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Geochemical identification of episodes of gold mineralisation in the Barberton Greenstone Belt, South Africa

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ABSTRACT

The morphology and mineral chemistry of gold and associated sulphides at Sheba, Fairview, and New Consort gold mines in the Barberton Greenstone Belt (BGB) identify two main types of mineralization. The first type occurs associated with sulphides (mainly pyrite), either as inclusions (10–30 μm) or as sub-microscopic gold. The second gold type consists of large gold grains (≥100 μm) within the silicates (mostly quartz).

LA-ICP-MS studies reveal that some gold and associated sulphide grains contain high values of Cl, Br, Na, and I. The elemental relationships reflect the different chemistry and precipitation processes of possible source fluids, and identify several episodes of mineralisation in the study area, one of them formed due to a boiling process in a supercritical hydrothermal environment. This paper reports on the compositional characteristics of these gold grains, the significance of the halogen contents, and the implications for possible sources of the gold and associated sulphides.

1. Introduction

The Barberton Greenstone Belt (BGB) of the Kaapvaal Craton, South Africa (Fig. 1), is one of the oldest granite-greenstone belts in the world (Anhaeusser, 1976, 1986; van Kranendonk et al., 2009; Van Kranendonk, 2011), and one of the most studied Early Archaean greenstone belts worldwide (Anhaeusser, 1976, 1986; Brandl et al., 2006; De Wit et al., 2011; Van Kranendonk, 2011). It is also one of the most important gold producing terrains in South Africa (Ward, 1995, 1999; Goldfarb et al., 2001; Brandl et al., 2006), with gold production starting in the late 19th century. More than 350 gold deposits have been reported in the BGB, with more than 85% of the approximately 345 tonnes of gold produced coming from the Sheba, Fairview, and New Consort Mines between 1884 to 1995 (Anhaeusser, 1976, 1986; Ward, 1999; Dirks et al., 2009). These three mines have a continued production of ~2.9 t of gold annually (Pan African Resources, 2015).

Situated in the northern terrane of the BGB, in fairly close proximity, the Fairview, Sheba and New Consort Mines show very distinct characteristics (controls and conditions of mineralisation) (Dziggel et al., 2006; Otto et al., 2007; Dziggel et al., 2010; Munyai et al., 2011; Agangi et al., 2014). The regional geology and structural evolution of the BGB is complex, as reflected in the extensive literature, which makes unravelling the sequence of events leading to the timing and mode of emplacement of the gold mineralisation complicated. The gold distribution in the BGB is structurally controlled (Dirks et al., 2009), and recent work has shown that the main phase of gold mineralisation in the BGB was controlled by pre-existing faults and fractures, and postdates the main structural and metamorphic episodes (Dziggel et al., 2010; Munyai et al., 2011; Dirks et al., 2013). Dirks et al. (2013) proposed that the principal stage of gold enrichment in the BGB occurred after tectonic and thermal stabilization of the Kaapvaal Craton, suggesting that brittle–ductile shear zones allowed mineralising fluids to exist during cratonic extension. Similarly, Micklethwaite and Cox (2004) have shown that the lode gold deposits in the Kalgoorlie terrane, Western Australia, in the Archean greenstone sequence of the Yilgarn craton, were the result of episodes of focused fluid flow through a pre-existing high-permeability network over extended periods.

For this investigation the mineralised assemblages, especially those containing gold, were looked at with the aim of identifying chemical clues to link gold mineralisation parageneses to possible modes of formation. Previous studies which focussed on the origin of the mineralisation based on chemistry of the ore minerals did not look at the chemistry of the gold, but rather of the associated mineral assemblages (e.g. De Villiers, 1957; Saager and Koppel, 1976; Cabri et al., 1989; Otto et al., 2007; Agangi et al., 2014).

Analyses by Warren and Thompson (1944) and Steele and Carlton (1961) of some gold grains from various mines in the BGB showed gold with both high and low Ag contents, in addition to trace amounts of other elements. Warren and Thompson (1944) found that differences in gold composition were related to metallogenic zones rather than to the type of deposit. Gay (1963) reviewed gold compositions from the literature of gold around the world, including the BGB, in order to identify the genetic type of the mineralisation. He then looked at gold from Zwartkoppie Reef at Sheba Mine (Gay, 1964) and came to the

