Improvements on 2D modelling with 3D spatial data: Sn prospectivity of Khartoum, Queensland, Australia

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

Kenex Ltd, 16 Oroua Street, Eastbourne, Lower Hutt, New Zealand
[1] connie@kenex.co.nz

Abstract

Auzex Exploration Limited owns a number of exploration tenements over the historically tin rich Khartoum area near Herberton, north Queensland, Australia and Kenex Ltd has completed both 2-dimensional prospectivity modelling and a 3-dimenional geological interpretation over this region. The initial 2-dimensional prospectivity model of intrusion related tin mineralisation is limited by the 2D nature of the data used, and regions of known Sn mineralisation were not identified, particularly in the contact zones of shallow dipping highly fractionated tin granites. To rectify this, a 3D geological model was created using Leapfrog Geo modelling software, and 3D spatial data has been projected to the surface topography and incorporated into an updated 2D prospectivity model of the region using ArcGIS software. The 2D and 3D models utilise newly compiled digital data including historical exploration data; geological data compiled from detailed geological mapping of north Queensland, academic literature and company exploration mapping; recent geophysical data collect by Fathom Geophysics Australia Pty Ltd; ASTER data analysed for alteration; and historical exploration geochemical data including rock-chip, stream sediment and soil sampling. The weights of evidence modelling technique was used to determine spatial correlations between known deposits and predictive maps in 2D, created from the available data, that represent each component of the currently accepted minerals systems model for intrusion related tin mineralisation defined for this project. The final updated 2D prospectivity model partially resolves the limitations of the initial 2D model, successfully identifying many of the areas originally missed.

Keywords: 2D prospectivity modelling, 3D geological modelling, Khartoum, tin mineralisation, weights of evidence.

Introduction

Kenex Ltd has completed 2D prospectivity modelling over the Khartoum region, near the Mount Garnet Township, northern Queensland, Australia. It is a region that has a number of historical workings, the majority of which have been explored or mined for hard-rock and alluvial tin. Over the last 100 years mall syndicates have exploited these alluvial and lode tin deposits, however, a downturn in the tin value brought mining in the area to a halt in 1983. Recent increases in tin prices has resulted in a renewed interest in tin in this region in which AEL have a number of tenements over this area.

The Khartoum study area is located 13 km north of the Mount Garnet Township, north Queensland (Fig. 1). Kenex Ltd has utilised the weights of evidence technique to assess the prospectivity for intrusive related Sn mineralisation over the area. An initial model confirmed the potential for Sn mineralisation over the area, however, a number of well-known deposits (e.g. Claret Creek) and current mines (e.g. Pinnacles) were not identified by the model. The model was then revaluated, and granite contact data from a 3D geological model created by Cunningham et al. (this volume) was included to better represent the extent of contacts, thought to be an important factor in the formation of trap for tin mineralisation in this region. The updated model has improved results, highlighting the previously missed known areas and increasing the predictive efficiency of the model. This indicates the importance of including 3D data in prospectivity modelling. It is important to note that in 2D prospectivity maps, the areas of high prospectivity may not necessarily be at the surface. While some 3D data has been used (magnetic and gravitational interpretations, depth to granite contacts) it has been projected onto a 2D surface, so an interpretation of what depth mineralisation may be occurring cannot be made. This study describes the prospectivity modelling undertaken for the Khartoum region, and shows how it can be improved using 3D data.

Figure 1. Location of the Khartoum study area.

