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# Complexity gradients in the Yilgarn Craton: fundamental controls on crustal-scale fluid flow and the formation of world-class orogenic-gold deposits

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Fractal-dimension analysis is an effective means of quantifying complex map patterns of structures and lithological contacts, which are conduits for hydrothermal fluid flow during the formation of orogenic-gold deposits. In this study, fractal dimensions, calculated on a 10 km grid across a geologic map of the Yilgarn Craton of uniform data quality, highlight relationships between geologic complexity and the location and size of Archaean orogenic-gold deposits. In the Kalgoorlie Terrane and Laverton Tectonic Zone, the largest gold deposits occur along steep gradients defined by fractal-dimension values. These steep gradients in the greenstone belts occur between massive sedimentary rock sequences of low complexity, and volcanic and intrusive rock units with more complex map patterns. The formation of world-class orogenic-gold deposits requires that hydrothermal fluids become focused from a large volume of well-connected rocks at depth, towards narrow, high-permeability zones near the location of deposit formation. Connectivity is indirectly related to permeability, and the degree of connectivity is related to the density and orientation of fluid pathways, which are quantified in map patterns using fractal-dimension analysis. Thus, fractal dimensions are a measure of the potential for increased connectivity and the likelihood of increased permeability. Greater complexity, as measured by larger fractal dimensions, implies that a certain area has the potential to produce more interconnected pathways, or zones of high connectivity. Therefore, the steep complexity gradients defined in the Kalgoorlie Terrane and Laverton Tectonic Zone correspond to areas that focused large volumes of hydrothermal fluid and enhanced the potential for significant gold mineralisation. Fractal-dimension analysis thus provides a link between empirical map features and the processes that have enhanced hydrothermal fluid flow and resulted in the formation of larger orogenic-gold deposits.

**KEY WORDS: fluid flow, fractal dimensions, orogenic gold, percolation networks, Yilgarn Craton.**

## INTRODUCTION

Orogenic-gold deposits are structurally controlled, and genetic models suggest that structural and lithologic complexity are fundamental factors that control their size and location in orogenic belts (Phillips *et al.* 1996; Groves *et al.* 2000). An underlying assumption of the continuum model for the formation of orogenic-gold deposits, as defined by Groves *et al.* (1998), is that mineralising fluids are widespread in the crust and require a focusing mechanism for deposit formation. Networks of structures and lithological contacts provide the pathways for this focused fluid flow. Therefore, an investigation of the complexity of geologic features, as represented by map data within a GIS, should provide a means to distinguish map-scale areas that are more or less favorable for the formation of larger deposits. Results can be used to develop a better understanding of factors that control the spatial distribution of larger gold districts in orogenic belts.

The majority of gold deposits in the Yilgarn Craton formed late in the tectonic evolution of the craton (Groves *et al.* 1995). This implies that geological map patterns are indicative of the upper crustal geometry at the time of gold mineralisation. It is assumed that the complexity of the exposed crust reflects the complexity in three dimensions due to the flat topography and generally steep dip of exposed faults and lithologic contacts in the Yilgarn Craton. The objective of this study is to determine whether there is a relationship between the size of deposits (in terms of contained amount of gold) and geologic complexity as displayed in map patterns.

## PREVIOUS STUDIES

### Geology and gold deposits of the Yilgarn Craton

The Yilgarn Craton (Figure 1) is one of the largest Archaean granitoid–greenstone assemblages in the

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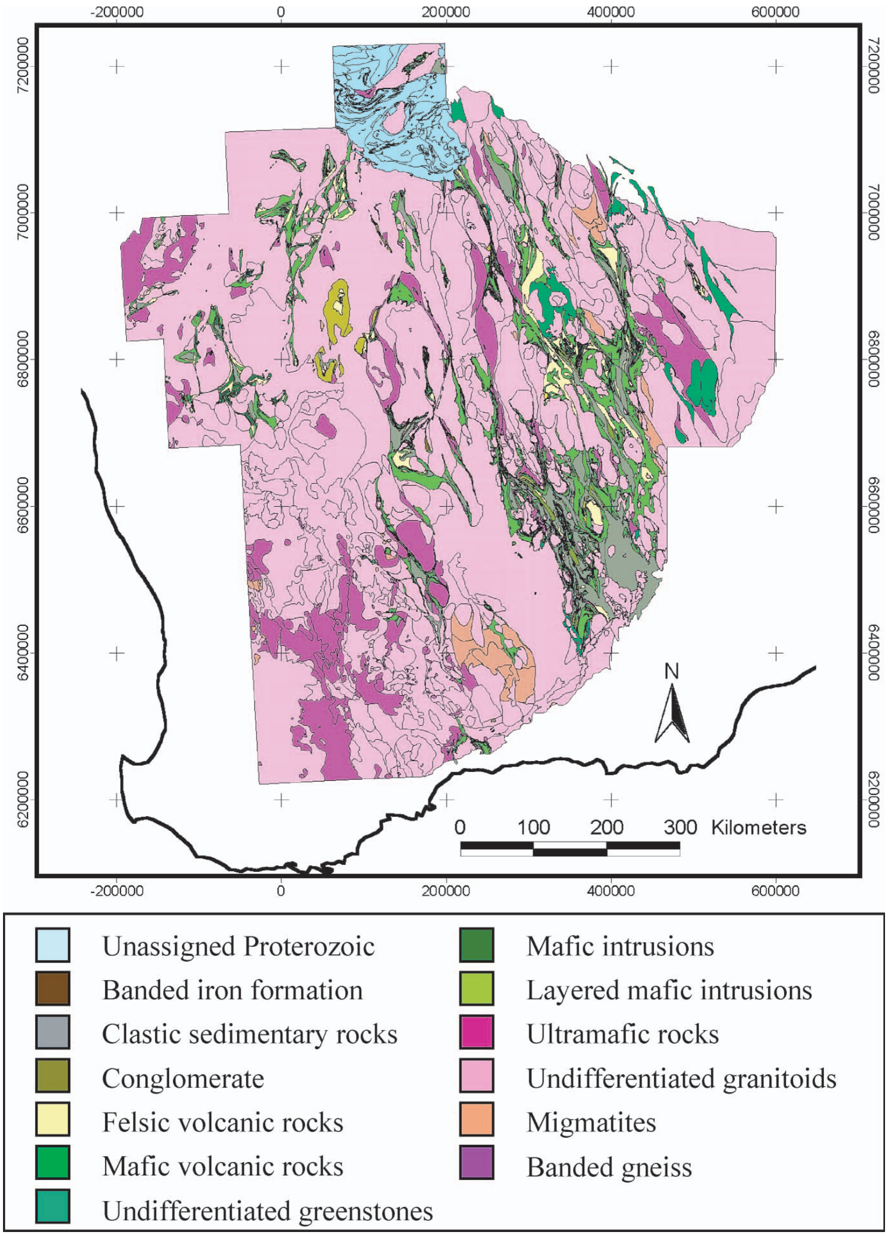



