THE CHÁRNOCKITIC ROCKS OF THE SAND-COVERED MOROKWENG IMPACT STRUCTURE,
SOUTHERN KALAHARI, SOUTH AFRICA: EVIDENCE FOR A POSSIBLE IMPACT MELT ORIGIN.

Marco A.G. Andreoli1,2, Lewis D. Ashwal3, Rodger J. Hart4 and Marianne Tredoux5.
1Atomic Energy Corporation of S. Africa, P.O. Box 582, Pretoria, 0001, S. Africa; 2Schenland Research Centre, University of the Witwatersrand, P.O. Box 3, Wits, 2050, S. Africa; 3Department of Geology, Rand Afrikaans University, P.O. Box 524, Auckland Park, 2060, S. Africa; 5Department of Geological Sciences, University of Cape Town, Private Bag, Rondebosch, 7700, S. Africa

The recently discovered Morokweng Impact Structure (MIS) is located in the North West Province of South Africa, about 140 km NW of Vryburg and 100 km south of the Botswana border (Andreoli et al., 1995). Although entirely buried by Phanerozoic sediments, the MIS was recognized by examining cores from five boreholes drilled in a circular airborne magnetic anomaly, previously interpreted as a plug-like intrusion (Corner, 1991). The MIS apparently consists of an eroded, multi-ring crater with an original diameter probably in excess of 70 km and an approximate age of -1.4 ± 0.2 Ga (Andreoli et al., 1995). The core of the structure hosts a texturally complex, sheet-like body (diameter ~30 km, maximum thickness ~120 m) of weakly differentiated plutonic rocks ranging from charnockite and charnoenderbite to quartz-norite. Here we report how multiple intrusive pulses, incipient fractionation, frequency of clasts, anomalous Ir, Ni, Cr contents, and disseminated Ni-rich spinels/oxides may be explained by impact melting of target rocks and a relatively protracted cooling history.

The MIS is located in the northwestern sector of the Kaapvaal Craton, close to the centre of a broad (D ~350 km), ring-like circular uplift of Late Archaean granites and greenstone belts known as the Ganyesa dome (Beukes, 1987; Andreoli et al., 1995). Because the MIS is shifted 30 km west of the centre of this "dome", and because the entire area is largely buried beneath Permian to Recent Karoo and Kalahari deposits, the relationship between these two structures remains uncertain (Andreoli et al., 1995). The thickness of the Late Palaeozoic to Recent cover above the MIS ranges from a minimum of ~15 m near the centre, to a maximum of 240 m along the Pre-Kalahari palaeovalleys at its flanks (Smit, 1974).

The cores display numerous examples of cross-cutting relations between at least four successive "pulses" of hypersthene-bearing granitoids (charnoenderbites). These "pulses" differ from each other in terms of: grain size (pegmatitic, coarse grained, fine grained); composition (hematite-granite, charnockite, charnoenderbite, quartz norite); degree of homogeneity (homogeneous, hybrid); and distribution of inclusions. Only one borehole reached the Archaean granite basement, against which the charnoenderbite developed a chilled contact; the other four boreholes were stopped above this contact. The Archaean granite basement is extensively annealed and cut by breccia and pseudotachylite veins, and the shock metamorphic features in quartz and feldspars are partly obliterated (Andreoli et al., 1995).

The igneous rocks of the MIS are characterized by plagioclase, quartz, K-feldspar, appreciable (>5 percent) orthopyroxene, and subordinate clinopyroxene. Because of this mineralogy, the rocks should be generally referred as charnoenderbites. Original opaque minerals included oxides such as Fe-spinels of the trevorite-magnetite series (NiO 4-25 wt. %), ilmenite (roughly in subequal amounts), and traces of a yet-undefined oxide with 70% NiO. Red-brown biotite is present in all samples, but is a secondary replacement product after pyroxenes. Other secondary minerals in a few specimens include brown amphibole and serpentine. Although there is considerable variability in grain size within and between the rocks examined, the bulk of the intrusion contains plagioclase crystals that average between 0.6 and 1.0 mm in length. Textures of MIS rocks are extremely varied, but the most abundant rocks consist of lath-shaped, randomly-oriented plagioclases and smaller stubby to elongate orthopyroxene crystals, with interstitial micropegmatitic intergrowths of quartz and K-feldspar, the latter commonly with microporphyritic texture. Subordinate clinopyroxene is always interstitial, with subophitic texture. Plagioclase is ubiquitously zoned (Anmax). Some plagioclase crystals consist of an euhedral core, surrounded by a highly zoned rim that in some cases grades into interstitial micropegmatite. Hydrous minerals (biotite, amphibole, serpentine) generally appear to be late-stage replacement products of mafic silicates and Fe-Ti-oxides.

