THE SIZE AND THE CENTER OF THE AGOUDAL IMPACT STRUCTURE (CENTRAL HIGH ATLAS, MOROCCO).

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Introduction: Agoudal is the only known impact structure in Morocco [1; 2; 3; 4]. It was confirmed by the observation of shatter cones in a mid-Jurassic marly limestone formation. Outcrops with shatter cones appear to be restricted to a region of ~700 x 400 m. Field work and satellite image analysis did not reveal a circular structure associated to the shatter cones observations. However, vertical to overturned strata, not observed elsewhere in the surrounding area, and trending N150-N160, were reported [4]. Therefore, it was concluded that the crater is highly eroded and there is no direct constraints about the size of the impact structure, except that the crater was probably larger than the areas with shatter cones [4].

Materials and Methods: In order to constrain the center and size of the highly eroded crater, structural measurements were spatially interpolated using the natural neighbor interpolation technique to produce a continuous map of dip angles and dip azimuths of sedimentary strata (see [5] for more detail about the technique). We applied the technique of concentric deviation which quantifies the deviations of observed strikes from concentric strike for a given center. The technique reveals, for instance, the structural asymmetries of impact craters [6]. In our case, this technique is used in order to estimate the likelihood of the location of the center of the crater. We make the assumption that axial symmetry should be maximum when the center of the polar coordinate system corresponds to the center of the impact structure.

350 measurements of strike and dip directions of the strata along with latitude and longitude values, taken over the central disturbed area of ~1500 m x 1500 m, were translated from a geographic reference system into polar coordinates. Eight potential centers, including positions near the main shatter cones area or near the river, were tested with the concentric deviation method.

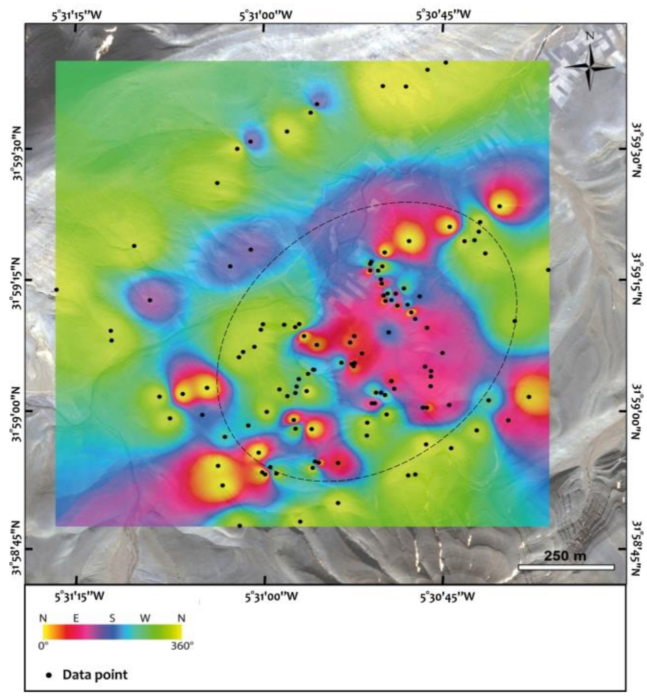

Fig. 1. Interpolated dip azimuths of strata measured over the impact structure site are displayed. Interpolation is done by the inverse distance weighting data points.

Results: Dip azimuth ranging from 50° to 230°, appearing in blue on the dip azimuth map of the strata (Fig. 1), appears to be correlated to the shatter cone area (in dash circle, Fig.1). The main hill, with shatter cone outcrops, is surrounded by sub-horizontal beds. On the other hand, the map of dip angles interpolation, covering the central area of 2.25 km^2 (Fig. 2), shows a disturbed area (elevated dip angles in red) with a diameter of 0.12 km^2, with two domains with enhanced dipping (vertical to overturned strata), which correspond to the shatter cone outcrops (in dash circle, Fig. 2). The vertical and overturned strata show either a WNW-ESE bedding orientation or a NE-SW orientation [4].

