SETTING AND SIGNIFICANCE OF ZIRCON/BADDELEYITE IN BASAL UNIT OF ROOIBERG GROUP, STAVOREN INLIER, 2,055 Ma BUSHVELD COMPLEX, SOUTH AFRICA

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BACKGROUND

Unique Size and Complexity

The Bushveld Igneous Complex (BIC) is unique in complexity and size (~67,000 sq. km without Molopo Farms; Fig. 1); its origin remains enigmatic in spite of >1670 Georef entries.

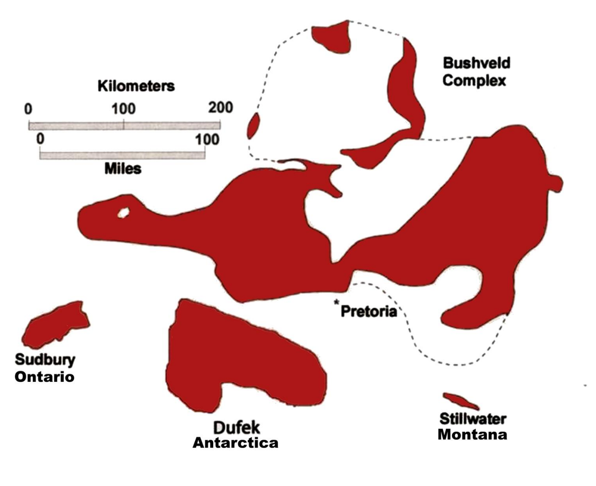

Figure 1. Comparative sizes

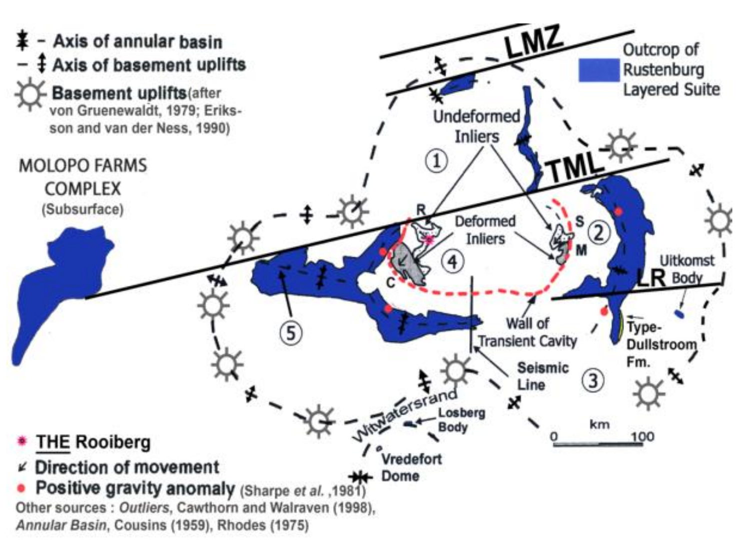

Figure 2. Tectonic sketch map

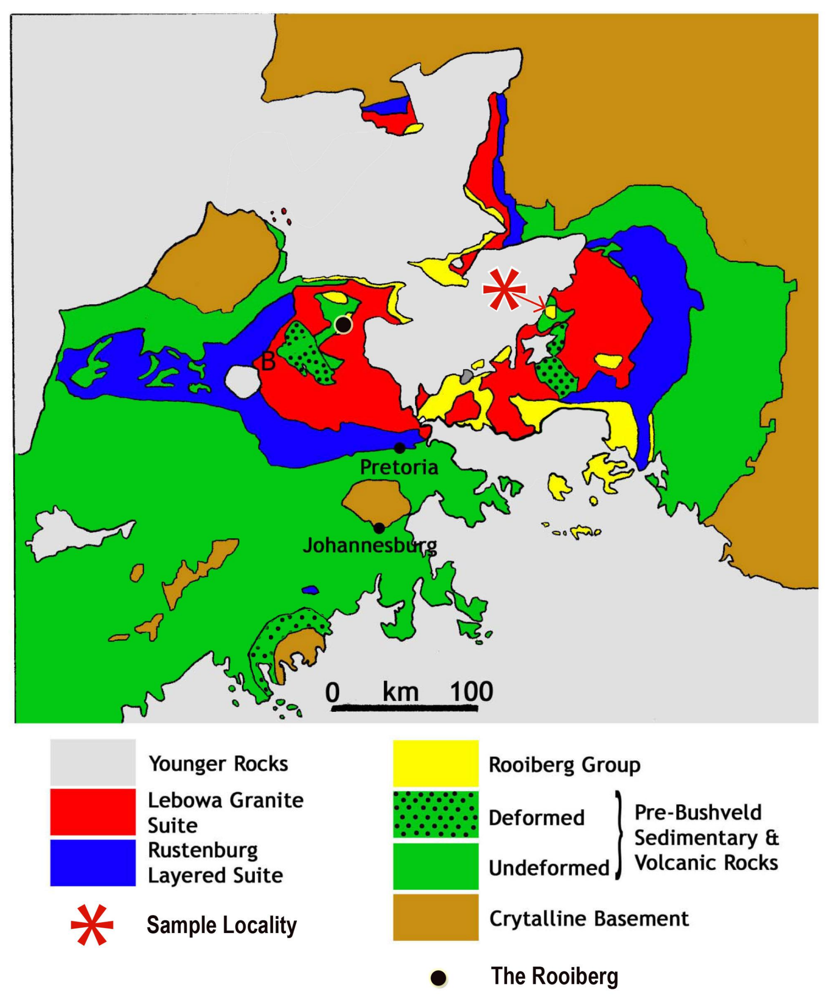

Fig.3. Geologic sketch map

Structure

On maps (Figs. 2, 3), the structure of the BIC looks misleadingly simple: four overlapping basins and a western extension, splashed on the Kaapvaal craton and its thick sedimentary (and lesser volcanic) cover (Transvaal Supergroup, to t=19 km). Continuity of Bushveld units allows the East and West Basins to be treated as single structural basin.

The Rocks

Each of the three major BIC units is the most voluminous of its kind in the geologic record. Each has many subunits and granophyric facies, collectively called the *Rashoop Granophyre Suite* (not shown on Fig. 3). Outcrop belts, inward from the basin periphery, are:

