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**Introduction:** The Maniitsoq region in the North Atlantic Craton of West Greenland has been proposed to host a ~3 Gyr old impact crater, allegedly the oldest on Earth [1]. If confirmed, such structure would represent a source of Archean impact ejecta [2]. Various geological features in the Maniitsoq region have been proposed to result from a large meteorite impact [3,4], however, these interpretations are unconventional [5] and have been challenged [6]. Preservation of impact-related features in ancient rocks is hindered by pervasive overprinting associated with magmatism, metamorphism, and deformation related to tectonic reprocessing. Zircon is not easily recrystallized and can preserve evidence of shock metamorphism even after intense secondary processes [7,8]. In addition, high-pressure shock deformation features in zircon—such as deformation twin lamellae or high-pressure polymorphs—are diagnostic of impact and have been found in zircon from many of Earth's ~200 confirmed impact structures [9]. We present results of a comprehensive investigation of zircon from across the Maniitsoq region in West Greenland (dominated by granulite-facies orthogneiss and amphibolite) to evaluate if the region hosts an ancient impact structure.

**Methods:** To test the Maniitsoq impact hypothesis, we conducted the most extensive investigation of this feature to date, involving new fieldwork, the largest electron backscatter diffraction (EBSD) microstructural surveys of zircon thus far reported, and complementary detailed isotope geochemistry of zircon. EBSD orientation mapping was used to investigate if zircon from throughout the Maniitsoq structure records evidence of shock metamorphism. Zircon U–Pb geochronology and O isotope analysis was used to evaluate putative evidence of impact-induced hydrothermal alteration [3].

Over 5,000 zircon grains were analyzed by EBSD. This includes 18 bedrock samples; 9 with crystallization ages >3.0 Ga (i.e. older than the alleged age of impact [3]) and 9 with crystallization or depositional ages <3.0 Ga. In addition, 10 stream sediment samples (from drainages across the region) were also investigated to account for eroded source rocks that may no longer be present in the bedrock. In total, we analyzed 5,587 zircon grains from the Maniitsoq region. Analyses were conducted with a Tescan MIRA3 field emission gun scanning electron microscope at Curtin University [10]. Oxygen isotope ratios and $^{16}O^{1}H/^{16}O$ values were measured for zircon from 5 samples (granitoids and an orthogneiss) from the Maniitsoq region using a Cameca 1280 at the Centre for Microscopy Characterization and Analysis, University of Western Australia [11].

**Results:** Of the 5,587 grains analyzed across the sample suite, most yield high-quality diffraction patterns indicating crystalline zircon, with some grains displaying evidence of radiation damage (**Fig. 1**).

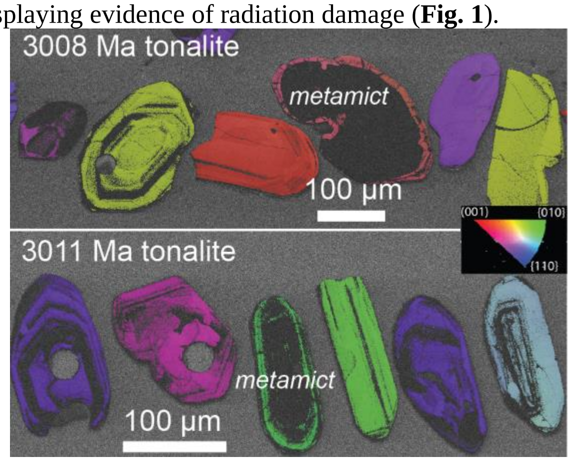


**Figure 1:** Electron backscatter diffraction orientation maps (inverse pole figures) of representative zircon from the Maniitsoq region. Colors indicate crystallographic orientation. Grains are largely crystalline with local metamict (radiation damaged) portions that do not yield diffraction patterns and are black. No planar deformation features, twins, or high-pressure phases were found (modified from [12]).

