TEM ANALYSIS OF NATURALLY DEFORMED ZIRCON FROM THE CENTRAL VREDEFORT DOME. W.U. Reimold1,*, H. Leroux2, and R.L. Gibson1. 1Impact Cratering Research Group, Department of Geology, University of the Witwatersrand, Private Bag 3, P.O. Wits 2050, Johannesburg, South Africa (wbur@cosmos.wits.ac.za); 2Laboratoire de Structure et Propriétés de l’Etat Solide – ESA CNRS 9009, Université des Sciences et des Technologies de Lille, 59655 Villeneuve d’Ascq, France (hugues.leroux@univ-lille1.fr).

Summary: Two naturally deformed zircon grains from an Archean gneiss sample of the central part of the Vredefort Dome were studied by optical and transmission electron microscopy (TEM). The grains were selected, as planar microdeformations were visible at the optical microscopic scale, spaced at about 20 µm. The TEM investigation reveals the presence of numerous dislocations that originated from deformation. Most of the dislocations are organized into subgrain boundaries, showing that the grains have been annealed after plastic deformation. Frequently, the subgrain boundaries are planar and, thus, they are probably the cause of the planar features visible at the optical scale. As annealing strongly modified the deformation microstructure, it is not possible to infer the origin of the deformation (shock or tectonic origin). In addition to the deformation and recovery events, the zircon grains are partially amorphous (at the TEM scale!) as a result of metamictization due to alpha-decay damage caused by the presence of radiogenic elements.

Background: Zircon is a mineral with physical and chemical characteristics that make it a highly refractory and chemically resistant mineral. Consequently, this mineral resists metamorphic overprint to conditions of granulite metamorphism and is highly weathering-resistant. Optically resolved shock deformation features in zircon from a number of confirmed impact structures and from the K/T boundary have been reported since the early 1990’s [e.g., 1, for a review]. These features include planar microdeformations, and the so-called granular or strawberry texture comprising numerous tiny, euhedral zircon crystals grown on the surface of a target rock zircon crystal. The nature of the planar features has been enigmatic. Optically it has not been possible to resolve whether they represent planar fractures or PDF (planar deformation feature)- equivalent amorphous or glass+solid lamellae. A detailed shock experimental study by [2] showed that shock pressures between 20 and 40 GPa produced pervasive micro-cleavage and dislocation patterns. A sample shocked to 40 GPa was partially transformed to scheelite-structure, and some (few!) <10-nm-wide amorphous lamellae (i.e., PDFs) occurred in relic areas of zircon-structure, whereas up to 50-nm-wide twin lamellae occurred abundantly in scheelite-structure areas. A 60-GPa sample was completely converted to scheelite structure. It was established that the narrow PDFs are formed in the zircon (zircon) structure, prior to conversion into scheelite-type material. Due to the limitation of PDFs in the experimentally shocked samples to submicroscopic lamellae, it appeared safe to conclude that the optically visible planar features in these shocked grains represented cleavage = planar fractures. However, as both microcleavage (planar fractures) and PDFs were formed in this experimental study, the question which of these phenomena represent(s) planar features in naturally shocked zircon still remains unanswered. For the present investigation, two crystals of naturally deformed zircon from the highly shocked (>20 GPa) central part of the Vredefort Dome [compare 3] were chosen for optical and TEM deformation analysis.

The sample: Sample HM2 is a migmatic, granulite-facies metapelite from Farm Helpmekaar, ca. 6 km west of the Inlandsee Pan in the central part of the Archean Basement Complex forming the core of the Vredefort Dome. HM2 is mainly composed of cordierite, garnet and orthopyroxene, besides lesser biotite and sillimanite. Zircon in this sample is rare, but some 20 grains, all exhibiting optically discernable planar features, about 80-150 µm in size, and generally of rounded to subrounded, typically “metamorphic” shapes could be separated. In small areas, these crystals appeared metamict. Two of these zircon grains were subjected to ion thinning and subsequent TEM analysis of thin
film areas. Obviously the sample has experienced pre-impact granulite metamorphic conditions [4]. Rocks from this part of the central uplift structure, the Vredefort Dome, were subject to strongly heterogeneous degrees of shock metamorphism in excess of 20 GPa. Locally, shock melts are observed [3], which implies for target rocks at pre-impact temperatures of approximately 500°C that shock pressures of at least 40 GPa must have been reached locally. As demonstrated by Stevens et al. [5], the impact event into hot crust was succeeded by a period of sustained regional metamorphism and slow cooling.

**TEM results:** Both crystals studied are highly deformed and annealed. Deformation is indicated by the presence of abundant dislocations, most of which are organised into subgrain boundaries. These subgrain boundaries, in turn, are frequently arranged along the (100) planar crystallographic orientation in such a way that they occasionally resemble “some kind of planar feature”. The presence of these subgrain boundaries, in certain areas, gives the appearance of small (typically of the order of 0.5 µm) subgrain aggregates. One is tempted to assume that this could be the expression of the “strawberry texture”. However, these subgrains are similarly oriented, with differences in orientation of <1-2 degrees. It appears that this microtexture is the result of deformation followed by annealing. This annealing is also illustrated through the presence of dislocation junctions. These junctions, and the subgrain boundaries, are the result of dislocation climb – a thermally activated process which leads to the re-organization of the dislocation into a more favorable energetic configuration. These observations also indicate that - at least, some dislocations had been formed prior to the annealing event – either due to tectonic deformation or the impact event. It should be noted that the optical planar features could be also due to fracture healing. The small differences of orientation are, in this case, easy to understand, and a small difference of orientation on both sides of the healed fracture would be accommodated by dislocations (similar to subgrain boundaries).

Both zircon grains are also highly metamict, as a result of damage caused by alpha-decay of radiogenic elements such as U, Hf, and Th, which typically occur in significant amounts in zircon, as a result of incorporation into solid solution during zircon growth. Metamictization of zircon is characterised [e.g., 5, and refs. therein] by the formation for nanometer-sized amorphous domains (patches). In the samples studied here, the local presence of amorphous material is evidenced by diffuse haloes around the central spot in diffraction patterns. These amorphous domains are typically very small (several nm). It is clear that this metamictization occurred after deformation and annealing, as the formation of dislocations and their recovery requires crystalline conditions (i.e., dislocations cannot propagate in an amorphous phase), and also because the annealing of a metamict state induces crystallization of small ZrO₂ crystallites from the amorphous phase [5]. The fact that the amorphous phase is still present (and ZrO₂ crystallites absent) illustrates that the thermally activated processes were no longer effective during or after metamictization.

**Conclusion:** The results of this TEM investigation are: (1) The identification of three different processes – deformation, annealing, and metamictization that occurred in the history of these grains. (2) It was possible to determine the succession of these events: first, plastic deformation, followed by annealing, and, finally, by metamictization. (3) Deformation and annealing would have occurred early in the grain history; considering these grains are of likely Archean (minimum 3.1-3.2 Ga [1]) age, this phase must be linked to Archean crystal growth and metamorphism. (4) While it is likely that major deformation was associated with the impact event, distinct impact-generated deformation, such as PDFs, could not be observed. It appears, however, that the likely impact-derived, planar features that can be observed at the resolution of the optical microscope represent planar subgrain boundaries.