Geology

The Khartoum study area is located in north Queensland, where Paleoproterozoic metasedimentary rocks are overlain by Cambrian-Ordovician mafic to felsic meta-volcanics and their related metasedimentary rocks (Pollard, 1984). These lithologies are intruded by Silurian S-type and Devonian-Carboniferous I- and S-type granites and late felsic volcanics. Mesozoic-Cainozoic sedimentary rocks and extensive basalt sheets form widespread areas of cover. Metamorphism in the area ranges from lower greenschist to granulite facies. The Silurian to Early Devonian (ca. 430-420 Ma) granites are associated with deformation, retrogressive metamorphism and gold mineralisation (ca. 425-400 Ma) in the Etheridge Province. Major uplift and erosion occurred during this period. The Carboniferous to Permian (ca. 330-300 Ma) I-type and S-type volcanic and plutonic rocks are extensively distributed throughout the area and are part of the Kennedy Province, which forms two belts: the Townsville-Mornington Island Belt and the Badu-Weymouth Belt. The Townsville-Mornington Island Belt forms a WNW trending zone (1,100 km long and 100 km wide), in which approximately 80% of rocks are igneous. It extends parallel to the coast from Home Hill to the Atherton area, then west to the north of Georgetown. The Badu-Weymouth Belt extends from Cape York to Papua New Guinea. These granites are one of the best worldwide examples of highly evolved I-type granites developed on a large scale, with volumes greater than 8,000 km^2 averaging approximately 74wt% SiO_2. These granites contain several prospective supersuites with highly fractionated I-type intrusions. Mineral occurrences associated with these intrusions contain a range of metals including Au, Mo, Sn, W, Cu and Bi.

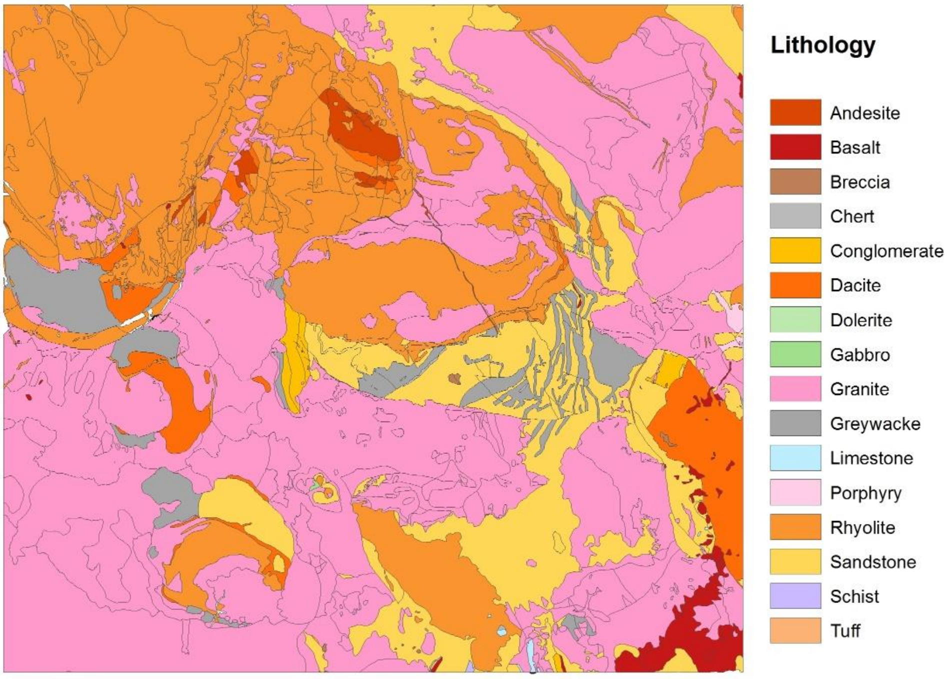

Figure 2. Geology of the Khartoum study area.

The Khartoum study area is at the south-west margin of the Hodgkinson Province, the northern extremity of the Tasman Orogenic Zone in Australia. Widespread lower Palaeozoic metasediments and basic volcanic rocks cover the northern extremity of the Tasman Orogenic Zone. The Hodgkinson Province consists of folded lower Palaeozoic metasediments, largely comprised of sequences of greywacke, sandstone and conglomerate, with intermittent siltstone and shale (Lam, 2009). Late Palaeozoic intrusive and extrusive igneous rocks in the region form extensive batholiths, calderas and ring complexes. In the Khartoum study area the Emuford Granite forms a relatively large pluton, covering an area approximately 200 km^2 on the surface and underlying approximately 75% of the study area (Pollard, 1984). It is a coarse grained granite and is intruded by a number of late-stage smaller bodies of fine-medium grained biotite-granite and adamellite, covering an area of approximately 10 km^2 within the Emuford Granite. The Billings Granite is the most extensive of the late stage intrusives, and forms a sheet-like body to the northwest of the study area. To the south-west of the study area the granite, diorite and volcanics of the Ootan Supersuite form a part of the Gurrumba Ring Complex surrounding an inlier of sandstone and siltstone of the Hodgkinson Formation. Figure 2 shows the geology of the study area.

