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GEOLOGICAL INDICATORS FOR IMPACT - THE ANOMALOUS CASE OF THE VREDEFORT STRUCTURE, SOUTH AFRICA.

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The Vredefort Dome is located within and almost central to the Witwatersrand basin in its presently known extent. It exposes a central Archean granite core (some 45 km in diameter) which is surrounded by a collar of supracrustal rocks. These collar rocks outline a strong polygonal geometry. The Archean core is comprised of two concentric zones, the Outer Granite Gneiss (OGG), and the more central Inlandsee Leucogranofels (ILG). The rocks of the inner core display granulite facies metamorphism, whilst the OGG is in amphibolite facies. The inner core is believed from recent drill hole information to be underlain by mafic and ultramafic gneisses (1), the extent of which cannot be assessed at present. A fairly broad zone of charnockites seperates the OGG and ILG domains (1). This zone is characterised by a high concentration of pseudotachylite and ductile shearing (2,19). Whereas a number of other domical structures are located within or surrounding the Witwatersrand basin, the Vredefort structure is anomalous, in that it has: **(a)** a partly polygonal geometry; **(b)** extensive alkali intrusives in the northwestern sector; **(c)** granophyre dykes (ring-dykes peripheral to the contact collar-basement and NW-SE or NE-SW trending dykes within the Archean basement); **(d)** contact metamorphism of the collar supracrustal rocks; **(e)** the overturning of collar supracrustals in the northern sectors; **(f)** deformation phenomena widely regarded as representing shock metamorphism (pseudotachylite, (sub)planar microdeformation features in quartz (cf. (3)), shatter cones and occurences of high-P quartz polymorphs); **(g)** a positive 30 mgal gravity anomaly; and **(h)** high amplitude magnetic anomalies. We attempt here to summarise recent geophysical, structural and petrological evidence pertinent for the identification of the processes that led to the formation of the Vredefort structure.

The explicit <u>geophysical expression</u> of the Vredefort structure is that of a positive concentric (bulls-eye) Bouguer gravity anomaly (Fig.1) indicating the presence of excess mass below and central to the structure. Also, a ring-like distribution of complementary high amplitude magnetic anomalies is present, the centre of which is coincident with both the gravity response and the structure (Fig.2). Geophysical signatures of possible impact craters display weak, or more commonly pronounced negative gravity signatures (4, 5, 6). Their magnetic signatures may be variable. The mass deficit is attributed to pervasive brecciation (re crater fill and basement) and microfracturing. In contrast, large intraplate volcanoes are recorded to have geophysical signatures similar to that at Vredefort, namely strong positive bulls-eye gravity anomalies (20 - 70 mgal) with or without complementary magnetic signatures (7). The gravity anomaly is caused by a dense intrusive complex in the root zone. These structures have radial symmetry and the intrusive complex can vary in composition from ultrabasic to felsic.

<u>**Fig.1**</u>

<u>**Fig.2**</u>

<u>Fig.1:</u> Bouguer gravity pixel map and <u>Fig.2:</u> Total field magnetic pixel map, over the Vredefort structure. Grey scales represent, respectively, a range of values from black to white of: -160 to -90 mgal (gravity field) and -500 to +500 nT (magnetic field); scale: 1cm is approximately 33km.

Detailed mapping within the Archean basement revealed that the basement structure is essentially that of the pre-3.0 AE Archean basement (8,9). In addition there is scarce evidence for a later phase of subvertical shearing (at 2.0-2.25 AE?) (8). No radial structural elements are present (9).