The major element data for the more representative igneous rocks show a substantial degree of chemical uniformity (SiO2 ~59-65%) and similarities to calc-alkaline rocks such as tonalite and diorite; the CIPW normative minerals plot instead in the fields of charnoenderbites (opdalites) and quartz...
The concentrations of Ir (avg. = 20 ppb), Cr (avg. = 358 ppm), Ni (avg. = 486 ppm), U (avg. = 2 ppm) are, instead, far higher than expected for typical calc-alkaline rocks or charnockites, and exceed levels of siderophiles in typical continental basalts such as BCR-1 (Govindaraju, 1989). Rare earth elements are remarkably uniform, showing moderately fractionated patterns (avg. La/Tb = 4.2), with negative Eu anomalies. By contrast, the underlying granoids show background levels of Ir (< 1 ppb), Cr (avg. 10 ppm), Ni (avg. 4 ppm), U (avg. 0.7 ppm), and more variable trace element abundances, including the REE that have slightly more fractionated patterns (ave. La/Tb = 7.3). Despite the overall chemical homogeneity in the charnoenderbites, certain elements such as Ti, V, K, Ba present slight, but consistent variations with depth that may indicate an upward increase in mafic silicate and Fe-Ti oxide minerals (notably pyroxene and magnetite). These subtle geochemical changes with depth support macroscopic observations of core samples that the MIS is composed of various magmatic components.

The overall bulk chemical homogeneity of the charnoenderbites, (coupled to the lack of fractionation among the REE, and the isotopes of Sm, Nd, Rb, and Sr) is coherent with the well documented homogeneity of impact melts (Floran et al., 1978; Grieve et al., 1977). When compared to Manicougan, the slightly greater chemical dispersion of the Morokweng rocks may be attributable to weak crystal fractionation effects, as discussed below. Moreover, the Rb/Sr and Sm/Nd isotope systematics, when considered in conjunction with the regional stratigraphy, favour derivation of the charnoenderbites from a Mid-Proterozoic melting of 3.1 Ga Archaean granitic crust. The high contents of siderophile elements such as Ir and Ni may also be consistent with an impact melt origin, as observed in meteorite-contaminated melts from the Rochechouart (Ni up to 600 ppm, Ir up to 15 ppb; Lambert, 1977), the Besumtwi crater, Ghana, and the Clearwater East structure, Canada (30-40 ppb Ir, 880-950 ppm Ni; Palme et al., 1978). We have no explanation, however, for the U, Cs, and W enrichment in the MIS unless it represents a contribution from the impact melting of mineralized pegmatites. A dominant crustal component in the Morokweng igneous rocks is supported by isotopic data: L= 0.7154 - 0.7160, and epsilon Nd = -14.6 to -15.0 (both calculated at 1.5 Ga) (Andreoli et al., 1995). Additional support for impact melt origin is the clastic material recognizable in the MIS, with individual fragments ranging in size from about 3-4 cm to below microscopic resolution. Much of the finer grained clastic material appears to have been disaggregated, and original boundaries can be difficult to identify due to interaction with the host melt (Floran et al., 1978).

If the charnoenderbites of the MIS are impact melts, then their composition must theoretically be controlled by a mixture of about 70% basement granite, 30% amphibolite/greenstone of basaltic composition, and refractory residues from the impacting meteorite (only occasionally recognized as the trace element level). Finally, the complex reorientation by the various "pulses" mentioned above, and the evidence for incipient fractionation suggest that the crystallisation history of the melts in the MIS was appreciably longer and more complex than the majority of known terrestrial impact products.

REFERENCES