SAQQAR IMPACT STRUCTURE: A BURIED 34 KM CRATER IN SAUDI ARABIA.

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Introduction: We present the first definitive evidence for an impact origin of a circular structure named Saqqar with an apparent diameter of 34 km, centered at 29°35'N, 38°42'E, which is partially buried under ~400 m of Cretaceous-Paleogene strata in the Nafud basin in northwestern Saudi Arabia (Fig. 1). Saqqar was first reported as a crater structure, without conclusive evidence for impact origin, by [1]. Other impact craters to date on the Arabian peninsula proven by shock effects are the very young and small craters of the Wabar crater field [2, 3] and the 6 km Jebel Waqf as Suwwan crater in Jordan [4, 5].

Remote sensing and surface geology: Saqqar is situated in a low relief desert environment (Fig.1a) covered by Quaternary, Tertiary, and Cretaceous sediments (Fig. 1c). Deformation at the Saqqar structure affects Devonian strata but not the overlying Upper Cretaceous and younger beds. Deformed Devonian strata are exposed in the southernmost part of the structure. Landsat imagery shows that the drainage is largely to the N-NNE. Along the southern rim the wadi drainage pattern deflects parallel to the mapped underlying structure (Fig.1b). The Devonian strata along the southern margin were mapped by [6, 7] as the Ja'alat as Samra fault and fold system. The unusual deformation includes overturned bedding of Devonian Tawil and Jauf formations, but not of the overlying Maastrichtian Formation. The steep inclinations of Devonian bedrocks, their concentric strike, and associated fold hinges are interpreted here to be structures related to the Saqqar impact structure.

Geology and Geophysics: The subsurface structure of Saqqar was mapped from a grid of two-dimensional reflection seismic lines (Fig. 1e). In particular, the drilling of five shallow wells in the central uplift was instrumental to map the structure, enabling palynology to establish stratigraphic tops in the Cambrian-Silurian interval within the uplift. The central uplift and surrounding moat have positive and negative gravity excursions, respectively, in relation to the regional field (Fig. 1d). Figure 1f shows a structural map of the base of the Qusaiba Member (base Silurian), which is indicated by a prominent seismic reflection throughout the Nafud Basin. This final interpretation integrates seismic interpretation, well control, gravity data, and outcrop observations. First order structural feature is an uplifted central high that is surrounded by a concentric, moat-like syncline (Fig. 1f). The perimeter of the structure, defined

