WHAT IS THE VREDEFORT DOME TEACHING US ABOUT THE SEARCH FOR OTHER ERODED LARGE IMPACT STRUCTURES? Roger L. Gibson, School of Geosciences, University of the Witwatersrand, PO WITS, Johannesburg 2050, South Africa; roger.gibson@wits.ac.za.

Introduction: Vredefort has long been held to be the oldest, largest and most deeply exhumed impact structure on Earth; however, in recent years its pre-eminence in all three aspects has been challenged. Evaluating the scientific debate around the claims of the challengers [1,2,3] to these titles invokes a sense of déjà vu when one considers the decades-long history of debate about whether Vredefort itself originated by impact. This presentation briefly reviews the debate around the impact-related features in the Vredefort Dome, with the main focus being the extent and intensity of impact-induced thermal effects that play a significant role in masking potential diagnostic features.

Size isn't everything: Although it is generally listed as the largest terrestrial impact structure, at 250-300 km diameter (see [4] and references therein), the original limits of the Vredefort crater have been obliterated by up to 10 km of subsequent erosion; in fact, size estimates range much more widely (from 340 km to 170 km) [4]. The commonly accepted range is based on an assumption that the central uplift diameter (80-90 km) should be approximately one-third of the diameter of the final crater; however, such norms are typically based on surface measurements of uneroded craters rather than deep profiles. Moreover, [5] suggested that large central uplifts may act in a far more fluid manner, collapsing outwards to occupy considerably more of the crater than originally thought. Given that a central uplift should typically widen both upwards and downwards, size estimates based on its diameter are strongly dependent on the depth of post-impact erosion, raising further uncertainty about final diameter.

Use of the limits of the Witwatersrand Basin as a constraint on the original crater diameter lacks substantiation. Whilst the downwarping in the rim syncline surrounding the Vredefort Dome played a major role in enhancing the basin a significant part of the basin, bona fide impact-related structures (faults, folds) have yet to be confirmed beyond the axis of the syncline. Large impacts affect significant thicknesses of the crust, which inevitably means that they interact with rocks covering a wide age range. This means that at least the older rocks are likely to contain pre-impact tectonic features. The Vredefort impact affected rocks ranging in age from 3400 Ma to 2060 Ma, all of which show significant tectonic disturbance. One of the results of this has been the recognition that significant amounts of the pseudotachylite found in the Witwatersrand Basin may have formed along pre-impact faults, ergo, the extent of these breccias cannot be used as an indicator of the original limits of the impact structure.

With at least half the vertical extent of continental crust typically being crystalline, a major problem may arise with trying to identify central uplifts on lithological or geophysical grounds; and traces of the wider crater dimensions are even less likely to be defined.

Age: The 2020 ± 5 Ma age of the Vredefort impact is based on U-Pb single-zircon geochronology of a variety of melt types. Dating of igneous zircons from the impact-melt rock has been complemented by others from voluminous pseudotachylitic breccias from the central parts of the Dome [6], as well as granitic anatectic melt formed as a result of impact heating [7]. Evidence of 'mantle decompression melt' [8] or 'foliated impact melt' [9] in the central parts of the Dome that contain zircons of impact age is equivocal, and does not consider the effects of anomalous ultrahigh-T post-impact metamorphism on pre-impact lithologies and its effects on both the crystallization and subsequent recrystallisation of pseudotachylitic breccias. Recent studies of detrital zircon populations from the Dome [10] have reinforced that even an impact the size of Vredefort did not induce substantive resetting of U-Pb systematics in pre-impact zircons. Even in melt-rocks, the overwhelming majority of zircons appear to be inherited from the precursor rocks. Vredefort provides salutary lessons in using discordant zircons to infer both the age of impact and precursor rock ages.

Impact-diagnostic features (or not): The first unusual features to be identified in the Vredefort Dome that are now unequivocally linked to the impact were melt rocks - *"pseudotachylyte"* and the *Granophyre* (impact-melt rock). However, pseudotachlite is not unique to impacts, and the exact genesis of the breccias in the Vredefort Dome remains contested, with evidence for both shock and friction melting being described [4]. The rarer dykes of impact-melt rock have a unique, reportedly homogeneous, bulk composition, including a 0.2% isotopic trace of a meteorite component; however, more recent studies have suggested significant evidence of in situ wallrock clast populations that may warrant re-evaluation of some of these diagnostic criteria. Evidence of fractionation of large impact-melt sheets may also contribute to impact-melt compositional variability. The variable composition of meteorites themselves may preclude being able to identify an extraterrestrial chemical component.

