IMPACT-RELATED STRUCTURES IN THE CENTRAL UPLIFT OF THE VREDEFORT IMPACT STRUCTURE, SOUTH AFRICA. F. Wieland, wielanf@science.pg.wits.ac.za, R.L. Gibson, gibsonr@geosciences.wits.ac.za, and W.U. Reimold, reimoldw@geosciences.wits.ac.za, Impact Cratering Research Group, School of Geosciences, University of the Witwatersrand, Private Bag 3, P.O. Wits 2050, Johannesburg.

Summary: A structural investigation of the well-exposed northern and western parts of the Vredefort dome has established the geometry and chronology of pre-, syn- and post-impact deformation features. The strata display a crude polygonal geometry with zones of complex monoclinal or symmetric folding, and radial oblique-slip faulting separating relatively straight segments. Pseudotachylitic breccia is ubiquitous, but shows a morphological and volumetric correlation with rock type, in addition to an overall decrease in abundance outwards from the center of the dome. Multiple joint sets are intensely developed in all rock types and include sets displaying normal-slip displacements, which are consistent with radial and tangential collapse of the central uplift. These joints may postdate pseudotachylitic breccia veins.

Introduction: The 2.02 Ga, ca. 300-km-wide Vredefort impact structure in South Africa is one of the largest impact structures on Earth [1]. Between 7 and 10 km of erosion has led to the removal of the crater and its impact breccia fill, and has exposed the deep levels of the structure. At the heart of the structure lies the ~80-km-wide Vredefort dome – the root zone of the central uplift. Recent structural mapping in the Archean gneissic basement in the 40-km-wide core of the dome by Lana et al. [2,3,4] has shown differential rotation of the rocks related to doming. Gibson et al. [5] have established that the centralmost parts of this core experienced shock pressures in excess of 30 Gpa, including local shock melting. However, comprehensive structural studies of impact-related deformation effects in the gneisses of the central core terrane are hampered by poor outcrop. In contrast to the core, exposure in the 15-20-km-wide supracrustal-dominated collar of the dome is generally good. The present study is focused on the northern and western sectors of the collar, in rocks of the 2.71-2.98 Ga Witwatersrand Supergroup. These rocks form the innermost collar, at a radial distance of ~20-30 km from the center of the dome, and have been uplifted by at least 15 km relative to the deepest part of the rim syncline [6]. They are, in turn, surrounded by less well-exposed rocks of the Ventersdorp and Transvaal Supergroups.

This study: First results stem from a large-scale structural investigation of available Landsat images and aerial photos of the study area, as well as from surface mapping of several radial traverses across the Witwatersrand Supergroup. The supracrustal rocks show a broadly circular shape on a large-scale view, (although the southern and eastern half of the dome is buried beneath Phanerozoic sediments). However, on a smaller scale, the strata display a polygonal pattern, in which individual segments characterised by relatively uniform subvertical to overturned orientations are separated by narrow zones of monoclinal flexure or folding, and associated radial faulting parallel to the fold axial planes. The largest of these radial faults appear to have sinistral offsets of up to hundreds of meters, although definitive kinematic indicators are lacking. Stratigraphic thickness variations across at least one of these faults indicates that it had a pre-impact history. A prominent set of transverse faults, which are oriented at an oblique angle to the radial faults, shows both dextral and sinistral movements, and may represent a conjugate strike-slip set. Together, the folding and faulting suggest a brittle-ductile response to doming, with the asymmetry of the major structures suggesting an accommodation of the tangential shortening in the manner of an iris-diaphragm.

The bedding of well-exposed, mostly quartzitic, strata is gently to tightly folded on a meter-scale, suggesting further accommodation of tangential compressive stresses. These “curtain-folds” may display a crude axial planar fracture cleavage marked by millimeter- to centimeter-wide veinlets of pseudotachylitic breccia.

On an outcrop-scale, the fracture pattern is complex. At least four different orientations of faults and fractures have been observed:

- a radial set of subvertical joints,
- a bedding-parallel set,
- a shallowly outward-dipping set, and
- an oblique radial joint set dipping at an angle up to 45° to the subvertical radial joints.

