PSEUDOTACHYLITIC BRECCIA AND MICROFRACTURE NETWORKS IN ARCHEAN GNEISS OF THE CENTRAL UPLIFT OF THE VREDEFORT DOME, SOUTH AFRICA. T. Mohr-Westheide[1], W. U. Reimold[1], U. Riller[2], R. L. Gibson[3], [1]Museum for Natural History (Mineralogy), Humboldt University, Invalidenstrasse 43, 10115 Berlin, Germany (Tanja.Mohr@museum.HU-Berlin.de), [2] School of Geography and Earth Sciences, McMaster University, Hamilton, Canada, [3]Impact Cratering Research Group, School of Geosciences, University of the Witwatersrand, Private Bag 3, P.O. Wits 2050, Johannesburg, South Africa.

Objectives: Pseudotachylitic breccias represent the most prominent impact-induced deformation structures in the central uplift of the Vredefort Impact Structure [1, 2]. The Vredefort dome is the type locality for "pseudotachylyte", which can be investigated in detail in a range of different host lithologies. The exact mechanisms by which such melt breccias in impact structures form remains enigmatic (see reviews in Reimold and Gibson 2005); formation of pseudotachylitic breccias has been variously ascribed (e.g., [3, 4]) to impact (shock compression) melting, friction melting, decompression melting, or a combination of these processes. As pseudotachylyte (modern spelling: -ite) is generally considered friction melt formed along fault/shear zones, we prefer the nongenetic term "pseudotachylitic breccias". The genesis of the dome would suggest that such movement zones may occur in abundance, but the enormous volumes observed in the dome seemingly can not be produced along fault/shear zones [5]. And besides, the large displacement zones that such voluminous friction melting might require are not in evidence. While previously some work has focused on orientation and geometry of pseudotachylitic breccia veins, detailed geometric analysis has been hampered by limited outcrop and has not been adequately related to micro-deformation studies of pseudotachylitic breccia bearing rock and associated brittle deformation. This study uses a different by analysis of a polished 3 x 1.5 m granite slab [Fig. 1] from a dimension stone quarry in the core of the Vredefort Dome. The structural analysis of the granite slab was accomplished to add to the statistical outcrop-scale approach of previous work that has focused on the larger veins and dykes and the limited micro-scale work that has suggested that thin veins are shock features. It provides an ideal opportunity to investigate the relation between generation of fractures with and without melt, fracture and breccia intensity, and other geological parameters such as lithology, grain size and mineral fabrics.

Method: Characterization and mapping of microfracture and pseudotachylitic breccia networks with special regard of their orientation, intensity, and 3D geometry forms the basis for this work, on the granite slab and in the field. Hundreds of measurements of the orientations of microfractures and pseudotachylitic breccias were taken in a quarry in the northern part of the Vredefort dome. Also, first investigations of microstructures and pseudotachylitic breccias by optical and scanning electron microscopy will be reported at the conference.

Results: Besides a several dm-wide breccia zone, two types of structures, which mutually cut each other, are macroscopically observed in the granite slab, i.e., generally dark grey to black veinlets of pseudotachylitic breccias and a network of thin, often reddish-brown microfractures. Pseudotachylitic breccias occur as curved or anastomosing veins that commonly include mineral and rock fragments of the host granite gneiss. Five sets of thin, red microfractures are inclined towards each other at angles between 30 and 115°. An observed variation of fracture intensity seems to depend on the mineralogy of the host rock, which is mainly reflected in the variation of plagioclase and K-feldspar modal abundances of the host granite.

Two microfracture systems are apparent in the granite slab. One crosscuts pseudotachylitic breccia matrices and host-rock fragments, the other fracture system is characterized by complex crosscutting relationships to pseudotachylitic breccias: Some pseudotachylitic breccias are cut and displaced by these microfractures, but in larger volumes of massive melt this fracture system is spatially limited to crosscutting only host rock fragments entrained in the breccia matrix. The fracture system limited to fragments in massive melt zones defines the formation of an older microfracture system, which formed prior to fragmentation. Reassembling the rock fragments inside the breccia zone, with respect to an infinite number of paths that the fragments may have taken, allows one to reconstruct their geometric configuration prior to opening of the fracture zone. The investigated breccia zone contains a number of fragments within the melt, which are transected by microfractures of the older fracture system. The microfractures cross the gaps between adjacent fragments but do not transect melt areas.

In the field, a high fracture intensity can, in general, be observed close to large melt-filled fracture zones as well as close to local networks formed by many mm- to cm-wide pseudotachylitic breccia veinlets. With increasing distance from such melt zones, red microfractures display low fracture intensities in the granite gneiss. The structural measurements of thin pseudotachylitic breccia veins and microfractures in stereographic projections from several outcrop sections show that these structures feature characteristic geometric concordance: they mostly occur with similar orientations.

First investigations of microstructures and pseudotachylitic breccias by optical and scanning electron microscopy revealed that the matrix of such melt breccias consists predominantly of silicate phases composed of Si, Al, O, K, Na, Ca and Mg. Additionally, zircon, sphene, magnetite and other iron oxides were recognized within the melt. K-feldspar fragments within the melt are mostly completely recrystallized, unlike quartz or quartz-rich fragments that are only partially annealed. Microstructures of the older fracture system are filled mainly by chlorite. In addition, reflected light microscopy indicates a high content of iron oxide and revealed individual cubiform (probably original magnetite) crystals commonly altered to goethite, which is thought to be responsible for the red coloration. The younger fractures are open micro-joints that are partially filled with carbonate. In some cases, the color of thin pseudotachylitic breccia veinlets changes abruptly from black to red. Black areas contain melt that is rich in Si, Al, O, K, Na, Ca, Mg and Ti. Red areas reflect joint segments, the margins of which are coated with iron oxide. Microscopic evidence for dilation was found at the contacts between breccia veins and host rock. Evidence of melt in cross-cutting microfractures was also recognized on the macroscopic scale [Fig. 2]. Movement (flow) of melt into dilational sites could be detected as various scales (cm to submillimeter) in the form of flow laminations in the matrices of these melt breccias.

