A GIS-Based Mineral Prospectivity Analysis of Central Africa

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Research aims:
This research sought to conduct a GIS-based mineral prospectivity analysis of central Africa with the following deliverables:

• An assessment of the quality of the existing geoscientific data
• Generation of mineral prospectivity maps for Central Africa
• A report on key areas for mineral potential and recommendations
• Release the new maps via the IM4DC server
• Visit to Nigeria to communicate results with key stake holders

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IM4DC
Action Research Report

International Mining for Development Centre

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A GIS-based mineral prospectivity analysis of central Africa

Geoscientific data is often acquired by national and provincial geological surveys but remains underutilised due to a lack of resources or in-house expertise. One way to utilise this data is to produce prospectivity maps which can assist with mineral exploration and land management decisions. Such prospectivity mapping exercises have previously been undertaken with the Geological Survey of Western Australia for the similar purpose of attracting investment dollars into the region from exploration companies. Prospectivity maps also assist in providing advice for government agencies in terms of where to focus future budgets. The mineral potential maps generated give an indication of where further data acquisition and analysis may be of most practical use or where more field mapping may be necessary.

Central Africa is of interest for the global mineral exploration and mining sector due to the existence of known precious and base metal mineralisation, as well as being an established diamond producing region. However, geoscientific information in the region relevant to minerals has been limited in quantity, difficult to access, lacking modern data organisation and with little inter-country synthesis.

A previous IM4DC Action Research project – the Central African GIS Database project – made significant inroads into compiling available data and organising it in a coherent manner. The aim of the current project was to build upon this work to not only provide new geoscience products, but also to present an example of best practice release of precompetitive data. In this case, the precompetitive datasets generated were mineral prospectivity maps of Central Africa, to include gold, copper, tin and other commodities.
A GIS-Based Mineral Prospectivity Analysis of Central Africa

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Introduction

Central Africa is of interest for the global mineral exploration and mining sector due to the existence of known precious and base metal mineralization, as well as being an established diamond producing region. Geoscientific information in the region relevant to mineral has been limited in quantity, difficult to access, lacking modern data organisation, and with little inter-country synthesis. The IM4DC Central African GIS Database project, a previous IM4DC action research project, made significant inroads into compiling the available data and organising it in a coherent manner.

The aim of this project, titled “A GIS-Based Mineral Prospectivity Analysis of Central Africa”, was to build on this work to not only provide new geoscience products, but also to present an example of best practice release of precompetitive data. In this case, the precompetitive datasets generated were mineral prospectivity maps of Central Africa. Specific deliverables on the project were:

1. An assessment of the quality of the existing geoscientific data.
2. Generation of mineral prospectivity maps for Central Africa (and more detailed maps of Nigeria if data is supplied).
3. A report on key areas for mineral potential and recommendations.
4. Release the new maps via the IM4DC server. These will aim to include gold, copper, nickel, tin, uranium, iron ore and other commodities.
5. Visit to Nigeria to communicate project results and methodology with key stakeholders.

The initial project proposal also indicated that a more detailed study of Nigeria could be undertaken provided that the data was supplied by the Nigerian Geological Survey. Although several face to face meetings were held to establish an agreement with the Nigerians to obtain the data, an agreement could not be reached within the timeframe provided to complete the project. As such, the results presented here focus solely on an analysis of the publically available geoscience data from the IM4DC Central African Database project as per the project agreement.

Geoscientific data is often acquired by national and provincial geological surveys but remains underutilized due to a lack of resources or in-house expertise. One way to utilize this data is to produce prospectivity maps which can assist with mineral exploration and land management decisions. Such prospectivity mapping exercises have previously been undertaken with the Geological Survey of Western Australia for the similar purpose of attracting investment dollars into the region from exploration companies (e.g. Joly et al., 2013; Witt et al., 2014). Prospectivity maps also assist in providing advice for government agencies in terms of where to focus future budgets. The mineral potential maps generated give an indication of where further data acquisition and analysis may be of most practical use or where more field mapping may be necessary.

The project area for Central Africa, as defined by this project, is shown in Figure 1, covering the nations of: Benin, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Equitorial Guinea, Gabon, Nigeria, Republic of Congo, São Tomé and Príncipe, and South Sudan.
Figure 1: Central Africa study area highlighted in red.
Review of Data for Central Africa

The data compilation for Central Africa hosted on the IM4DC server contains many datasets. However, the quality of these datasets is variable, and their coverage incomplete and inconsistent over the entire Central Africa study area. In order to be of practical use in the prospectivity mapping exercise over Central Africa, the datasets used must have complete coverage over the study area, and have a relatively homogeneous level of detail in the mapping.