Shatter cone features were first identified in the Dome by [11]; however, few true cones have been described – in most cases the "cones" are actually parabolic surfaces with consistently converging striations; these may grade into curviplanar surfaces with misoriented domains each comprising sets of parallel striations that could equally be slip surfaces. Confirmed shatter cone features in the Dome are also restricted to a fairly narrow domain less than 10 km wide in which appropriate fine-grained rock types are found – most of the Dome's rocks are either texturally inappropriate for, or experienced shock pressures incompatible with, shatter cone development [4].

Microscopic evidence of shock in the Vredefort Dome (*PDF* in quartz, zircon; *coesite* ± *stishovite*; shock cleavage in garnet) is more ubiquitous than other features; once again, however, the significant depth of erosion means that it is restricted to only the innermost 10% by radius of the original crater extent [4]. In part this may reflect the distribution of non-quartz-bearing rocks, but it reinforces that identifying eroded impact structures needs to concentrate on only the innermost parts of the structure. Even then, as recent debates have shown, high residual heat following the shock acts against unequivocal identification of shock glass and PDF in the inner parts of the structure [12].

Depth of erosion and the metamorphic conundrum: [1] have recently proposed that the so-called Maniitsoq structure represents the remnant of an impact that has been eroded by almost 25 km. Arguably the greatest stumbling block to universal acceptance of an impact origin for the Vredefort Dome was the assumption that impact would not significantly disturb the thermal structure of the target on time scales compatible with conventional metamorphism (several hundreds of thousands to millions of years). The seeds of this revolution, sown by [13,14], and confirmed by modelling [5], led to a re-appraisal of many of the impact-related features of the Dome. The challenge, however, remains how to see through the metamorphic overprint that seeks to obliterate shock features via recrystallization and/or metamorphic reactions and even melting, and which may enhance plasticity within the rocks that, in turn, might alter key features such as PDF. The Vredefort Dome provides several lessons for the identification of deep levels beneath large impacts, the first of which is that the extent to which impact-induced thermal effects dominate over more conventional shock features appears to be relatively small – in the Dome, the so-called *granofels zone* [12] comprises < 10% of the central uplift diameter. The second is that associating high levels of shock in the central parts of the structure with enhanced mineral- or rock-scale brecciation is unfounded. In fact, the opposite is true in the Dome - mesoscopic breccias actually appear to decrease in abundance and volume in rocks in which a major constituent (feldspar) is capable of absorbing considerable shock compression by forming glass. Third, plasticity is enhanced in rocks that remain close to their solidus T for several-hundred-thousand years after impact; however, clear textural indicators of the unusual origin of the metamorphism remain – new foliations are not formed and grain size is two or more orders of magnitude smaller than conventional metamorphic textures; furthermore, where appropriate bulk compositions occur, mineral assemblages are consistent with conditions in the upper part of the ultra-high-T spectrum. Finally, more so than shock effects, which are notoriously heterogeneous, impact-induced thermal effects show a smooth bullseye progression towards the centre of the structure with both an exceptional horizontal thermal gradient and exceptional maximum T without any sign of a magmatic heat source.

Conclusions: The history of investigation into the Vredefort Dome provides numerous salutary lessons for those searching for other large, deeply eroded, impact structures. The Dome is sufficiently deeply eroded to demonstrate the strong centripetal thermal effects that overprint the impact shock effects, but not too deep that the shock effects are obliterated or that the well-layered upper crust that helps to define the telltale concentric lithological and geophysical character of the central uplift has been lost; it also demonstrates that shock features may owe their origin as much to the types of lithologies found in different parts of the structure as to the actual shock pressures; finally, the evidence in the Dome indicates that diagnostic shock and thermal effects are highly restricted in extent, making the chances of discovery even smaller. Whilst larger, more deeply eroded, impact structures might be better capable of generating datable melts, the chances are that shock-diagnostic features may prove more difficult to find in such cases.

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