HOW LOW CAN CRATERS GO? TESTING THE MAXIMUM IDENTIFIABLE DEPTH OF ERODED IMPACT CRATERS AT THE VREDEFORT IMPACT STRUCTURE.

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Introduction: Although impact cratering is a fundamental process of the Solar System, occurring since the earliest moments of planetary formation, the record of impact structures on Earth only extends back to 2.2 Ga [1]. Geological processes on the surface of the Earth are known to remove impact craters over time, principally through processes of plate tectonics and erosion. Identification of Archean impact craters would require that the crater survive these processes, possibly by deep burial prior to erosion, and remain identifiable to researchers. A possible way to identify buried craters would be geophysical characteristics.

The geophysical characteristics of craters on Earth are controlled by physical changes that occur when target rocks are damaged by the passage of the shockwave and subsequent deformation during the cratering process [2]. For example, recent observations of the upper portions of the intact peak ring of the Chicxulub impact structure (IODP/ICDP Expedition 364 drill core [3]) demonstrated a significant increase in porosity as well as a decrease in density and sonic velocity.

Alteration of physical properties can create gravity anomalies whose extension and magnitude increase with the size of the impact structure [2]. On Earth, such changes are predicted to not extend below ca. 10 km depth. If this is the case, then there should be no observable difference in physical properties to the rocks below this depth.

The Vredefort impact structure, South Africa, is the remnant of one of the largest impact structures in the world [4] (Fig. 1). The structure is estimated to have eroded 8-10 km [5] in the last 2.02 Ga [6], thereby providing an ideal test case of the deep architecture within the central uplift of a large impact basin.

In this study, we examine a cross-section through the basement rocks of the Vredefort impact structure to determine the depth extent to which physical changes occur in a large impact basin.

Methods: A profile of 11 samples were collected from the crystalline basement of the Vredefort structure, starting at the Inlandsee (the approximate center of the structure), and extending 21.5 km to the NW to the Kopjeskraal farm. The samples consist of a variety of granitoids of the TTG suite.

The samples were processed by the Core Laboratories company in Houston, TX, USA, for ultrasonic velocities (V_p and V_s) and porosities, measured by the pulse-transmission and Boyle's Law method, respectively. Point counting results of mineral abundances were used with a Voigt-Reuss-Hill average rock physics model to determine theoretically expected values of P and S wave velocities for our samples and and 5 reference granitic rocks.

The iSALE shock physics code [7] was used to simulate the Vredefort event. Input parameters were based on [8], with the addition of a dilatancy model [9] to predict changes in target porosity. South African gravity data were obtained from the Council for Geoscience.

Results: The results of the measured physical properties are summarized in Fig. 2. The porosity of the samples ranges from 0.23 to 1.20%. The porosities of the reference samples are all <2%. For comparison, the porosities of granites from the Chicxulub peak ring are up to 10% [3]. The V_p of the Vredefort samples ranges from 5.17 to 6.09 km/s. The V_p of the reference samples are 3.95 to 4.95 km/s. The average V_p of Chicxulub samples is 4.10 [3]. When corrected for mineralogical content, the calculated V_p of Vredefort, and reference samples are similar for two reference samples, but higher than the other reference samples or the Chicxulub sample. The V_s of the samples ranges from 3.14 to 3.59 km/s. The V_s of the reference samples range from 2.37 to 3.00. The average V_s of Chicxulub samples is 2.37 [3]. When corrected, the calculated V_s of Vredefort are similar to two reference samples, but higher than other reference samples or the Chicxulub sample.

The iSALE modeling shows a maximum increase of 4.5% in porosity in the supracrustal rocks at 8-10 km depth, but the core crystalline rocks would experience <0.4% porosity increase (Fig. 3).

The Bouguer gravity anomaly of the Vredefort structure has a maximum of -95 mGal, with a broad peak of 37 km diameter. The lowest anomaly is -130 mGal. At the same time, the gravity anomalies over the Kaapvaal craton range from -30 mGal to -180 mGal.

