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Encouraging Minerals Investment Using GIS: The establishment of Minerals GIS in Zambia and Mauritania.

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Geographical Information Systems provide the ideal tool to help manage and advertise the mineral potential of a country. Information on a particular mineral occurrence which is stored within a database can be displayed and queried spatially through the use of a GIS. It also enables the mineral locality to be placed in context by displaying further information such as local geology and infrastructure detail. Customisation of the GIS interface enables simple tasks to be automated and increases the usability of the system. This paper will describe two such systems developed using different GIS software. The first has been developed in MapInfo for the Republic of Zambia and the other is being developed using ArcView for the Islamic Republic of Mauritania. Funding for both projects has been provided by the World Bank and have been undertaken with the Geological Survey of Zambia (GSZ) and Geological Survey of the Islamic Republic of Mauritania respectively.

The Zambia Mineral Resources Geographical Information System (GIS) has been developed to display the mineral location data stored within the accompanying Mineral Resources Database and to integrate and display other digital spatial datasets. An active link between the Database and the GIS allows for rapid and easy updates of the mineral location map as new mineral locations are discovered. Together, the GIS and database currently contain information on over 2500 separate mineral occurrences within Zambia.

The GIS includes complete digital geological coverage for the whole of Zambia at 1:1 Million scale, geological coverage at 1:250 000 for the Copperbelt and a set of 1:100 000 geological maps covering the Luangwa Valley area in the east of the country ($\approx$ 3000 km^2 of the Luangwa Valley). The 1:100 000 maps have been attributed in such a way that they can display either the lithostratigraphy, chronostratigraphy or underlying regional tectonic framework depending upon the needs of the user. The 1:100 000 data is the first digital geological dataset available at this scale for any area of Zambia.

The Mineral Occurrence GIS for the Islamic Republic of Mauritania is still in the developmental phase. The system to be developed will draw upon the successful principles utilised in Zambia. A Minerals GIS for the northern part (Inchiri) of the Mauritanides Belt and the southern part of the Mauritanides Belt in the Islamic Republic of Mauritania has already been developed by the Collaborative Research Centre 525 (CRC 525) using ArcView. These two regions were chosen to cover the major Mauritanian copper mineralisation in the Mauritanides Belt. The general goal of this particular project of the CRC 525 is the evaluation of the potential of undiscovered copper-gold deposits in Mauritania. Based on the GIS, mineral potential mapping will be carried out which will lead in a final stage to estimating the amount of undiscovered copper-gold deposits. The GIS includes digital geological coverage on a 1:100 000 scale based on 1:50 000 scale geology maps for the Inchiri region, and digital geological coverage on a 1:250 000 scale based on 1:100 000 scale geology maps for the southern part of the Mauritanides Belt. Moreover, the GIS includes, airborne geophysical data and geochemical exploration data (rock, soil and drainage samples as well as drilling data). The work involves key collaborative research with international mining companies currently operating in the regions and the British Geological Survey.

The Mineral Resources GIS and associated databases developed for both countries provides the user with easy access to digital data sets and provides an invaluable aid to future mineral planning and development.

Introduction

The sustainable development of a country's economy is dependent upon adequate supplies of a wide range of mineral raw materials obtained from the natural environment, whether at home or overseas. Indigenous mineral resources represent valuable national assets, or capital, and their extraction and, more importantly, use make a major contribution to economic growth. It is, therefore, necessary to identify and understand the spatial relationships between the distribution, nature and relative importance of mineral resources. The management and stewardship of such mineral resources is a substantial responsibility and represents a key area where Geographical Information Systems (GIS's) can make a valuable contribution.

The input, analysis and display of complex spatial and non-spatial datasets in an integrated manner forms a major part of a GIS's capabilities. These capabilities provide an ideal tool in assessing and auditing the mineral potential of a country. Further, the ability to analyse and model the diverse relationships between data sets within a GIS means that models may be developed and utilised to undertake more specific tasks such as mineral potential mapping.

This paper describes the application of GIS in both of these arenas. The first details a national minerals GIS developed for the Republic of Zambia whilst the second details a GIS that is being developed to undertake specific mineral potential mapping within the Islamic Republic of Mauritania.

