Targeting tin mineralisation using "3D Common Earth Models" in the Khartoum region, North Queensland, Australia

F.W. Cunningham[1], A.J. Wilkins, C.E. Payne, S.H.H. Nielsen and G.A. Partington

[1] Kenex Ltd, P.O. Box 41136, Eastbourne, Wellington, New Zealand
fraser@kenex.co.nz

Abstract

The use of modern day 3D GIS software packages such as GOCAD, GeoModeller and Leapfrog Geo has dramatically changed the way exploration targeting can be carried out compared to the last twenty years of using 2D Geographic Information System (GIS) for exploration. This is especially true in the last five years in which computer and GPS technology has developed to the stage where it is possible to digitally locate, accurately store, visualise and manipulate geological data in 3D at the scale of a mineral system, which is usually much greater than mine scale where most of the current 3D work is focussed. Most GIS can store, manage and manipulate data in 2D, with some able to visualise information in 3D. However, there are a number of packages that allow full 3D GIS functionality, including querying and modelling, allowing geologists to start exploration targeting in a 3D system. Auzex Exploration Limited owns a number of exploration tenements over the historically tin rich Khartoum area located near Herberton in North Queensland, Australia, exploring for Tin-Tungsten mineralisation. A 3D geological interpretation was created over a 60 km by 60 km region in Khartoum using Leapfrog Geo to improve targeting for tin systems adjacent and above buried granites and shallow dipping granite contacts, followed by 3D targeting using a Multi-Class index Overlay workflow of GoCAD Mining. The ranking of the 3D maps were based on a 2D prospectivity mapping exercise using the weights of evidence technique. By modelling geology and targeting in 3D, complex subsurface relationships and the correct vertical extents can be constrained. This will be invaluable for defining potential drill-hole targets.

Keywords: 3D geological modelling, mineral prospectivity modelling, tin-tungsten, Khartoum.

Introduction

Mineral prospectivity modelling using GIS is becoming more popular in the geoscience world. While two-dimensional (2D) prospectivity modelling is a powerful tool for exploration targeting that is often used by the exploration industry, developments in computer software, modelling techniques and availability of digital data are allowing us to work with greater detail. Feltrin et al., (2008), McInerney et al., (2008), and McGaughey et al., (2009) have extended the capabilities of mineral prospectivity modelling to now include three-dimensional (3D) analysis. There are a number of modelling techniques that can be used, including weights of evidence, fuzzy logic, artificial neural networks, and applied to a range of mineral deposit types (Porwal et al. 2010; Lindsay et al., 2014). The need to improve predictors of mineral deposits are driving the need to visualise exploration data in 3D space, pushing us towards a 3D analytical world.

The weights of evidence technique (Bonham-Carter, 1994) has been used to complete mineral prospectivity modelling in both two- and three-dimensional space for tin mineralisation across an area centred over several exploration licences owned by Auzex Exploration Limited (AEL) near the Mount Garnet Township (Fig. 1). Information from a 3D geological model created for this project was has been used to improve the results of the 2D prospectivity model (Payne et al., this volume), from which the results have been critical for the development of the 3D

prospectivity model. In this study we describe the 3D geological modelling, and the 3D prospectivity modelling for intrusion related tin mineralisation over the Khartoum study area.

