that remain consistent across domains thus making cross-disciplinary information exchange feasible. The major proprietary GIS software packages have begun to support this model.

However, in the area of web-mapping and associated web-services, the launch of tools such as Google Maps and Google Earth in 2005, and more recently, GeoSoft's Dapple (http://dapple.geosoft.com) has probably had a broader impact than all the well-meaning efforts of standardization organizations. The popularity of Google products is largely due to three features:

1. The quality of the interfaces
2. The availability of a continuous base map, including high-resolution imagery (even if the quality was patchy)
3. Transfer of the KML format and the service operation syntax to the public domain, allowing the development of a thriving community of programmers developing applications that leverage Google products.

Recognizing this leverage, and the opportunities created, Google have recently submitted KML for publication as an OGC standard.

The Geoscience Community Response

The challenge for the exploration community is to create the necessary governance arrangements for the development and adoption of standards at the level of granularity necessary for effective information exchange. A number of initiatives are underway, though at time of writing none have yet reached operational status. These include:

- XMML (the eXploration and Mining Markup Language; https://www.seegrid.csiro.au/twiki/bin/view/Xmml/WebHome): primarily focussing on observational data including limited geophysics and boreholes. The project was based at CSIRO in Australia with primary support from government and local exploration service companies, but also from a number of international resource companies and some international Geological Surveys
- ADX (Assay Data Exchange language): Focussing on geochemistry reporting and driven primarily by the lab and database sectors. This initiative is currently being coordinated by the Mining Industry Geospatial Consortium (below).
- GeoSciML (https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/GeoSciML): focusses on interpreted geology (i.e. geologic map data) and observations. This project is the successor to both XMML and NADM (the North American Data Model). Successful WMS- and WFS-based testbeds were run in 2004 and 2006. It is being undertaken under the auspices of the IUGS Commission for the Management and Application of Geoscience Information (CGI, http:// www.cgi-iugs.org) and is supported by a growing number of Geological Surveys.

The need for metadata, and other standards, drove the creation in 2004 of the Mineral Industry Geospatial Consortium (MIGC; http://migc.org). The MIGC charter states:

"The objective of the MIGC is to identify the most significant software and data-related problems being faced by the minerals industry and to identify possible solutions. The Consortium will then act to see these solutions implemented. By acting as a unified industry voice, the MIGC expects to increase the mining and exploration industry influence on software developers, consultants, and governments and ultimately reduce the data and software costs of its members."

The MIGC is currently developing a metadata profile for the mining industry that is based on existing international metadata standards as well as supporting the development of the previously-mentioned ADX schema for geochemistry data.

However, alongside the development of open standards through community processes, "de-facto" standards continue to play a significant role. Most data providers (including Geological Surveys) deliver data primarily in proprietary formats.

Some Innovative Geoscience Data Access Projects

Open standards are often a catalyst to establishment of public-domain software based on the standards and can even promote initiatives to provide more data access. The OneGeology project is an example of this effect.

OneGeology (http://www.onegeology.org) is a international geological survey initiative, launched in the International year of the Planet Earth (2007-2008) (http://www.esfs.org) which will make public and Internet-accessible the best available geological map data worldwide, initially at a scale of 1:1 million, to better address the needs of society. OneGeology is made possible by the availability of technology and standards, like the GeoSciML data exchange schema that are able to meet the project requirements. From an exploration perspective, the scale of 1:1 million is too small for most uses; however tools and systems, developed initially for OneGeology, are likely to be adopted more broadly in future for distribution of geological data at larger scales.

OneGeology is a example of the new "open" business paradigm described in the book 'Wikinomics' (2006) by Tapscott and exemplified by Google, Wikopedia, and others. These initiatives remove restrictions on access to information and focus on mass collaboration within a large user community. Within the exploration community, the 'Goldcorp Challenge' provides an interesting example of this new thinking.