Republic of Zambia

The Government of Zambia introduced a new mining policy, with the Mines and Minerals Act of 1995. The new policy aims to encourage foreign investment in exploration and new large-scale developments, and to encourage private investment in medium and small-scale mining. This is achieved by legislation, which gives the following basic assurances: secure title to mining rights, stability of the fiscal regime, foreign exchange retention, right to market mine products, right to assign (right to trade the mining right), stability in environmental management, access to international arbitration and freedom of commercial operation (*Coats et al.,* 2001).

Within the new economic climate the BGS started a World Bank funded project in 1997. The Economic Recovery and Industrial Privatisation Technical Assistance (ERIPTA) project was undertaken with the collaboration of the Geological Survey Department (GSD) under the Auspices of the Ministry of Mines and Mineral Development of Zambia. The project had three components:

- New 1:100 000 scale geological and geochemical mapping of the Mwinilunga area in the North-West of the country (see *Key et al.,* 2001).
- New 1:100 000 scale mapping and mineral occurrence investigations in the Luangwa area in the North-East of the country (see Mosley *et al.*, 2000).
- The development of a national minerals GIS and database detailing the mineral potenial of the nation to accompany a new account of the geology and minerals of the whole country (see Coats *et al.,* 2001**)**.

Mapping was undertaken utilising satellite imagery, geophysical and field based invesitgations.

Minerals Occurrence database and GIS

To host the GIS and database a small networked computer suite was installed at the GSD and relevant software applications have been installed.

The Minerals Occurrence database has been developed in Access 97 and contains details on over 2500 individual occurrences. Information on each mineral occurrence that had traditionally been stored on paper cards was input along with new occurrences discovered during geological mapping.

Input and viewing of the data is aided by a series of customised forms that guide the user to the information that they require (Fig. 1)

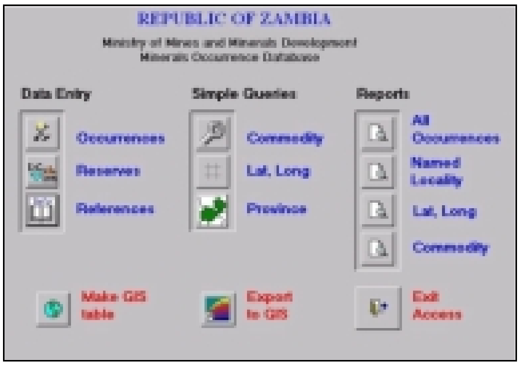

Fig. 1. Opening form for the Minerals Occurrence Database developed for Zambia.

The Zambia Mineral Resources Geographical Information System has been developed to display the mineral location data stored within the accompanying Mineral Occurrence Database and to integrate and display other digital spatial datasets generated by the project. The minerals GIS has been developed using MapInfo. It hosts a large amount of data and information at national, regional and local levels. In addition to the mineral occurrences (Fig. 2) the GIS holds complete attributed geological coverage for the whole of Zambia at 1:1 Million scale, attributed geological coverage at 1:250 000 scale for the Copperbelt and 1:100 000 scale attributed geological data for the North East of the country.

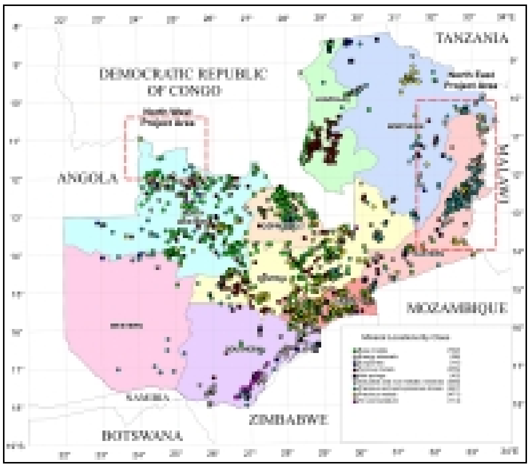

Fig. 2. A link from the GIS to the databse enables the display of the mineral occurrence points.

The 1:100 000 maps have been attributed in such a way that they can display either the lithostratigraphy, chronostratigraphy or underlying regional tectonic framework depending upon the needs of the user (Fig. 3).

