EFFECT OF IMPACT ANGLE ON THE OFF-SET OF OUTER VS. NESTED CRATER FOR CONCENTRIC IMPACT STRUCTURES IN LAYERED TARGETS: A TOOL TO DETERMINE DIRECTION OF IMPACT.

J. Ormö[1] and A. P. Rossi[2]. [1]Centro de Astrobiología, (INTA-CSIC), 28850 Torrejon de Ardoz, Spain (ormoj@cab.inta-csic.es), [2]Jacobs University Bremen, Germany (an.rossi@jacobs-university.de)

Introduction and aim of study: Most natural impacts occur with an oblique trajectory of 45°. Still, due to the high kinetic energy most impacts produce circular craters with rather centro-symmetric ejecta layer. However, a lowering of the impact angle with respect to the horizon affects the expression of the resulting impact crater in several ways (e.g. elongated shape, non-uniform cross-section, non-uniform ejecta distribution). The effect of impact angle on the ejecta distribution has long been used as a tool to establish the projectile trajectory for craters: At angles below 45° the ejecta distribution gets more downrange preference. With continued decrease of impact angle there is a drastic reduction of uprange ejecta and a "forbidden zone" develops. At very low angles a "forbidden zone" also develops downrange of the crater, leading to a "butterfly" pattern [1].

One of the few craters on the Earth that maintains an ejecta layer that still displays the direction of impact is the Lockne crater in central Sweden [2]. Lockne´s morphology is also strongly affected by the weak upper target layer (seawater and sediments) that covered the rigid crystalline basement. The crater displays a 3.5km wide brim surrounding an 8km wide, nested, basement crater. The brim is a surface partially stripped from both water and sediments before the deposition of basement crater ejecta. The resulting concentric shape is in analogy with lunar craters in regolith-covered rock [cf. 3]. In experimental craters formed in water over sand it is noticed how the outer crater in the water cavity may be much wider than the nested crater and how a shallow excavation flow develops along the interface with the more resistant substrate [4]. The same effect is noticed in the numerical simulations of the Lockne crater [5; 6]. Furthermore, 3D simulation shows how the brim gets wider on the down-range side than on the up-range side of the nested crater [6]. Consequently, there is an apparent off-set between the nested crater and the surrounding outer crater in the weaker, upper part of the target (Fig.1). Our aim is to develop this off-set crater concentricity into a method to determine impact direction and obliquity for layered-target craters, especially for cases when the ejecta layer is poorly preserved.

Method: Layered targets are frequent on both the Moon and Mars, but possibly also elsewhere in the Solar System such as on some of the natural satellites of the outer planets, and on certain asteroids. To evaluate the influence of the obliquity on the amount of off-set at a concentric crater it is a prerequisite that the crater also shows a well preserved ejecta layer. In a first step we are comparing two selected craters on Mars with the terrestrial analogue Lockne, as well as craters from oblique impact experiments in the Experimental Projectile Impact Chamber (EPIC) at Centro de Astrobiología, Spain.

The morphology of the Lockne crater is obtained from publications by the first author and other researchers based on extensive fieldwork. The selected Martian craters are studied by the means of HiRISE, CTX, and THEMIS imagery. The EPIC hardware used in the experiments consist of a 20mm compressed N_2 (200bar) gun shooting a 5.7g delrin projectile at 400m/s under 1atm air pressure. The target consist of a thin layer of dry sand covering a more rigid layer of compacted wet sand.

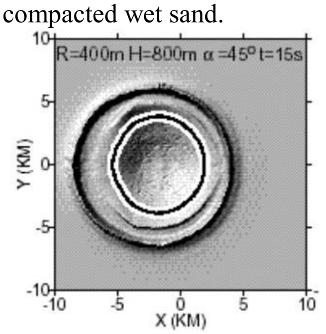

Fig. 1. Numerical (3D) simulation of an oblique impact into a weak target layer covering a rigid basement. Image adapted from [6]. Impact from the right. The here displayed numerical model represents one extreme in an iterative process to pinpoint the Lockne target water depth (The final result gave projectile radius R=300m for the target water depth H=500-700m). The outer circle represents the rim of water/sediment cavity, and the inner circle the rim of the basement crater surrounded by ejecta.

Results and discussion: The two selected Martian craters show both offset concentricity and pristine ejecta with a distribution diagnostic for oblique impact. The first crater, here called "Case-1" (194.847 E 46.582 N), is about 700m wide and located in Arcadia Planitia (Image not shown here due to lack of space). It has a set of two concentric, shallow, outer craters surrounding a deeper, nested crater, probably as an effect of a multi-layered target. The ejecta distribution reveals that the outer craters are off-set down-range with respect to the nested crater. "Case-2" is the 2km wide Ada crater (356.8 E 3.1 S) in Meridiani Planum (Fig. 2A&B). It has a rather steep-walled outer crater surrounding a nested crater with a mainly down-range ejecta flap in analogy with the Lockne basement crater.

In Case-2 a THEMIS IR image reveals the direction of impact based on the ejecta distribution (Fig. 2B).

The morphology of Case-2 corresponds well with the laboratory impact crater shown in Fig. 3. Allthough the projectile velocity in the experiment is about twice the speed of sound in the dry sand layer (i.e. hypervelocity) the effect of obliquity is exaggerated in laboratory experiments of this relatively low projectile velocity. Thus, before proper scaling relationships have been applied, a direct comparison of impact angles between experiment and natural crater should be avoided. Nevertheless, the crater´s cross-section with the down-range development of an outer crater, as well as the ejecta distribution with the nested crater ejecta covering the outer crater are comparable to both Case-2 and Lockne.