A summary of the various datasets is provided below:

Geological Maps

Geological map coverage for the whole of the Central Africa region was available via datasets from the United States Geological Survey (USGS) and the Bureau de Recherches Géologiques et Minières (BRGM – French Geological Survey). Datasets available included:

- Solid geology maps
- Basins
- Calderas
- Impact craters
- Volcanoes
- Karsts
- Earthquake locations

Cross-validation of the geological maps with other data sources indicated that many were inconsistent – especially when compared to the available geophysical data. The 1:1,000,000 geological map produced by the USGS, and the 1:2,500,000 geological map produced by BRGM were shown to be the most spatially consistent. However, while the USGS geological map was relatively accurate with its spatial location, the level of detail provided in the GIS database was extremely limited, consisting of very broad age dates and simplified descriptions of the rock types. The BRGM geological map was also relatively accurate in its spatial extent, however the GIS database also contained more detailed information on the age and rock type descriptions compared to the USGS geological map.

A map showing the location of the sedimentary basins was produced by the American Association of Petroleum Geologists (AAPG), however this map could not be used for a GIS prospectivity exercise. For example, known sedimentary hosted copper deposits in the copperbelt in the southern part of Democratic Republic of Congo (mineralization is related to basin formation and inversion; Sillitoe et al., 2010), have no correlation with the AAPG sedimentary basins. As a result this map was not used in the analysis.

An additional map of the basins in Central Africa produced by the USGS was available on the server, however other than the location of the basins, no constructive information was contained within the corresponding table. This is consistent with the other geological data layers available on the server – there are many points, lines, or polygons within the maps, but they lack the metadata providing detailed information as to what they represent.

As such, the 1:2,500,000 scale geological map produced by BRGM was used in the prospectivity mapping exercise for Central Africa.
Structural Maps

Only one structural map for Central Africa was present in the data compilation on the IM4DC server. This structural map was produced by BRGM, and has some inconsistencies with the 1:2,500,000 scale geological map. Cross-validation of the BRGM structural map with the available geophysical data (Bouguer and free-air gravity) highlighted that some major boundaries had not been included in this structural map (major structural boundaries are a key control on the location of major mineral deposits).

A new structural map was generated during the course of the project through interpretation of the 1:2,500,000 geological map produced by BRGM, as well as the available gravity datasets, as highlighted in Figure 2. This was used as an input layer in the prospectivity analysis and has been made available on the IM4DC server.

Geophysical Images

A gravity dataset was found in the IM4DC Central Africa data compilation. This dataset was a Bouguer gravity anomaly map over Central Africa that had been compiled from the available data from Bureau Gravimétrique International (BGI¹). Further processing of the data was necessary to highlight the details required in order to perform a structural analysis. The data was processed through the CET dynamic range compression tool to produce a more usable output. The reprocessed gravity image has been made available on the IM4DC server.

In addition to the existing gravity data hosted on the IM4DC server, a free air gravity map was produced from freely available data at Scripps Institute of Oceanography at the University of San Diego². This dataset was also able to highlight sufficient detail from which a structural analysis could be performed.

A magnetic intensity image was downloaded from the World Digital Magnetic Anomaly Map³, however the quality of this data was found to be poor over the Central Africa study area. It was found that multiple surveys had been stitched together with no attempt at levelling the data across different survey areas. Attempts to level the data proved to be unsuccessful due to lack of metadata provided to go with the map.

Additional geophysical data hosted on the IM4DC server includes Landsat ETM+, SRTM, and seismic data points. The Landsat ETM+ and SRTM data is of high quality, and covers the whole of the Central Africa study area. However due to the degree of regolith, these datasets were of limited practical use in the prospectivity mapping exercise.

¹ http://bgi.omp.obs-mip.fr/data-products/Gravity-Databases/Land-Gravity-data
² http://topex.ucsd.edu/WWW_html/mar_grav.html
³ http://geomag.org/models/wdmam.html
Figure 2: Structural interpretation from BGI gravity data (shown) and 1:2,500,000 BRGM geology map.
Mineral Deposits

Mineral deposit datasets from the USGS and the Canadian Geological Survey were contained within the IM4DC Central Africa data compilation. The quality of these datasets is variable.

The USGS dataset was found to have issues with location accuracy, with deposits plotting on the map in Central Africa that were actually located in North America in reality. While obvious issues like this were resolved by removing the points from the Central Africa database, there will still be some issues with location accuracy of the other data points contained within the database. This is very common in data sets for developing world countries due to issues with manual digitisation of hard copy maps.

