ORIGIN OF SUEVITE BY MECHANICAL MIXING OF FRICTION MELT AND CATACLASITE DURING PEAK RING FORMATION IN THE MOROKWENG IMPACT STRUCTURE, SOUTH AFRICA.

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Introduction: Suevite is regarded as one of the diagnostic lithologies produced by hypervelocity impact. It is defined as “a polymict impact breccia with particulate matrix containing lithic and mineral clasts in various stages of shock metamorphism and cogenetic glassy or crystalline impact melt particles” by [1], and occurs most voluminously as crater fill. Recently, attention has focussed on whether post-impact explosive interaction between impact melt and infiltrating surface or groundwater may play a role in its formation [2,3]. As a consequence of the ambiguity around its origin, [4] has argued that the name itself should be replaced by “impact melt-bearing breccia”.

Sub-crater floor suevite intersections have been reported in drillcores in several impact structures, where they are most commonly attributed to crater fill trapped between blocks or injected into basement fractures, although [2] suggests an origin in the Ries crater by mechanical fragmentation of an impact-melt dike. Based on a study of core from a 368 m deep borehole drilled ~18 km NNW of the center of the Morokweng impact structure in South Africa, we present evidence of numerous dike intersections of a lithology that meets all the requirements of suevite but which reveal a further, alternative, formation mechanism to those previously proposed in other impact structures.

Geological Setting: The 145 ± 2 Ma [5,6] Morokweng impact structure is largely buried beneath up to 150 m of Cenozoic sands of the Kalahari Group. It is mainly constrained from regional geophysics and samples recovered from borehole cores [7]. Although the structure is poorly defined and was clearly eroded prior to deposition of the Kalahari Group, the most likely original diameter was 70-100 km [8]. The M4 hole is one of five exploration holes drilled into the central geophysical anomaly. It is the only one not to intersect the impact-melt sheet, and lies only 6 km from the M3 hole, which intersected 800 m of differentiated, noritic, impact melt rock [9]. Instead the M4 core comprises brecciated crystalline Archean granitoid gneisses, ferruginized metachert, metadolerite and dolerite, which are cut by cataclasite, suevite and melt-matrix breccias that together constitute ~12% of the core. Individual breccia dike widths range from <5 mm up to 6 m and include an ~30 m wide zone comprising close to 50% melt breccia. Shock petrography, including PDF measurements in quartz, indicate relatively uniform peak shock pressures of >22 GPa throughout the core, including in the melt breccia and suevite. Based on comparison with the other central core logs, these elevated shock pressure estimates are interpreted as suggestng that the M4 core intersects the partially eroded peak ring of the Morokweng structure.

Impact-generated breccias: Three principal breccia types are noted in the M4 core. All contain quartz clasts with decorated PDF and display intense alteration grading from chlorite-epidote-pyrite-garnet in the deeper levels of the core to clay-zeolite-magnetite-haematite in the upper levels. XRD and EMP analysis confirms that no glass or crystalline melt has survived.

Large parts of the core that show complex, cross-cutting, mm- to dm-spaced shear fractures that grade into cataclasite zones that may reach several cm in width. The shear fractures are marked by slickenlines and mm-scale displacements; although no larger-scale displacements can be unequivocally confirmed, most lithological contacts appear to be marked by intense fracturing or core loss (suggestive of intense fracturing). Strictly speaking, much of the core is brecciated and could be described as a *lithic breccia*, however, the term is confined here to areas where anastomosing or intersecting cataclasites have isolated cm- to dm-sized lithic fragments that have undergone relative displacement and/or rotation. Cataclasite is dominated by angular quartz mineral clasts with minor epidote, biotite and magnetite/ilmenite, all of which are common in the granitoid gneisses. These commonly show evidence of comminution and cataclastic flow. Feldspar is notably absent, but the matrix is dominated by clay and zeolite, suggesting significant alteration of the feldspars.