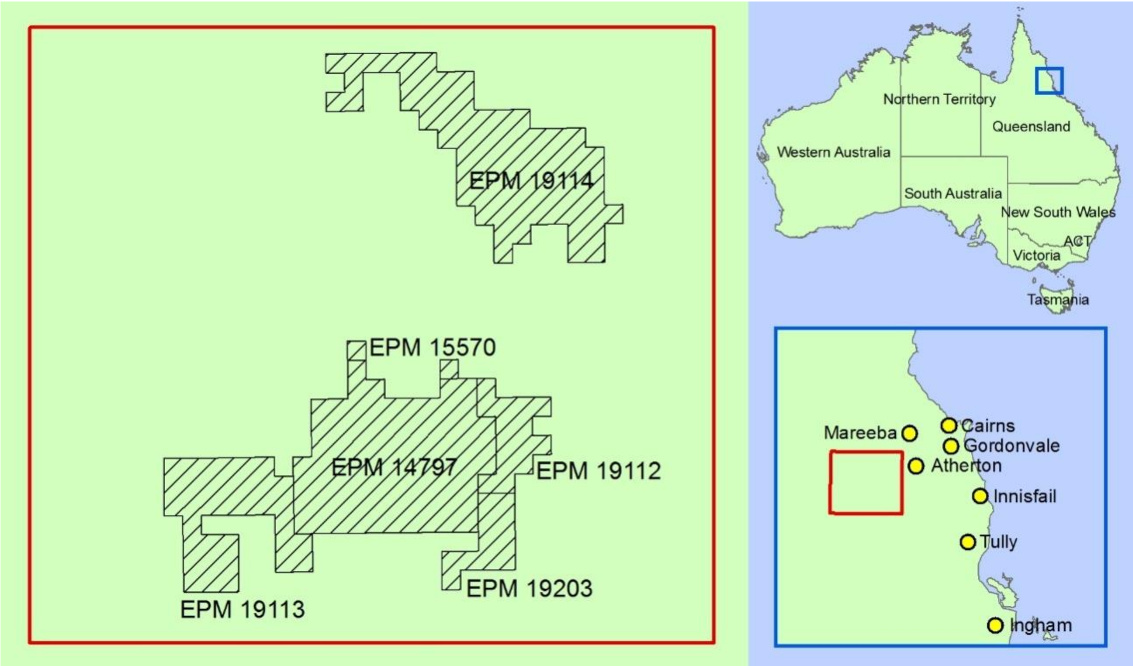

Figure 1. Location of the Khartoum study area (red square).

Geology

The Khartoum study area is situated toward the southwest margin of the Hodgekinson Province, an extensive area of lower Palaeozoic metasediments and basic volcanic rocks that form the northern extremity of the Tasman Orogenic Zone in Australia. The folded lower Palaeozoic meta-sediments of the Hodgekinson Province consist largely of greywacke, sandstone and conglomerate, with minor siltstone and shale. Upper Palaeozoic granites and volcanics in the region form extensive batholiths, cauldrons and ring complexes (Pollard, 1984).

The Emuford Granite forms a relatively large pluton greater than 200 km^2, and underlies approximately 75% of the Khartoum permit area (Figs 1-2). The Emuford Granite is a coarse grained granite that is intruded by numerous small bodies of late-stage fine and medium grained, sparsely to moderately porphyritic, biotite-granite and adamellite. Most of the late-stage granites form dykes, sheets and small plutons (less than 10 km^2) that occur along the margins of, and within, the early granites. The late-stage granites generally have sharp contacts, however, there is local evidence of gradational contacts. The Billings Granite is the most extensive of the late stage granites and forms a sheet-like body in the northwest of region.

Granite, diorite and associated volcanics assigned to the Ootan Supersuite form part of the Gurrumba Ring Complex (Pollard, 1984) and surround an inlier of sandstone and siltstone of the Hodgekinson Formation. The Nanyeta Volcanics in the Khartoum area is a volcanic sequence of rhyolitic to andesitic composition, and is interpreted as co-magmatic with the O'Brien Creek Supersuite. The Featherbed Volcanics crop out in the north of the region. To the west of the Nanyeta Volcanics is a narrow north-west trending exposure of Silurian Chillagoe Formation.