The USGS mineral deposit database was compared to the mineral deposit database from the Canadian Geological Survey. Consistencies observed between the two gave confidence in the accuracy between those data points.

Maps relating to oil and gas projects produced by the USGS were also available, and showed limited information contained within the data tables.

Administrative Maps

A number of administrative maps were available in the Central Africa data compilation hosted on the IM4DC server. These included political boundaries, transportation infrastructure, water resources, and energy infrastructure. Although there are many objects contained within the maps, there is little information attached in the corresponding tables. It should also be noted that while there are maps with the location of airports and ports, there remains no map of the road infrastructure.

Targeting Models

Based on a combination of availability of relevant literature, and the availability of geoscience data as discussed in section 2, a series of targeting models were generated for different styles of mineralization within the Central Africa study area.

Limited information is available on the regional scale geology or metallogeny of the Central Africa region, at least in the public domain. Searches for relevant literature online produced little of practical use for developing mineral exploration targeting models at such a large scale. Although, it should be noted that it is the understanding of the authors that much of this information exists, but resides outside of the public domain.

Targeting models were produced for gold, copper, tin-tungsten, and diamonds within the Central Africa study area. It is probable that lead-zinc mineralization is present in the Kantangan copperbelt near the border between Democratic Republic of Congo and Zambia, as such mineralization is thought to be present on the Zambian side of the border, although not enough information relating to its geological setting could be found in order to develop a targeting model. Although there is likely potential for other styles of mineralization within Central Africa, not enough information was available in the literature from which a targeting model could be generated. The targeting models for gold, copper, tin-tungsten and diamonds are discussed further below.
Gold Targeting Model
Gold mineralization is located throughout the Central Africa study area. Schlüter (2008) indicates that both alluvial and lode gold mineralization is present in many areas, although the known economic mineralization is structurally controlled and located in greenstone belts of Archaean age (Dostal et al., 1985).

Based on the available data for Central Africa, a fault map was generated, and the potentially relevant geological units extracted from the 1:2,500,000 scale BRGM geological map.

Copper Targeting Model
Known copper mineralization in the Central Africa study area is predominantly located in the southern part of the Democratic Republic of Congo near the border with Zambia (Schlüter, 2008). This region is known as the Central African Copperbelt and is known to host significant economic copper mineralization.

The copper mineralization in the copperbelt is sediment-hosted, stratiform, and ranges from Neoproterozoic to Cambrian in age (Schlüter, 2008; Sillitoe, 2010). Although copper is the main commodity, the economic deposits are known to have high concentrations of cobalt, lead, and zinc. Although there is not enough information available to develop targeting models for these styles of mineralization, their high concentrations indicates that there may be exploration potential for these commodities within the copperbelt.

Based on the available information for the Central Africa study area, a structural map, and a map of the Proterozoic sedimentary units from the 1:2,500,000 BRGM geological map were generated.

Tin-Tungsten Targeting Model
Known tin-tungsten mineralization is present in Nigeria and is hosted within Proterozoic granites within the Jor plateau, and contains contain high concentrations of Au (Schlüter, 2008). Although no deposits have yet been discovered, geochemical analysis within the Kibara belt in Democratic Republic of Congo indicates potential for the discovery of an economic deposit (Pohl, 1994). Known mineralization is limited, although the geological setting in the Central Africa study area indicates a high potential for the discovery of economic mineralization in the future.

Based on the available information over Central Africa, a structural map was generated, and the Proterozoic igneous intrusive rocks extracted from the 1:2,500,000 scale BRGM geology map.

Diamond Targeting Model
Information relating to the geological setting of diamondiferous kimberlite pipes in the Central Africa study area was available. Schlüter (2008) indicated that the diamonds were predominantly found in alluvial deposits of varying age. Information that could be used to target diamondiferous kimberlite pipes (the source of the alluvial diamonds) was lacking in the data base. A targeting model for the alluvial deposits would require totally different data bases. A check of known alluvial deposits with available depth to moho map available on the IM4DC server and gravity data found no correlation. Should higher quality and new datasets become available, a diamond targeting model could be implemented.
Prospectivity Analysis

Given the limited number of mineral deposits contained in the available mineral deposit databases, the prospectivity mapping exercise was limited to a knowledge-driven approach. The method implemented in this study of Central Africa was the fuzzy logic method. Fuzzy logic does not rely on the existence of a robust mineral deposit database like data-driven methods such as weights of evidence or neural networks, but instead relies on the knowledge of an expert geologist in order to determine the inputs for the prospectivity map. The geologist must select the data layers that they believe to be the most important for the style of mineralization being targeted. Subsequently, it is the decision of the geologist to determine what critical thresholds must be applied (e.g. what distance from a fault may be considered to be favourable for the formation of a structurally controlled mineral deposit?), and what weighting to assign the different areas of favourability.