**Figure 1** GIS map of the Yilgarn Craton used in this study (Knox-Robinson *et al.* 1996).

world. Approximately 80% of the craton is composed of granitic gneiss and granitoid rocks, with the remainder made up of metamorphosed sedimentary and volcanic rocks in arcuate greenstone belts. The craton consists of several tectonostratigraphic subdivisions, which are based on the age and nature of dominant rock types and structural styles. The subdivisions include the Eastern Goldfields and Southern Cross Provinces, and the Murchison, Narryer and Southwest Composite terranes (Myers 1997).

Approximately 5300 t (170 million oz) of gold have been produced from orogenic-gold deposits in the Yilgarn Craton since the 1890s (Phillips 2004). The most recent review of the geological setting and nature of gold deposits is provided by Hagemann *et al.* (2001), and a brief summary is provided here. The ore fluid responsible for deposit formation is generally interpreted to be a low to moderate salinity, mixed aqueous–carbonic hydrothermal fluid capable of carrying gold, but with a limited capacity to transport base metals. Despite a broadly uniform ore-fluid composition, deposit characteristics are highly variable, including features such as host lithologies, structural styles of mineralisation and alteration mineral assemblages. Deposits are hosted in all lithologies, including mafic–ultramafic extrusive and intrusive rocks, volcaniclastic and sedimentary rocks, porphyry dykes and granitoids. Structural styles of mineralisation include brittle–ductile shear zones with quartz veins systems, disseminated lodes associated with shear zones and fault systems, and sheeted quartz vein sets and stockworks. Mineralisation styles are influenced by a number of factors during deformation, including (i) contrasts in host-rock rheology, (ii) heterogeneity in regional to local stress fields, (iii) fluid-pressure variations, and (iv) pervasive versus focused fluid flow. Hydrothermal alteration assemblages generally show enrichment in K, $CO_2$, and S. Variations in alteration mineralogy and zonation in host rocks are the result of fluid–wall-rock interaction, which is largely controlled by the composition of the host rocks, prevailing temperature–pressure conditions, and fluid–rock ratio. The diversity of characteristics in orogenic-gold deposits is a result of the complex interplay of physical and chemical processes at deposit sites at various palaeocrustal levels, ranging from sub-greenschist to upper amphibolite facies metamorphic environments, with gold precipitation over a correspondingly wide range of pressures and temperatures (Hagemann *et al.* 2001).

### Map features and gold endowment

Previous studies of relationships between map features and gold endowment in the Yilgarn Craton have used stress-mapping techniques (Holyland & Ojala 1997; Mair *et al.* 2000), shape analysis (Gardoll *et al.* 2000) and prospectivity analysis involving fuzzy logic (Knox-Robinson 2000) or neural networks (Brown *et al.* 2000). In general, these methods have been applied in a scale-bound manner, in which geologic features are measured and analysed using one map scale.

Fractal methods, similar to those developed in this study, are scale independent because they measure patterns of self-similar objects, such as geological structures, where small-scale features are similar to, or mimic, large-scale features. Importantly, fractal-dimension analysis has not been used previously in the Yilgarn Craton. Previous fractal studies in economic geology include those used to quantify the spatial distribution of fractures and faults (Gillespie *et al.* 1993; Magde *et al.* 1995; Roberts *et al.* 1998, 1999), and those used to characterise the distribution of ore-deposit locations (Carlson 1991; Blenkinsop & Sanderson 1999). Fractal dimensions of fracture and fault patterns have been used to measure connectivity, which can influence seismic risk (Hirata 1989), oil and gas migration (Barton 1996) and hydrothermal fluid flow (Sanderson *et al.* 1994; Roberts *et al.* 1999). Fractal dimensions have also been used to characterise high-energy and low-energy brecciation processes in hydrothermal systems (Jébrak 1997).

## METHODS

### GIS database

In order to study the complexity of geologic features on maps, it is necessary that the maps used have a homogeneous level of detail. If the level of detail varies across the map, the level of complexity will vary independently of true geological complexity. Obviously, this is especially important for determining relationships between the complexity of geologic features and the location of larger gold deposits.

The GIS geologic database of the Yilgarn Craton used in this study (Knox-Robinson *et al.* 1996) is based on Geological Survey of Western Australia geological maps at scales of 1:100 000, 1:250 000 and 1:500 000, as well as Australian Geological Survey Organisation (now Geoscience Australia) regional aeromagnetic data, high-resolution multiclient aeromagnetic data, and gravity data. The GIS database covers approximately 600 000 $km^2$ (40 × 1:250 000 map sheets), with a uniform level of geologic detail across all terranes in the Eastern Goldfields, Southern Cross and West Yilgarn Provinces (Knox-Robinson *et al.* 1996). The uniform level of geological detail in the map was required for the types of spatial analyses performed on it [e.g. proximity, association and abundance relationships, and Bayesian analysis (Knox-Robinson *et al.* 1996); shape analysis (Gardoll *et al.* 2000); GIS studies (Yun 2000)].