Sn mineralisation in North Queensland

There are several styles of Sn-mineralisation in the Khartoum district (Belvin, 1998; Pilcher, 2008; Lam, 2009), and are recognised on the basis of vein morphololgy, mineralogy and wall-rock alteration. These include pegmatite related W-Mo deposits, quartz-cassiterite veinlets in albitised granite, Sn-W hosted greisens, quartz-tourmaline-cassiterite bearing veins, and quartz-chlorite-cassiterite-sulfide bearing veins. The characteristics of formation of these different styles of mineralisation can be generalised into two styles of mineralisation related to greisen alteration; endo-contact (granite–wall rock) mineralisation, and exo-contact mineralisation. In general tin mineralisation occurs in a number of cross-cutting facture zones within granite and near granite contacts in metasediments, associated with granites of the O’Briens Creek Supersuite.

Endo-contact mineralisation occurs within the granite body, and is recognised as greisen alteration. It largely consists of quartz and mica (generally muscovite) in conjunction with topaz, fluorite, tourmaline and apatite. Tin bearing ore minerals associated with this mineralisation include cassiterite, wolframite and various sulphides such as pyrite, sphalerite, and arsenopyrite. Exo-contact mineralisation occurs outside the granite body. In Khartoum this is usually wall-rock alteration forming narrow quartz veins (< 2 m) and brecciated zones within metasediments, but may occur as skarn mineralisation where the wall-rock is carbonate rich.

Prospectivity modelling methodology

Mineral systems approach

The petroleum systems approach that has been 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; McCuaig et al., 2010; 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. 3).

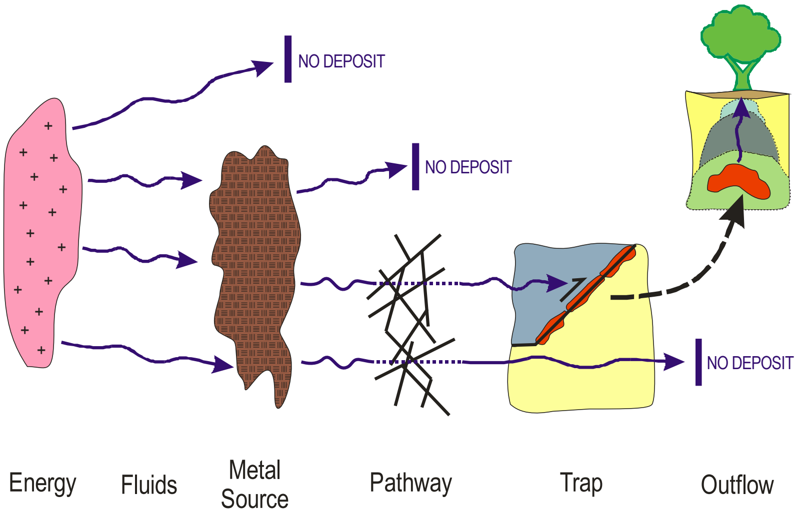

Figure 3. The mineral systems concept of ore formation from source of energy and metals through transport mechanisms to trap.

There are five essential geological components that define a mineral system: (1) a source of energy that drives the system; (2) sources of fluids, metals and ligands; (3) pathways along which fluids can migrate to trap zones; (4) trap zone in which fluid flow can be focussed and its composition modified; (5) outflow zones for discharge of the residual fluid (Wyborn et al., 1994; Knox-Robinson and Wyborn, 1997; Hronsky, 2004; McCuaig et al., 2010; Joly et al., 2012, Linday et al., 2014). Ore deposit formation will be precluded where a mineral system is lacking in one or more of these components. As the application of the mineral system approach is process-based, it is not restricted to any geological setting or limited by a specific ore deposit type. Therefore this approach is flexible, and allows for multiple deposit styles to be recognised within a single mineral system, acknowledging the natural variability among many ore deposits (Knox-Robinson & Wyborn, 1997; McCuaig et al., 2010). The identification of the critical ore-forming processes and mappable elements that characterise a particular mineral system at various scales are required when applying this method to mineral exploration (Porwal & Kreuzer, 2010). Processes may be identified from geological, geochemical, geophysical and structural data using a variety of analytical techniques before spatial analysis of these maps. These techniques include traditional statistical analysis of geochemical data, modelling of geophysical data, structural analysis and detailed analysis of geological data attributes. Once analysed, maps with the best spatial correlations that represent each aspect of the mineral system will be considered for inclusion in the final prospectivity model.