Previous studies indicate that the best practice is to assign a class weight, map weight, and uncertainty weight to each favourability class with values in the range between 0 and 1. Each class within a map is assigned an individual class weight indicating its relative favourability – this can represent decreasing favourability as you move further away from the feature of interest. Each map is then assigned a map weight which indicates how important that map is relative to other maps – this could indicate that the faults may be considered more important than the host rock. Finally, each map is then assigned an uncertainty weight which represents a measure of the quality of the input map. The class weight, map weight, and uncertainty values are then multiplied together in order to generate a fuzzy membership value (or weight) for each favourability class in each map.

The maps are then combined using a fuzzy operator (Bonham-Carter, 1994), which produces a prospectivity map for the style of mineralization of interest. For this case study, the fuzzy PRODUCT operator was used to generate all of the prospectivity maps.

For Central Africa, the data layers and their parameters for gold mineralization are listed in Table 1. The corresponding gold prospectivity map is shown in Figure 3.

Table 1: Prospectivity mapping parameters for gold mineralization in Central Africa

<table>
<thead>
<tr>
<th>Input Layer</th>
<th>Distance</th>
<th>Class Wt.</th>
<th>Map Wt.</th>
<th>Uncertainty Wt.</th>
<th>Fuzzy Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Fault</td>
<td>0-5 km</td>
<td>0.95</td>
<td>0.90</td>
<td>0.70</td>
<td>0.5985</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.75</td>
<td>0.90</td>
<td>0.70</td>
<td>0.4725</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.70</td>
<td>0.60</td>
<td>0.0063</td>
</tr>
<tr>
<td>Distance to Archaean Units¹</td>
<td>0-5 km</td>
<td>0.80</td>
<td>0.70</td>
<td>0.60</td>
<td>0.3360</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.60</td>
<td>0.70</td>
<td>0.60</td>
<td>0.2520</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.70</td>
<td>0.60</td>
<td>0.0042</td>
</tr>
<tr>
<td>Distance to Proterozoic Units²</td>
<td>0-5 km</td>
<td>0.80</td>
<td>0.50</td>
<td>0.60</td>
<td>0.2400</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.60</td>
<td>0.50</td>
<td>0.60</td>
<td>0.1800</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.50</td>
<td>0.60</td>
<td>0.0030</td>
</tr>
</tbody>
</table>

¹ Archaean Units – Sediments, volcanosediments, metamorphosed, plutonic, and volcanoplutonic units of Archaean age as mapped from the 1:2,500,000 scale BRGM geology map.

² Proterozoic Units – metamorphosed, volcanosedimentary, and volcanoplutonic units of Proterozoic age as mapped from the 1:2,500,000 scale BRGM geology map.

The data layers and their parameters for the copper prospectivity map are shown in Table 2. The corresponding copper prospectivity map is shown in Figure 4.
Table 2: Prospectivity mapping parameters for copper mineralization in Central Africa

<table>
<thead>
<tr>
<th>Input Layer</th>
<th>Distance</th>
<th>Class Wt.</th>
<th>Map Wt.</th>
<th>Uncertainty Wt.</th>
<th>Fuzzy Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Fault</td>
<td>0-5 km</td>
<td>0.95</td>
<td>0.90</td>
<td>0.70</td>
<td>0.5985</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.75</td>
<td>0.90</td>
<td>0.70</td>
<td>0.4725</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.90</td>
<td>0.70</td>
<td>0.0063</td>
</tr>
<tr>
<td>Distance to Proterozoic-Paleozoic Units</td>
<td>0-5 km</td>
<td>0.75</td>
<td>0.70</td>
<td>0.50</td>
<td>0.2625</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.50</td>
<td>0.70</td>
<td>0.50</td>
<td>0.1750</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.70</td>
<td>0.50</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

1 Proterozoic-Paleozoic Units – sedimentary, volcanosedimentary, and metamorphic units of Proterozoic-Paleozoic age as mapped from the 1:2,500,000 scale BRGM geology map.

The data layers and their parameters for the tin-tungsten prospectivity map are shown in Table 3. The corresponding tin-tungsten prospectivity map is shown in Figure 5.