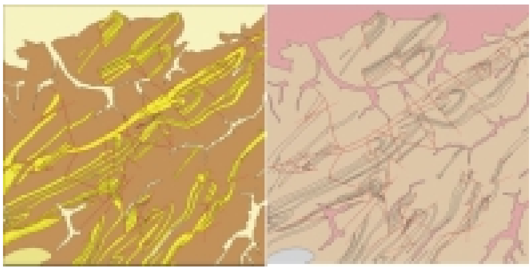

Fig. 3. Extract from the Illondola 1:100 000 geological map depicting lithostratigraphy on the left and chronostratigraphy on the right.

Digitising was undertaken by both members of the GSD and members of the Computo-Geological Advisory Unit (CGU) at the University of Zambia. Geophysical data and satellite imagery are also stored within the GIS (Fig. 4). This is the first attributed GIS data held by the GSD and presents a significant increase in data holdings.

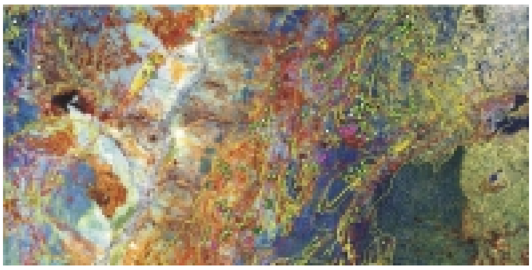

Fig. 4. Mineral occurrences and geological linework displayed on a Landsat 7 Thematic Mapper Satellite Image.

The GIS also stores data on the current state of geological map coverage at 1:100 000 and 1:250 000 for the country including map and report titles for completed areas and whether digital data is available for the area. An active link from the GIS opens up the accompanying reports in Portable Document Format (PDF) for the 1:100 000 maps stored within the GIS. Storing the reports in this manner enables the GSD to print reports on demand.

The principal output from the GIS is a new 1:1 Million scale mineral occurrence map of Zambia (*Mankelow et al.*, 2001). This comprises four sheets showing the known mineral occurrences (with their unique database number) on a geological base.

To aid use of the GIS a customised graphical user interface (GUI) was developed that draws on the existing functionality of MapInfo (making it more accessible to new users) and which automates commonly undertaken tasks through the use of MapBasic programming. Specific examples include password access to data and information, automated spatial query at either province, district or parliamentary constituency level, automatic map layout generation and a gazetteer. As with all GIS systems they are only as good as the users who utilise them, therefore training in the principles of GIS, and the use of the system developed formed a key element of the project.

Islamic Republic of Mauritania

The BGS is currently at the beginning of a new 2.5 year World Bank funded project in the south of the Islamic Republic of Mauritania. A similar project has been running in the north of the country and is being undertaken by BRGM of France. Like Zambia there are several components to the Project de Renforcement Institutionnel du Secteur Minier de la Republique Islamique de Mauritanie (PRISM) project. One part of this is the developemt of a Minerals GIS assembling data and information from both the BGS and BRGM projects. In addition to mineral occurrence information the GIS will host the new 1:500 000 scale geological map of the country as interpreted by geologists using satellite imagery, geophysical and field based investigations. The ArcView GIS application is being developed to host this data. Again the GIS will be customised to aid the users of the application. As with much GIS development it will draw on the experience and data of people developing GIS's within the country. Once such application is being developed by the Collaborative Research Centre 525 (CRC 525) in Germany.

The long-term goal of the Collaborative Research Centre 525 (CRC 525) "Resource-Orientated Analysis of Metallic Raw Material Flows" is the identification of key options for resource-sensitive supply and processing of metallic raw materials, considering restrictions imposed by geology, technology, as well as societal, economic and environmental factors. In this context, traditional estimates of resource quantity are no longer meaningful as they do not account for many ecological and social concerns placed on mineral extraction and benefaction.

The CRC 525 is divided into 9 sub-projects with 12 participating institutes of the University of Technology Aachen and one institute of the Forschungszentrum Jülich, and is funded by the Deutsche Forschungsgemeinschaft (German Governmental Research Foundation).

During the current phase of the research programme, the copper production cycle is being analysed in detail.

The general goal of this particular sub-project of the CRC 525 is the evaluation of the potential for undiscovered copper-gold deposits in the Islamic Republic of Mauritania. This will include the development of new efficient methods, that place a strong emphasis on the concept of sustainable development of non-renewable mineral resources.