The main geological features used to determine the prospectivity of the Khartoum region for intrusion related tin mineralisation include: (a) presence of highly fractionated granite and metasediments rock units; (b) proximity to greisens; (c) proximity to Palaeozoic faults; (d) proximity to linear fracture zones; (e) proximity to endo- and exo-contacts between granite and host rocks; (f) presence of altered granite; (g) presence of tin in excess of 500 g/t.

Weights of evidence modelling

The weights of evidence technique for predictive modelling was first used in medical diagnostic and has been adapted and applied to the mineral exploration industry (Speilgelhalter, 1986; Bonham-Carter, 1989; Bonham-Carter, 1994). The weights of evidence approach uses Bayesian statistics, this allows for the analysis and combination of spatial data to predict the occurrence of point data, i.e. mineral occurrences (Harris et al., 2001; Deng, 2009). The technique uses the presence or absence of a characteristic and the occurrence of point data (known mineral occurrences known as training data; Raines & Bonham-Carter, 2006) to create predictive maps. These are analysed and the best are chosen to be combined to make the final prospectivity map. Missing data are a common problem when using data from mineral exploration, perhaps due to a lack of sampling or poor data quality. The weights of evidence technique includes missing data in the statistical calculations, which is an important issue to handle. A confidence map, allowing the assessment of the uncertainty of results, is also created when using the weights of evidence technique so the data coverage and density of a particular area can be evaluated.

Conditional dependence is a common issue with weights of evidence modelling (Bonham-Carter et al., 1989; Bonham Carter & Agterberg, 1990; Bonham Carter, 1994; Raines et al., 2000; Lindsay et al., 2014), which occurs when bias is introduced into resulting prospectivity maps when using predictive maps that are spatially correlated to each other with respect to the training data (i.e. predictive maps have similar map patterns). This is a major issue when modelling mineral systems as the processes that act in mineral systems are seldom independent of each other. Therefore the resulting posterior probability values in the resulting prospectivity map can be biased, and should be considered to be relative values of prospectivity rather than the actual probability of occurrence. The prospectivity map can then be used as a tool to significantly reduce the target area for exploration and as a result may greatly increase the chance of finding an economic deposit in a particular study area. Conditional independence can be resolved by combining or removing correlated maps, which means information is lost during analysis and exploration targeting. Logistic regression can also be employed to statistically determine predictor maps to include in the model, a technique that is now feasible in ArcGIS

10. ArcGIS 10.1 was used in the creation of this model, whilst a Logistic Regression has not been applied in this study, it is planned for future validation work related to this model.

The weights of evidence method can be nicely summarised into five steps: (1) Estimation of prior probability, i.e. the probability of finding a mineral occurrence in the study area without any existing data; (2) the determination of the weighting coefficients of spatial data, i.e. creating the predictive maps; (3) calculation of posterior probability, i.e. the probability of finding an occurrence after analysis and combination of predictive maps; (4) testing for conditional independence; and (5) validation. Lindsay et al. (2014) provides a good overview of the weights of evidence approach to prospectivity modelling, including the statistical calculations for posterior probability, and weighting coefficients.

Data sources

The majority of data used in this study was supplied by Auzex as MapInfo TAB files, or is a part of the Kenex mineral occurrence and geochemistry databases. Data used in the 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.

Spatial Analysis

The spatial analysis was carried out using the weights of evidence technique using the Spatial Data Modeller extension developed for ESRI's ArcGIS 9.3 and 10.2.1 GIS software. The spatial correlation of a feature can be calculated by using the relationship of the area covered by the data variable being tested and the number of training data points that fall within that area. This produces a W+ result when the feature is present and a W- result when the feature is absent. A contrast value C is then calculated from the difference between W+ and W-.

