IN SITU U-Th-Pb GEOCHRONOLOGY OF DETRITAL SHOCKED MONAZITE IN PLEISTOCENE FLUVIAL DEPOSITS ALONG THE VAAL RIVER, SOUTH AFRICA.

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Introduction: Recent provenance studies have focused on using microstructural and isotopic data to demonstrate that detrital shocked minerals in modern siliciclastic sediments in the Vaal River, South Africa were sourced from the 2.0 Ga Vredefort Dome impact sturcture [1,2,3], including sediments transported to distal locations (>750 km) [4,5]. Here we report microstructural and in situ U-Th-Pb age data for detrital shocked monazite grains found in a Pleistocene (ca. 1.6 Ma) fluvial deposit near Windsorton South Africa, 500 km downstream from the Vredefort Dome. The shock microstructure and ages of these grains demonstrate they originated at the Vredefort Dome impact structure. These results demonstrate that detrital shocked monazite can preserve a long lasting record of eroded continental impact basins in siliciclastic sediments. The evidence of impact recorded in these grains survives sedimentary transport to distal locations and burial in ancient sediments, and can be used to reconstruct ancient or eroded impact structures.

Background: The 2.0 Ga Vredefort Dome is the largest and oldest impact structure found to date on Earth [6]. The structure, located in the Archean Kaapval craton, has an exposed diameter of 90 km, but it is believed that the original diameter was about 300 km [6]. Shocked minerals have previously been documented to be widespread in Vredefort target rocks [6,7,8]. The Vaal River is entrenched in bedrock at the Vredefort Dome, and flows west to the Orange River. Fluvial terraces (paleochannel deposits) of the Vaal River, ranging in age from Cretaceous to Holocene, occur throughout the Vaal River valley. In this study, we focus on the Rietputs Fm., a Pleistocene age terrace deposit of coarse gravel and cobble conglomerate that occurs at 12-14 m above the modern Vaal channel [9]. Cosmogenic nuclide burial dating shows the deposition of the coarse Rietputs gravels occurred ca. 1.6 Myr ago [9].

Samples: Four samples of the Rietputs Fm. were investigated in this study. The samples were collected from Windsorton, South Africa, a site on the Vaal River ~500 km downstream from the Vredefort Dome. Two samples from the east side of the Vaal (Sec-01C and Sec-03D) were analyzed in the burial dating study of [9]; two additional samples from the west side of the Vaal (09VD-29, 09VD-31) were collected in 2009. These four samples also contain detrital shocked zircon [10] and detrital shocked quartz.

SEM results: Detrital monazites were studied for evidence of shock deformation using backscattered electron (BSE) imaging. The Rietputs monazites are generally large (up to 750 µm), dark yellow to orange, opaque, and highly rounded, with most grains showing no identifiable crystal faces. A total of 73 detrital monazites were examined from the four Rietputs Fm. samples. Of these, 51 (70%) were found to preserve evidence of impact deformation (Fig. 1). The shock microstrctures identified are planar fractures (PFs), similar to that found in zircon. Up to four orientations of PFs were found in single grains of detrital shocked monazite.

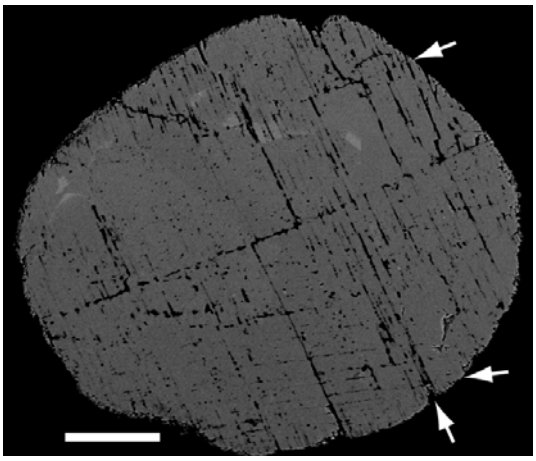

Figure 1. BSE image of detrital shocked monazite from Rietputs sample 09VD29. Arrows indicate orientation of PFs. Scale bar is 50 µm.