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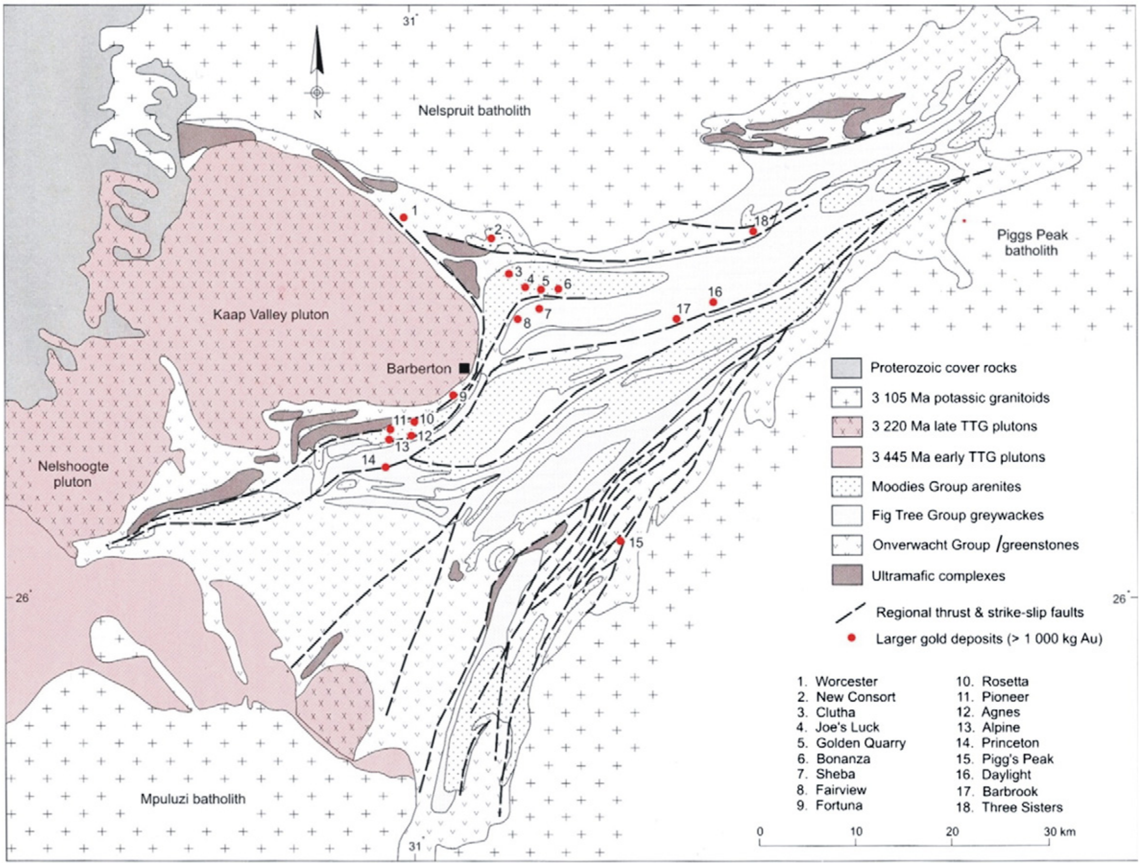

Fig. 1. Simplified geology of the Barberton Greenstone Belt.
After Ward and Wilson (1998).

conclusion that there were two episodes of gold mineralisation, echoing de Villiers (1957) finding that free gold occurred late in the paragenetic sequence, except where it was enclosed in arsenopyrite. These analyses, however, were of handpicked gold grains which had been separated out of the ore, and melted together (Gay, 1964), so grains of different compositions from a single sample could have been combined.

Our study looked at the composition of individual sulphide and gold grains from the Sheba, Fairview and New Consort gold mines from the BGB (Fig. 2), as determined by EMPA and LA-ICP-MS. It evaluates the contribution that chemical variation of ore minerals has in clarifying the events that led to the gold mineralisation.

2. Analytical procedures

In order to assess the variability of mineral compositions, the major and trace elements were measured, respectively using a CAMECA SX-100 electron microprobe (University of Pretoria) and Laser Ablation ICP-MS (Forensic Science Laboratory, Pretoria). The measurements were performed on epoxy mounted polished sections and are presented in Table 1. Quantitative phase analysis (XRD) was performed to obtain weight percentages of minerals in the various samples.

2.1. Electron probe microanalysis (EMPA)

Imaging and elemental analysis were performed using an electron microprobe in the gold and sulphide ores from the Sheba, the Fairview, and the New Consort Mines. The spectra were processed by ZAF corrections. Analysis of the samples was performed with an accelerating voltage of 20 kV, a current of 20 nanoAmpere (nA), and a focused spot (<1 μm diameter). Counting times were 10 s for all elements. The standards used for calibration were as follows: albite (Si, Na, K), MgO (Mg), Al_2O_3 (Al), topaz (F), apatite (P), andradite (Ca), orthoclase (K), Fe_2O_3 (Fe), vanadinite (Cl) and MnTi standard (Mn, Ti).

2.2. Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS)

Electron-microprobe work by Hayward et al. (2005) on Witwatersrand gold grains and Merkle et al. (2008) on gold grains from the Merensky Reef shows that gold grains are heterogeneous and may contain inclusions, so bulk analyses have limited potential in working out genetic relationships based on elemental distributions. Accordingly, mineral grains were analysed by LA-ICP-MS in order to determine elemental distribution within the grains.

The trace elements were measured using an Agilent 7500 CX inductively coupled plasma mass spectrometer coupled to a New Wave 213 nm laser. Ablation was performed in He, and the gas then mixed with Ar prior to delivery to the MS. Between run normalization was achieved using the bracketing technique over an NIST 612 glass (Pearce et al., 1997) analysed every 20 spots.

For spot analyses, the samples were ablated using a spot size and depth of 25 μm, with an energy of 5 J/cm^2 and a 4 Hz repetition rate, for 45 s. The resolution of the laser spot is not as small as that which is achievable by an electron microprobe, but elemental concentrations of a wide range of elements down to ppb levels are possible. The LA-ICP-MS results are not quantified to standards, but expressed as count per seconds (cps). Some grains were mapped on a grid pattern, with continuous ablation via successive line scans to determine elemental distributions. A laser spot size of 10 μm was selected, with a scan speed of 10 μms^{-1} and a sampling rate of ~0.25 s. This translates to an effective sampling area of 2.5 × 10 μm. The utility of this methodology in increasing the resolution compared to spot analyses has been discussed by