The standard deviations of W and C (Ws and Cs) are also calculated as part of the contrast calculation. This provides a Studentised value of the contrast (StudC), which is the ratio of the standard deviation of the contrast Cs to the contrast C. StudC gives an informal test of the hypothesis that C=0 and as long as the ratio is relatively large, implying the contrast is large compared with the standard deviation, then the contrast is more likely to be real. Ideally a StudC value larger than (-) 1.5 can be considered as a positive or negative correlation. This ratio is best used as a relative indicator of spatial correlation, rather than an absolute sense. In this study a strong correlation is inferred from C values > 2.0, StudC values >1.5; moderate correlations inferred from C values between 1.0 and 2.0, StudC values >1.5; weak correlations inferred from

C values between 0.5 and 1.0, StudC values between 1.0 and 1.5; and poor correlations inferred from C values < 0.5 or StudC values <1.5.

Tin mineralisation prospectivity modelling

Two prospectivity maps were developed for the Khartoum study area using the weights of evidence technique. The models both use predictive maps that represent all stages of the mineral system model defined for intrusion-related tin mineralisation. The predictive maps for the models were chosen as having the best regional coverage, a significant spatial association with the mineral system model being considered and minimal duplication of predictive map patterns. Using maps with similar map patterns introduces problems with conditional dependence to the resulting model. The predictive maps listed in Table 1 and 2 were added after the map values for each cell were weighted by their W+ and W- spatial correlation values. The models were developed using Arc-SDM software in ArcGIS 9.3 and 10.2.1.

Initial 2D model

The initial prospectivity model confirms that there are a number of high potential areas for intrusion related tin tungsten mineralisation in the Khartoum study area including historical deposits with further potential and new prospects. The highly prospective areas of the model occur within highly fractionated granites and are proximal to the granite contacts with the Hodgekinson metasediments. This is expected due to the nature of the geological data, the mineralisation model, and the location of the majority of training points in the Khartoum study area. A significant limitation for 2D modelling with respect to tin mineralisation in buried granites is a lack of accurate depth data as tin ore deposits are typically located in the roof zones of granite intrusions. The extent and distribution of prospective areas are expected to change to include more areas outside the granites if 3D granite contact depth information is included in the model. Where hydrothermal fluids have breached these systems tin mineralisation occurs within the host rocks and this is evident with historical mining in and around the Khartoum study area.

The predictive capacity of the model was tested statistically by using the *Area Frequency Table* tool in the SDM toolbox. It gives a value for the success rate of the model based on it’s ability to identify the training points in the prospectivity map. The efficiency of prediction (i.e. how well the model identifies mineral occurrences not used as training data) can also be calculated using this tool. Values greater than 50% indicate statistically valid efficiency values. The performance of the model improves as the values approach 100%. The training data gave a success rate value of 92.3% and the mineral occurrence data gave an efficiency of prediction value of 76.6%. These measures confirm that the model has a high predictive efficiency, and is statistically valid. Various measures to test the conditional independence assumption were also made using the *Agterberg-Cheng CI Test* tool in the SDM toolbox. Conditional independence was found to be a significant problem in the model, which is not unusual with geological datasets as the processes acting in a mineral system are rarely independent of each other. Therefore, the results should be viewed as a relative measure of favourability for the factors controlling mineralisation in the project area rather than an accurate calculation of the probability of mineralisation. The probability values, however, provide an objective way of ranking an area’s prospectivity and highlight those areas where mineralisation may be present. These areas require field checking and more detailed data collected to allow drill targeting.