1. ***Rustenburg Layered Suite***, sills of mafic cumulates (total to t=8 km), with the world's largest PGE, Cr, V deposits. Seismic (Du Plessis and Levitt, 1987), gravity, and geoelectrical surveys (Meyer and de Beer, 1987) indicate that the Rustenburg sills occupy a discontinuous belt of inward *dipping sheets* with limited extent, not the continuous *lopolith* of textbooks. Sills also occupy the western extension and the subsurface Molopo Farms Complex of Botswana (Fig. 2), apparently controlled by fault zones with pre-, intra-, and post-Bushveld movements (Du Plessis and Walraven, 1980). The two other major units are confined to the four basins.
2. A-type *Lebowa Granite Suite*, "a sill-like pluton" (A>30,000 sq.km; t=2.5-3.5 km; Kleeman and Twist, 1989). It obscures the interior of the Bushveld Basin, except for *The* Rooiberg (granophyric top of Rooiberg source?) in the West basin, and *inliers* of pre-Bushveld Transvaal units in the East and West Basins (Fig. 2). These remain as islands in a sea of Lebowa granite and provide important clues to the structure and origin of the BIC.
3. Flows of the *Rooiberg Group*, traditionally *felsite*, preserved in remnants to t=5 km. Rustenburg and Lebowa sills invaded their base, even as they accumulated throughout Bushveld time (Hatton and Schweitzer, 1995). They form the roof of the BIC. It has long been known (but often forgotten) that the BIC is *extrusive* (Daly and Molengraaff, 1924). There is no intruded roof of pre-Bushveld rocks.