Most zircon grains (>99%) show no evidence of crystal–plastic deformation. Three zircons have cumulative angular misorientations of >5°. Two of these zircon grains have sub-parallel low-angle grain boundaries (**Fig. 2a**) and one shows evidence of localized recrystallization (**Fig. 2b**). All of these features are consistent with those found in zircon from tectonic and magmatic settings [13,14]. No zircon analyzed contained deformation twin lamellae or high-pressure polymorphs (e.g. reidite) that are diagnostic of impact-related shock deformation [15].

Oxygen isotope analyses of six grains indicate elevated $^{16}O^{1}H/^{16}O$ values, associated with metamict cores, indicative of water in the zircon structure. These analyses yield secondary $\delta^{18}O_{VSMOW}$ values. 36 zircon grains from 5 samples, with $^{16}O^{1}H/^{16}O$ values within the crystalline range, yield primary $\delta^{18}O_{VSMOW}$ values of 5.0 to 7.0 ‰ that are consistent with or slightly heavier than mantle values [16]. These values are inconsistent with growth or recrystallization in a reservoir buffered by seawater. Therefore, there is no stable isotope evidence in zircon from Maniitsoq that indicates any involvement of pervasive seawater or hydrothermal influx during zircon growth. Moreover, most zircon grains preserve magmatic oscillatory zoning patterns with oxygen signatures consistent with global TTG suites.

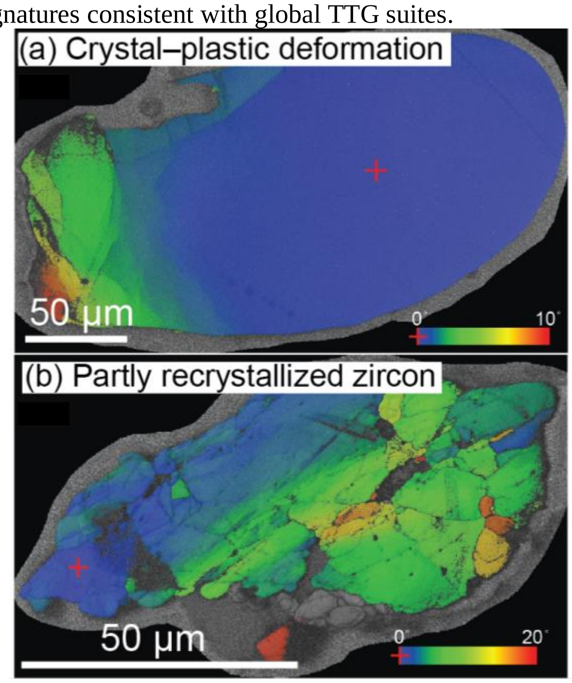


**Figure 2:** Electron backscatter diffraction orientation maps of rare deformed zircon grains from the Maniitsoq region that show cumulative misorientation >5°. Misorientation in the Maniitsoq zircon is accommodated mostly by sub-parallel low-angle grain boundaries (a) or local recrystallization (b). Such features are found in magmatic settings [13] and shear zones [14]. No evidence of shock deformation was identified. Figure modified from [12].

**Implications:** Shock features in zircon are ubiquitous in granitoid target rocks at terrestrial impact structures, including at ancient and deeply eroded structures, e.g. [8, 17]. A comprehensive analysis of 5,587 zircon grains from granitoids and fluvial systems across the Maniitsoq region of West Greenland has yielded no evidence of impact-related microstructures in zircon. Furthermore, oxygen isotope ratios and preservation of igneous zoning patterns support neither pervasive alteration by seawater nor recrystallization, both of which were proposed to follow impact [3]. The timing of magmatism, metamorphism, and deformation as constrained by campaign geochronology across the entire region is incompatible with a >3.0 Ga Maniitsoq impact [13]. Zircon microstructures and stable isotope ratios in the Maniitsoq region are consistent with existing models of endogenic processes related to magmatism, metamorphism, and deformation associated with tectonometamorphic reworking and stabilization of the North Atlantic Craton in the late Archean [12]. The absence of any intact impact structures from the Archean Eon makes the 2.23 Gyr old Yarrabubba structure the oldest confirmed meteorite impact structure on Earth [17].

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