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Analysis and mapping of soil geochemical anomalies: Implications for bedrock mapping and gold exploration in Giyani area, South Africa

Martiya Sadeghi [a,*], Alazar Billay [b], Emmanuel John M. Carranza [c]

[a] Geological Survey of Sweden, Uppsala, Sweden
[b] Council for Geoscience, Pretoria, South Africa
[c] James Cook University, Townsville, Australia

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ABSTRACT

Previous exploration activities in the Giyani greenstone belt (GGB) were guided by the availability of outcrops, particularly iron formation, as this rock was considered to be the main host rock for gold mineralisation in the belt, although the majority of the known prospects/deposits are hosted by mafic rocks. However, there is no reliable lithological map available for the GGB, because most of it is covered by regolith, and thus in the early 1990s most mining and exploration companies in the GGB have abandoned their work as they were discouraged by the scarcity of outcrops, the small sizes of existing deposits and the low gold prices at that time. In the present study, major and trace element geochemical data from a high-density soil geochemical survey (1 sample/km^2) have been subjected to statistical and spatial analyses to support bedrock mapping and gold exploration. Maps are presented for major oxides, trace elements and selected respective ratio maps, and principal components (PC). The PC analysis was performed on clr-transformed data of selected trace elements known to be associated with gold mineralisation. The first six PCs explain about 78% of the total variance. PC4 representing Sb–As–Te–Cr–Au association best reflects the known gold mineralisation and was, therefore, used as a thematic layer. The information provided by various composite maps of different major/trace element data, as well as PC maps, has been used to produce an interpretive bedrock map outlining major lithological units in the study area. As gold mineralisation in the Giyani greenstone belt is hosted by certain known lithologies, the map is useful in indicating potential gold bearing areas.

1. Introduction

Various state geological surveys, including the Council for Geosciences (CGS) of South Africa, have been investigating ways for effective analysis and interpretation of soil geochemistry data for mineral exploration and bedrock mapping purposes. Methods of multivariate data analysis, such as principal component (PC) and factor analysis, are widely used for the statistical processing of exploration geochemical data (e.g., Carranza, 2010; El-Makky, 2011; Sadeghi et al., 2013a; Zuo, 2011). These methods commonly aim to reduce the dimensionality of variables or to identify a few but relevant factors depicting processes that explain a large proportion of variance in a multivariate data set (Davis, 1973, 1986, 2002; Reimann et al., 2008).

During the last few decades, several publications address the effect of outliers and anomalies on compositional data processing (e.g., Carranza, 2011; Grunsky et al., 2014; Pawlowsky-Glahn and Buccianti, 2011; Reimann et al., 2008, 2012). Outliers in geochemical data should always be examined carefully to ascertain that they are not the result of analytical or sampling error (Grunsky, 2010; Reimann et al., 2008; Thompson, 1983). In practice, outliers are usually assessed by graphical examination of upper and lower rankings of data, and the identification of values that occur as distinct breaks from the background population (Grunsky, 2010; Lepeltier, 1969; Sinclair, 1976, 1983, 1986, 1991; Tennant and White, 1959).

Geochemical data are typically reported as parts of a total composition (ppm, weight %, etc.) and, thus, geochemical data analyses are affected by the closure problem (Grunsky et al., 2014; Reimann et al., 2008, 2012). Accordingly, since geochemical data are compositional, every data set should be opened, prior to its statistical treatment, using a preferred method from a variety of suggested methods (Carranza, 2011; Reimann et al., 2008). There are three different log-ratio transformation methods for opening of compositional data, namely (1) additive log-ratio or alr (Aitchison, 1986), (2) centred log-ratio or clr (Aitchison, 1986), and (3) isometric log-ratio or ilr (Egozcue et al., 2003). There is much debate as to which method gives the best result for mapping spatial distribution of pathfinder elements in mineral exploration. Carranza (2011) has shown that either clr- or ilr-transformed stream sediment geochemical data are superior to alr-transformed stream sediment geochemical data for recognising anomalous multi-element signatures associated with mineralisation. This is

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* Corresponding author at: Geological Survey of Sweden, Villavägen 18, PO Box 670, SE 751 28 Uppsala, Sweden. Tel.: +46 18 179232; fax: +46 18 179210.
E-mail address: martiya.sadeghi@sgu.se (M. Sadeghi).