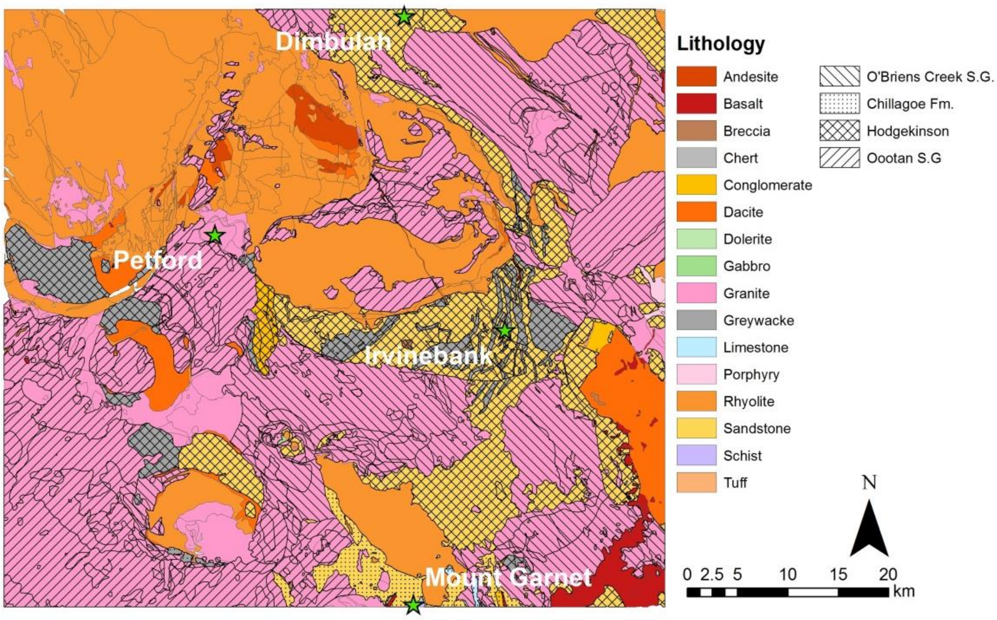

Figure 2. Geology of the Khartoum study area, the extent is the same as the study area.

Tin mineralisation in North Queensland

Tin and base-metal sulphide mineralisation occurs in a number of cross-cutting fracture zones within the granites and in the metasediments, especially near the granite contact. Alteration, especially greisenisation, is extensive and most O'Briens Creek Supersuite rocks contain anomalous amounts of tin, tungsten, molybdenum and fluorine mineralisation. Most of the tin mineralisation in the Herberton, Irvinebank, Emuford, Mt Garnet and Tate River areas is associated with granites of this supersuite.

Several styles of mineralisation are recognised in the Khartoum district on the basis of vein morphology, mineralogy and wall rock alteration (Blevin, 1998; Pilcher, 2008; Lam, 2009). These are pegmatite related tungsten-molybdenum deposits, quartz-cassiterite veinlets in albitised granite, tin-tungsten greisens, quartz–tourmaline cassiterite veins and quartz-chlorite-cassiterite-sulphide-veins. The distribution of mineralisation within the late-stage granites suggests a close relationship; they are thought to be the source of the mineralising fluids. A simple metal zoning pattern is apparent in the area, with tin-tungsten mineralisation occurring in and around the late-stage granites, and tin-copper mineralisation in the metasediments that are the host rocks to the granites. The reasons for this zoning probably relate to temperature and activity gradients in the fluids, and the effects of wall rock reaction and host rock lithology on fluid evolution and mineral deposition.

Endo-contact Greisen Mineralisation

Mineralisation within the granite contact comes in the form of greisenisation. Greisen alteration of the host granite consists largely of quartz and mica (usually muscovite) together with minerals such as topaz, fluorite, tourmaline and apatite. The main ore minerals associated with greisen-style deposits include cassiterite, wolframite and a variety of sulphide minerals including pyrite, chalcopyrite, sphalerite and arsenopyrite.

Exo-contact Mineralisation

Some of the earliest mineralisation in the Emuford district occurs in the metasediments adjacent to the granite contact. These deposits usually form narrow (less than 2 m) veins and breccias zones within silicified and tourmalinised metasediments or as skarn mineralisation in carbonate-rich lithologies. Features of the wall rock alteration in these deposits include the replacement of plagioclase, feldspathic rock fragments and the matrix of the greywackes by quartz, muscovite and tourmaline, while K-feldspar is initially preserved and in some cases possibly recrystallised. At more advanced stages of alteration all the feldspars and mica are replaced by quartz and tourmaline, although minor muscovite and chlorite occur in some examples. Vein mineralogy in these deposits is dominated by quartz and tourmaline with often two or three phases of vein-filling apparent from cross-cutting relationships. Tourmaline occurs in a wide range of colours including deep blue, blue-green, green, and brown-green and as acicular crystals either singly or in clusters and usually fine grained (less than 1 mm). Other minerals occurring in the quartz-tourmaline veins include cassiterite, chlorite and minor beryl. Cassiterite is generally deep red, weakly pleochroic, occurring as needle-like or irregular crystals up to 1 mm in length.