An example of the uniform level of geological detail in the GIS map is shown in comparisons of the maps of the Kalgoorlie District in Figure 2. The Kalgoorlie District is arguably the most studied area in the Yilgarn due to its gold endowment, and therefore has the potential to be the area represented in most detail on the map. A comparison of two maps at different scales [Kalgoorlie and Yilmia 1:100 000 map sheets (Hunter 1993) and the 1:500 000 GIS map used in this study (Knox-Robinson *et al.* 1996)] shows that there is significantly more detail in the 1993 geological map, compared to the 1996 GIS map used here, indicating that the geology has been simplified in the GIS map in order to match the level of detail in other areas across the Yilgarn Craton. Due to this uniform level of geologic detail, the GIS map was deemed appropriate for this fractal study.

In addition, the flat topography and generally steep dip of most exposed shear zones and lithologic contacts in the Yilgarn Craton means that trends on the GIS map mostly reflect the true strike of geological features. This allows the map to be used as an exploration tool for measuring geological complexity at depth.

### Minedex database

The locations and sizes of gold deposits in the Yilgarn Craton were obtained from the Minedex database of the Geological Survey of Western Australia (Townsend *et al.* 2000). It includes information on production and remaining resources from over 11 000 historic mines and 1000 recent mines and deposits in the Yilgarn Craton. These data are an especially important part of the study, as they allow direct comparisons between geologic complexity and gold endowment. In all cases, estimations of pre-mining resources are given. These estimates include remaining tonnes of gold, corresponding to inferred, indicated, and measured resource categories of the JORC code (JORC 2004) plus any historic and recent production.

The combination of historic production and current resources is the best way to provide order-of-magnitude estimates of the district-scale pre-mining gold endowment for the comparison purposes of this study, despite differences in mining techniques and cut-off grades. For example, pre-1980 historic production was typically from underground operations that could only support average grades greater than $\sim$30 g/t Au, while post-1980 large-scale openpit operations could profitably mine average grades of $<$5 g/t Au (Groves & Ho 1990).

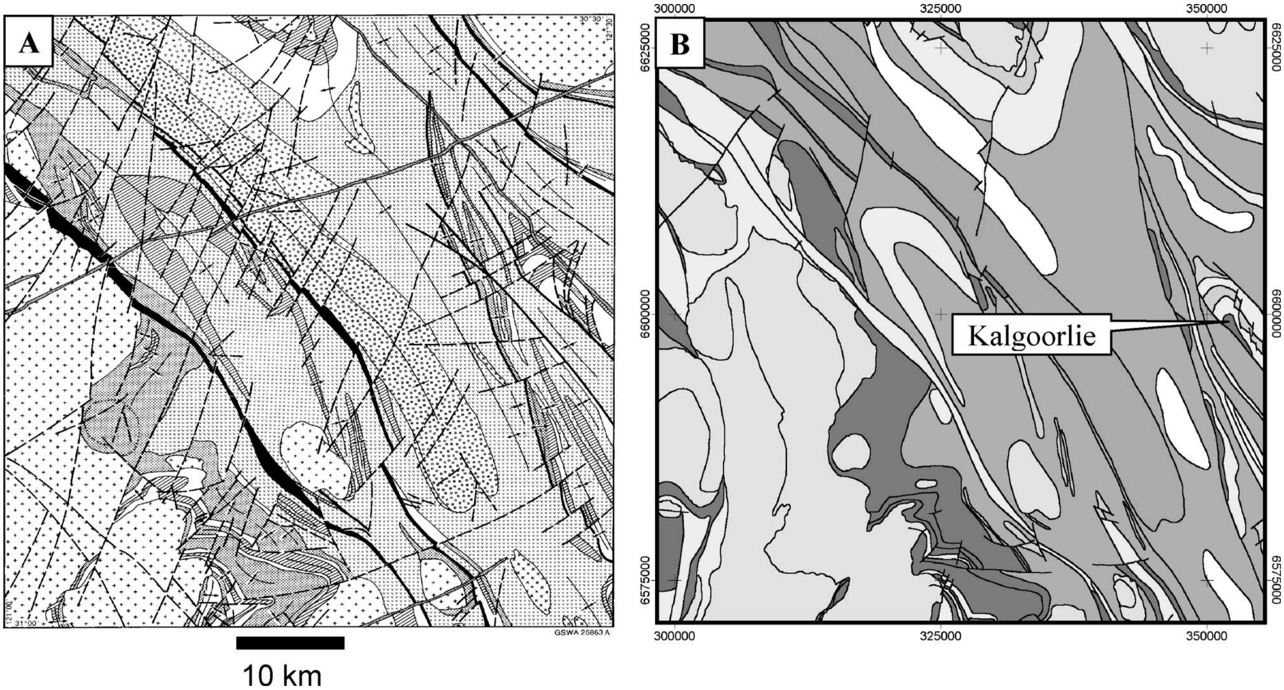



**Figure 2** Comparison of geologic detail in two maps of the same region in the vicinity of Kalgoorlie, which is at centre right in both maps. (a) GSWA 1:100 000 map (Hunter 1993). (b) AMIRA P383 GIS map (Knox-Robinson *et al.* 1996). In the 1996 AMIRA map compilation, the detailed geology available from the 1993 GSWA map was simplified in order to provide a uniform level of geologic detail across the Yilgarn Craton.

## Fractal-dimension analysis

Self-similarity in geology is pervasive, meaning that a geologic feature commonly has similar geometric patterns when viewed at different scales. Self-similarity is why scales are required in geologic images, and fractal-dimension analysis is an effective means of quantifying it. In this study, self-similarity of geologic patterns in the Yilgarn GIS database is assumed, and is quantified using fractal dimensions, which are measured using the box-counting method (Mandelbrot 1983; Hirata 1989). Previous fractal studies of precious metal deposits have typically examined the distribution of deposit locations (Carlson 1991; Blenkinsop 1994; Blenkinsop & Sanderson 1999). In this study, the fractal dimensions of the underlying geology (i.e. structures and lithological contacts, as represented in a GIS database) are measured in order to determine relationships between geologic complexity, and the location and size of orogenic-gold deposits.