In March 2000, Goldcorp released all geological data concerning the company's property at Red Lake, Ontario to the public online. It offered rewards for the most helpful contributions to finding the 'next six million ounces of gold'. Within weeks, submissions flooded in from around the world, not only from geologists but also from mathematicians, consultants, students, and others. Capabilities and techniques never used before for mineral exploration were applied to and the contestants identified 110 new targets on the property. Over 80% of the new targets yielded substantial quantities of gold, and since the challenge over 8 million additional ounces of gold have been found.

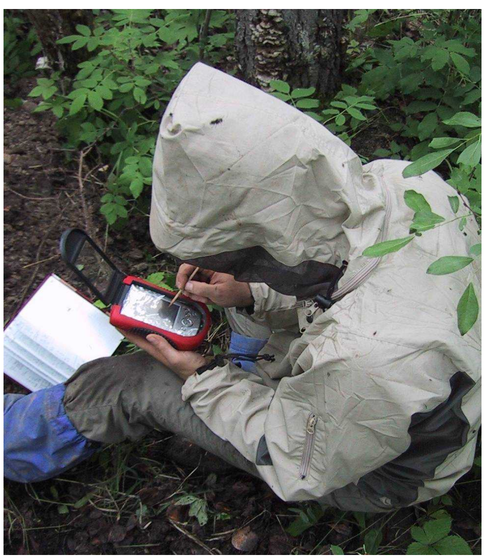

Figure 3: Handheld Field Data Acquisition system in use.

Data Acquisition Systems

Compact handheld field data acquisition systems also increased in sophistication and became popular during this decade (Figure 3). Integrated GPS receivers provide instantaneous and accurate positioning of observations and measurements which is of great value when working in featureless terrain. Improved hardware and operating systems support more user-friendly application software with graphical user interfaces. Many field systems were built upon ESRI's ArcPad software.

By carefully integrating handheld systems with personal computers and corporate data management systems, a seamless user environment can be created that supports fast and accurate transfer of field data into corporate databases and encourages the collection of consistent data. In Canada, use of digital field data acquisition systems has doubled since 2003 and least 25% of field geologists now use these systems.

Three Dimensional Modelling

Geographic information systems (GIS) are now standard tools used by all exploration staff - not simply GIS specialists. While there has been continuing advancement in the areas of two-dimensional (2D) data integration, empirical analysis, and imaging, developments in modelling has been more dramatic.

Three-dimensional (3D) models of mining camps are instrumental in developing more detailed understanding of geological structure and the distribution of important indicators of mineralization. Increasing exploration activity in known mining camps, emphasized the value of constructing detailed 3D models as a tool to focus exploration work. 3D models are increasingly seen as a wise investment as it increases the value of camps by increasing the likelihood of identifying the location of additional economic ore.

Figure 4 clearly shows how an integrated 3D visualization built from several data sets in a greenfield's block is superior to the corresponding 2D visualization.

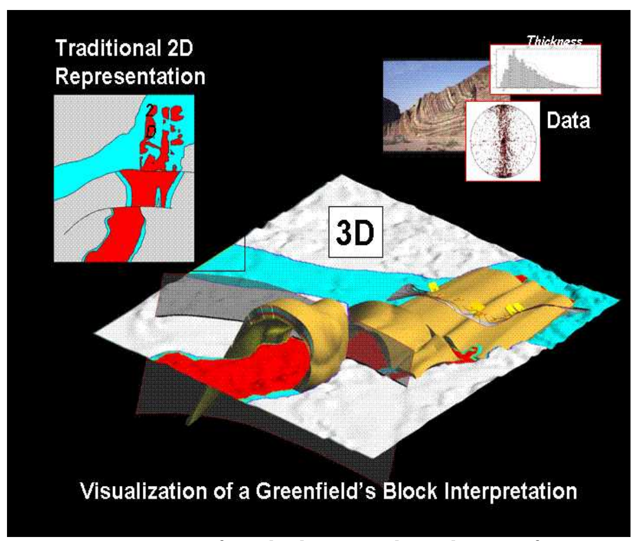

Figure 4: Comparison of 2 and 3 dimensional visualization of a greenfield's block interpretation demonstrating the value of the 3D approach.