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due to the fact that ilr is an isometric transformation and the direct relation to the elements is lost, while in the clr-transformation each variable is divided by the geometric mean of all elements measured, followed by log-transformation and, therefore, preserves the so-called Aitchison distance in the sample space of compositional data. The alr-transformation is not isometric, because it uses one variable for the ratio, and different results can be expected when a different variable (elements/oxide) is used as denominator (Aitchison, 1986; Egozcue et al., 2003).

Since 1973, the CGS has been conducting regional (1 sample/km^2) soil geochemical surveys for mineral exploration so as to recognise new prospective areas in geologically favourable terranes (Lombard et al., 1999). One such geologically permissive terrane is the Archaean Giyani Greenstone Belt (GGB) in the Limpopo Province, South Africa, which is known for its gold mineralisation. In the GGB, there are at least 40 currently known gold occurrences (Ward and Wilson, 1998), which are hosted mainly in mafic metavolcanic rocks and iron-formations (Billay et al., 2009). Due to the scarcity of outcrops in the GGB, there is a lack of an accurate bedrock map to support recognition of new prospective areas. Therefore, the aim of this paper is to demonstrate and to highlight the benefits of soil geochemical data processing and interpretation for bedrock mapping and gold exploration in the GGB.

2. Study area

At their present level of exposure, the Archaean rocks of the Kaapvaal Craton are dominated by 3.64 Ga granitoid gneiss (Armstrong et al., 1990) and various 2.65 Ga granitoid masses (Barton and Van Reenen, 1990). Within this granite–gneiss terrane, belts of metavolcanic rocks occur, of which the Barberton, Murchison, Pietersburg and Giyani greenstone belts are spatially the most dominant (McCourt and Van Reenen, 1992).

The NE-trending GGB is situated at the north-eastern edge of the Kaapvaal Craton in the Limpopo province of South Africa (Fig. 1). It is ~15 km wide and ~70 km long and bifurcates towards its south-western end into the northern Khavagari branch and the southern Lwaji branch. The supra-crustal rocks in the GGB (Giyani Group; SACS, 1980) are flanked to the north by migmatised tonalitic gneiss (Klein Letaba Gneiss) and to the south by younger granite. Within the GGB, geophysical modelling by Kleywegt et al. (1987) indicates the thickness of the Giyani Group to be between 1.5 and 3 km, increasing towards the SE margin of the belt. They also concluded that the GGB is not situated along a major crustal boundary. The GGB is predominantly made up of ultramafic–mafic rocks with minor intercalations of various types of iron-formation, felsic schist and pelitic metasediments (Brandl et al., 2006; McCourt and Van Reenen, 1992; Prinsloo, 1977).

The GGB has been subjected to complex polyphase deformation. The most comprehensive structural studies on the GGB can be found in McCourt and Van Reenen (1992) and De Wit et al. (1992). In summary, McCourt and Van Reenen (1992) describe three ductile-deformation phases comprising (i) an older penetrative deformation (D$_1$), (ii) a younger non-penetrative deformation (D$_2$) and (iii) the latest deformation event (D$_3$) characterised by discrete strike–slip shear zones. The D$_1$ phase gave rise to N-trending regional schistocity and was responsible for ENE–WSW and E–W-trending, north-dipping oblique to reverse shear zones, as well as the associated reclined sheath folds and a well-developed mineral lineation. The non-penetrative D$_2$ phase was superimposed on D$_1$ structures, and can be recognised by either eastward plunging folds of the regional foliation or related horizontal