## Box-counting technique

In the box-counting method (Mandelbrot 1983), grids with square boxes, of side length $d$, are superimposed on a map and the number of boxes containing lines (representing structures or contacts) is $N_d$. (Figure 3). The length of the side of the box, $d$, is then halved and the process is repeated. $N_d$ is the total number of boxes that contain lines for a given box size. The fractal dimension, $D$, is determined from the slope of a line on a log–log plot of $N_d$ vs $d$, such that:

$$N_d \propto d^{-D}$$

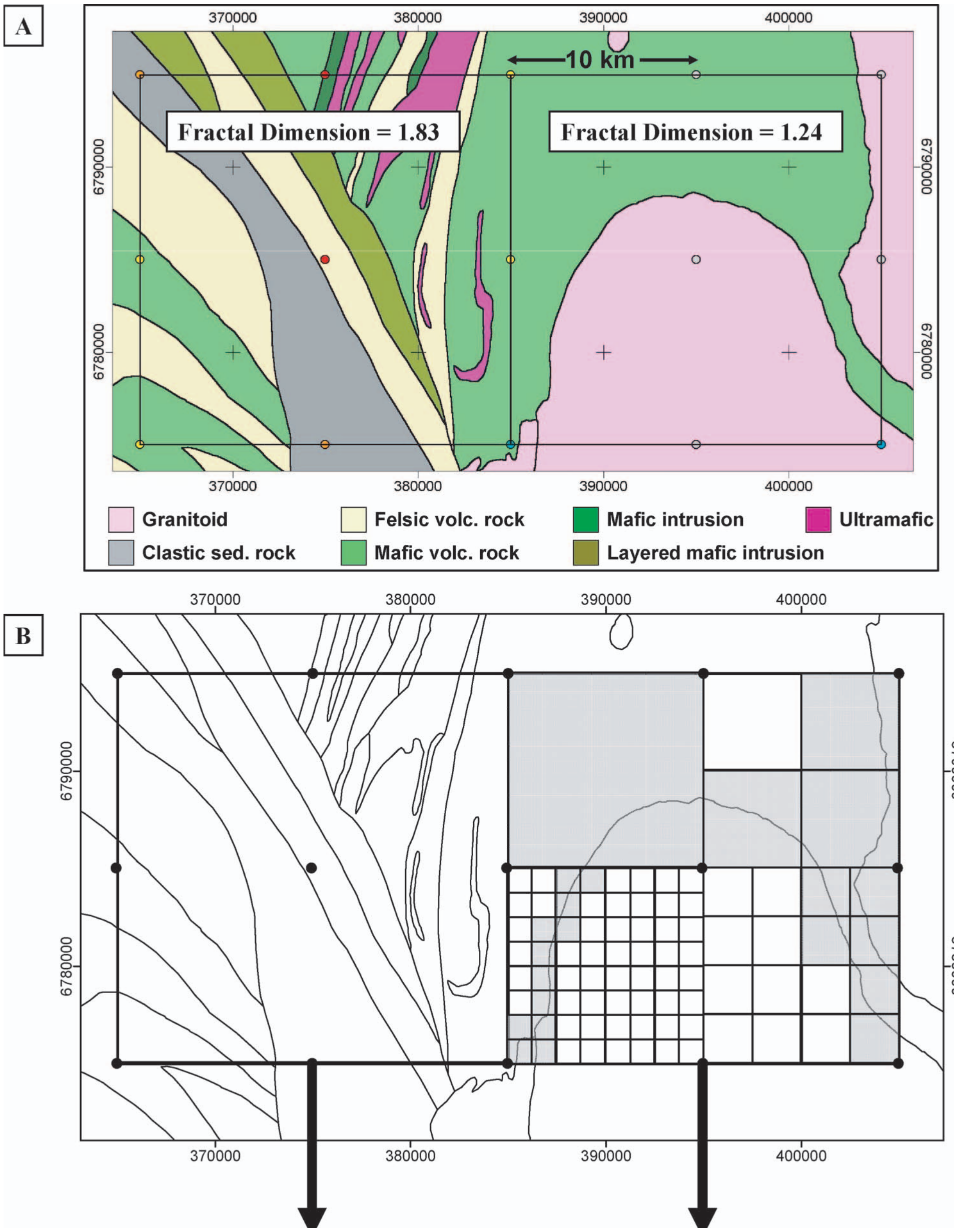
and $D$ is a value between 1.0 and 2.0 for a two-dimensional map. The term fractal is derived from fractional dimension (Mandelbrot 1983): for example, a dimension between one and two. In the case of a single line on a two-dimensional surface, $D$ equals 1 (i.e. a line has one dimension); in the case of the lines covering the entire two-dimensional surface, $D$ equals 2 (i.e. a plane has two dimensions). In this study, the lines represent structures and lithologic contacts. The box-counting computer program used in this study is an ArcView Avenue file, and is based on the methodology outlined in Hirata (1989).

In this study, fractal dimensions are calculated on a 10 km grid across the Yilgarn Craton. The box sizes used in the four-level box count are 10, 5, 2.5 and 1.25 km. The 10 km grid spacing is appropriate for the level of geologic detail in the 1:500 000-scale map of the Yilgarn Craton, based on the methodologies of Gillespie *et al.* (1993), Walsh and Watterson (1993) and Turcotte (1997). The grid spacing is related to the map scale, and smaller spaced grids would need to be applied to more detailed maps.

# RESULTS

## Fractal-dimension contours and deposit locations

Fractal dimensions of structures and lithologic contacts were calculated on a 10 km grid across the Yilgarn Craton, and used to determine the relationship between geologic complexity and the distribution and size of orogenic-gold deposits. A contour map of fractal dimensions (Figure 4a) reveals that zones of high complexity,

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| Level | Box Size (km) | Total Boxes | Box Count |
|---|---|---|---|
| 1 | 10 | 4 | 4 |
| 2 | 5 | 16 | 16 |
| 3 | 2.5 | 64 | 59 |
| 4 | 1.25 | 256 | 179 |

| Level | Box Size (km) | Total Boxes | Box Count |
|---|---|---|---|
| 1 | 10 | 4 | 4 |
| 2 | 5 | 16 | 9 |
| 3 | 2.5 | 64 | 23 |
| 4 | 1.25 | 256 | 51 |