3D geological interpretation

The 2D geology interpreted for the Khartoum study area was compiled from detailed geological mapping at 1:100,000 scale, prospect scale mapping and detailed outcrop mapping supplied by AEL. As the study area is large compared to the prospect and outcrop scale mapping, a pragmatic approach has been taken when completing the 3D geological interpretation using Leapfrog Geo. The polygons were exported from ArcGIS as polylines and imported into Leapfrog Geo, and a series of cross-sections giving the structural and temporal information for the units were used to guide the 3D modelling process. The eighteen lithologies that occur in the study area have been simplified into nine units. These are limestones of the Chillagoe Formation; the Chillagoe formation (siliclastic rocks); the Hodgekinson Formation (metasediments); felsic volcanics (rhyolite, dacite and andesites of the Featherbed Volcanics); cherts from both the Chillagoe and Hodgekinson Formations; highly fractionated, fractionated and unfractionated granites; and porphyry dykes. The elevation of the polyline of each of the units was set by draping it over the topographical surface, and a mesh surface created. Structural data, interpreted from drill-hole data, geological mapping and geophysical data, was added to the mesh. This allowed the extents of the lithological units to be constrained and assisted the software to make an objective interpretation of the extent of each geological unit. The "Surface Chronology" tool was used to order the geological units, allowing the software to determine the stratigraphic order of the volumes and sensibly remove overlaps between geological units when building the 3D model (i.e, the older geological units are cut by the younger units, so the overlap area removed is in the older unit: Fig. 3).

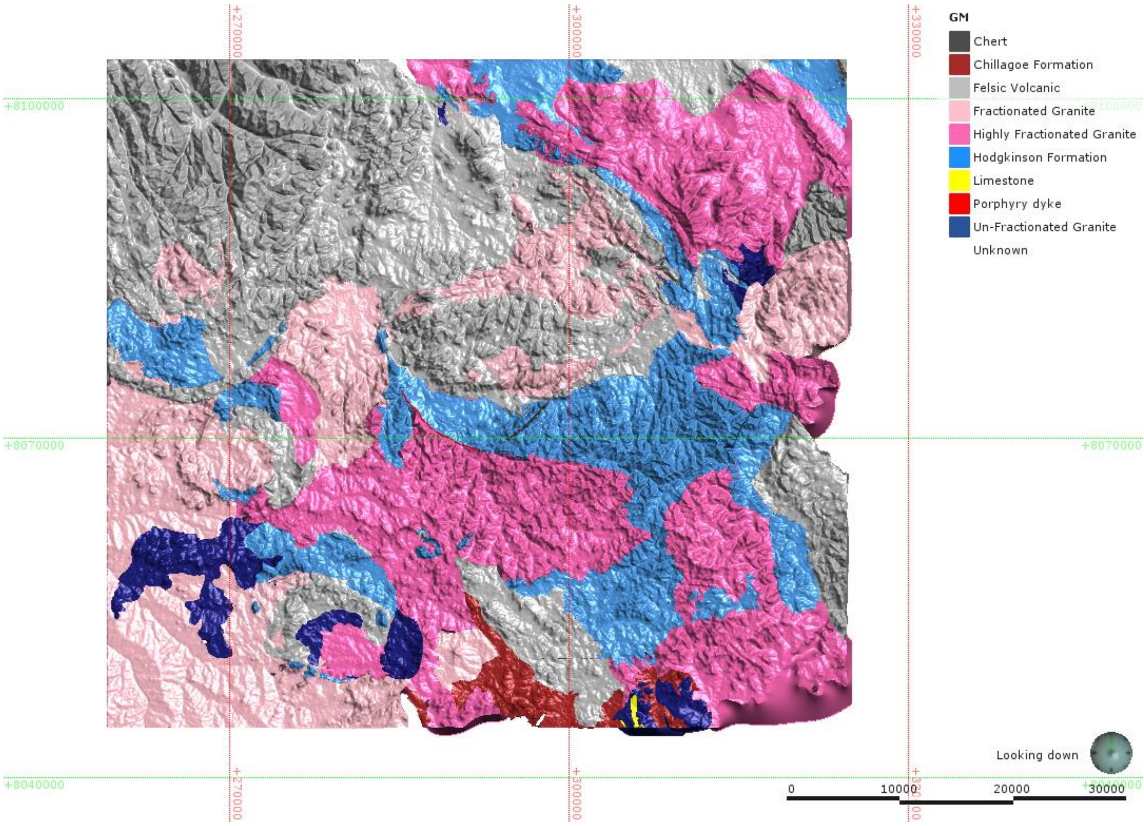

Figure 3. 3D geology of the Khartoum study area, the extent is the same as the 2D study area.

