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Structural and compositional constraints on the emplacement of the Bushveld Complex, South Africa

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ABSTRACT

Despite a plethora of petrological studies, the emplacement mechanics of the world's largest layered intrusion, the 2.05 Ga Bushveld Complex, are still poorly understood. Early models considered the intrusion to comprise separate, lopolithic intrusions or even concentric cone sheets, but recently, overwhelming support for a sill-like intrusional form has emerged. Examination of the contact aureole reveals three groups of emplacement-related structures: interfinger deformation zones and bridges, formed between intruding and dilating magma fingers, preserved in both the western and eastern parts of the Complex; sub-Bushveld Complex intrusions, that reflect finger-like emplacement into the underlying contact aureole; and diapiric domes that characterize the eastern contact aureole, formed by diapiric amplification of initial interfinger deformation zones associated with the earliest mafic–ultramafic pulse of the Bushveld Complex. Most of these structures exhibit a strong NW–SE preferred orientation, while longitudinal terminations and divergence of the sub-Bushveld intrusions away from their source horizons indicate magma emplacement towards the SE. This emplacement direction is supported by petrological data, lateral lithological facies variations and mineral chemical variations within specific horizons. The thickest and most chemically primitive accumulations of the Lower Zone of the Complex are found adjacent to, and thin towards, the NE and SE, away from the Thabazimbi–Murchison lineament (TML), a crustal-scale lineament that has undergone polyphase reactivation since at least 2.7 Ga. The Bushveld Complex was most likely fed by a feeder dyke that utilised the TML, spreading laterally from the dyke-axis to form its current sill-like geometry. The stress field at 2.05 Ga was suitably oriented to allow for dilation of the ENE-trending TML, suggesting the Kaapvaal craton was subject to a component of NW–SE extension. During this time NW–SE directed collision of the Kaapvaal and Zimbabwe cratons is recorded in the Limpopo belt, which would suggest emplacement under conditions of far field extensional stress within a back-arc setting. This is corroborated by petrological data that supports a significant component of subducted crust in the Bushveld magmas.

1. Introduction

Despite being the world's largest layered intrusion, the Bushveld Complex of South Africa is still poorly understood in terms of its emplacement into the Kaapvaal craton, while consensus is yet to be reached on the tectonic setting of its emplacement. The overwhelming majority of studies of the Complex deal exclusively with petrogenetic aspects and are not integrated with regional-scale, let alone crustal-scale, observations of the intrusion, while only a handful of studies have discussed the tectonic setting of the Complex.

Historically neglected, the contact aureole of the Bushveld Complex has become an extremely useful source of information about tectonic processes operating during and after emplacement (e.g. Uken, 1999; Clarke et al., 2005). In any form of intrusion, substantial information regarding emplacement history is usually recorded in the country rock and the Bushveld Complex is no exception. In this paper we use structural criteria from the Bushveld Complex contact aureole in conjunction with published compositional data, to constrain aspects of the emplacement of the mafic–ultramafic part of the Complex. In particular, floor structures and intrusions into the floor are used to constrain emplacement direction, and these are consistent with lateral facies variations in the layered suite of the Complex and the detailed petrological emplacement model of Kruger (2005). The emplacement pattern also allows inferences to be drawn about the tectonic setting of the Complex.

The scale of the Bushveld Complex, coupled with its enigmatic tectonic setting, suggests that it is globally unique amongst layered intrusions. By attempting to remove some of the uncertainty surrounding its