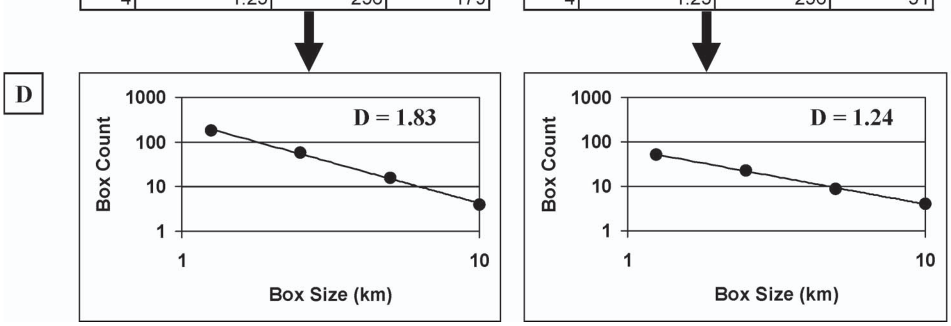


**Figure 3** Example of box-counting method used to determine fractal dimensions of geologic patterns on a 10 km square grid. (a, b) Comparisons of two 20 km grid squares (centred on 10 km grid points) from the GIS map (Knox-Robinson *et al.* 1996), with typical greenstone belt contacts at left and an arcuate granitoid – greenstone contact at right. (c) Results of box counting method. The number in the Box Count column equals the number of boxes of a particular size, within which a line occurs. In (b), these are shown in grey with examples of each box size. (d) The fractal dimension is obtained from the slope of a line on a log – log plot of box count *vs* box size. The relatively simple granitoid – greenstone map pattern (right-hand side) has a fractal dimension of 1.24. The more complex greenstone belt map pattern (left-hand side) has a higher fractal dimension of 1.83.

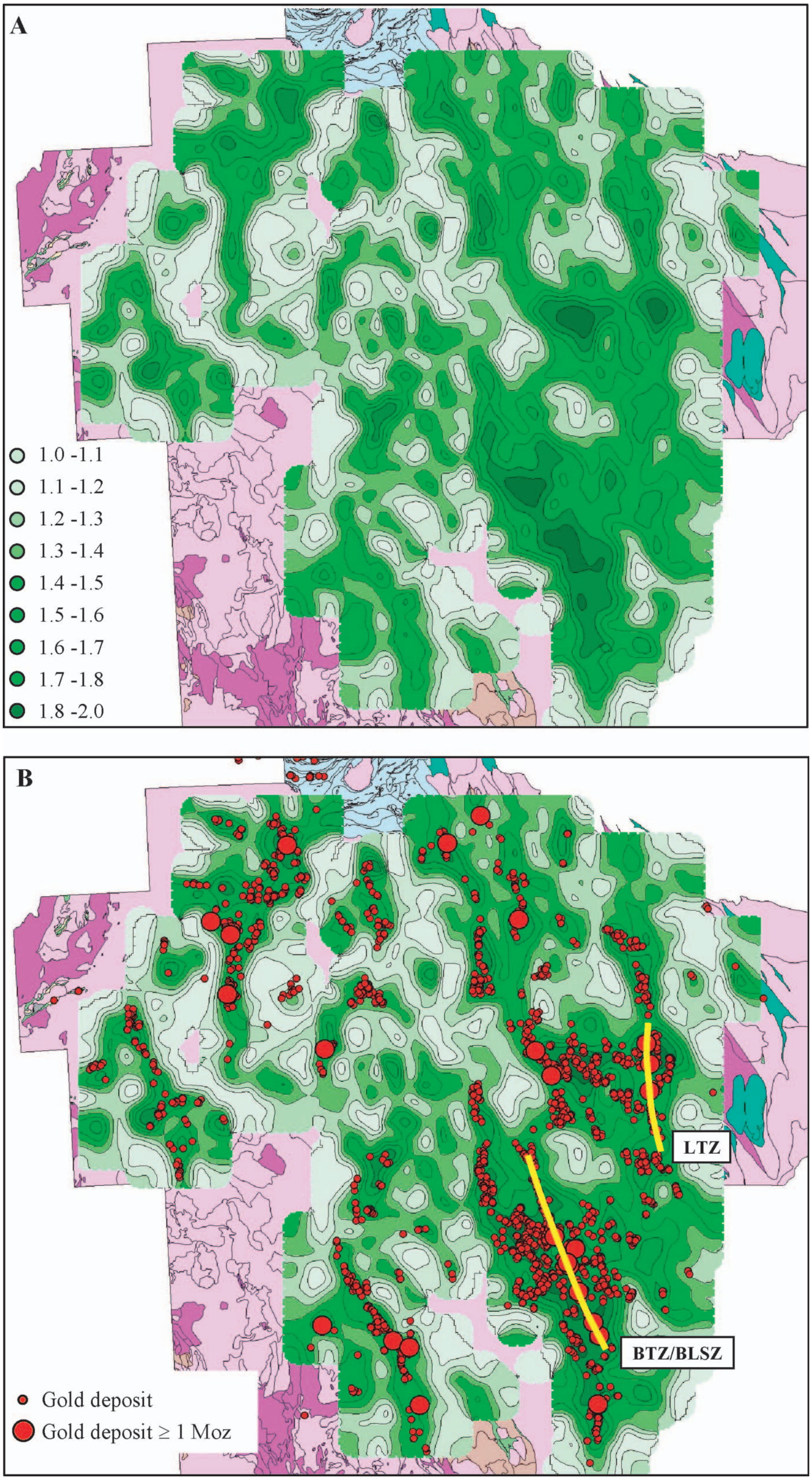


**Figure 4** Fractal dimensions were calculated on a grid with 10 km node spacing across the Yilgarn Craton. (a) Contour map of fractal-dimension grid, with darker shades of green indicating larger fractal dimensions (i.e. greater complexity). Compare regions of high *D* with distribution of greenstone belts in Figure 1. (b) Locations of historic and recent lode-gold deposits, from the Minedex database (Townsend *et al.* 2000). Larger red circles indicate deposits with >1 million oz (>30 t) gold. Yellow lines show locations of the Bardoc Tectonic Zone and Boulder–Lefroy Shear Zone (BTZ/BLSZ) in the Kalgoorlie Terrane and the Laverton Tectonic Zone (LTZ).