The joint density increases towards the traces of large-scale faults. The most prominent set represents the radial joints, which display small strike-slip offsets. The bedding-parallel joints appear to be extensional, with slickenside surfaces indicating a normal dip-slip character. They are listric in places, dipping towards the center of the dome. The outwards-dipping joints also display striated surfaces and a normal sense of slip, displacing the hanging-wall outwards. Due to the character of the exposures, the slip magnitude is not clear, but it appears to be on the millimeter- to centimeter-scale.

Pseudotachylitic breccias are ubiquitous in the collar rocks. Most commonly, they are found along bedding planes where they reach centimeters in width and sometimes can be traced for many hundreds of meters, but they also occur oblique and perpendicular to the strike of the bedding. The abundance of pseudotachylitic breccia appears to increase towards fault and fold structures, and, in places, is especially prominent in the hinge zones of large-scale (hundreds of meters) folds. Thinly-bedded pelitic sediments typically display pseudotachylitic breccia vein-fracture networks with a fracture spacing of centimeters to a few tens of centimeters. Vein thicknesses increase to up to 10-20 cm along the contacts between more massive meta-diabase sills (where some meter-wide pods or network breccias have also been observed) and quartzite or shale.

The most frequent occurrences of pseudotachylitic breccia are found parallel to the bedding in submillimeter to centimeter wide veins. Although evidence of displacement along these veins is generally lacking, in a few cases the veins display en echelon tension gashes as well as displacements of up to several centimeters in a sinistral and/or dextral sense.

In general, the intensity of faulting, folding, jointing and pseudotachylite veining decreases radially outwards.

Shatter cones are present throughout the collar and show two general orientations: prominent partial cone fractures are commonly found on bedding planes, but random orientations of apices are also frequently observed at numerous localities. The distribution of shatter cones seems to be related to different rock types, as there is a relative abundance of shatter cones in the rocks in the outer parts of the collar, and fine-grained argillitic rocks are preferred strata for high-abundance development of shatter cones and related fractures. More detailed field and sample-based studies of this fracture phenomenon will be carried out in due course.

Discussion: Analysis of the initial results from the regional and field mapping suggests that the formation of the Vredefort central uplift involved partitioning of strain into radial zones of high strain. Although the zones are arranged at angles of ~30-45° to one-another, at least one of these zones appears to represent a reactivated pre-impact fault. The consistent sinistral asymmetry of these large-scale zones may reflect development of the central uplift in a target sequence with a pre-existing northwesterly dip; however, more work is required on this issue. Whilst the large-scale features are consistent with tangential shortening associated with the initial formation of the central uplift, most of the small-scale joints appear to be related to radial extension, which most likely occurred during the collapse of the central uplift. It is probable that this collapse triggered the radial compression in the surrounding rim syncline noted by Simpson [7,8], indicating a complex distribution of stresses within the crater basement. The temporal relationships between these features and the large-scale fold-and-thrust features described by Brink et al. [9,10,11] from the outer parts of the rim syncline are, however, not well established, especially as Killick [12] inferred inward-directed extensional collapse along major faults in this region to generate the voluminous pseudotachylitic breccias visible in the goldfields.

The timing of pseudotachylitic breccia development remains enigmatic. In recent studies, Gibson and Reimold [13] and Dressler and Reimold [14] proposed a shock origin for the bulk of the breccias. Given the features observed in the present study, it is possible that shock-generated veins might not have quenched prior to the onset of the crater modification phase and, thus, could have been mobilized into younger fractures. Alternatively, however, some of the breccias may have a non-shock origin, as has been suggested by workers such as Martini [15].

Conclusions: Brittle and ductile structural features in the collar rocks of the Vredefort dome can be related to different stages in the formation of the Vredefort impact structure. Mesoscopic shock-related features include shatter cones and (at least some) pseudotachylitic breccias. Large- and small-scale subvertical folds and radial and transverse faults appear to be related to the initial formation of the central uplift, with more shallowly-dipping fractures linked to subsequent radial and tangential collapse.

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