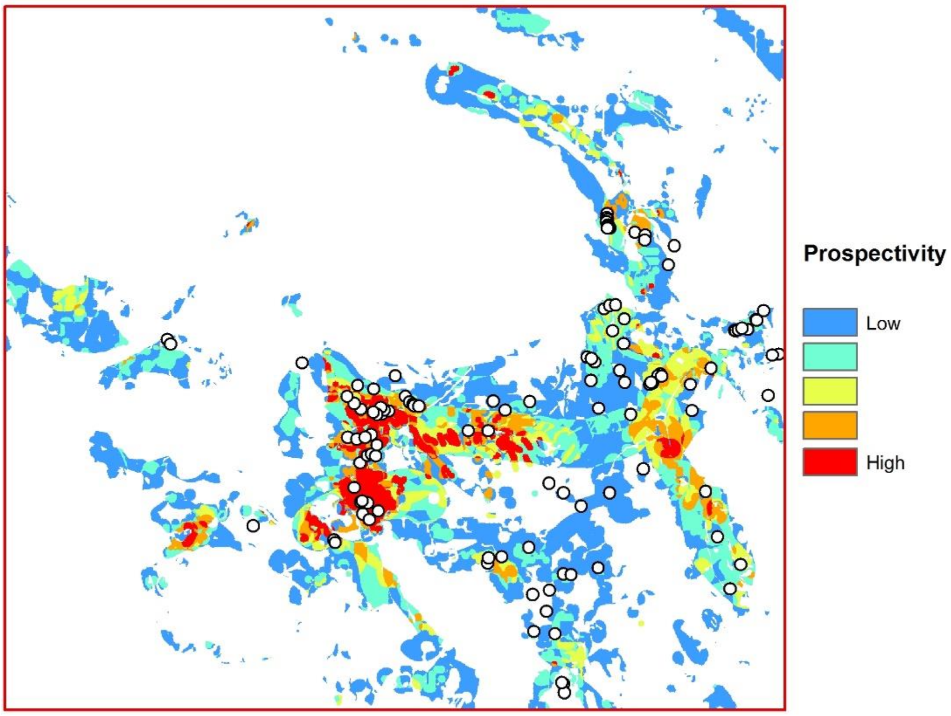

Figure 4. The results of the initial intrusive-related Sn mineralisation prospectivity model over the Khartoum study area. The prospective areas have been classified using natural breaks and range from highly prospective (red; < 0.997) to prospective (blue; < 0.030). The remaining area is below the prior probability (0.030385) and is assumed to be not prospective for intrusive related tin mineralisation. White circles are tin training points and the red outline is the study area.

Figure 4 is the initial 2D intrusive related Sn mineralisation prospectivity map. It should be noted that several areas of well-known Sn mineralisation have not been highlighted in this prospectivity study. These include the Pinnacles deposit, to the south of the study area, and Claret Creek deposit, to the south-west of the study area. The predictive maps that were used in the creation of this model are given in Table 1.

Table 1. Predictive maps used in the initial intrusion related tin mineralisation model.

Mineral System	**Description**	**Variable**	**W+**	**W-**	**C**	**Stud C**
Source of energy and fluids	Association with host lithology	Basalt	-0.4	0.0	-0.4	-0.4
		Sandstone	1.2	-0.4	1.6	8.7
		Greywacke	1.8	-0.2	1.9	8.1
		Conglomerate	0.4	0.0	0.3	0.3
		Highly Fractionated Granites	0.3	-0.1	0.4	2.0
		Unfractionated Granites	-1.8	0.0	-1.8	-1.7
		Highly Fractionated, Oxidised Granites	-1.0	0.0	-1.0	-1.0
		Highly Fractionated, Reduced Granites	1.3	0.0	1.3	2.4
	Proximity to mapped dykes	800 m buffer	0.7	-0.3	1.1	5.5
Migration pathways	Proximity to crustal-scale faults	1,200 m buffer	1.3	-0.3	1.6	7.3

Mineral System	Description	Variable	W+	W-	C	Stud C
	Proximity to centroids of radial fractures	500 m buffer	0.3	-0.7	1.0	4.6
	Proximity to radiometric high U measurements	700 m buffer	0.5	-2.7	3.2	3.1
	Proximity to mapped I type granite contacts	1600 m buffer	0.1	-0.5	0.6	2.3
Deposition of metal and outflow of fluids	Proximity to mapped greisens	250 m buffer	2.8	-0.2	2.9	11.0
	Association with anomalous Sn from combined rock-chip and drill-hole geochemical data	Samples greater than 19.4 ppm buffered to 1,000 m	0.3	-3.4	3.78	3.7
	Association with anomalous W from combined rock-chip and drill-hole geochemical data	Samples greater than 11 ppb buffered to 1,000 m	0.8	-1.8	2.6	4.2
	Association with high gravity slope between igneous intrusive fluids and heat source and resultant surrounding hydrothermally altered rock.	High gravity slope	1.1	-0.4	1.5	8.0