3D prospectivity modelling

Mineral systems approach

The petroleum systems approach was developed and is used as standard practise by the oil industry has been adapted for targeting mineral deposits (Wyborn et al., 1994; Knox-Robinson and Wyborn, 1997; Hronsky, 2004; Joly et al., 2012). Whilst mineral systems are more complex and diverse than petroleum systems, the critical parameters of ore deposit formation can be summarised as the geological factors that control the generation and preservation of mineral deposits. That is the processes involved in mobilising ore components from a source, and then transporting and accumulating them in a concentrated form; and the processes that allow preservation through subsequent geological history (Fig. 4).

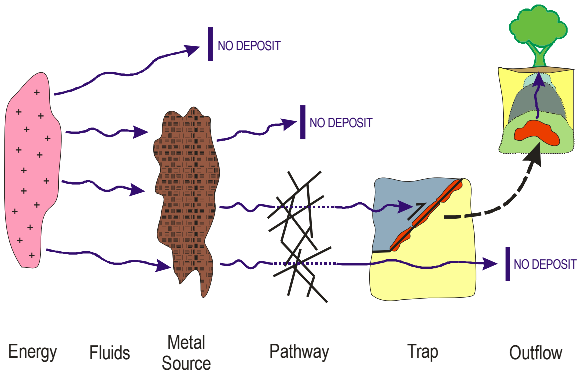

Figure 4. The mineral systems concept of ore formation from source of energy and metals through transport mechanisms to trap.

There are five essential geological components that define a mineral system, a source of energy that drives the system, sources of fluids, metals and ligands, pathways along which fluids can migrate to trap zones, a trap zone in which fluid flow can be focussed and its composition modified and outflow zones for discharge of the residual fluid (Wyborn et al., 1994; Joly et al., 2012, Lindsay et al., 2014). Where a mineral system is lacking one or more of these components, ore deposit formation will be precluded. The application of the mineral system approach is process-based, and so it is not restricted to any particular geological setting or specific ore deposit type. This makes using this approach flexible, allowing for multiple deposit styles to be recognised within a single mineral system, and it acknowledges the natural variability among many ore deposits (Knox-Robinson & Wyborn, 1997). It is required that the critical ore-forming processes and mappable elements characterising a particular mineral system at various scales are identified when applying this method to mineral exploration (Porwal & Kreuzer, 2010). Processes can be identified from geological, geochemical, geophysical and structural data using a range of analytical techniques prior to the spatial analysis of these maps. These techniques may include traditional statistical analysis of geochemical data, modelling of geophysical data, structural analysis and detailed analysis of geological data attributes. The maps with the best spatial correlations representing each aspect of the mineral system that are suitable for interpretation in 3D were considered for inclusion in the final 3D prospectivity model.

Data sources

The majority of data used in this study was supplied by AEL as MapInfo TAB files, or was extracted from the Kenex global mineral occurrence and geochemistry databases. The data that could be translated into 3D were reformatted using GOCAD and Leapfrog Geo. Data used in the 3D prospectivity modelling includes:

- Complete geological mapping, 100K Lithology – Queensland Geological Survey;
- Detailed geological mapping over prospect areas;
- Outcrop mapping over prospect areas;
- Detailed structures over prospect areas;
- Structural measurements over prospect areas;
- Structural interpretation of aeromagnetic data;
- Soil geochemistry;
- Rock-chip and drill-hole geochemistry;
- Fathom Geophysics structural detection interpretation of aeromagnetic data;
- Complete coverage of aeromagnetic geophysical data;
- Complete coverage of ASTER Landsat data;
- Complete coverage of radiometric geophysical data.

3D multiclass index overlay model

The prospectivity modelling in 3D was carried out in GOCAD Mining Suite 2009.4, the modelling was based on the results from the 2D prospectivity modelling spatial correlations (Payne et al., this volume). The properties used in the 3D model were derived from the 2D model where the variables could be extended into the subsurface. The predictive 3D maps were created in Leapfrog Geo, and the surfaces then imported into GOCAD, the exception being the topographic surface, which was generated from the available DEM point-set and simplified to

fit the model resolution. Grade shells for geochemical data were also created in Leapfrog Geo and imported into GOCAD. A multiclass binary index targeting method was used for the prospectivity modelling, assigning weights determined from the 2D prospectivity modelling (Table 1). The main geological features used to determine the 3D prospectivity of the Khartoum region for intrusion related tin mineralisation include: (Fig. 5a) association with host lithology; (Fig. 5b) association to highly fractionated granite alteration halo; (Fig. 5c) proximity to faults; and (Fig. 5d) presence of tin in excess of 500 ppm.