REINTERPRETATIONS

Focus: zircon-baddeleyite

The preliminary findings of submicroscopic zircon-baddeleyite pairs in Rooiberg rocks (Tegtmeier *et al*., 2011). If confirmed, provides evidence for the *impact hypothesis of BIC origin,* unknown to earlier supporters (Rhodes, 1975) and skeptics (French, 1990). It is here proposed that the four Rooiberg formations (Dullstroom, Damwal, Kwaggasnek, Schrikkloof; Schweitzer *et al*., 1995) are repeated overflows from an initially superheated Sudbury-type impact melt pool. zircon-baddeleyite grains occur in a quenched matrix of a high-T debris flow in the basal ~200 m of the Dullstroom Formation. Their site, the eastern inlier, is proximal to an inferred melt pool in the Bushveld basin. Elsewhere, the basal Rooiberg zone was destroyed by contact with Rustenburg sills.

Setting: The Extraordinary Inliers

Beyond the BIC, ridge-forming Magaliesberg quartzites (~500 m) allow a regional division of the Transvaal Supergroup into pre-Magaliesberg, Magaliesberg, and post-Magaliesberg formations. In the inliers, a strike-slip fault zone juxtaposes undeformed post-Magaliesberg units, capped (in the eastern inlier) by basal Rooiberg debris flows, against metamorphosed, attenuated, and deformed pre-Magaliesberg formations (Hartzer, 2000; Figs. 2, 4). The Magaliesberg Formation is absent. Regionally, no known orogenic tectonic event disturbed the Transvaal stratigraphic succession, or removed its most prominent unit.

The focus here is on the eastern inliers: *Marble Hall* (deformed; Figs. 4 a, b) and *Stavoren* (undeformed; Figs 4c, d). The critical basal Rooiberg zone is covered in the western undeformed inlier.