characterised by high fractal dimensions, coincide broadly with greenstone belts, with significant variations between different segments of these belts. It might be expected that the largest gold deposits would occur in those areas of greatest complexity, based on proposed empirical relationships between complexity and gold endowment (Phillips *et al.* 1996; Groves *et al.* 1997, 2000). Although many large deposits do occur in zones of high fractal dimensions, the largest gold deposits occur along the steeper fractal gradients (Figure 4b). These gradients generally correspond to tectonic or structural domain boundaries, and most gold deposits are aligned along these gradients, as highlighted by comparing the locations of fractal gradients and gold deposits in Figure 4 with major shear zones shown in Figure 1. The steepest complexity gradients occur along granitoid – greenstone contacts, as would be expected due to the homogeneity of the granitoids. Within greenstone belts, there are more subtle complexity gradients associated with lithologic contacts. These gradients occur, for example, between massive sedimentary rock sequences of low complexity and volcanic and intrusive rock units with more complex lithologic map patterns, as discussed in more detail below.

### Complexity gradients and gold endowment

In order to examine this relationship spatially, profiles of gold endowment and fractal dimensions were plotted along the Bardoc Tectonic Zone and Boulder – Lefroy Shear Zone in the Kalgoorlie Terrane, and in the Laverton Tectonic Zone (Figures 4b and 5). These zones were chosen as they are deformation zones of variable width that control the location of the larger gold deposits (Hodkiewicz 2003) and hence provide appropriate transects along which to plot the variables. The profiles display large changes in gold endowment and fractal dimensions along these structural corridors and therefore highlight gradients in geological complexity.

Four world-class gold districts occur along the Bardoc Tectonic Zone and Boulder – Lefroy Shear Zone of the Kalgoorlie Terrane. The largest is the Kalgoorlie District, which occurs at a steep complexity gradient (Figure 5). This gradient corresponds to the transitional zone between complex patterns of geologic contacts, associated with mafic intrusive and basaltic units in the anticlinal culmination in the Kalgoorlie area, and less complex patterns associated with a thick, overlying sequence of clastic sedimentary units (Black Flag beds) to the north at Gidji (Figure 2). The Black Flag beds are dominantly thin-bedded sandstones and siltstones derived from the erosion of felsic volcanic units (Swager *et al.* 1995). Paddington also occurs at a steep gradient north of Kalgoorlie. To the south, St Ives occurs at a less steep gradient and New Celebration, the smallest of the world-class districts, occurs within the portion of the profile characterised by larger fractal dimensions.

In the Laverton Tectonic Zone, Cleo – Sunrise Dam occurs along the steepest complexity gradient, adjacent to the Celia Lineament. Significantly, this complexity gradient is also associated with a contact between thick sedimentary (i.e. low complexity) units and more complex patterns of mafic to intermediate volcanic host rocks.

Thus, some large orogenic-gold deposits occur at steep fractal-dimension or complexity gradients. In Figure 5, the significant changes in fractal dimension are approximately 0.3 over three grid points at Kalgoorlie (20 km) and 0.4 over four grid points at Laverton (30 km). Based on these results, significant fractal gradients are 0.3 – 0.5 fractal dimensions over three to five consecutive grid points. The distance between grid points, which is related to the selection of appropriate box sizes, will vary with map scale, as discussed above. However, because of the scale-independent nature of fractal dimensions, the same definition of significant gradient should apply regardless of map scale. Testing this on more detailed maps is suggested as a topic for further study.

## DISCUSSION

Previous studies of map patterns in the Eastern Goldfields Province (Hodkiewicz 2003; Weinberg *et al.* 2004) have shown that there is a strong relationship between shear zone azimuth and gold endowment along the Boulder – Lefroy Shear Zone (Figure 6). This indicates that measurements of regional- to district-scale features on high-quality geological maps can be used to determine relationships between map patterns and gold endowment. This has been similarly demonstrated by the studies of Gardoll *et al.* (2000), Knox-Robinson (2000) and Brown *et al.* (2000). Likewise, fractal-dimension analysis of map patterns indicates a strong relationship between steep complexity gradients and orogenic-gold mineralisation in the Eastern Goldfields Province.

### Fluid pathways and fluid-pressure gradients

Faults and associated fracture zones are the dominant permeable fluid pathways in orogenic-gold mineral systems. The movement of hydrothermal fluids through pathways in the crust is driven primarily by pressure gradients, and significant vertical and lateral pressure gradients are established at all crustal levels due to repeated and episodic deformation (Cox *et al.* 2001).

The large volumes of focused fluid flow necessary for the formation of large orogenic-gold deposits requires the accumulation, and intermittent, high-flux discharge, of strongly overpressured fluids in the mid-crust (Sibson 2001). Hydrothermal fluids can become overpressured if there is a cap or seal on the hydrothermal system. At Kalgoorlie and Laverton, the thick sedimentary (i.e. low complexity) rock units sited adjacent to the largest gold deposits are interpreted to have acted as seals that caused steep fluid-pressure gradients and overpressured hydrothermal fluid flow.

### Percolation networks and connectivity

Hydrothermal mineral systems develop in active fault and shear systems where and when there is sufficient connectivity to create fluid-pathway networks that link fluid sources and favorable deposit sites (Cox *et al.* 2001). In the early stages of deformation, faults and shears may be short, isolated structures. With increasing deformation, structures increase in length and surface area, and the connectivity of the fluid-pathway network increases. Fluids play a role in the fracturing process by decreasing pressure, which leads to yielding. The percolation threshold is reached when enough fluid pathways connect to allow fluid flow across the entire width of the fracture percolation network (Sahimi 1994). In orogenic-gold