Mauritania has been chosen as a country of focus because it is underexplored by international standards and its mineral potential is recognised by the international mining industry. Therefore, the country provides considerable opportunity for prospectors and developers of mineral resources. The investigation of the economic potential of undiscovered copper-gold deposits in Mauritania is a pilot project, which supports a government initiative to stimulate foreign investment in the mining sector with the aim of promoting economic growth and the well-being of the people. The work involves key collaborative research with international mining companies currently operating in Mauritania, the British Geological Survey and the OMRG.

Methodology

The basis for evaluating the potential for undiscovered copper-gold deposits in the Islamic Republic of Mauritania is the development of a Geographic Information System (GIS) for mineral exploration in which regional geological, geophysical, geochemical, and environmental data are brought together into a single database accommodating spatial and non-spatial information. This has been done for the northern part ("Inchiri") and the southern part ("Mauritania South") of the Mauritanides Belt using ArcView (Fig. 5). These particular regions are focused on, as the major Mauritanian copper-gold mineralisation of economic interest is located in these parts of the Mauritanides Belt (Fig. 5).

Detailed geological maps, geophysical and geochemical exploration data for these regions have been made available by international mining companies, which strongly support this study.

The first step in developing the Minerals GIS was to set up a comprehensive geological database for the Inchiri and Mauritania South regions. The geological maps had to be input into the GIS. This was followed by the development of a large geochemical exploration database containing the data obtained from mining companies. Geophysical exploration data was only available for the Inchiri region. Finally, the geological, geochemical, and geophysical databases were brought together into a single GIS for each region.

Fig. 5. Inchiri and Mauritania South GIS coverage including main copper-gold occurrences in the Mauritanides.

Inchiri GIS

The Inchiri region is located in the northern part of the Mauritanides Belt (Fig.5) and is known for its significant copper-gold occurrences. The only previously worked copper-gold deposit in Mauritania, the Guelb Moghrein deposit, is located in the Inchiri region near the town of Akjoujt (Fig. 5 and Fig. 6), 260 km north-east of the capital Nouakchott.

The Inchiri GIS includes digital geological coverage on a 1:100 000 scale based on 1:50 000 scale geology maps for the Inchiri region and covers an area of 7000 km^2. In particular, the digital geology consists of complex detailed lithology, detailed mineralisation and alteration, and complex detailed structural geology representing five different deformation events. Apart from the Guelb Moghrein deposit, the GIS also contains a further number of known copper-gold occurrences. Infrastructural information such as villages, roads, pipelines, mine-site etc. and geographical information such as drainage systems were added to the geological database.

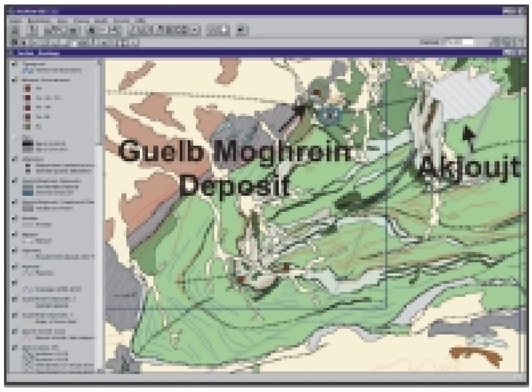

Fig. 6. Inchiri GIS screenshot, showing the geology of the Akjoujt region and the Guelb Moghrein deposit.

The geochemical exploration database consists of about 7000 collected samples of stream sediments, rock chip, BLEG (Bulk Leach Extracted Gold) and soil samples. The database also contains exploration drill hole data. The geochemical sample density is presented in Fig. 7.

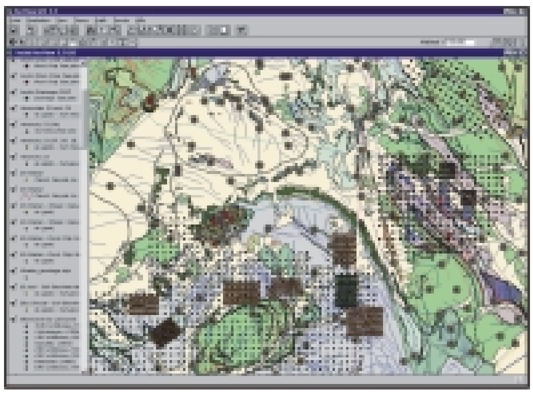

Fig. 7. Inchiri GIS screenshot, showing the geochemical sample density in south-eastern Inchiri and the geology.