The observation of <u>coesite and stishovite</u> associated with pseudotachylite in two samples of Kimberly-Elsburg quartzite from the NE collar (10) is widely regarded as ultimate proof for impact genesis of the Vredefort structure. As (10) pointed out, both mineral phases form unusually large crystals in comparison with occurences from known impact structures. In order to preserve metastable stishovite immediate cooling to $T \leq 250°$ C (11) would be required at the time of a possible shock event. However, one could consider the possibility that the stability fields of coesite and stishovite (especially of SiO_2 HP-polymorphs <u>and</u> fused quartz, a paragenesis which seems to lower the stishovite formation pressure (12)) could have been entered due to local increases in P, T, and strain rate by tectonic processes acting in an already low-grade (greenschist facies) metamorphic environment. Metastable stishovite could possibly be frozen-in-state by immediate dissipation of friction heat from mm-cm wide pseudotachylite zones.

Shatter cones are very prominent at Vredefort. However (13) showed that these cones are intimately related to Multipli-Striated Joint Sets (MSJS) cutting across collar and basement rocks in a number of different orientations. Such joint surfaces generally are striated. Apices of striation sets may point into different directions along one joint. At intersections of MSJS of different orientations cone-like striated features can be formed. Further investigations have to show whether this phenomenon requires formation by shock wave propagation, or can be achieved by brittle tectonic deformation. These striated fracture surfaces closely resemble fast-fracture phenomena, widely described in the metallurgical or ceramic literature. Striated cones have been observed in the northern Witwatersrand basin more than 70 km from the centre of the Vredefort Dome. Structural work (8) showed that formation of MSJS postdates the upturning of the collar.

Pseudotachylite (pt) from Vredefort has been interpreted as shock-produced breccia (14). The following observations with respect to Vredefort pt were made in recent years: **(a)** more than one generation of pt can be observed in Vredefort rocks (15, 16), and more than two breccia (pt or mylonite) generations can be observed in the Witwatersrand basin (15, 17); **(b)** major pt occurences are concentrated along the transition zone (19) between OGG and ILG, and close to the contact between collar and basement; **(c)** there is no radial pattern of pt occurences, nor any increase of pt volume towards the centre of the structure; the only confirmed impact structure of marked pt volume - the Roter Kamm crater (18) - exhibits major pt occurences in radial or rim-parallel orientation; **(d)** the distribution of pt in the Witwatersrand basin is asymmetrical (15, 17) with major occurences in the N and NW portions, none in the East Rand and only limited (<1cm veins) pt or mylonite occurences in the S and SW; **(e)** orientations of pt veins and dykes in the Vredefort structure follow the regional structural trends (19,9); **(f)** occurences of pt in the Witwatersrand basin are associated with major faults, bedding faults and shears (15,17,20); **(h)** ^{40}Ar-^{39}Ar ages ranging from 1.1-2.2 AE (21) suggest that there were several phases of pt formation at Vredefort (cf. (a)). Recent Rb-Sr isotope analyses of biotite and feldspar from Vredefort rocks (some in contact with "young" pt) yielded ages of $\geq$ 2.0 AE, which is in direct opposition to the criticism (Hargraves, pers. comm.) that post-Vredefort thermal events could have caused local resetting of pt at times since ca 1.95 AE ago.

In the light of the above results and bearing the microtextural evidence (3) in mind, it could be concluded that tectonism (8,9,17) perhaps in conjunction with rapid uplift (22) could have caused the Vredefort structure rather than a single catastrophic, central shock event. Although we provide contra-indications to "shock phenomena", observations of some ground accelerations in the near-field region of earthquake faults are suggested to be due to localised Mach-waves (hence, shock-waves) (23,24). Thus, shock events of tectonic origins are possible and must not be discounted. In addition, Vredefort's geophysical signatures, particularly the gravity, are an exception from observations made over other cryptoexplosion structures. The argument for a deeply eroded readjusted impact site necessitates a large impact crater where the ring synclinorium is within the size of the Wiwatersrand basin (25). The geophysical evidence suggests that Vredefort conforms more readily with signatures observed over large intrusive complexes. Without reflection seismic profiles accross the Dome and drilling information it will be difficult to determine the deep structure of the Vredefort Dome.

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