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Structural analysis and 3D modelling of major mineralizing structures at the Phalaborwa copper deposit

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ABSTRACT

The c. 2060 Ma Phalaborwa Igneous Complex forms an elongate intrusion into Archean granitic gneiss. The carbonatite within the central pyroxenite core of the complex (Loolekop) is well-mineralized in copper. Open pit mining operations started in 1965, followed by underground block caving in 2003. Although little attention has been paid to large-scale structures associated with intrusive phases and mineralization, ongoing infrastructure development and block caving, as part of the new Lift II Project, require far greater resolution of structural discontinuities. 3D modelling of these structures, from over 50 years of data, reveals that Loolekop occurs at the confluence of several major shears or fault zones. Of these, five major structures were pivotal in the emplacement of banded carbonatite, transgressive carbonatite and very late-stage, narrow, E-W trending, sulphide veinlets with short down-dip and along-strike extensions, which form the bulk of mineralization. Modelled structures typically have two or more segments, which are rotated with respect to one another, in turn suggesting repeated rotation or torsion of the entire intrusive volume, aided by cross-cutting structures. The oldest structure is the N-S trending Mica Fault Zone, which shows the same trend as the entire carbonatite complex and the nearby eastern edge of the Kaapvaal Craton and the Lebombo Lineament. The youngest structure is the Central Fault, which shows an E-W inflection that is co-incident with the carbonatite and the E-W, vein-hosted Cu mineralization trend. Based on cross-cutting relationships, sinistral movement along the Central Fault Zone and its localized E-W dilational jog is invoked as a mechanism for transgressive carbonatite emplacement and the introduction of late-stage Cu-rich fluids into numerous tensional veinlets. This shearing would have been caused by an E-W trending maximum principal stress orientation. In turn, this corresponds with the orientation of near-field, eastward-directed stress along the eastern lobe of the Bushveld Complex during its emplacement and subsequent deformation.

1. Introduction

The Palabora Cu-Fe-phosphate-vermiculite deposit forms part of the *c.* 2060 Ma Phalaborwa Igneous Complex (Wu et al., 2011; Fig. 1). Early work by Verwoed (1967) identified a differentiated mass of mafic and alkaline intrusives, along with numerous syenite and carbonate-bearing injection breccias, plugs and dykes. It is generally accepted that the first stage of magmatic activity involved the intrusion of an apatite-bearing pyroxenite, followed by an alkaline phase consisting predominantly of syenite. The center of the three pyroxenite "cores" of the Phalaborwa Igneous Complex, originally named Loolekop, is particularly well-mineralized in copper. Consequently, open pit mining operations on Loolekop started in *c.* 1965, followed by underground block caving in 2003.

While numerous intrusive phases, alteration zones, metasomatism and varied mineralogy have been extensively documented, relatively little attention has been paid to the geometry of large-scale structures that may have been associated with intrusive phases and mineralization. However, ongoing infrastructure development and block caving require significantly greater resolution of structural discontinuities within and around the mining volume. A new 3D model of major structures, created for geotechnical design, geohydrological modelling and mine planning, provides an ideal opportunity to assess the interrelationship between major structures, mineralization and various intrusive phases. This new model

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