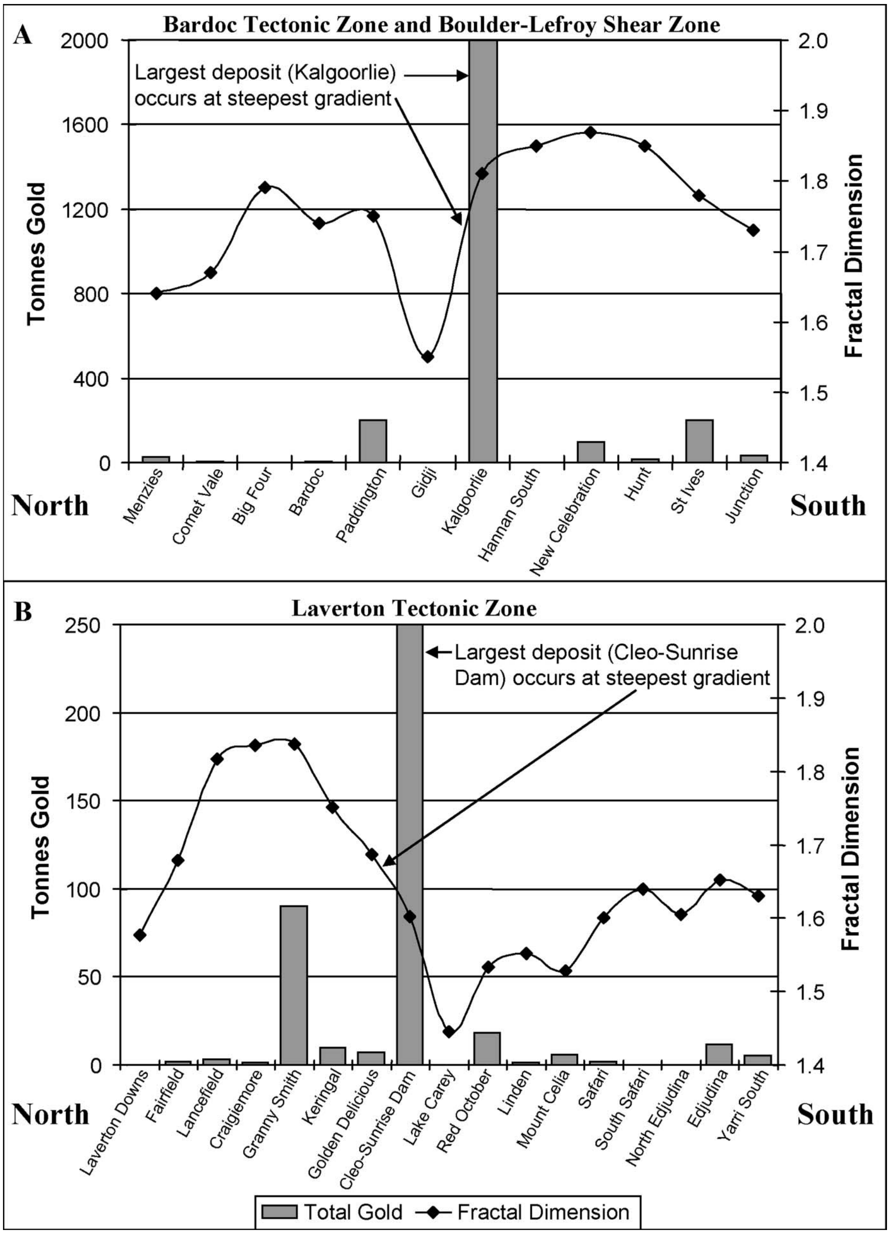


**Figure 5** Profiles showing the relationship between fractal-dimension gradients and gold endowment along (a) the Bardoc Tectonic Zone and Boulder–Lefroy Shear Zone (profile length ~250 km) in the Kalgoorlie Terrane, and (b) the Laverton Tectonic Zone (profile length ~170 km). Gold tonnages for individual deposits (from Townsend *et al.* 2000) were totalled in each grid square along the tectonic zones.

mineral systems, the percolation threshold corresponds to the onset of crustal-scale fluid flow (Cox 1999).

The three components of a fracture percolation network are backbone, dangling and isolated elements (Figure 7). Backbone elements provide a direct connection between fluid source areas and deposit sites, and carry the bulk of the fluid flux. Dangling elements branch from the flow backbone and, in the upstream part of the system, act as fluid feeders to the backbone. In the downstream part of the system, dangling elements allow fluids to discharge from the flow backbone. Isolated elements are disconnected from both the backbone and dangling elements in the network. They are low fluid-flux structures that are not connected to the fluid reservoirs.

High-connectivity zones along the flow backbone are represented on maps by a high density of fluid pathways (i.e. faults and lithologic contacts), and generally larger fractal dimensions. Steep complexity gradients occur between domains of large and small fractal dimensions, and correspond to areas where dangling elements attach to the backbone in a percolation network. Therefore, fractal dimensions analysis provides a method for highlighting areas where there is a greater potential for focusing and discharge of large volumes of hydrothermal fluids, resulting in greater potential for significant gold mineralisation.

Assuming that fractures and shear zones are the main pathways for hydrothermal fluids in the upper crust, regions with large fractal dimensions represent zones with a higher probability of having well-connected pathways. In areas with larger fractal dimensions, fluid flow may not be focused optimally, due to the existence of many alternative pathways. In areas with smaller fractal dimensions, there are fewer, and less well-connected, pathways, and therefore less fluid flow. In transitional areas (i.e. those represented by steep fractal gradients), fluids become focused from areas with low fractal