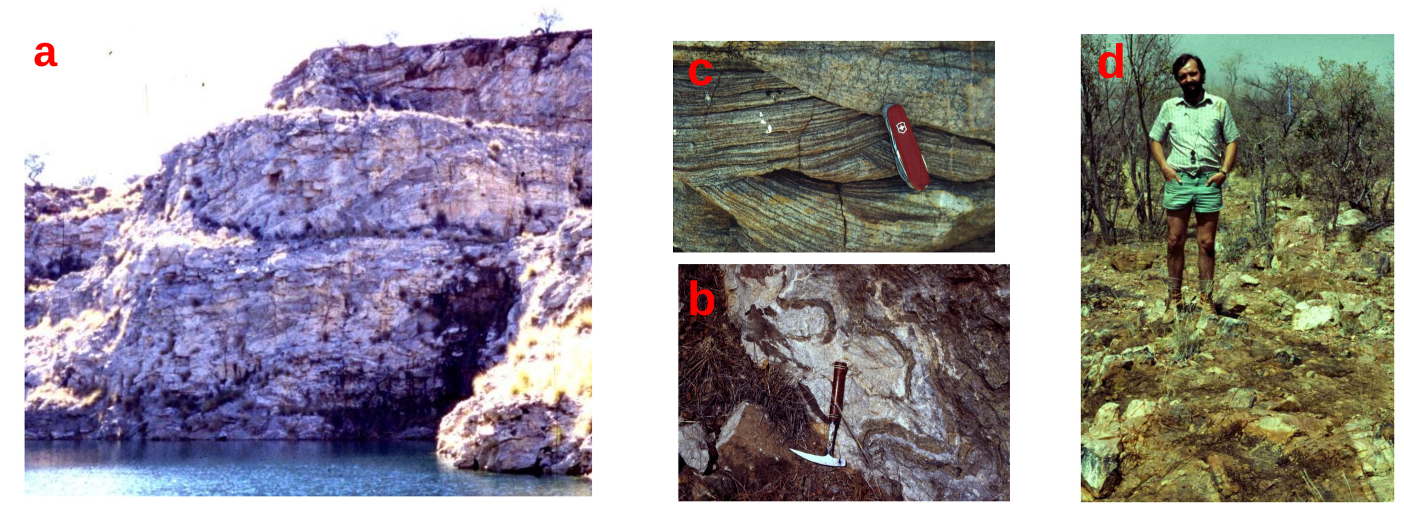

Figure 4. Deformed and undeformed inliers: a. Marble Hall: pre-Magaliesberg calc-silicate marble, deformed by recumbent isoclinal folds, thrust faults. b. Marble Hall: close-up of pyroxene bands in deformed marble. c. Stavoren: post-Magaliesberg quartzite, undeformed. d. Stavoren: Top of Rooiberg debris flow: quartzite clasts in melt matrix.

Proposed Scenario: Heat Dominates Shock

Zircon-baddeleyite are products of the first of three proposed BIC development stages, each linked to a rock suite: 1. impact (Rooiberg Group; Fig 5); 2. mantle upwelling and endogenic melting (Rustenburg Layered Suite; Fig. 6); 3. endogenic crustal melting and caldera-like collapse (Lebowa Granite Suite; Fig. 7).

Impact models by Ivanov and Melosh (2003) concluded that an impact capable of triggering massive endogenic melting is "possible …but…highly improbable…in the last 3.3 b.y…" It is proposed that the improbable actually happened, at least once.

French and Koeberl (2010, p. 133) included "decomposition of zircon… to baddeleyite" among "indicators of impact-induced high temperatures." Indications of primary baddeleyite reacting to form zircon in basal Rooiberg suggest even higher temperatures, beyond those generated by smaller impacts. Melting of the target would destroy the shock features widely regarded as diagnostic of impact. The zircon-baddeleyite relationships described by Tegtmeier *et al.* (2011) may provide an alternative criterion for a unique mega-impact.

PROPOSED SCENARIO

PLEASE NOTE: Figures 5, 6, 7 are CARTOONS, not drawn to scale. Reality is far too complex to be covered by a poster.

First Catastrophe: Impact (Fig. 4))

Multiple quasi-simultaneous impacts by a fragmented object produced an unstable lobate multi-ring crater (Figs 2, 4a, 4b)