Discussion: The Vredefort and Chicxulub impact structures represent remnants of two of the three largest known impact structures. These structures provide two different views of a large impact structure, with Chicxulub preserving the uppermost portions, and

Vredefort preserving a deep transect. Comparison of the results of the Vredefort transect with samples from Chicxulub and unshocked reference samples demonstrates that the basement rocks of Vredefort are geophysically indistinguishable from unshocked basement rocks, and are quite unlike the highly shocked peak ring rocks from Chicxulub. Accordingly, numerical simulations predict little change at such depths. It is likely that re-equilibration and metamorphism at depth would have had the effect of closing any newly opened pore space that also may have affected velocities.

The physical properties of the samples from the transect do not correspond to increases or decreases in the Vredefort gravity anomaly. The magnitude of the gravity anomaly is not significant, particularly when compared to the surrounding Kaapvaal craton. If there were no surface exposure of Vredefort, it is unlikely that it would be possible to identify the structure as being impact related.

Vredefort has not yet been totally removed from the geological record. Present outcrops preserve high-pressure polymorphs of minerals, shocked quartz, and shocked zircon [e.g., 10], but the shock features are most easily identifiable within the impact melt dikes. Impact melt dikes at Vredefort have been shown to have a maximum depth detent extending <10 m below the present surface [11].

Based on our findings, even the largest impact structures are unlikely to be preserved in the geological record if eroded by >10 km. A modest average crustal erosion rate of 5 m/Ma would result in 10 km of erosion within 2 Gys. Any preserved impact structure significantly older than 2 Ga must have experienced unusual preservation.

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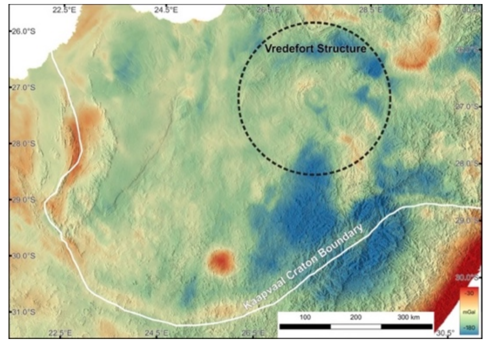

Figure 1: Gravity map of the Kaapvaal Craton with the position of the Vredefort structure outlined. Note that the magnitude of the Vredefort structure is lower than the surrounding areas of the Kaapvaal Craton.

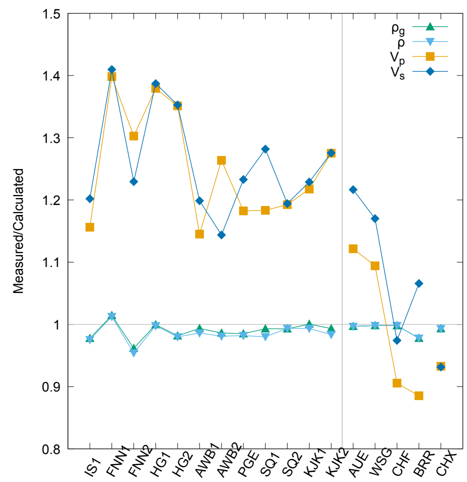

Figure 2: Measured values of density, porosity, and ultrasonic velocity normalized to the theoretical values. Reference samples AUE=Aue granite; WSG=Westerly granite; CHF=Chelmsford granite; BRR=Barre granite; CHX=Chicxulub.

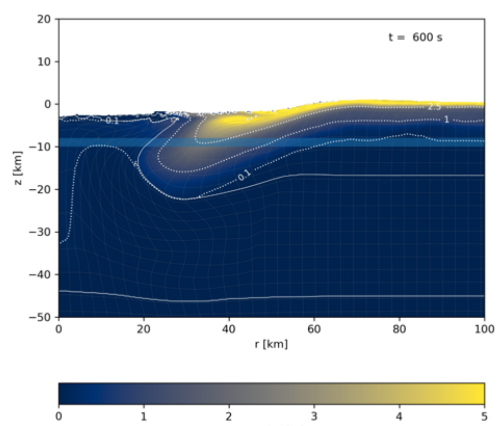

Figure 3: Last step of iSALE simulation showing porosity increase due to the Vredefort impact and the 8-10 km erosional level (light-blue line).