MICROSTRUCTURAL AND ISOTOPIC CONSTRAINTS ON IMPACT BASIN PROVENANCE OF DETRITAL SHOCKED MINERALS IN THE VAAL RIVER, SOUTH AFRICA

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Introduction: Detrital grains of shocked zircon, quartz and monazite eroded from the Vredefort Dome have been found in modern sediments of the Vaal River at distal locations (>750 km) from the impact structure. The evidence for their origin at the Vredefort Dome is the presence of shock microstructures [1,2,3]. Here we present new in-situ U-Th-Pb geochronology that confirms the Vredefort Dome as the origin of these far-traveled grains. The ability to source detrital shocked minerals at distal locations (100s to 1000s of km) from a known impact is evidence that shocked minerals survive significant sedimentary transport while retaining microstructural and isotopic information about the impact basin. This result demonstrates that a detrital record of ancient eroded impact structures may reside within early Archean and Proterozoic sedimentary rocks.

Vredefort Dome: The 2.02 Ga Vredefort Dome in South Africa is the oldest and largest documented terrestrial impact structure [4]. The Vaal River cross-cuts the Vredefort Dome before joining the Orange River further downstream (Fig. 1). The Vaal-Orange system is the largest drainage basin in southern Africa, draining the majority of the Kaapvaal craton, and thus has the potential to distribute a detrital record of impact for 1000s of km across the continent.

Channel sediments were collected from multiple locations along the Vaal River to search for the presence of detrital shocked minerals. Thin sections were prepared from the light mineral fraction to identify shocked quartz. Detrital zircon and monazite were imaged with an SEM.

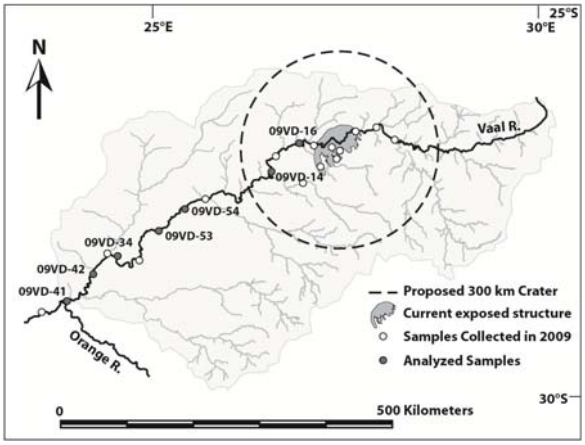

Figure 1: The Vredefort Dome in the Vaal River basin, South Africa. Detrital shocked minerals have been found at all sample sites in the Vaal River.

SEM imaging: Detrital grains of shocked quartz, monazite, and zircon were found in every sediment sample from the Vaal River, including samples from near the confluence of the Orange River, >750 km from the Vredefort Dome. In each sample, 200-500 zircons were examined; shocked grains comprise 2-14% of each population (Table 1). Shock features in zircon and monazite were confirmed with detailed imaging of both external and internal microstructures using a scanning electron microscope (SEM), while shocked quartz was identified petrographically.

Shocked zircons were identified based on the presence of planar fractures (PFs) [5], which occur in up to five orientations in a single grain. Shocked monazite was identified as rounded grains with up to four orientations of PFs. Shocked quartz contains one orientation of planar deformation feature (PDF). PFs in zircon are readily visible in BSE images of the surface, and PFs can be observed using CL in polished epoxy grain mounts.

Table 1. Detrital shocked zircon and monazite downriver from the Vredefort Dome

samples	dist. km	zrn imgd	shock zrn	% zrn shock	mnz imgd	shock mnz	% mnz shock
09VD-16	103	452	63	14%	116	71	61%
09VD-14	200	256	13	5%			
09VD-54	362	485	7	1%			
09VD-53	469	390	28	7%	51	30	59%
09VD-34	608	208	4	2%			
09VD-42	674	426	23	5%	90	47	52%
09VD-41	759	253	5	2%	1	0	0%
Total		**2470**	**143**	**6%**	**258**	**148**	**57%**

Zircon U-Th-Pb geochronology: Geochronology analyses were made using the SHRIMP-RG at the Stanford USGS MicroAnalysis Center. Detrital shocked zircons show a range of ages and discordance (Fig 2). Zircons were analyzed with single and multiple spots to evaluate U-Pb systematics. Single spot analyses were made on 61 zircons, and 7 additional grains were analyzed with multiple spots. A population of 27 grains with single U-Pb ages form a discordia with upper intercept ca. 3080 Ma and a lower intercept of ca. 1100 Ma (Fig. 2). Additionally, 3 of the grains with multiple spot analyses yield a similar age of ca. 3080 Ma (e.g., Fig 3). The ca. 3080 Ma age recorded in the detrital shocked zircon suite corresponds to known bedrock ages at the Vredefort Dome [4,6].