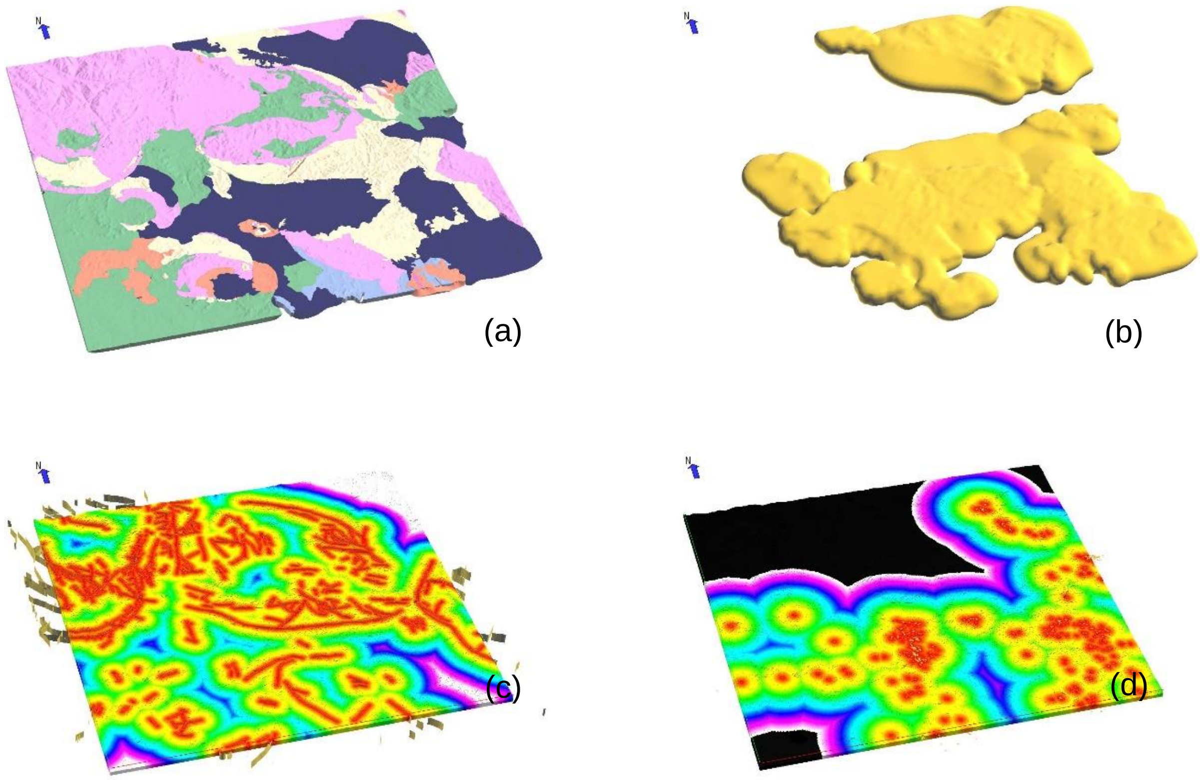

Figure 5. Predictive maps used in the 3D prospectivity model

Table 1. Predictive maps used in the 3D intrusion related tin mineralisation prospectivity model

Property	Variable	Weight
Geology	Chillagoe Formation	4.59
	Hodgekinson Formation	4.59
	Highly Fractionated Granite	3.04
	Limestone	2.54
	Felsic volcanics	1
	All other units	0
Granite alteration halo	1000 m buffer around highly fractionated granites	5.3
Faults	700 m buffer	3.36
	> 100 m buffer	1
Sn grade shells	< 100 m buffer	4.35
	> 100 m buffer	1

Results

The total model volume is 60 km long, 60 km wide, and 1,700 m deep and the targets based on the MCIO workflow are shown in Fig. 6. The alteration zone around the highly fractionated granites appears to be controlling the prospective areas in both 2D and 3D models. Several faults appear as priority targets in the 3D model, but are not so prominent in the 2D model, although they are still identified as areas of interest. Only a few of what can be presumed to be the more important fault lines are being highlighted as areas of interest in the 3D model.

