Central uplift formation in very large impact structures: evidence from the Vredefort dome. C. Lana, R.L. Gibson and W.U. Reimold, Impact Cratering Research Group, School of Geosciences, University of the Witwatersrand, Private Bag 3, P.O. Wits 2050, Johannesburg, South Africa. E-mail: lanac@science.pg.wits.ac.za

Summary: The 80-km-wide Vredefort dome is a deeply eroded remnant of the central uplift of the Vredefort Impact Structure. It exposes upturned Archean to Paleo-proterozoic supracrustal strata and a core of Archean crystalline gneisses that have previously been interpreted as an on-edge profile of the crust and upper mantle. Our structural analysis of the gneisses in the core of the dome indicates that substantial impact-related rotation is restricted to a narrow zone close to the contact with the supracrustal strata and that the rocks responded in an essentially ductile way during doming (no megabreccia development). Furthermore, the strong orientation asymmetry of the supracrustal sequence, which is overturned in the NW sector and moderately steeply dipping in the SE sector, is attributed to symmetric rotation of an originally NW-dipping sequence, rather than asymmetric impact or post-impact tilting. Ductile deformation recorded in the basement complex is essentially Archean and, except for the pseudotachylitic breccias, no other impact-related deformation has been identified. The mechanism of fabric rotation and its relationship with the pseudotachylites are discussed.

Background: It is now widely accepted that large impact events can promote intense modification of deep levels of the Earth's crust. This modification is attributed to gravitational collapse of the unstable bowl-shaped transient crater cavity formed immediately following the impact. The rock movement is believed to occur hydrodynamically, analogous to central jets that rise out of a collapsing cavity in water. This "hydrodynamic collapse" is based on the fact that the strong and quasi-instantaneous ground motions triggered by the collision considerably affect the target rock rheology [1]. The abrupt change in rock property, generally referred to as acoustic fluidization, is attributed to the extreme pressure variations and/or thermal softening caused by the passage of shock waves through the target rocks during the compression and decompression stages [1].

As the effects of "rock fluidization" have yet to be constrained by geological observations, structural effects related to the formation of central uplifts remain one of the most problematic areas in impact cratering studies. This is partly due to lack of exposure of deep levels of most impact structures. Well-documented deep levels of crater basement are, however, extensively exposed in the Vredefort dome, the eroded remnant of the central uplift of the 2.02 Ga Vredefort Impact Structure [2]. The dome comprises an ~80-km-wide roughly circular structural feature with a collar of up to overturned supracrustal strata and an ~40-km-wide core of Archean crystalline basement rocks. The estimated depths of erosion of the crater range between 5-10 km [2]. Previous studies in the core of the dome proposed that formation of the central uplift promoted a complete overturning of the crust in the core of the dome with uniform 110^{o} dips along a NW-SE oriented section and that lower crust and upper mantle are exposed in the center of the dome [3]. This model failed, however, to recognize the three-dimensional space problem related to these complete crustal overturning.

This study: Comprehensive field-based structural mapping of the Archean Basement Complex has been undertaken with the aim of elucidating the structural evolution of these rocks in terms of (a) their Archean tectonometamorphic history, and (b) the 2.02 Ga Vredefort impact event.

Archean deformation events: The basement lithologies record a complex Archean tectonometamorphic history involving four ductile deformation events (D1 to D4). Structures related to the earliest recognizable deformation event (D1) do not have a regional expression. They are only locally preserved due to the intensity of D2, D3 and D4. The D2 and D3 events were synchronous with high-grade metamorphism and migmatisation of the basement lithologies. S2 is generally subhorizontal except at the collar-basement contact where it is vertical with a circular trend, roughly parallel to the collar strata. Steep NW-SE trending D3 shear zones cross cut the D2 fabric in the NW and SE sectors of the dome. The central part of the core is dominated by banded gneisses and migmatites, which display the vertical S3 fabric. A km-wide NE-trending vertical mylonitic shear zone (D4) separates the high-grade migmatites and gneisses from amphibolite-facies greenstone rocks in the SE sector. The mylonitic zone transposes the S2 and S3 structures in the migmatites and greenstone rocks. D1 to D4 are crosscut by the impact-related pseudotachylitic breccias. Field relationships indicate that D1 to D4 predated the deposition of the collar strata [4].