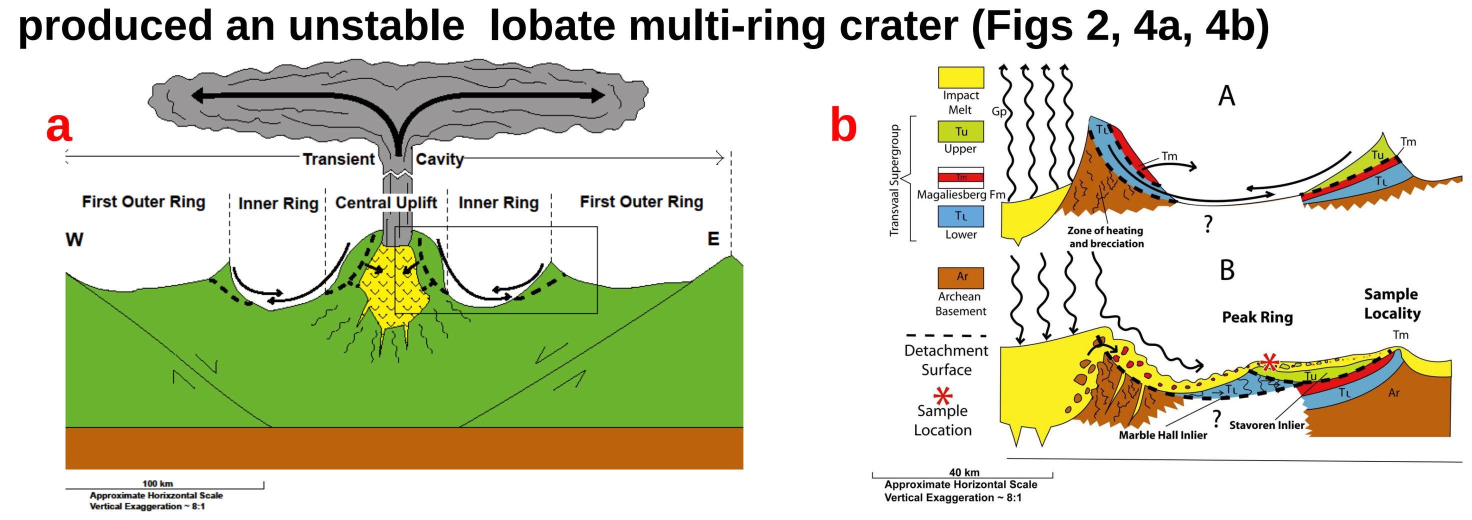

Fig. 4, a. Closely clustered multiple impacts from a fragmented extraterrestrial body created an unstable lobate multiring transient cavity with central uplift and an incipient superheated melt pool with rising eruptive column (cf., plinian volcanic column, nuclear mushroom). b. Details from box in a: A. Incompetent Magaliesberg Fm. detaches from lower and upper Transvaal units. B. Collapse forms inliers: deformed inliers from "hot" Lower Transvaal off central uplift, undeformed inliers from "cool" crater wall Jointly form *peak ring* (model by Collins *et al*., 2002). "Missing" Magaliesberg, detached from collapsing central uplift, mixes with collapsing eruptive column, spreads as inflated flows, and is deposited as basal Rooiberg.

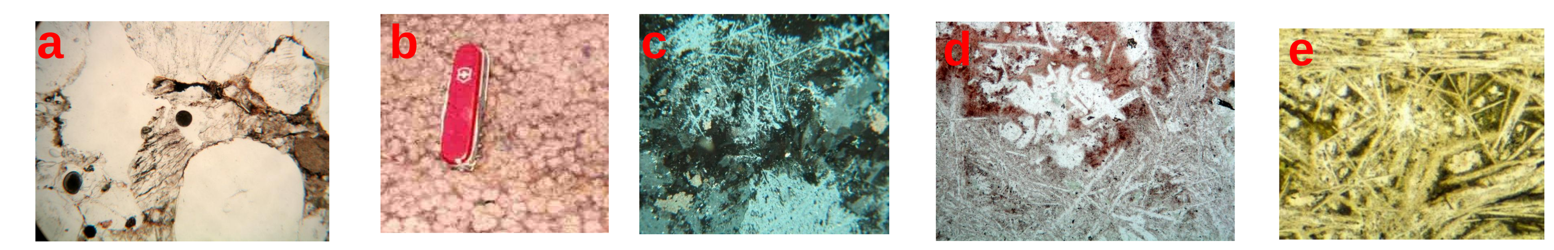

Fig. 5. Sedimentary component of basal Rooiberg, temperature increases L to R. The microtextures and high-T silica polymorphs are unknown in volcanic rocks. a. Basal paleochannel; cataclastic deformation: brecciated quartz grains with percussion fractures squeeze "soft" K-spar (center); matrix partly melted. Field 1 mm. From a rare "cool" spot; a search may yield shock features. b. Pseudospherulites: partly resorbed quartzite clasts in high-T melt with *zircon-baddeleyite microlites*. c. Interior of pseudospherulite: solid-state inversion of quartz grains into a high-T silica network. Each original quartz grain retains optical continuity (X polars, 1 mm). d, Border of pseudospherulite. Bottom: quartz inverted to network; a lath-shaped polymorph formed by reaction with melt in embayment pocket. Top: devitrified glass with "tridymite" quench needles; also known from Onaping Fm. (Sudbury; Stevenson, 1963). 1 mm. e. Pseudospherulites are nearly resorbed; quench needles are segmented (seen with X polars), commonly doubly terminated ("swallow-tailed") and may be visible to the naked eye; alignment indicates flow, field 2 mm. Note on silica polymorphs: All of the observed silica polymorphs have inverted to quartz paramorphs,. Their prior identity is unknown. A bewildering array of high-T silica phases has been reported in the ceramic literature, mainly from silica-brick linings industrial furnaces.