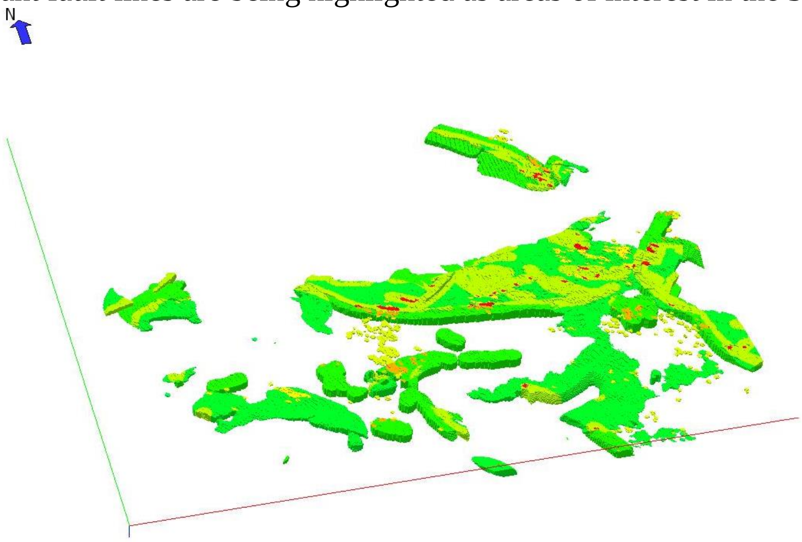

Figure 6. Identified targets. Volumes that are below the prior probability have been removed.

Discussion

Both the 2D and 3D prospectivity models of intrusion related tin mineralisation in the Khartoum study area confirm and map the location of high priority potential areas for tin mineralisation. The results from the 3D prospectivity model over the Khartoum study area show a number of similarities to the 2D prospectivity model (Fig. 7). Both 2D and 3D models highlight the same general areas as prospective. However, the 2D highly prospective areas at the surface are reduced in size in 3D, and now extend into the subsurface (Fig. 8).

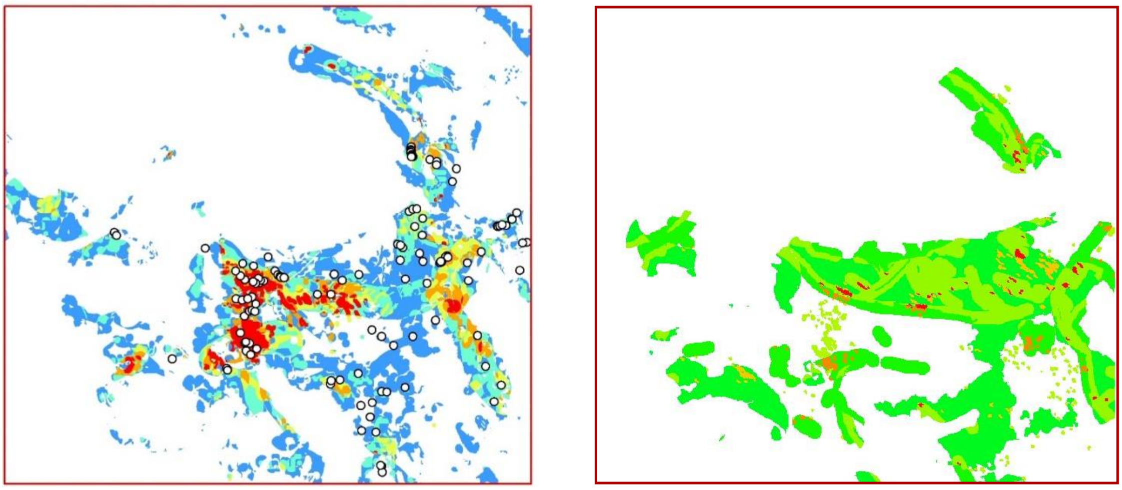

Figure 7. Comparison of the 2D and 3D intrusion related tin mineralisation prospectivity models.