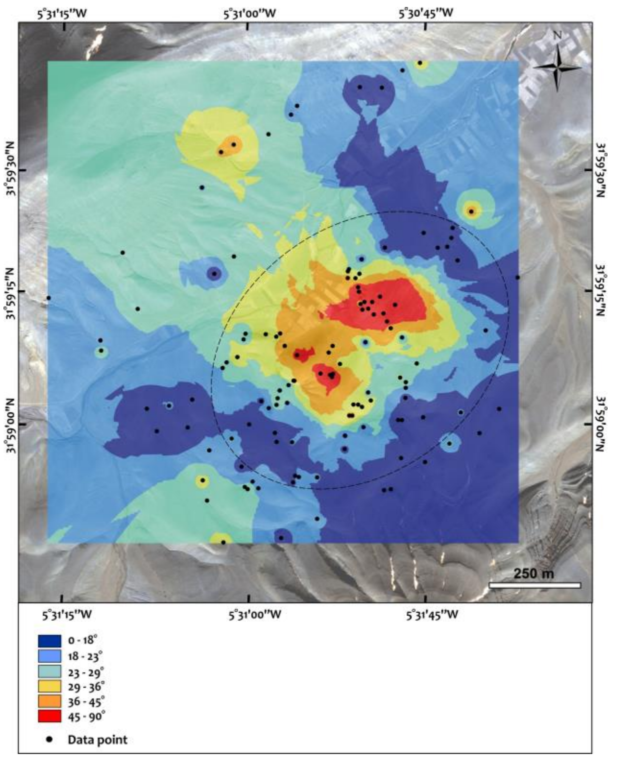

Fig. 2. Interpolated dip angles of strata measured over the Agoudal impact site are displayed. Interpolation is done by the inverse distance weighting using 10 neighboring data.

The Concentric-Deviation-Method was applied for 8 test points. The points were selected within the disturbed zone and within the observed maximum spatial extent of in situ shatter cones. For each point, we have considered the entire set of collected strike measurements of the stratification planes of the central zone, where shatter cones in situ and vertical to overturned strata are reported. The lowest degree of deviation from pure concentric strike is found if the center is placed in the main hill ("MH" in Fig. 3) at 31°59'13.73" N, 5°30'55.14" W (point 6). The other selected points show a significantly higher degree of deviation from pure concentric strike compared to point 6.

Discussion: Although no circular structure is observed on remote sensing data or inferred from structural or geological observations around the shatter cones locations, the map of dip angles interpolation of the central area with shatter cone outcrops shows a disturbed zone of 0.15 km^2 with two domains of enhanced dipping corresponding to the vertical and overturned strata. In the absence of other tectonic origins, the vertical or overturned strata are interpreted as target rocks that were tilted during excavation and collapse phases of the impact cratering event, considering that the surrounding formations are sub-horizontal.

Conclusion: In the case of a simple crater, the vertical to overturned strata could correspond to a remanent of a crater rim, but shatter cones are not expected to be common at the crater rim of a simple crater. For a complex crater, the structural features and area of shatter cones occurrences and vertical to overturned strata may be the relict of a central uplift, and the main hill location seems to represent the center of the remanent of a deeply eroded impact structure. As shatter cones are not unambiguously reported for structures smaller than 1 km in diameter [7] and from the fact that they generally occur within an area corresponding to 1/6 to 1/2 of the estimated original diameter of the impact crater, we suggest that the original impact crater of Agoudal had more likely a diameter of 1 km to 3 km [4].

References: [1] Sadilenko, D.A. et al. (2013) MAPS, v. 48, [2] El Kerni, H. et al. (2014) MAPS, v. 49, [3] Lorenz, C. A. et al. (2015) MAPS, v. 50, [4] Chennaoui Aoudjehane, H. et al. (2016) MAPS, v. 51, [5] Kenkmann, T. et al. (2017) MAPS, v. 52, [6] Poelchau, M. and Kenkmann, T. (2008) MAPS v. 43, [7] Baratoux, D. et al. (2016) MAPS, v. 51.

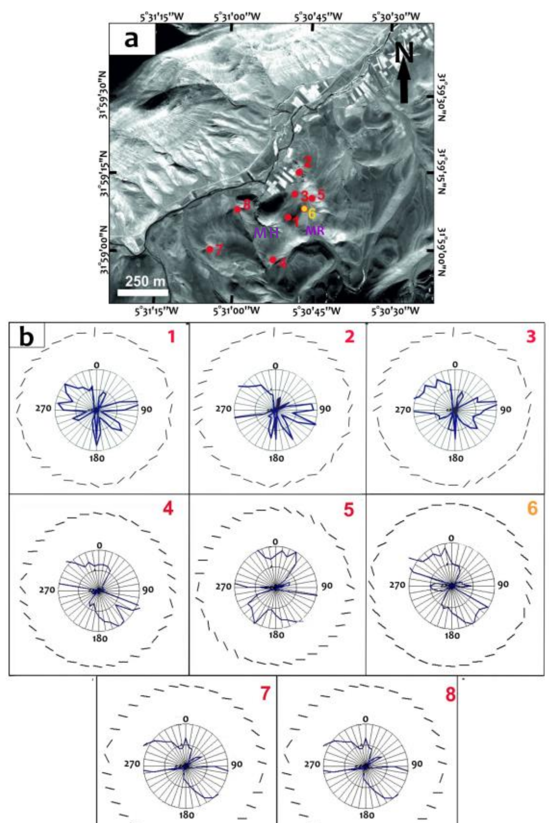

Fig. 3. a) Location of the eight points used for the application of the concentric deviation method. These points are a selection of possible centers of the Agoudal impact structure, ploted on a satellite image WorldView-2 of the studied site of Agoudal ("MR" and "MH" refer to the main river and the main hill respectively). b) Polar plots corresponding to the deviation from concentric strike bedding. Point 6 is associated with the lowest deviation from concentric strike bedding (31° 59' 13.73" N and 5° 30' 55.14" W).