Substantial improvements in 3D technology during the last decade were largely driven by the requirements and investments in other domains such as medicine, entertainment/gaming, and petroleum exploration. Because much of the functionality developed in other areas cannot be applied directly to mineral exploration, adoption of 3D technology for mineral exploration has followed at a slower pace. Techniques and tools developed for oil and gas exploration are not suited to the more complex geology encountered during mineral exploration. The widely-scattered nature of subsurface data also hampers modelling of mineral exploration environments. Research is being done on the modelling of such sparse data sets and in particular extrapolation of surface observations to depth constrained by the limited subsurface information.

The core tools for developing and exploiting mine, camp and regional scale 3D Common Earth Models are now available. New technologies are emerging for automating model construction leaving the expert free to interpret and test exploration criteria. Advances in 3D inversion and geology-geophysics integration are also contributing to improved interpretations (de Kemp, 2006). When applied by multidisciplinary teams, this approach has great potential to improve mineral exploration success.

Personal computers capable of processing 3D data have been a readily available for several years. Although they incorporate excellent user interfaces, many desktop 3D systems focus primarily on flashy 3D visualization and do not provide full 3D analysis and editing capability. Large commercial GIS packages are often also challenged by 3D editing and analysis because they do not incorporate a 3D vector data model and the necessary spatial operators. However, it does appear likely that the evolution of 2D GIS will be followed closely by 3D GIS and broader 3D functionality will soon be available.

Interoperability and visualization of 3D data sets is further complicated by the lack of a widely-accepted 3D data exchange format. Internet visualization of 3D models is possible using VRML and X3D, which are based on Constructive Solid Geometry models, however, there is limited support for property-variation within model elements. This limitation makes it difficult to visualize the full richness of mining models using these tools.

As stated earlier, software for the visualization of 3D models is widely available. Because the standard computer monitor is inadequate for 3D visualization, techniques utilizing coloured, shuttered or polarized eyeglasses combined with dual-image displays are often used. Recognizing that the maximum benefit of investments in 3D data sets can only be realized if the model can be clearly visualized and interacted with, there has been growth in the installation of immersive environments for 3D visualization. These immersive environments allow teams of geoscientists to clearly visualize and interact with the model.

In spite of their substantial cost, the effectiveness of immersive environments for communicating complex 3D models and objects to non-experts has resulted in rapid growth in the number of installations worldwide for many different applications. Figure 5 shows the immersive 3D environment at Laurentian University's (Sudbury, Ontario) Virtual Reality Laboratory (VRL) which is managed by (MIRARCO) – Mining and was designed specifically for use by the mining industry.

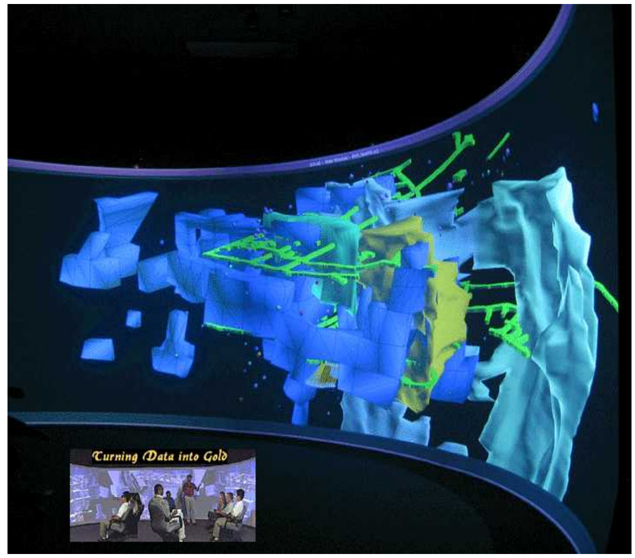

Figure 5: Images from the Mirarco Virtual Reality Laboratory showing visualization of undergrownd mine layout integrated with geological data.

THE FUTURE

The importance of effective management of exploration data is now more broadly recognized than ever. Successful exploration requires discovery, access, and integration of diverse data types. A highly-paid geoscientist's time must be spent finding ore bodies - not be wasted trying to find, format, and organize data. Viewed this way, there is almost immediate cost recovery for investments in data management. Implementing and adhering to simple, cost-effective data management procedures dramatically reduce the incidence of lost data, and ensure data are available and usable.