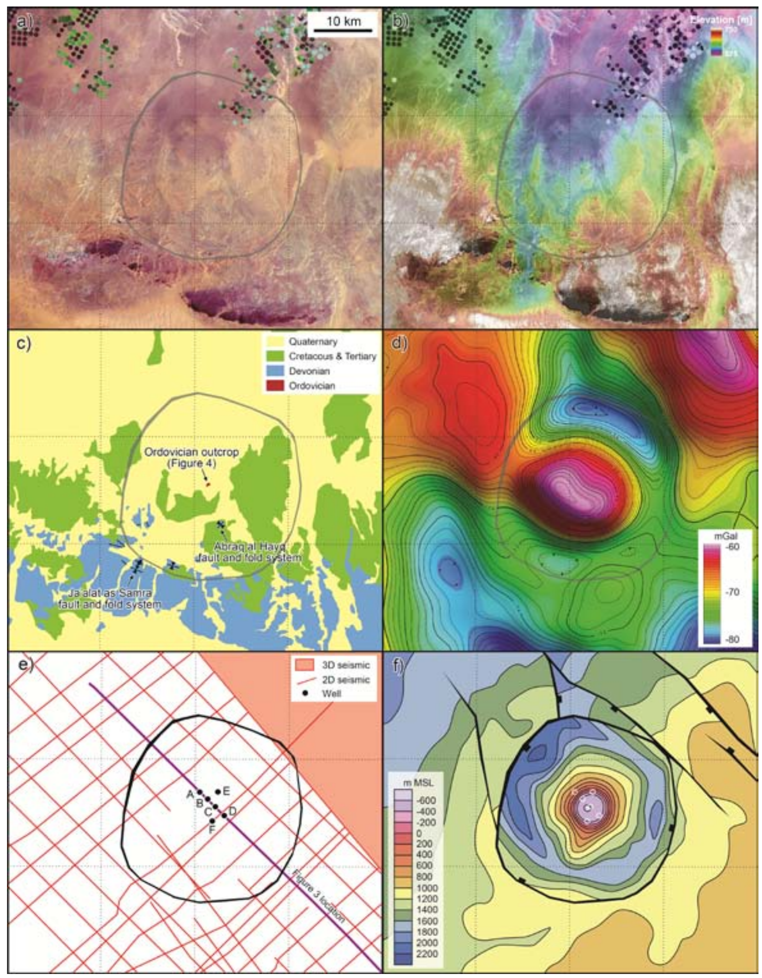

Figure 1. A) False-color satellite image of the Saqqar region. B) Shuttle Radar Topography Mission digital elevation model. C) Surface geology, modified after [7]. D) Airborne Bouguer gravity. A local gravity high of -60 mgal is surrounded by a low of -80 mgal. The former corresponds to the central uplift, the latter to the ring syncline. E) Wells and seismic lines. Well A is SAQR-2, well B is U-75400, well C is U-75282, well D is U-75272, well E is U-75410, well F is U-75286. F) Base Silurian map. The map is based on work published in [1], with a revised geometry of the central high. White rings are well locations.

by a circumferential normal fault, deviates slightly from a circle and contains straight segments. The entire structure is tilted slightly to the northwest; consequently, the ring syncline is approximately 300 m deeper in the northwest flank of the structure relative to the southeast flank.

Petrography of core samples: Drilled wells in the center of Saqqar structure encountered Ordovician strata. Most of the investigated rocks are pure quartzite sandstones but two samples contain dark, mica-rich interbeds and detrital feldspar grains. In particular the samples from wells U-75400 and U-75286 are pervasively deformed. These coarse-grained sandstones are transformed into dense quartzite rocks of extremely low porosity and a high fracture density. Almost all of the quartz grains contain regularly spaced sets of planar fractures that commonly form conjugate sets of shear fractures. This is in stark contrast to otherwise undeformed Paleozoic rocks of the Nafud Basin.

Shock metamorphism: The presence of shock features was confirmed for most of the investigated 11 core samples including the wells U-75400, U-75272, U-75410 and U-75286. Only the samples of well SAQR-2 are apparently devoid of a visible shock metamorphic overprint. The most intense shock metamorphism is recorded in wells U-75400 and U-75286 (Fig. 2), where PDFs, PFs and FFs were found in quartz, sometimes in a tight spatial context within a single grain. In the four sandstone samples of well U-75286, almost all grains display planar fractures that commonly form conjugate shear systems. Bleaching of these sandstones is a result of the high fracture densities within the quartz grains. PDF lamellae in quartz grains in these samples are developed along crystallographic planes parallel to $\{10\bar{1}3\}$, $\{10\bar{1}1\}$, and to a lesser degree along (0001) and $\{10\bar{1}4\}$ (Fig. 2b, c). PFs in quartz grains exist predominantly along (0001) and $\{10\bar{1}1\}$ orientations, and accommodate grain shape flattening. Other shock indicators for elevated pressures, such as diaplectic glass, high pressure phases, or lechatelierite, could not be observed in any of the samples. Based on these findings and the circumstance that the investigated rocks have subordinate porosities we derive a shock pressure of ~10-15 GPa for well U-75286 between 455-458 m depth and 5-10 GPa for well U-75400 at ~200 m.