Table 3: Prospectivity mapping parameters for tin-tungsten mineralization in Central Africa

<table>
<thead>
<tr>
<th>Input Layer</th>
<th>Distance</th>
<th>Class Wt.</th>
<th>Map Wt.</th>
<th>Uncertainty Wt.</th>
<th>Fuzzy Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Fault</td>
<td>0-5 km</td>
<td>0.95</td>
<td>0.70</td>
<td>0.70</td>
<td>0.4655</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.75</td>
<td>0.70</td>
<td>0.70</td>
<td>0.3675</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.70</td>
<td>0.70</td>
<td>0.0049</td>
</tr>
<tr>
<td>Distance to Proterozoic Pluton</td>
<td>0-5 km</td>
<td>0.80</td>
<td>0.80</td>
<td>0.60</td>
<td>0.3840</td>
</tr>
<tr>
<td></td>
<td>5-20 km</td>
<td>0.60</td>
<td>0.80</td>
<td>0.60</td>
<td>0.2880</td>
</tr>
<tr>
<td></td>
<td>&gt;20 km</td>
<td>0.01</td>
<td>0.80</td>
<td>0.60</td>
<td>0.0048</td>
</tr>
</tbody>
</table>

1 Proterozoic Plutons – plutonic units of Proterozoic age as mapped from the 1:2,500,000 scale BRGM geology map.

The prospectivity maps generated have been published as freely available precompetitive datasets on the IM4DC server and are available as of June, 2014. Additionally, the gravity map produced using the dynamic range compression tool, and the new structural interpretation generated as part of this project have been published on the IM4DC server.
Figure 3: Gold prospectivity map for Central Africa with known gold deposits highlighted as yellow filled circles.
Figure 4: Copper prospectivity map for Central Africa with known copper deposits highlighted as green filled circles.
Figure 5: Tin-Tungsten prospectivity map for Central Africa with known tin-tungsten deposits highlighted with light green filled circles.
Discussion

The prospectivity maps in Figures 3-5 clearly highlight areas of increased prospectivity outside of known mineral districts within Central Africa.

Results of the prospectivity mapping for gold mineralization clearly show a large, highly prospective area in Benin and western Nigeria. This is due to the presence of Archaean greenstones, and the clear structural complexity in the region. The structural complexity may be explained by the fact that this area falls on the margins of both the West Africa and Central Africa cratons. The known gold deposits within Central Africa are predicted by the areas of higher prospectivity within the study area.

Areas of higher prospectivity for copper are distributed throughout the Central Africa study area, with clearly defined large regions of high prospectivity in the copperbelt in southern Democratic Republic of Congo and in Benin and western Nigeria. Additionally a north-west trending structural corridor from Republic of Congo, through Gabon, to Equitorial Guinea also appears to be highly prospective for copper mineralization.

Prospective regions for tin-tungsten mineralization are largely in the northern part of the Central Africa study area, in Benin and western Nigeria. Additionally, Cameroon contains regions of high prospectivity for tin-tungsten mineralization. The correlation with the regions of tin-tungsten prospectivity with the regions of gold prospectivity are expected, as Schlüter (2008) indicates that the known-tin-tungsten mineralization in Nigeria is associated with high concentrations of gold.

Recommendations

Based on the results of the prospectivity mapping for Central Africa, the following recommendations are proposed:

- A further detailed mineral prospectivity study in Benin and Nigeria for gold mineralization using higher resolution data. It is understood that the Nigerian Geological Survey has access to high resolution geophysical datasets, including aeromagnetics and radiometrics over the entire country, as well as a comprehensive geochemical database, and more detailed geological mapping, all of which would benefit a more detailed prospectivity mapping project.
- A detailed mineral prospectivity study in Democratic Republic of Congo (and potentially across the border into Zambia) for copper mineralization. A collaborative effort between Zambia and DRC would be highly recommended due to the highly economic copperbelt extending across the border.
- A geochemical sampling program across Central Africa. In order to reduce the search space for economic mineralization, the analysis of both major and trace elements is of critical importance. This may also open up the exploration search space for other commodities such as lead-zinc, or uranium, which have not been addressed in this study.
- Publication of reports produced by the national geological surveys be made available in the public domain. Information on the regional-scale geology and mineralization in Central Africa published in scientific journal articles and books is limited, although effort has been made by various geological survey departments in collaboration with international development organisations and governments to produce these reports internally. Making these easily available online, even at a small cost, would improve the targeting models used in the prospectivity analysis.
• Publication of digital geoscience data online. One of the benefits of GIS-based prospectivity mapping is that it is a relatively low cost exercise compared to field mapping and laboratory work. However this cost benefit is negated if extended travel is necessary to acquire the data in person. By making this data available online for download, even for a small cost, the cost benefit may be maintained.

References


Pohl, W., 1994, Metallogeny of the northeastern Kibara belt, Central Africa – Recent perspectives. Ore Geology Reviews, v. 9, 105-130.