Factors which are driving renewed investment in corporate data management by majors include the ongoing globalization of exploration, the continuing shift in mining exploration expenditures from majors to juniors, and the need to adapt quickly in order to remain competitive. Global exploration teams need to communicate, exchange data, and share their expertise with their business partners throughout the world. Increased regulation of the industry also mandates more effective data management. Corporations (and lawyers!) increasingly see proper data management as a key aspect of due diligence and corporate accountability that ensures accurate information is available when needed.

The ideal data management system would manage all data in conformity with corporate standards and deliver those data immediately to users on demand. While there is currently no single database or GIS application that can efficiently meet all the diverse requirements of mining and exploration, recent developments in corporate database software promise to rectify this situation soon.

Relational databases were designed for business data and typically manage spatial attributes though the utilization of external "middleware" software layers between the database and client. Traditional geographic information systems (GIS) were designed primarily for 2D cartography and have limited ability to deal with sophisticated analysis, 3D data, and complex data types. In addition, many GIS use proprietary standards and formats. Although they are so widely used that they are de-facto standards, translation is required to interoperate with the growing volume of data managed according to open standards.

New data management tools are emerging which will utilize true 3D data models, data types, and data operators and provide native support of XML and other open data formats. To improve performance, these systems will support pre-processed or 'materialized' views of commonly used data combinations. New data management systems will manage uncertainties more effectively so that the effect on interpretations can be quantified. The exploration culture will also continue to change and companies will embed data management and quality control in standard operating procedures.

Data analysis and interpretation will continue to evolve away from the current empirical 2D data-driven approach to a 3D approach based on an understanding of ore-forming processes. In the future, multidisciplinary 'self-assembling" interpretations will be generated by weighted integration of multiple interpretations that more effectively integrate all available knowledge and data. These interpretation processes and models will be driven by algorithms that incorporate exploration expertise, exploration statistics, and data quality measures. Another anticipated feature of the new generation of 3D tools modelling tools that are capable of using soft, or 'fuzzy', polygon boundaries rather than "hard" step-function boundaries. This feature will allow more accurate representation of the gradational boundaries that characterize the real world. Algorithms for integrating data quality measures in interpretation will also start to emerge.

Finding economic ore deposits is increasingly difficult and 3D interpretation is clearly the next step in the evolution of mineral exploration techniques. It is incumbent on industry with its wealth of knowledge of specific ore-forming processes, its rich archive of 3D data sets, and a need to find increasingly elusive ore, to capitalize on 3D technology by collaborating with government and academia to develop 3D interpretations of prospective terranes.

This challenge will best be addressed through a collaborative global approach involving industry, government and academia. The benefits of an industry-government-academia approach are exemplified by recent successes and continuing progress in the area of open standards by the OGC and ISO.

CONCLUSION AND SUMMARY

Tracking the changes in data management and analysis over 4 decades illustrates that mineral exploration is evolving into a more rigorous and quantitative science. Data has always been an essential component of mineral exploration and the industry continues to benefit from current technological and business trends that will allow data to be more easily discovered, accessed, and used.

The easily-discoverable deposits have been found. In future, successful exploration will rely increasingly on integrated analysis of complex data sets in explored terrains rather than the simple detection of indicator minerals or anomalous conditions.

A lack of appropriate information technology is no longer a limiting factor. Our challenge now is not finding newer and more powerful technologies to serve our needs – it is organizing our activities to leverage those technologies more effectively. We have invested in technology, believing that technology, as such, will solve our problems but we have underestimated the efforts and investments needed for organizational change and new work practices. We must pay more attention to important non-technological areas such as defining and enforcing standard operating procedures such as data quality-control processes, data management training, metadata creation, and knowledge capture. Our goal must be to derive increased value from the information, data, -technology, and expertise we already have.

Finally, as the current generation leaves the workplace, there is real danger that corporate knowledge will be lost. We will need to invest more time developing strategies to reduce the impact of this exodus of expertise.

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