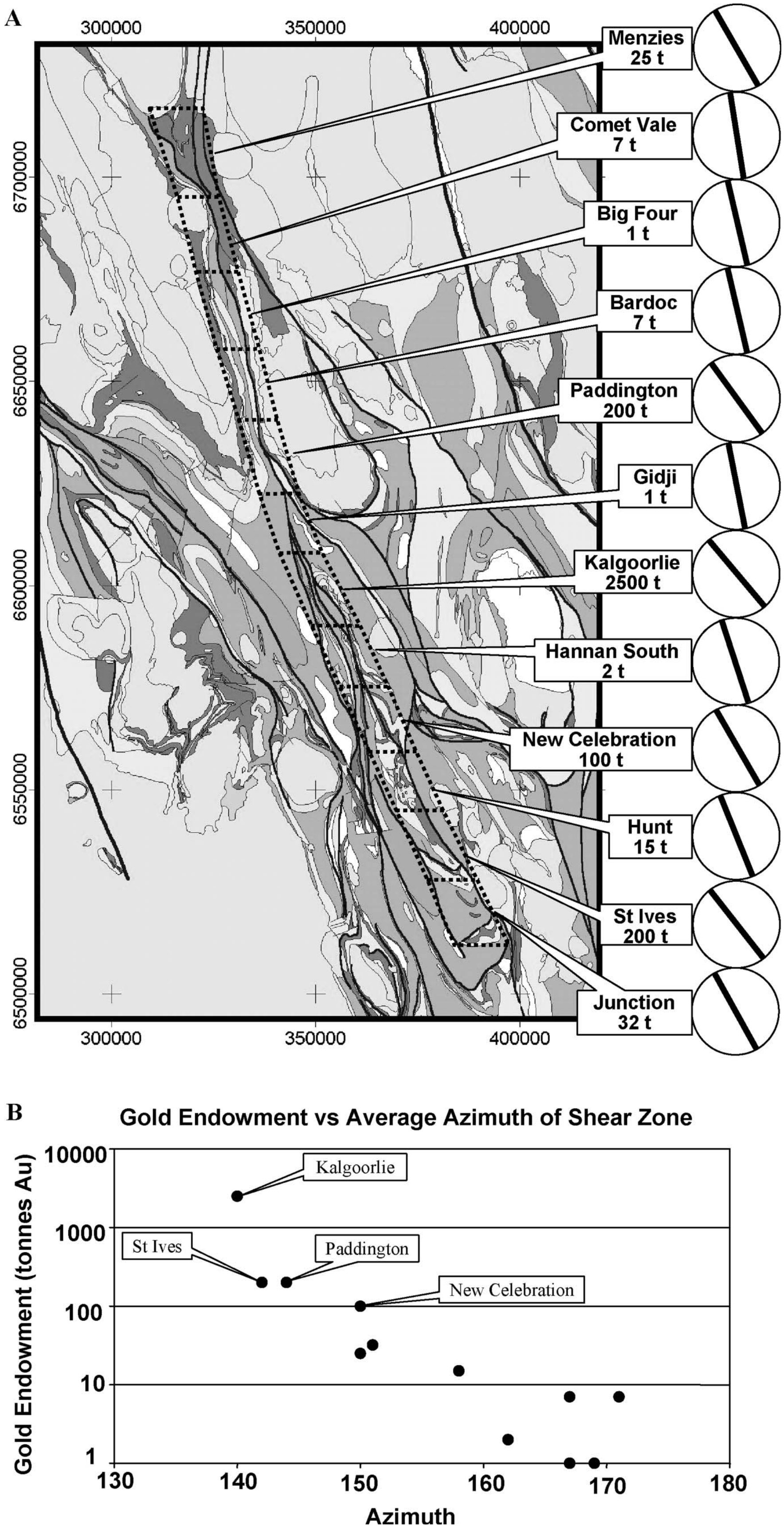


**Figure 6** (a) Map of 12 orogenic gold districts along the Bardoc Tectonic Zone and the Boulder–Lefroy Shear Zone in the Kalgoorlie Terrane. Average orientation of the shear zone in each district is shown in circles. Pre-mining gold tonnage is shown with each district name. (b) Plot highlighting the strong relationship between shear-zone azimuth and gold endowment for 12 districts shown in (a). Major deposits are labelled.

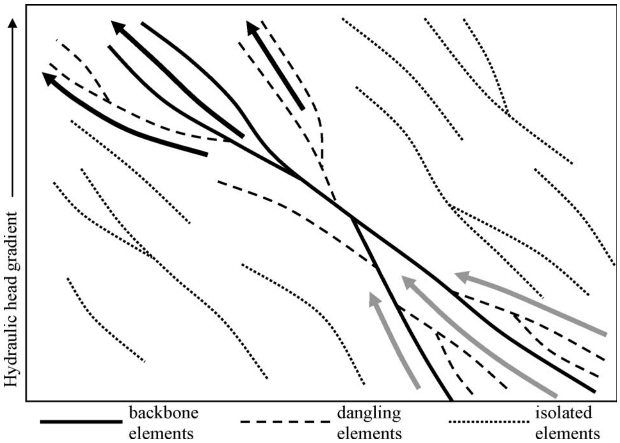


**Figure 7** Schematic plan view of faults representing a percolation network, with backbone, dangling and isolated elements (modified from Cox 1999). Most fluid flow is localised along the backbone. In the upstream (lower right) part of the system, dangling elements feed fluid to the backbone (grey arrows). In the downstream (upper left) part of the system, dangling elements discharge fluid from the backbone (black arrows).

dimensions towards well-connected pathways. This increases the volume of hydrothermal fluids passing through a particular portion of the structural network, and therefore increases the potential for the formation of larger orogenic-gold deposits.

## CONCLUSIONS

This is arguably the first study in which fractal-dimension analysis has been used to highlight the relationship between gold endowment and complexity. Steep complexity gradients, between domains of high and low fractal dimensions, correspond to district-scale regions that have the potential to focus the flow of large volumes of hydrothermal fluid, which is critical for the formation of significant orogenic-gold mineralisation. The steepest complexity gradients in greenstone belts commonly occur in areas where thick sedimentary units overly more complex patterns of lithologic contacts, associated with mafic intrusive and mafic volcanic units. The sedimentary units are interpreted to have acted as seals, or caps, to the hydrothermal systems and to have caused fluid-pressure gradients that drove fluid flow towards higher permeability zones.

Based on the results of this study, complexity gradients, as displayed in surface map patterns, are interpreted to be an indication of three-dimensional connectivity along fluid pathways at depth, between source areas and deposit locations in orogenic-gold mineral systems. Therefore, fractal-dimension analysis of high-quality geologic maps is potentially useful as an exploration-targeting tool for determining orogenic-gold endowment potential in underexplored areas. This method provides a link between map features and critical processes that focus larger volumes of hydrothermal fluids, and, in turn, result in the formation of larger deposits.

## ACKNOWLEDGEMENTS

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