Conclusions: The documentation and systematic measurement of orientations of distinctive planar features in quartz unequivocally verifies the impact hypothesis of Saqqar proposed by [1]. With an apparent diameter of 34 km, the presence of a central dome of over 2 km stratigraphic uplift, and an annular ring syncline surrounding the latter, Saqqar exhibits the morphological criteria of a complex impact structure.

References: [1] Neville A. S., et al. 2014. GeoArabia 19: 17-44. [2] Gnos E., et al. 2013. M&PS 48: 1-15. [3] Wynn, J. 2002. J. Environ. Eng. Geophys. 7: 143-150. [4] Salameh E., et al. 2008. M&PS 43: 1681-1690. [5] Kenkmann et al. 2010: GSA-SP: 465: 471-487. [6] Meissner, C. R., et al. 1989. USGS-OF-08-5, 35 pp. [7] Wallace et al. 2000. Geological Map. Ministry of Petroleum and Mineral resources, Saudi Geological Survey.

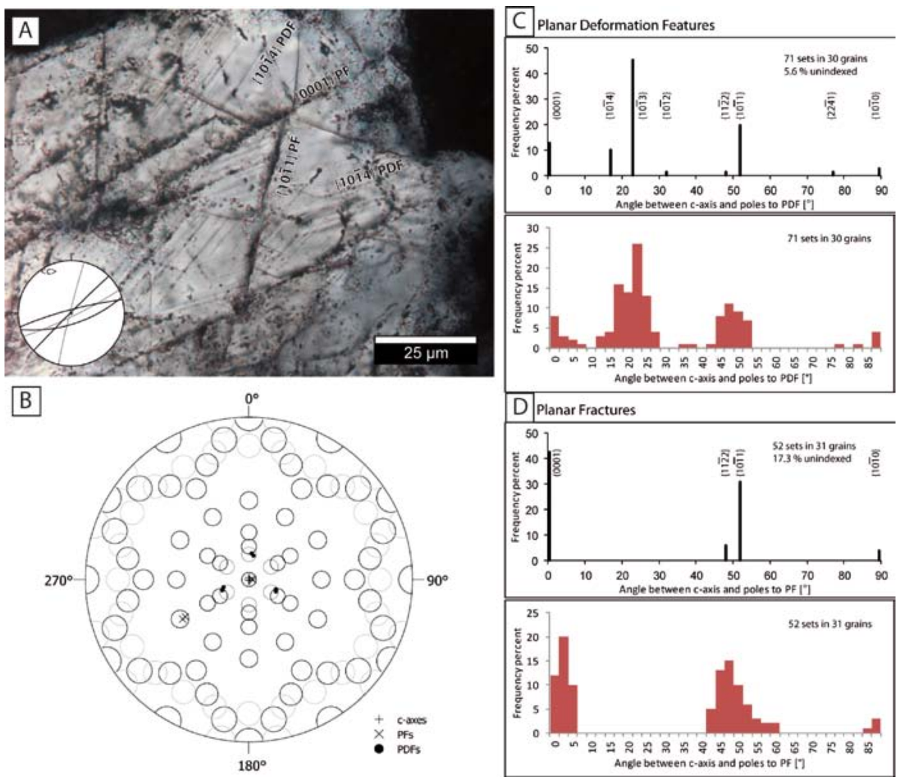

Figure 2 Well U-75286, depth: 455 m. A) Typical shocked quartz grain showing PF along (0001) and $\{10\bar{1}1\}$ and narrow spaced PDF lamellae along symmetrically equivalent $\{10\bar{1}4\}$ planes. B) Wulff-projection showing poles of the measured PF and PDF planes with the quartz c-axis in the center. The circles indicate, with 5% tolerance, the position of the quartz lattice planes. C-D) Frequency histograms of measured planar features. C) The most frequent PDF orientation is $\{10\bar{1}3\}$, followed by $\{10\bar{1}1\}$ and the basal plane (0001), D) PFs dominantly occur along (0001) and $\{10\bar{1}1\}$.