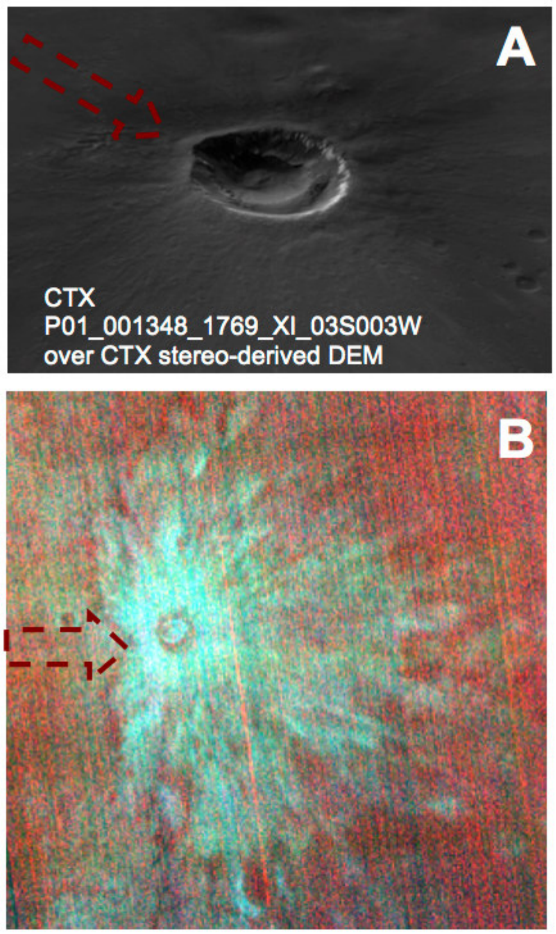

Fig. 2. The 2 km wide Ada crater ("Case-2") in Meridiani Planum. A) shows an oblique view of a stereo-derived DEM. B) shows a the ejecta distribution (bright blue-green) in a THEMIS IR image (I09581006RDR) [7]. Direction of impact is indicated by red arrows.

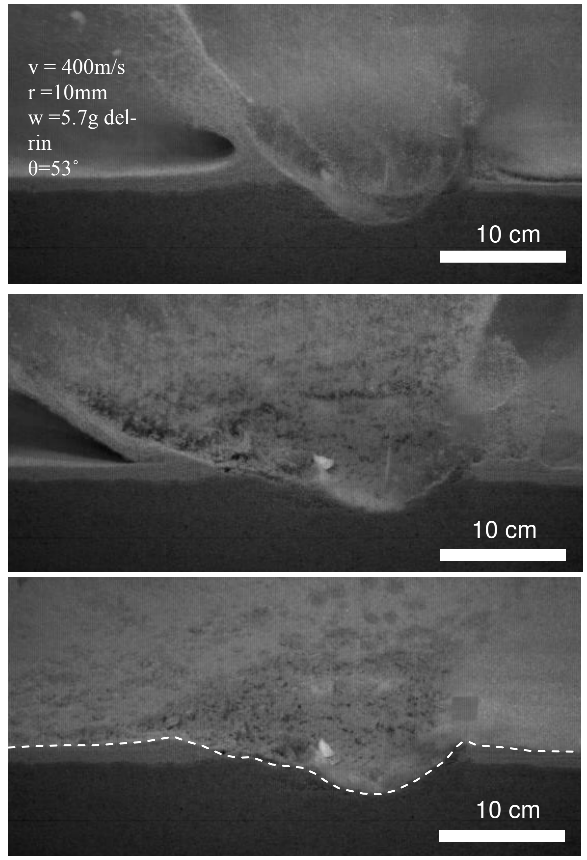

Fig. 3. Laboratory projectile impact experiment into dry sand (light grey) over wet sand (dark). Impact from the right. Profile of final crater indicated by stippled line.

Conclusions: The offset in concentricity of craters formed in layered targets is a viable complement to the ejecta distribution in determining the impact direction and angle for impacts into layered targets, especially in cases when the ejecta layer is poorly developed or eroded.

Acknowledgements: The work by J. Ormö is supported by the grant AYA2008-03467⁄ESP from the Spanish Ministry of Science and Innovation. HiRISE image credit: NASA/JPL-Caltech/Univ. of Arizona, and CTX image credit: NASA/JPL-Caltech/MSSS.

References:[1] Gault D. E. and Wedekind J. A. (1978) *Proceedings 9th Lun. Plan. Sci. Conf.,* 3843–3875]. [2] Lindström M. et al (2005) *Planet. Space Sci., 53(8),* 803–815. [3] Quaide W. L. and Oberbeck V. R. (1968) *J. Geophys. Res., 73,* 5247–5270. [4] Gault D. E. and Sonett C. P. (1982) *Geol. Soc. Am. Spec. Pap.., 190,* 69–102. [5] Ormö J. et al. (2002) *J. Geophys. Res., 107(12),* 31–39. [6] Shuvalov V. et al. (2005) *Impact Tectonics* (eds. Koeberl C., Henkel H.), Impact Studies, Springer, 405–422. [7] Christensen P.R., Gorelick N.S., Mehall G.L., and Murray K.C., THEMIS Public Data Releases, Planetary Data System node, Arizona State University, <http://themis-data.asu.edu>.