Updated 2D model with data from 3D geological model

The updated prospectivity model confirms that there are a number of high potential areas for intrusion-related tin tungsten mineralisation in the Khartoum study area, including historical deposits with further potential and new prospects. The endo- and exo-granite contacts have been defined from analysis of 3D modelling results that help map the extent of the buried granites underlying areas of cover and host rocks (Cunningham et al., this volume). This has significance in terms of identifying areas where tin ore deposits may be located in the roof zones of granite intrusions. The model predicts that 24% of the study area is prospective for tin-tungsten and also highlights areas currently being developed into operating mines e.g. the Pinnacles area in the SE quadrant of the study area.

The training data gave a success rate value of 89.1% and the mineral occurrence data gave an efficiency of prediction value of 87.0%. These measures confirm that the model has a high predictive efficiency, and is statistically valid. Conditional independence was also found to be a significant problem in the model, therefore results should be viewed as a relative measure of favourability for the factors controlling mineralisation and used as an objective way of ranking an area’s prospectivity.

Figure 5 is the updated 2D intrusive related Sn mineralisation prospectivity map. The highly prospective area is better defined in the updated prospectivity map compared to the initial, and both Claret Creek and the Pinnacles deposits have been identified as highly prospective.

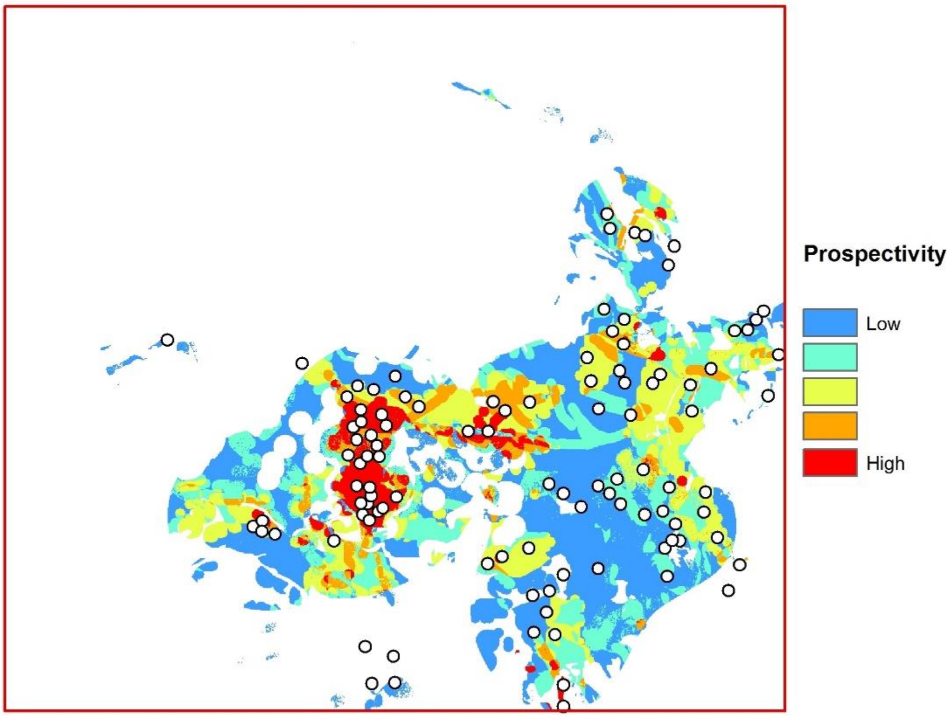

Figure 5. The results of the updated intrusive-related Sn mineralisation prospectivity model over the Khartoum study area. The prospective areas have been classified using natural breaks and range from highly prospective (red; < 0.998) to prospective (blue; < 0.019). The remaining area is below the prior probability (0.018746) and is assumed to be not prospective for intrusive related tin mineralisation. White circles are tin training points and the red outline is the study area.