Melt-matrix breccia is mostly dark red to red-brown, although pink, orange and gray varieties are locally present in the felsic target rocks. Locally, it displays fine-scale banding that defines complex flow folds. Meso- and microscopic analysis shows that the coarser, mm- to cm-wide, bands represent granitoid-derived quartz-feldspar breccia/cataclasite masses enclosed in the melt that have been attenuated by a combination of intrusion and flow folding. The melt also contains angular to rounded lithic clasts up to dm size, and mineral clasts that are granitoid-derived. Straight lithic clast edges typically parallel internal fractures within the clast and, where little clast rotation has occurred, may align with wallrock fractures, indicating that melt emplacement was controlled by the fracture network. This is confirmed by thin injections of melt along fractures in coherent wallrock. Lithic clasts may retain marginal lobes of cataclasite, again signifying that clast margins are shear fracture-related. The matrix is dominated by clays and zeolites, with a subsidiary iron oxide; grain size is typically 5-20 microns.

Suevite is commonly, but not always, spatially closely associated with the melt-matrix breccia. It is polymict, red to gray to green, and varies from matrix- to lithic-clast-supported. Lithic clast size varies from <1 cm to >5 cm (the core diameter); clasts are mostly angular to subangular. Granitoid-derived lithic and mineral clasts dominate although doleritic fragments are found in almost all dikes. Mineral clasts predominate over lithic clasts and range from angular to subrounded. All minerals found in the granitoid gneisses (quartz, microcline, Na-plagioclase, biotite, titanite, epidote, magnetite, apatite) are common, but those from the mafic rocks (Ca-Na-plagioclase, hornblende/actinolite, clinopyroxene) are rare. Mineral clasts show evidence of internal strain, brecciation and/or comminution consistent with features seen in the lithic breccia/cataclasite. Locally, clasts are aligned parallel to dike margins, indicating flow.

Melt clasts within the suevite range from <1 mm to >5 cm (core diameter). Whilst dark red to brown melt is most voluminous, pale pink, orange, gray and green clasts are also noted. Millimeter-sized orange and green clasts are abundant microscopically (although volumetrically dwarfed by red-brown and black varieties). Numerous clasts show flow-folded compositional laminations that are truncated by sharp clast edges, indicating initial ductile flow followed by quenching and brittle fracturing. Irregular, cuspate-lobate margins with the matrix indicate low melt viscosity at least initially during incorporation. Composite clasts comprising melt and fractured and cataclastically deformed lithic components are also common, including melt ‘drapes’ around lithic or large mineral clasts.

Given the limited volume afforded by a 5 cm diameter core, several breccia dikes are best described as composite. Extensive evidence exists for infolding between melt-matrix breccia and the lithic breccia/cataclasite and suevite, suggesting initial low viscosity contrast between the melt and the clastic-matrix breccias. Melt breccia and suevite clearly intrude along cataclasite-bearing fractures; however, both are also cut and displaced by shear fractures that also brecciate any melt bodies that they intersect.

Bulk-rock major, trace and rare-earth element XRF and ICP-MS analysis confirms that the melt breccia and suevite can be adequately explained by derivation from the target rocks intersected in the M4 core. More importantly, individual breccia compositions closely mirror that of their immediate wallrocks.

Discussion: The three impactite breccia types intersected in the M4 Morokweng core show evidence of contemporaneous, locally-constrained, derivation within a moderately-to-highly shocked crater floor package that shows abundant evidence of mm- to dm-scale shear-induced brecciation. Most target rock contacts in the core are, in fact, highly fractured, suggesting that M4 may represent a megabreccia. We propose that initial shear fracturing led to brecciation, cataclasis and friction melting. Ongoing block movements led to injection and interfingering of the friction melt into fractures hosting lithic breccia/cataclasite, and its variable quenching. Further movement along and across the hosting fractures, and the creation of new fractures, then led to brecciation of the quenched portions of the melt dikes and mechanical entrainment of melt fragments into the adjacent lithic breccia, producing a hybrid, suevitic, breccia. Complex, rapid, displacements during the modification stage of cratering associated with the formation of the peak ring of the Morokweng impact structure provide both a mechanism for generating the shear fractures and their cataclasite and (friction) melt, and a pumping-suction mechanism for active melt injection into the lithic breccia-hosting fractures and its subsequent post-quenching brecciation and entrainment via cataclastic flow. Whilst an onset of fracturing and melting during the waning shock compression stage cannot be ruled out, the evidence from the M4 core suggests that suevite, sensu lato, does not need to involve impact melt, sensu stricto, as proposed by [1,4] or an intermediate phase of airborne mixing. Suevite dikes such as intersected in the M4 core may be a common feature of the interior of impact peak rings, which experience both (comparatively) long-lived and extremely high strain-rate post-shock displacements within the affected target volume.

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