THE WAQF AS SUWWAN IMPACT CRATER, JORDAN: NUMERICAL MODELING OF CRATER FORMATION AND GRAVITY DATA K. Wünnemann[1*], H. Kühn[1,2], P. Janle[2], T. Kenkmann[3], [1]Museum für Naturkunde – Leibniz Institut an der Humboldt Universität zu Berlin, D-10115 Berlin, Germany, [2]Institute for Geosciences, Dept. of Geophysics, Kiel University, D-24118 Kiel, Germany, [3]Institut für Geowissenschaften, Universität Freiburg, Germany, (*kai.wuennemann@museum.hu-berlin.de).

Introduction: The Waqf as Suwwan impact crater in Jordan is a small complex crater structure, approximately 6 km in diameter. The crater was only recently identified as an impact structure [1,2] but has been investigated by seismic and gravity surveying in 1970 and 1980 on behalf of the National Resource Authority (NRA) of Jordan for ore and hydrocarbon exploration. Morphologically the structure is characterized by (Fig.1a) a well pronounced 1 km wide central uplift with a maximum elevation of 40 m above the average topographic level, surrounded by a relatively flat crater moat filled with yet unknown post-impact sediments and wadi deposits, and a hummocky circular structure standing approximately 30 m above the surrounding terrain which was interpreted as the remains of the crater rim [3]. In a recent geostructural field study the crater morphology is described in more detail [4]. Besides the well-exposed surface expression of the crater the most striking observation is a pronounced positive bouguer gravity anomaly above the central uplift of 6.5 mGal (Fig.1b). Most crater structures similar in size show a negative anomaly [5], which is usually interpreted by a mass deficiency, caused by brittle fracturing and open cracks underneath the crater. This study aims at developing (1) a numerical model of the crater formation consistent with the morphological, morphometric surface observations and structural subsurface deformations based on seismic data and (2) a model of mass distribution underneath the crater that explains the observed gravity anomaly and is consistent with the results from (1).

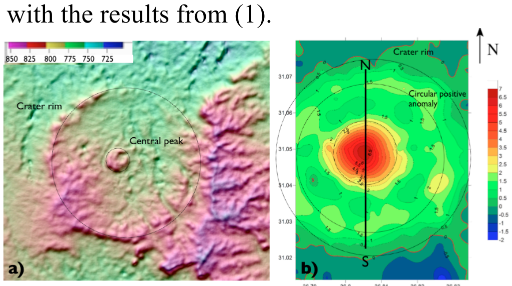

Figure 1: a) Digital elevation model; black lines indicate crater rim and central peak. b) Bouguer gravity anomaly (corrected according to regional trend); black lines indicate gravity profile shown in Fig. 2 (bold), boundary of topographic crater rim (outer circle), and circular positive gravity (inner ring).

Modeling approach: We use two different software packages to simulate crater formation (iSALE) and model the mass distribution underneath the crater (IGMAS). Both models are constrained by the given estimates on crater morphometry, morphology, and subsurface structural information from seismic imaging. Since no direct coupling between the models is possible an iterative procedure was applied where intermediate steps were compared qualitatively. For both models we assume a simplified three-layer setup of the pre-impact target stratigraphy where the upper most layer consists of limestone (300 m), overlying a sandstone unit (1400 m), above dolomite/shale. A detailed description of the target stratigraphy is given by [3].

(1)-iSALE is a numerical multi-material, multi-rheology model to simulate crater formation and shock wave propagation [6,7]. The thermodynamic behavior of the three different lithological units was modeled by ANEOS [8] for calcite, quartzite, and granite representing the limestone, sandstone, and dolomite layer respectively. More important regarding the crater formation is the rheological behavior of the different lithological units [9]. We use a brittle-ductile strength model [10] and acoustic fluidization [e.g.11,12] to calculate the mechanical resistance against plastic deformation. We assumed an impact velocity of 12 km s^{-1} and a projectile density of 2700 kg m^{-3} and varied the diameter of the projectile between 530-640 m and target rheology until we find a good agreement with the observational features. Since the amount of erosion is unknown but was estimated >100 m [3] we varied the thickness of the upper unit (limestone) between 400 m (corresponds to 100 erosion) and 800 m (corresponds to 500 m erosion).

(2)-IGMAS is a well-known software package to model gravity and magnetic data interactively in 3D [13]. We chose average density values for the three different lithologies from the literature [14] and introduced regions where density was decreases or increased due to brittle fracturing and structural deformations until we achieved a good match with the observed bouguer gravity anomaly. Note that the gravity data were corrected according to the regional trend.