The fabrics are interpreted to relate to polyphase tectonics involving synchronous high-grade metamorphism and melting at 3.1 Ga and are intimately related to major thickening of the craton prior to the deposition of the supracrustal strata [4].

Impact related deformation: Geophysical modeling of the Vredefort Impact Structure [5] indicated a minimum of 9 km of uplift of the collar-basement unconformity. The up- to overturned collar strata and the exposure of mid-crustal granulite-facies gneisses in the central parts of the Archean Basement Complex indicate that deformation related to the impact event caused significant uplift of the Archean crust. Our two-dimensional structural analysis of the dome shows that the fabric attitude across the structure is strongly variable. The collar rocks show a strong orientation asymmetry, with overturning in the NW sector opposed by moderate normal dips in the SE sector. Several explanations for this asymmetry can be considered – (1) oblique impact from the SE; (2) post-impact tilting of an originally symmetric structure; and (3) the collar strata were not horizontal prior to the impact.

We attempted to evaluate these possible explanations by reconstructing the pre-impact orientations of the collar strata and basement fabrics. Although the variation in the orientation of the S2 fabric indicates the geographic extent of rotation effects associated with the formation of the central uplift in the core, the actual amount of rotation is not known. We therefore considered several scenarios in which the fabrics could have been rotated, including rotation of a pre-impact subhorizontal collar-basement unconformity by different amounts in different sectors of the dome and symmetric rotation of non-horizontal collar strata. The best fit was obtained when a uniform 90^o rotation of a shallowly NW-dipping unconformity and supracrustal sequence was made. Results of backrotation of the Archean structures in basement lithologies also indicate that the pre-impact fabric orientations in the central parts of the core of the dome were not affected by the impact event. There is evidence of impact-related rotational strains only in the outer core, where the Archean S2 fabric is subvertical and trends parallel to the strike of the collar strata. The simplistic crustal overturning proposed by geochemical models [3] is, therefore, not consistent with the dips to the dominant fabric, which change to the subhorizontal farther 3-6 km from the collar-basement contact. The attitude of S2 and S3 also creates potential problems for the exposure of the lower and upper mantle rocks, which is, in any case, inconsistent with results of geophysical modeling and metamorphic studies [2].

The continuous distribution of the D2 and D3 fabrics across the entire structure excludes the presence of rotated megablocks in the core of the dome and implies a large-scale ductile response of the Archean crust during the formation of the dome. However, pervasive impact-related ductile features in the outer core of the dome do not exist. The only widespread impact-related feature is the pseudotachylitic breccia vein network, which may have induced strength reduction of the basement lithologies imposed during the extreme impact-related pressure conditions. Several pseudotachylitic breccia networks and veins in excess of 10 cm wide display evidence of enhanced shock effects along their margins, suggesting that these vein networks formed by interference of reflected or refracted shock waves travelling through heterogeneous target rocks.

Although there is no evidence of large offsets along major veins of pseudotachylitic breccia, the small displacements of the basement fabrics along the veins of pseudotachylite suggest that the high-strain deformation was distributed as discrete shear in the pseudotachylite-fracture network.

Conclusions: Ductile fabrics in the core of the Vredefort dome are Archean in age. Deformation related to the impact event caused rotation of the Archean fabrics only in the outer parts of the dome. No evidence of lower crustal and upper mantle rocks has been observed in the center of the dome. The impact probably occurred on moderately NW-dipping supracrustal strata. Structural relationships, linking the block oscillation expected for the so-called acoustic fluidization and the pseudotachylite veins, are not yet constrained. It is quite possible, however, that the effects of rock fluidization are partly expressed as localized slip systems in the widespread pseudotachylite-fracture network.

References: [1] Melosh J., 1989 *Oxford Mon. Geol. and Geophys.* [2] Gibson R.L. and Reimold W.U (2000) *Lect. and notes in Earth Science*, 91, 249-278 [3] Hart R. et al. (1990) *Chem. Geol.,* 82, 21-50; [4] Lana et al. (2003) *Tectonophys.* in press [5] Henkel and Reimold (1998) *Tectonophys. 287, 1-20.*