The Inchiri GIS contains a geophysical database, which includes airborne magnetical and airborne gravimetrical data.

Mauritania South GIS

The Mauritania South region is located in southern part of the Mauritanides Belt (Fig. 5). The Mauritania South GIS includes digital geological coverage on a 1:250 000 scale based on 1:100 000 scale geology maps and covers an area of about 20 000 km^2.
In particular, the digital geology consists of detailed lithology and structural geology. A number of copper-gold occurrences are known from the area. Infrastructural information such as villages, roads etc. and geographical information such as drainage systems are included in the GIS.

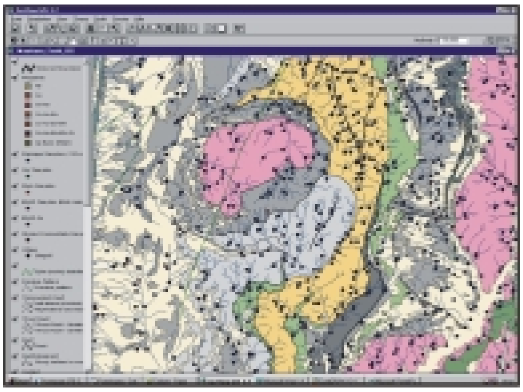

Fig. 8. Mauritania South GIS screenshot, showing the geochemical sample density and geology of the southern part of the Mauritanides Belt.

The geochemical exploration database consists of about 17 600 collected samples, distinguished into stream sediment, panned concentrate, rock chip, BLEG (Bulk Leach Extracted Gold) and soil samples. The database also contains exploration drill hole data. The geochemical sample density is presented in Fig. 8 and Fig. 9.

Outlook

The developed Geographical Information Systems for Inchiri and Mauritania South are the basis for mineral potential mapping which is currently being carried out. In a final stage this study will lead to estimating the amount of undiscovered copper-gold deposits.

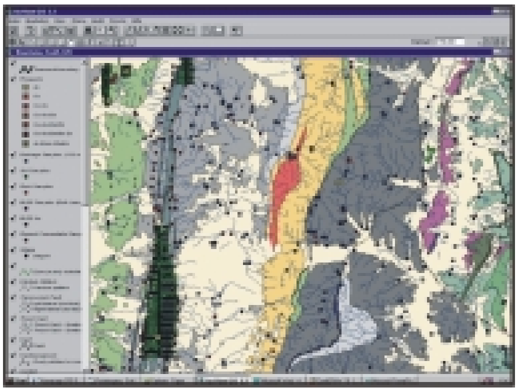

Fig. 9. Mauritania GIS screenshot, showing the geochemical sample density (soil sample lines) and geology of the southern of the Mauritanides Belt.

Discussion

Successful and sustainable management of a country's mineral resources requires the integration of a wide range of geological, mineral and related information. Without access to a wide range of information, sustainable development will be difficult to achieve. The mineral specific role of a national geological survey is a regulatory and promotional role. The contribution GIS can make to the management of minerals resources is significant. As with much GIS development the first significant impact is that the GIS stores diverse information that was once widely spread within an organisation. The development of Minerals GIS within relevant institutions in both Zambia and Mauritania will have provided the foundations for the management of potential mineral resources. The mineral potential of a particular area can be highlighted and details of any investigation undertaken within that area can rapidly be drawn upon. Further, due to the design of the systems details of any future investigations by mining companies can also be entered into the system thus keeping it up to date, relevant and contributing to an increasing minerals knowledge base. Such systems enable mining companies, both large- and small-scale to rapidly target potential areas worthy of further investigation.

The systems mentioned within this article represent two country applications within the minerals area. In addition to detailing the mineral potential of a country they can be developed to integrate mining cadastres that hold information on any mineral licences granted for the extraction of a particular mineral resource.

Both systems have been developed to enable the particular country to manage, model and advertise potential mineral wealth and encourage responsible investment by mining companies within those countries thus aiding sustainable national development.

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