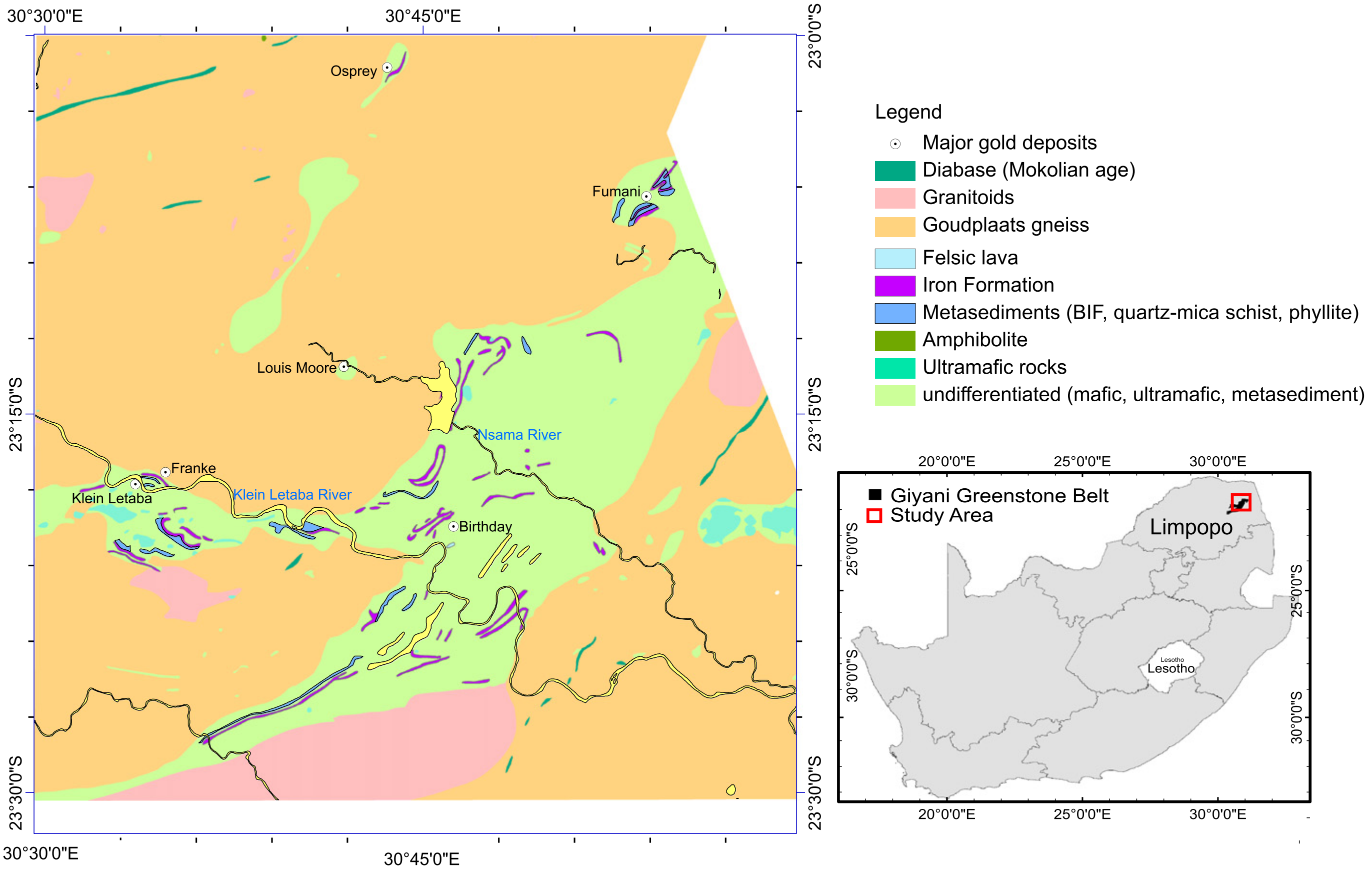

Fig. 1. Location (inset) and general geology of the Giyani greenstone belt and the surrounding granite–greenstone terrane.