Results: We conducted over 1000 iSALE models to fit the observational data. The best agreement was found for two different sets of target properties (weak and strong) and an impactor size of 530 m and 640 m in diameter, respectively (Fig. 2c,d). The level of erosion was assumed to be 500 m in both models. Although such a large amount of erosion exceeds most previous estimates significantly it is supported by the likely lack of impactites and the low degree of shock modification (planar fractures, feather features, shatter cones) [3]. Due to the fact that the central uplift except for the innermost area consists of limestone a large part of the transient crater must have been formed in the upper layer. After collapse and structural uplift material from the deepest point of the transient crater that just reached into sandstone strata (Kurnub sandstone) is transported to the inner most region of the central peak where it is exposed at the surface. Simultaneously, inward material movements from the sides of the crater contribute to the formation of the central peak. Note that the crater in our models is approximately 8 km in diameter before erosion.

Besides information about the structural transport and distribution of the different lithologies after impact the iSALE-models also calculate the degree of deformation in terms of total plastic strain. Regions that have accumulated a large amount of plastic strain (Fig. 2c,d), left panel, warm colors) have experienced pervasive fracturing which most likely results in an increase of porosity and a reduction of density. Accordingly, we introduced regions with reduced density in our gravity model (Fig. 2b). However, to explain the strong positive gravity anomaly at the very centre (Fig.1 b, 2a), a high-density region relatively close to the surface had to be assumed (Fig.2b). Additionally a small circular positive gravity anomaly of ~2 mGal occurs close to the crater rim at a radius of approximately 2.5 km (Fig. 2a). Only in the iSALE model where we assumed a “strong”-target rheology (Fig.2d) we find structural features in the sandstone unit that may explain the local circular high in the gravity data.

Discussion: Combined modeling of crater formation and gravity data at the Waqf as Suwwan impact crater shows qualitatively a generally good agreement of mass distribution and structural deformation in the crater subsurface. However, the observed strong positive anomaly of 6.5 mGal at the centre of the structure can only be explained by a region of highly compacted sandstone (2.75 g/cm3) close to the surface surrounded by fractured sandstone with a reduced density (2.6 g/cm3). Such a high-density concentration is difficult to explain, as there exist no hints for a buried melt body or uplifted high-density material. Possible explanations may be (1) shock-induced compaction of pore space in the sandstone or (2) post-impact sealing of fractures and flaws previously opened by shear bulking by centripetal mass movements during crater collapse. Further modeling work including porosity and the effect of an oblique impact is required.

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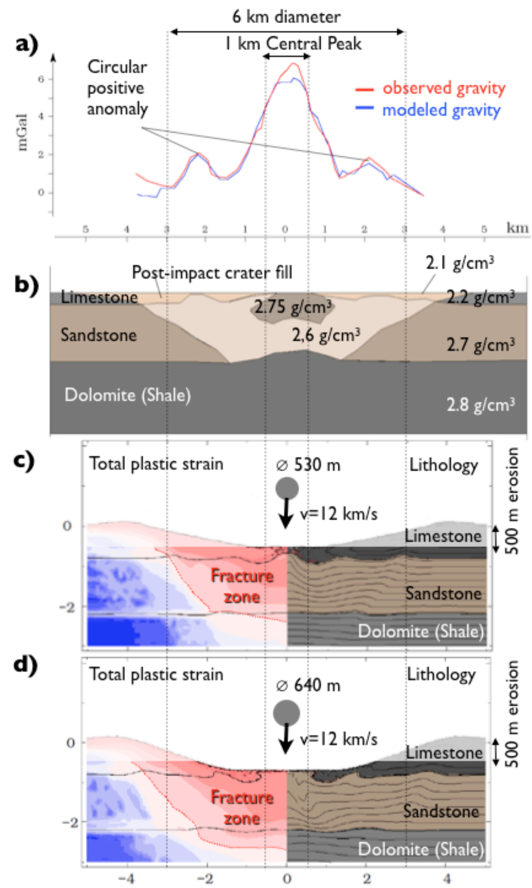

Figure 2: a) N-S-Profile of observed (red) and modeled (blue) bouguer gravity data. b) N-S-Profile of 3D-IGMAS model of density distribution. c) and d) final crater morphology of 2D cylindrically symmetric iSALE models for a soft (c) and hard (d) target rheology. The shaded area indicates the assumed 500 m of erosion. The left panel shows total plastic strain, the right panel structural deformation.