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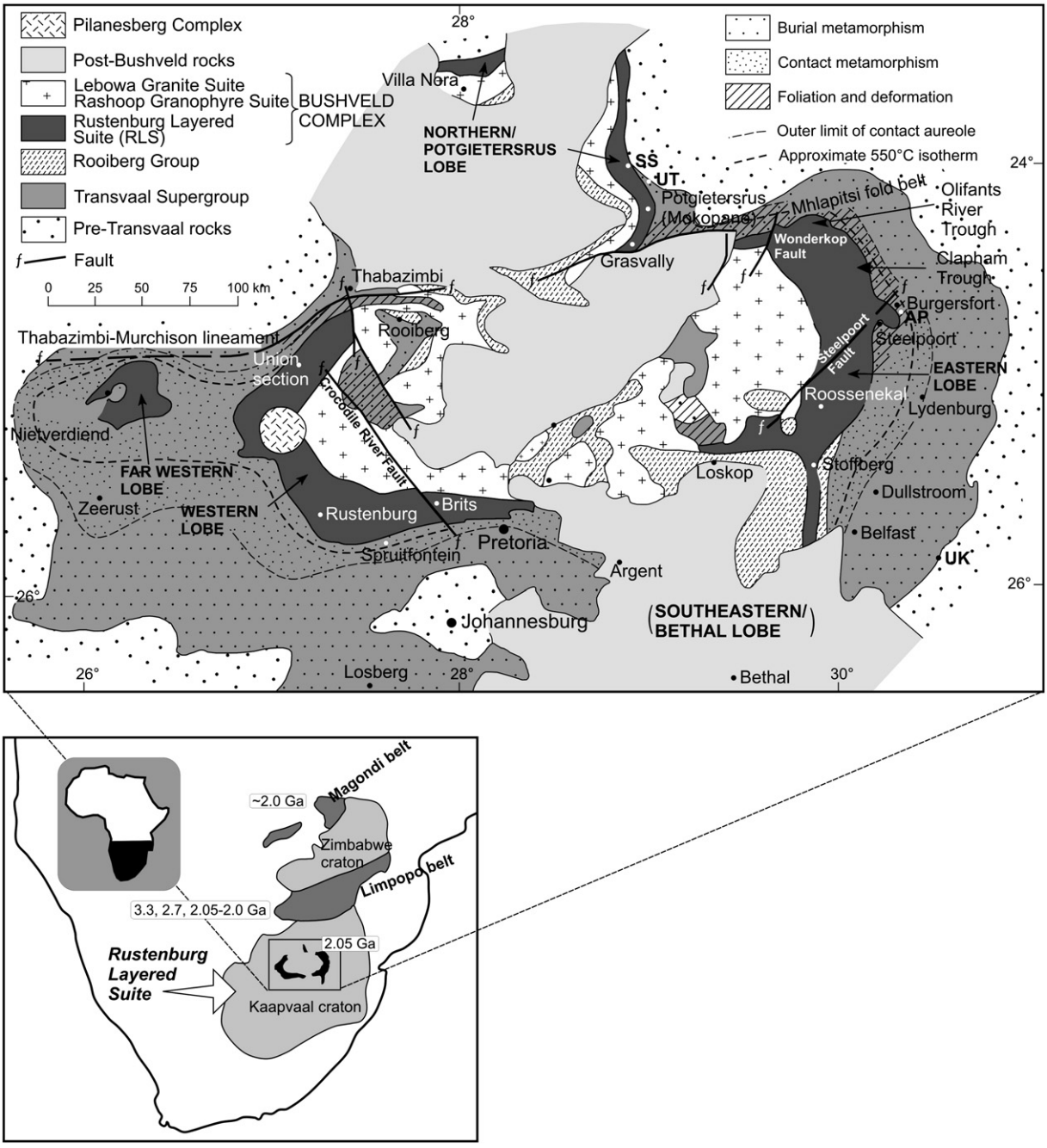

Fig. 1. Simplified geological map of the Bushveld Complex with inset showing its position on the Kaapvaal craton relative to major orogenic belts. Abbreviated features: UK — Uitkomst Complex, AP — Apiesdooringdraai peridotite, UT — Uitloop pyroxenite, SS — dolomite tongue at Sandsloot. The southeastern (Bethal) lobe is obscured beneath younger cover sequences. Modified after Cawthorn et al. (2006).

tectonic setting, it is hoped that this paper will facilitate application of modern emplacement and plate-tectonic models to other large layered intrusions.

2. The Bushveld Complex and its tectonic setting

The 2.05 Ga (Scoates and Friedman, 2007) Bushveld Complex (Fig. 1) is the world's largest layered intrusion, with an areal extent of ~65 000 km^2 (Eales and Cawthorn, 1996). It is also host to the largest known deposits of Cr, V and platinum group metals (PGM) on Earth. Emplacement of the Complex was preceded by the extrusion of the bimodal Rooiberg Group, which is the uppermost constituent of the 2.5–2.06 Ga Transvaal Supergroup (Eales and Cawthorn, 1996; Walraven, 1997). The mafic–ultramafic portion of the Bushveld Complex, the Rustenburg Layered Suite (RLS), hosts the economically important Cr, V and PGM deposits and is up to 9 km thick (Eales and Cawthorn, 1996). The RLS, subdivided into the Lower, Critical, Main and Upper Zones (Fig. 2) is intruded by the voluminous Lebowa Granite Suite.

2.1. Contact relationships with floor and roof sequences

The RLS was mostly emplaced subconcordantly into the Transvaal Supergroup, with the uppermost 2.06 Ga Rooiberg Group volcanics forming the roof to the Complex. In most places, the upper, clastic, Pretoria Group of the Transvaal Supergroup forms the floor to the Complex, with downward transgression into the Archaean granites only noted in the northern lobe of the Complex (Eales and Cawthorn, 1996). In the eastern lobe north of Steelpoort, the RLS intruded the