Interlude: Mantle Upwelling, Melting

Decompression melting at the head of an impact-induced mantle upwelling ("plume"; model by Jones *et al*., 2002) generated Rustenburg magmas, emplaced beneath Rooiberg flows in the *subsiding* outer ring. Basal Rooiberg is destroyed at contacts *except* in inliers and a "cool" distal facies (D in Fig. 6a).

Second Catastrophe: Crustal Melting, Collapse

Instability from crustal melting (Lebowa Granite) culminated in catastrophic caldera-like collapse. Meltpool equilibrated with invading granite magma; last Rooiberg overflows resemble conventional rhyolite mixed with collapse breccias (Fig 6b).

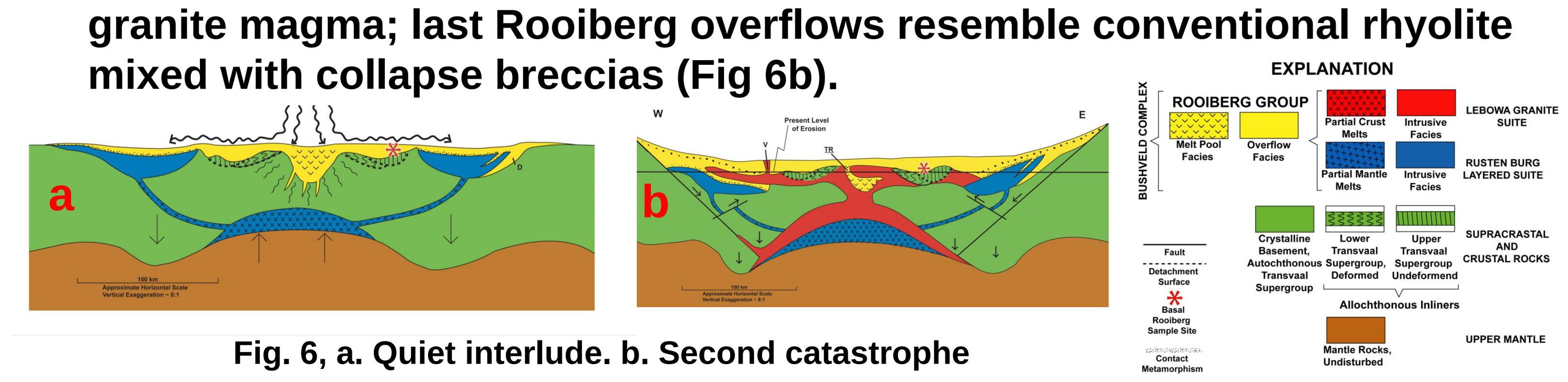

Fig. 6, a. Quiet interlude. b. Second catastrophe

Final Thoughts

The above scenario combines the concepts of mantle plume (popular) and impact (unpopular). It interprets the BIC as an impact structure hiding beneath an larger collapse structure.

References Cited: List furnished by request

Acknowledgments: This project began in 1974, in partnership with the late Rodney C. Rhodes. Logistical support for nine periods of field work since 1985 was generously offered by the University of Pretoria (Profs. von Gruenewaldt, de Waal, Eriksson). This study would have been impossible without field guidance and advice by geologists of far longer Bushveld experience , who soon became friends. D. Twist, J. K. Schweitzer, F. Hartzer. My ever-helpful field assistants and partners were E. G. Deal, M. Caress, T. Manyeruke, J. M. de Mor, and E. L. Tegtmeier. J. M. Williams prepared some of the illustrations for this poster. Finally, the hospitable people of South Africa made every visit a memorable experience.