Numerous prospective areas have been identified in the 3D model despite the limited coverage of data at depth. The most prospective areas are those associated within the highly fractionated granite alteration halo (1,000 m buffer around highly fractionated granites). Anomalous tin geochemistry is commonly associated with the high priority areas of interest, this emphasised the importance of geochemical prospecting in any exploration work. A number of prospective areas highlighted in the 2D model are not highlighted in the 3D model (Fig. 8), this is due to the large nature of the study area. A number of simplifications were required in order to process the data in 3D leading to a reduction in the detail of data represented in 3D. While some prospective areas are missing, those that have been identified extend into the subsurface, providing useful information to assist targeted drill-hole planning.

Substantial sub-surface information is desirable when constructing a 3D prospectivity model. However, these data are often limited as they were in this study, making the application of this methodology in 3D difficult. In creating a 3D prospectivity model, the 3D geometries of the geology need to be well constrained. In complexly deformed regions with limited sub-surface data and high density of faulting and stratigraphic complexity, creating 3D geological modelling is even more challenging. A pragmatic approach was utilised in the 3D modelling of this study, where surface geological mapping was used as the primary dataset to create a plausible interpretation of the subsurface. To test the reliability and improve the results of the 3D model, a detailed geological survey including further drilling are required. The 3D model can be further utilised to plan drilling depth, based on the vertical extent of the targets (Fig. 8). The model is flexible, and can be quickly updated and improved as new data become available. Also consideration should be given to using the geophysical data available to produce 3D inversion models to help map alteration and geology in 3D.

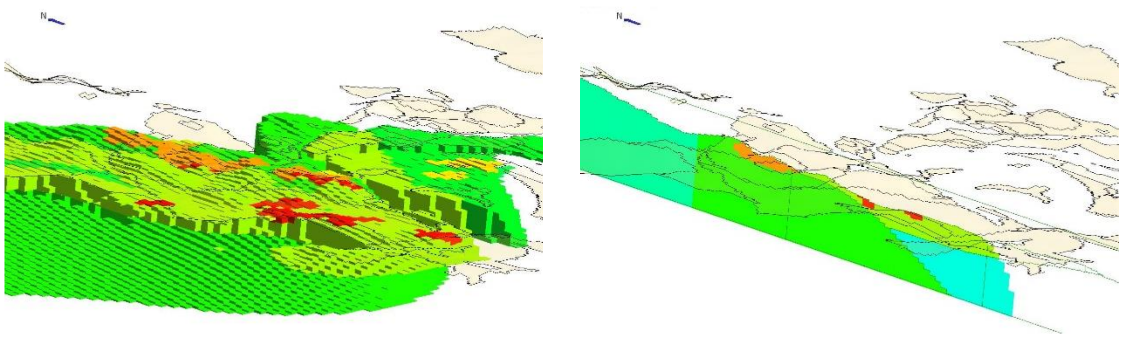

Figure 8. Illustration of 3D targets extending beneath the surface. The 2D targets are outlined and draped across the surface.

This study emphasises that in mineral exploration, 3D geology and any other 3D data should be incorporated at as early a stage as possible. This is so alternative geological interpretations can be tested quickly during the exploration phase, a critical phase for efficient and effective project development. The use of 3D geological models or mineral potential models in resource estimation studies can address issues that occur when using interpolation techniques, as metal grade can be estimated based on defined geological controls where mineralisation is known to occur. 3D models can be used as an aid to effectively plan ongoing exploration, i.e. drill-hole positioning. The use of 3D digital geological mapping data combined with other 3D exploration datasets (i.e. geochemical and geophysical datasets) has improved the understanding of the 3D spatial relationships between different datasets and how these relate to mineralisation.

Developments in GIS software such as GOCAD and Leapfrog Geo are making 3D interpretations possible in real-time in comparison to exploration development and mining

schedules. While 3D geological maps are generally based on 2D geological interpretations, they provide constraints on 3D geometries that are not possible in 2D (i.e. depths of targets). Complex geological relationships can be visualised, including multiple levels of targets at depth (Fig 7) allowing a greater understanding of the system of interest. Other 3D data, such as alteration, geochemical and geophysical datasets, can easily be used in conjunction with the 3D geological interpretations by integrating them into a common earth model (i.e. a block model). Using the new 3D GIS technologies this data can be visualised, managed and modelled allowing the potential for any type of mineralisation to be constrained in 3D.

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