U-Th-Pb results:

In situ U-Th-Pb age determinations were made with the SHRIMP-RG at Stanford University. A total of 19 analyses were made on 9 detrital shocked monazite grains from the Rietputs samples. BSE and reflected light imaging were used to choose spot locations away from PFs, which tend to accumulate common lead (^{204}Pb); with some grains, analyses on PFs were unavoidable. Most monazites yield slightly discordant analyses (Fig. 2), however several grains were reversely discordant. Five of the 9 shocked monazite grains form a discordia that when regressed through the impact age of 2020 Ma [7,8] yield an upper intercept age of 3005±62 Ma (MSWD = 1.7).

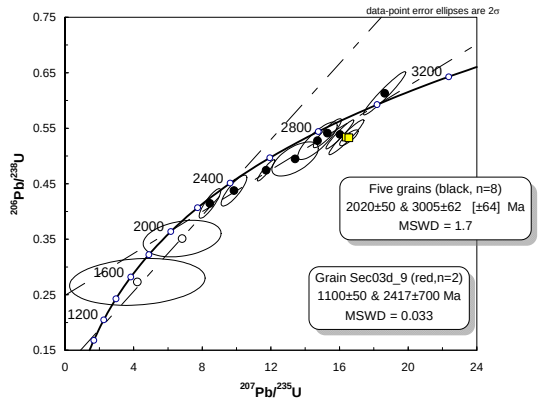

Figure 2. Concordia diagram for detrital shocked monazites from the Rietputs Fm. The black circles are grains that record impact age Pb-loss at ca. 2020 Ma. The empty circles are grain Sec03D-9 that shows secondary Pb-loss at ca. 1100 Ma.

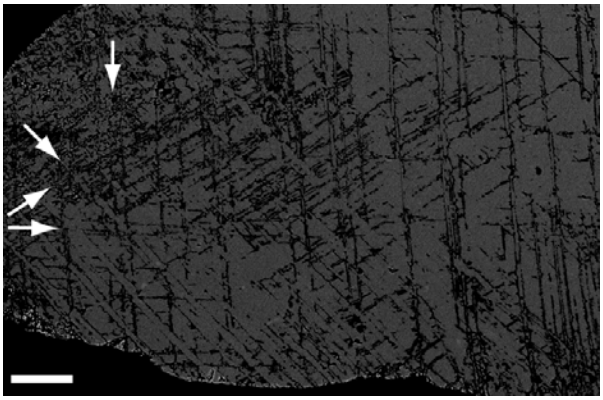

Figure 3. BSE image of detrital shocked monazite Sec03D-9 showing 4 orientations of PFs (arrows). Scale bar is 20 µm.

Two spot analyses were made on grain Sec03D-9, a grain with the most pervasive PFs thus far identified (Fig. 3). The analyses were made on PFs, and yielded high ^{204}Pb counts and younger ages. A discordia fit to these analyses and regressed through a lower intercept of 1100 Ma yields a remarkably good fit (MSWD = 0.03); the upper interecept crosses the 2020 Ma discordia defined by the main population of detrital shocked monazites.

Discussion: The detrital shocked monazites found in the Rietputs Fm. at Windsorton preserve 3 lines of evidence that support the conclusion that they originated from the Vredefort Dome: (1) shock microstructures (PFs), (2) U-Pb ages simlar to those found at the Vredefort Dome, and (3) Pb-loss history. PFs in the Windsorton monazites are similar to shocked monazites reported in bedrock [11] and modern sediment [1] at the Vredefort Dome. The age of ca. 3005 Ma defined by the main population of monazites is similar to ages determined from monazite in the core of the Vredefort Dome [11]. The observation that the majority of monazites form a discordia that can be regressed through the age of impact (2020 Ma, [7,8]) implies that most of the monazites lost Pb during the Vredefort impact. The pervasive PFs developed in grain Sec03D-9 suggest it experienced higher shock pressures; we interpret that the pervasive microstructure in this grain (Fig. 3) facilitated additional Pb-loss at ca. 1100 Ma that is not recorded in other monazites. The ca. 1100 Ma Pb-loss trajectory has previously been reported in studies of basement rocks at the Vredefort Dome [12,13].

Taken together, the results of this study demonstrate that detrital shocked monazite from the ca. 1.6 Ma Rietputs Fm. fluvial terrace found 500 km downstream originated from the Vredefort Dome impact basin. Detrital monazite is a ubiquitous heavy mineral in siliciclastic sediments, and along with detrital shocked zircon and quartz, can be used to reconstruct ancient or eroded impact events.

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