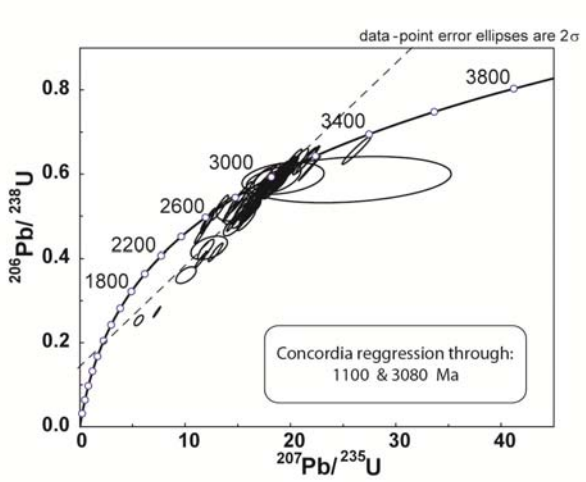

Figure 2. Concordia diagram for detrital shocked zircons from the Vaal River.

Detrital zircons with PFs do not record Pb-loss at the time of impact; apparent Pb-loss events occurred at ca. 1100 Ma and at ca. 450 Ma. The 1100 Ma (Kibaran?) and younger Pb-loss events have been previously documented in rocks at the Vredefort Dome [6,8,9,10]

Discussion: Meteorite impacts have been identified as a significant processes on the Early Earth, but there is little preserved evidence of early craters [7]. Questions remain about the rate of impacts and their effects on the development of the lithosphere and biosphere. The findings of this study show that shock microstructure within minerals common in continental crust (quartz, zircon, monazite) survive significant sedimentary transport, and that shock microstructures and isotopic systematics can be used to correlate distally transported shocked minerals to a known impact structure. Detrital shocked minerals may thus be used to identify evidence of previously unidentified ancient impact events, where the original structure has been lost to erosion. Detrital shocked minerals may be the best method for discovering the ancient impact record from the early Earth.

References: [1] Cavosie et al. (2010a) GSA Bulletin. [2] Erickson et al. (2010) GCA. [3] Cavosie et al. (2010b) GCA. [4] Gibson and Reimold (2008) Counc Geosci Mem 97. [5] Bohor et al. (1993) EPSL. [6] Armstrong et al. (2006) GSA Sp. Paper 405. [7] Koeberl (2006) Elements. [8] Flowers et al. (2003) J. Geol. [9] Moser et al. (2010) GCA. [10] Moser et al. (2011) Can J Earth Sci.

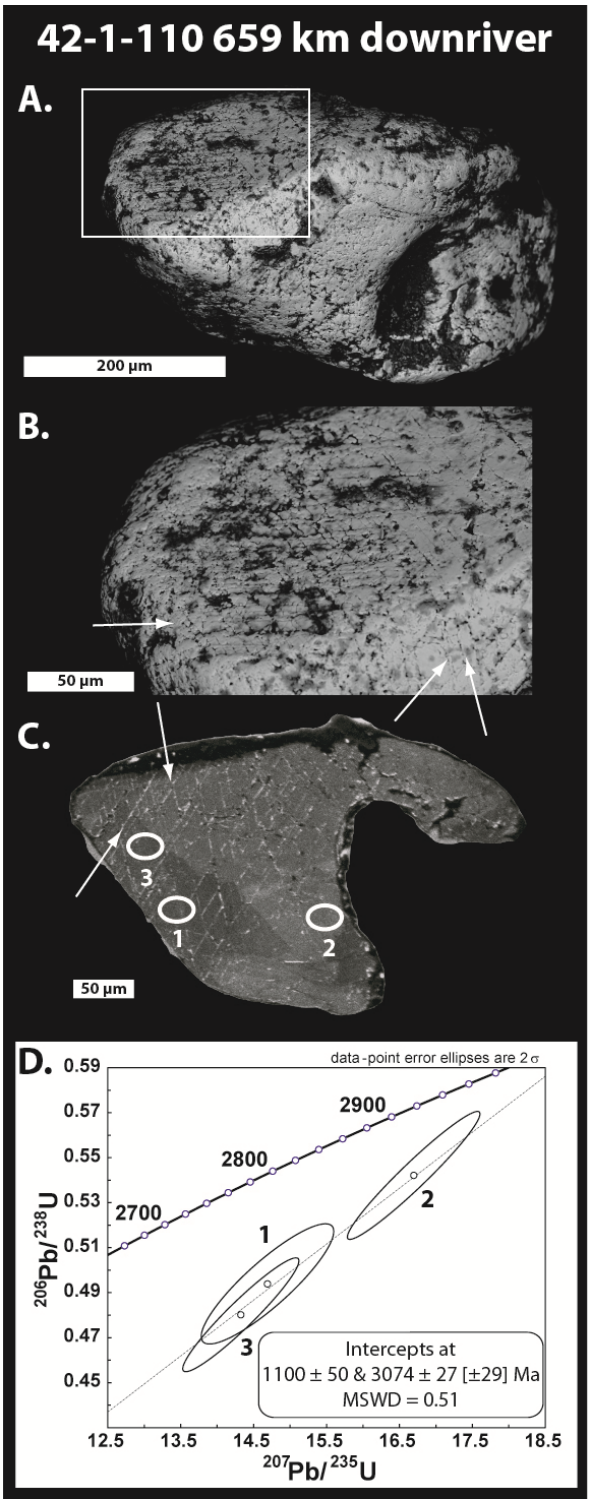

Figure 3. Images and U-Pb data for a detrital shocked zircon from the Vaal River, South Africa. A and B: BSE photomicrographs showing PFs on surface. C: CL photomicrograph of polished interior showing PFs (arrows) and location of SHRIMP analyses. D: Discordia showing ages.