Changes to the model include updating the model parameters (i.e. decreasing the unit area), ensuring there is not more than one training point per unit area, and recalculating and reassessing predicative maps to be included in the model (Table 2).

Table 2. Predictive maps used in the updated intrusion related tin mineralisation model.

Mineral System	**Description**	**Variable**	**W+**	**W-**	**C**	**Stud C**
Source of energy and fluids	Association with host lithology	Sandstone	0.7	-0.3	0.2	4.6
		Greywacke	0.5	0.0	0.3	1.7
		Limestone	6.6	0.0	2.6	2.5
		Conglomerate	0.1	0.0	1.0	0.1
		Highly Fractionated Granites	0.4	-0.2	0.2	3.0
		Fractionated Granites	-2.2	0.3	0.6	-4.2
		Unfractionated Granites	-2.2	0.1	1.0	-2.3
	Association with highly fractionated granite	Highly Fractionated Granite	0.7	-1.9	2.5	4.9
Migration pathways	Proximity to linear cooling fractures	500 m buffer	0.4	-0.3	0.7	2.5
	Proximity to faults older than 300 Ma	250 m buffer	1.0	-0.1	1.1	3.4
Formation of Trap	Association with endo/exo granite contacts	2D projection of granite contacts buffered to 800 m	0.4	-1.7	2.1	5.3

Mineral System	**Description**	**Variable**	**W+**	**W-**	**C**	**Stud C**
Deposition of metal and Outflow of fluids	Proximity to mapped greisens	450 m buffer	1.9	-0.3	2.2	9.0
	Association with illite alteration in granites	Illite in granite	0.3	-0.3	0.6	2.0
	Association with Sn from combined rock-chip and drill-hole geochemical data	Samples greater than 500 ppm buffered to 1,000 m	0.6	-3.8	4.4	4.4
	Association with high Sn sampling density from combined rock chip and drill hole data	High sample density	1.1	-2.2	3.3	9.0
	Association with high gravity slope between igneous intrusive fluids and heat source and resultant surrounding hydrothermally altered rock.	High gravity slope	0.8	-0.5	1.4	6.8

Discussion

Both the 2D prospectivity model of the Khartoum region confirm the potential for intrusive related tin mineralisation. The initial model was limited to 2D geological data with the inclusion of some 3D data (magnetic and gravitational interpretations), numerous prospective areas have been identified although several areas of known mineralisation were missed. The most prospective areas are those associated with the highly fractionated granites. Results of the initial two-dimensional prospectivity model can be improved by addition of further data, i.e. granitic cooling fractures, and the extent of granite contacts (both endo- and exo-contacts) at depth, which was not known until a 3D geological model was created for the region. This resolves some of the limitations of the previous model (i.e. identified the previously missed areas of known mineralisation), however it is still limited due to the 2D nature of the resulting model. It is important to note that in 2D prospectivity model areas of high prospectivity may not necessarily be at the surface. Whilst some 3D data has been used (magnetic and gravitational interpretations, granite contacts at depth) it is projected onto a 2D surface and so an interpretation of what depth mineralisation may be occurring cannot be made.

Currently, the majority of exploration targeting is performed using single predictive map variables, such as geochemistry, structural or geophysical data. Targets may also be developed using subjective criteria with no reference to statistical spatial correlations with known mineralisation or geology. This type of analysis has been effective to some extent in the past, however, it produces a large number of false anomalies reducing the probability of discovery. Effective targeting is best done if all relevant data are compiled and integrated in a way that matches the mineral system model being used, and combined into a single mineral potential map, such has been completed here in the 2D prospectivity model of the Khartoum region. Further refinement of target areas can be achieved by considering 3D prospectivity modelling such as that completed by Cunningham et al. (this volume). Whilst a 2D prospectivity map will highlight the surface area where there is more likely to be mineralisation, there is no information at depth as to where these targets are occurring to aid drill-hole planning.

Developments in GIS software such as GOCAD and Leap Frog 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, 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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