ORIGINAL SIZE OF THE VREDEFORT STRUCTURE, SOUTH AFRICA; A.M. Therriault,[1,2] A.M. Reid,[1] and W.U. Reimold;[3] [1]Department of Geosciences, University of Houston, Houston, TX 77204, USA; [2]presently at: Department of Geology, McMaster University, Hamilton, Ontario, L8S 4M1, Canada; [3]Economic Geology Research Unit, at the Department of Geology, University of the Witwatersrand, P.O. Wits 2050, Johannesburg, South Africa.

The Vredefort structure is located approximately 120 km southwest of Johannesburg, South Africa, and is deeply eroded. Controversies remain on the origin of this structure with the most popular hypotheses being: 1) by impact cratering about 2.0 Ga,[e.g., 1,2,3] 2) as a cryptoexplosion structure about 2.0 Ga,[e.g., 4,5] and 3) by purely tectonic processes starting at about 3.0 Ga and ending with the Vredefort event at 2.0 Ga.[6,7] In view of recent work in which the granophyre dikes are interpreted as the erosional remants of a more extensive impact melt sheet, injected downward into the underlying country rocks,[8,9] the impact origin hypothesis for Vredefort is here adopted.

In order to estimate the original dimensions of the Vredefort impact structure, it is assumed that the structure was initially circular, that its predeformation center corresponds to the center of the granitic core, and that the pre-Vredefort geology of the area prior to approximately 2.0 Ga ago is as suggested by Fletcher and Reimold,[10] Figure 4, p.229.

The spatial relationship between shock metamorphic effects, the shock pressures they record, and the morphological features of the crater have been established for a number of large terrestrial craters.[e.g., 11,12,13,14,15] The principles of crater formation at large complex impact structures, comparable in size to Vredefort, have also been established, although many details remain unresolved.[e.g., 16,17] An important conclusion is that the transient crater, which is formed directly by excavation and displacement by the shock-induced cratering flow-field (i.e., the particle velocity flow field existing in the region of the transient crater but behind the initial outgoing shock front), is highly modified during the late stage processes. The original transient crater diameter lies well within the final rim of the crater, which is established by structural movements during late-stage cavity modification.

Using current knowledge of impact cratering processes and following a treatment similar to that given by Grieve and co-workers[18] for the Sudbury Structure, an estimate of the transient crater diameter of the Vredefort structure can be made using the radial position of shock metamorphic effects and the location of outliers of the Transvaal cover rocks at Vredefort. Correction for the large amount of erosion implied over the Vredefort area, larger than at most other terrestrial impact structures, is added to the transient crater dimensions estimated.

At Vredefort, the present location of the limit of shatter cone formation at 26-37 km from the outer edge of the granitic core suggests a transient cavity diameter, at the present level of erosion, of 92-114 km (Table I). Shock-produced microscopic planar features in quartz occur out to a distance of about 13 km from the edge of the core.[3] The outermost planar features developed at Vredefort record shock pressures of at least 6 GPa, according to. Grieve and co-workers.[3] Shock pressures in this range occur at approximately 0.7 the radius of the transient cavity.[19] This would yield an estimate of about 94 km for the diameter of the transient crater at Vredefort, at the present level of erosion (Table I). The outliers of downfaulted Transvaal sediments north of the Vredefort structure[20] also provide a constraint on transient crater dimensions. In eroded complex craters, such as Manicouagan, West Clearwater and Charlevoix, outliers of original cover rocks occur outside the transient crater rim but within the final structural rim. The downfaulted outliers of Transvaal rocks occur at 50-60 km from the outer edge of the granitic core and give an estimated transient crater rim diameter of less than 140-160 km (Table I).

These three spatial estimates constrain the original diameter of the transient crater of the Vredefort structure between 114-140 km (Table I) at the level of present erosion. The final rim diameter of the Vredefort crater, using the same approach as Grieve and co-workers employed to reconstruct the original dimensions of the Sudbury Structure,[18] is then calculated to be 175-280 km, for the present level of erosion (Table II).

McCarthy and co-workers[20] estimated erosional depth of the Vredefort structure at between 5 and 10 km. The estimate of about 8 km of erosion above Vredefort, based on the impact cratering model described in the accompanying paper,[21] thus appears to be reasonable. Using this latter estimate, an additional 8 km of crust above the present level of erosion at Vredefort is worked into the calculations and yields an adjusted estimated transient cavity diameter of about 125-150 km and an adjusted final crater diameter of 192-300 km (Table I and II).

An impact structure of this size would have a complex, probably multiring form.[22] Complex impact structures are characterized by uplifted target rocks in their central areas. The occurrence of an apparent dome of granitic rocks in the core of the Vredefort structure, about 40-56 km in diameter, and representing a 36 km section of crustal rocks[23] is in agreement with uplifting of the target rocks. The exposure of granulite facies rocks, and thus rocks from considerable depths, in the center of the core is expected from the suggested size of the Vredefort structure. Using the relation $D_{cp} = 0.22\ D$,[24] where D_{cp} is the diameter of the central peak, the final crater diameter (D) of the Vredefort structure is estimated to have been 180-255 km at the present level of erosion. After adjustment for the amount of erosion that has occurred over the Vredefort area, these latter values are in agreement with the previous estimates of 192-300 km for the final crater diameter of the Vredefort structure. A maximum structural uplift (SU) of 20-32 km for a structure like Vredefort is determined using the relation $SU = 0.06\ D^{1.1}$,[25] where D is the final crater diameter and units are in kilometers, here D = 192-300 km. This estimated uplift is

in agreement with Hart and co-workers[23] who found that the overturned section of crystalline basement is approximately 25 km thick.

Recently, modeled gravity profiles across the Vredefort Dome have been interpreted to indicate a 100 km wide uplift,[26] which is about twice the diameter of the core of the Vredefort structure. Using this value for D_{cp} in the equation $D_{cp} = 0.22$ D, the final crater diameter of the Vredefort structure would be estimated at 455 km. This latter diameter estimate, although perhaps too high, would indicate that the high-end values of our 192-300 km estimates best represent the final crater diameter of the Vredefort structure about 2.0 Ga ago.

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Table I: Estimates of the diameter of the transient cavity (D_{tc}) of the Vredefort structure, South Africa.

Observation	Max. radial distance from the outer edge of the core, km	Constraint from other structures	Estimated D_{tc}, km
Shatter cones	26-37	$< D_{tc}$	92-114
Planar deformation features in quartz	13	$0.7D_{tc}$	94
Transvaal outliers	50-60	$> D_{tc}$	140-160

Table II: Estimates of the diameter of the final crater rim (D) of the Vredefort structure, South Africa.

Relationship	Source	Estimated D, km
$D_{tc} = 0.5\text{-}0.65\ D$	Grieve et al., 1981[24]	175-300
$D_{tc} = 1.23\ D^{0.85}$	Croft, 1985[27]	206-285
$D_{tc} = 0.57\ D$	Lakomy, 1990[12]	200-263

For D_{tc} = 114-150 km