Conclusions: The structures apparent in the Vredefort Dome constitute structural deformation-time indicators. This detailed, meter- to centimeter-scale mapping and sampling of breccias and microfractures in the Archean gneiss of the Vredefort Dome has shown that it was affected by 2 microfracture-forming deformation events, one preceding melt emplacement and one following the emplacement of pseudotachylitic melts in dilation zones in the Vredefort dome. Local microfracture intensity seems to be associated with the compositional in the granitic target rock.

The older microfracture system formed prior to melt emplacement but also occurs in cross-cutting relationships to pseudotachylitic breccia veins. We suggest that the cross-cutting relationships between the 2 structures depend on different cooling rates of pseudotachylitic melt, while microfracturing activity continued. Microfractures may well have formed contemporaneous with dilation and fragmentation. The fractures probably opened as the melt was intruded.

Optical microscopic and SEM analysis affirm evidence for movement (flow) of melt into dilational microfractures, which points to a melt flow from large- to small-scale dilational sites; this has also been observed at the macro-scale [Fig. 2]. Microstrucure fillings of the older fracture system contain chlorite, which is likely secondary infill. The filling of secondary carbonate in the younger fracture system indicates that this fracture system was filled in a much cooler environment – likely at a much later stage after impact. Another possibility is a formation of these fractures at times after the impact or due to post-impact reactivation of pre-existing microfractures.

The reconstruction of fragment configuration of the breccia zone investigated on the polished granite gneiss slab has shown that fragments match with each other in a jigsaw fashion, i.e. either no or very little material from the fragments has been “eroded” (melted off, or abraded) away to form melt. The fragmentation of the target rock resulted in volume increase by dilation. This points to mobility of melt but limited movement (rotation) of fragments and suggests that dilation was contemporaneous with melt emplacement.

Unravelling the development of single structural components resulted in a sequence of 4 processes involving both deformation of the target rock and melt emplacement into the deformed host rock. What remains is to unravel the stated problem of how this melt originated in the first place.

References: [1] Dressler, B. O. and Reimold W. U. (2004) Earth-Science Reviews, 67, 1-60. [2] Reimold W. U. and Gibson R. L. (2006) GSA SP 405, 407 pp. [3] Gibson R. L. and Reimold W. U. (2001) The Vredefort impact structure, South Africa, Memoir 92, Council for Geoscience, Pretoria, 110 pp. [4] Gibson R. L. and Reimold W. U. (2005) Shock pressure distribution in the Vredefort impact structure, South Africa. Large Meteorite Impacts III. GSA SP 384, pp. 329-349. [5] Melosh, H.J., 2005. The mechanics of pseudotachylite formation in impact events. In: Impact Tectonics, ed. by Koeberl, C. & Henkel, H.. Impact Studies Series, Springer, Berlin-Heidelberg, 55-80.

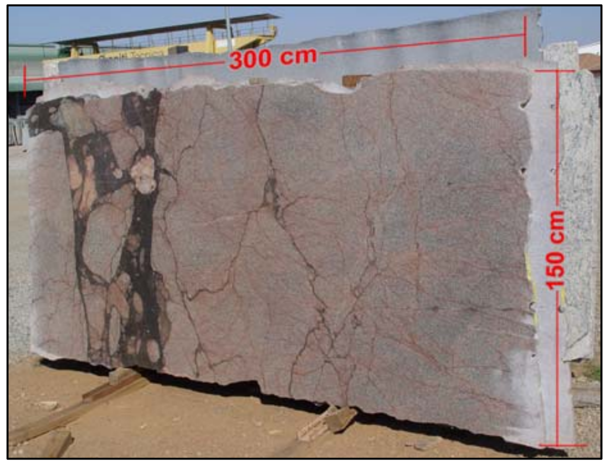

Fig. 1: Polished 3 x 1.5 m granite slab from a dimension stone quarry in the Vredefort Dome.

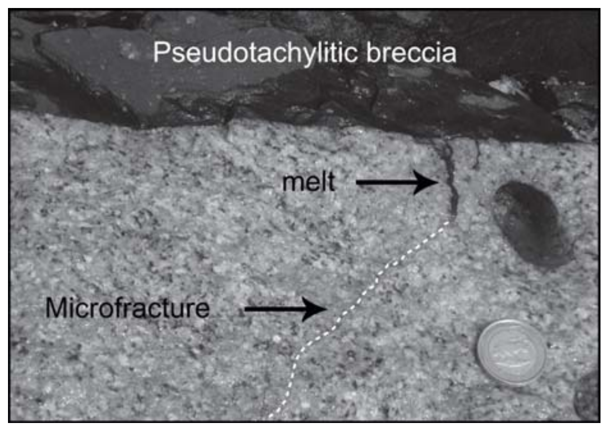

Fig. 2: Photograph of a melt-filled microfracture in the field. Melt has partially (only to the termination of the dark segment) filled an adjacent microfracture. Picture demonstrates melt transport from a large pseudotachylitic breccia zone into a smaller one.