THE MECHANICS OF POLYGONAL IMPACT CRATER FORMATION. T. Öhman[1,2], M. Aittola[2], V.-P. Kostama[2], M. Kallo[2] and J. Raitala[2], [1]Dept. of Geosciences, P.O. Box 3000, FI-90014 University of Oulu, Finland, (teemu.ohman@oulu.fi); [2]Dept. of Physical Sciences, P.O. Box 3000, FI-90014 University of Oulu, Finland.

Introduction: The major significance of crustal structures like faults, joints and fractures or other similar planes of weakness in the target material during the cratering process has been known for decades. This structural control has been confirmed by detailed field studies on a terrestrial crater [e.g. 1, 2], cratering experiments [e.g. 3, 4], and remote sensing studies of craters on various planets (including the Earth), asteroids, icy and rocky moons, and a comet nucleus [see 5 for a review]. Such structures affect the cratering process, and thus also the morphology of the final crater. Hence, information about the structures of the target can be obtained by studying the polygonal crater morphology resulting from an impact into target with some preferred orientations of crustal weakness [e.g. 6, 7].

According to current models, polygonal impact craters' (PICs, defined here as craters with at least two straight rim segments with a clearly discernible angle between them) straight rim segments reflect the orientations of the target differently depending on whether the crater is simple or complex [6]. In simple PICs formed in orthogonally fractured target, straight rim segments should make an angle of ~45º with the fractures. In complex PICs the straight rim segments should parallel the fractures. However, the ground truth data for PICs of simple crater size comes from detailed field studies of only one crater, namely the notably square-shaped Meteor Crater. Hence, it is in order to try to use other approaches to define whether or not it is truly validated to extrapolate ideas based on Meteor Crater to be the general rule of simple crater formation in fractured targets. This is emphasized by impact and explosion experiments [3, 4] that give a much more varied picture of the rim/fracture – relationship than the Meteor Crater. As well-preserved terrestrial craters are extremely few, we have studied impact craters on Mars, Venus, and recently also on the Moon to obtain a better understanding of cratering process in inhomogeneous targets.

Simple and complex PICs' rim strikes: If simple and complex PICs really reflect the target structures differently, the distribution of straight rim segment strikes in the same area should be dissimilar between simple and complex PICs. Continuing our previous work [8], we studied PICs north from the Argyre basin in the southern hemisphere of Mars (10ºW–74ºW, 26ºS–42ºS), using Viking Orbiter MDIM2.0 (Mars mosaicked digital image model) photomosaics (~231 m/px) for all the strike measurements, and the polygonal/non-polygonal classification. However, the simple/complex classification was based on Mars Odyssey THEMIS (thermal emission imaging system) infrared (~100 m/px) and visual channel images (35 m/px). Potential simple craters were pre-selected using 7 km (the average Martian simple/complex transition diameter) as the maximum size. From these craters, the few which showed incipient complex features – mainly enhanced slumping of the rim – were discarded. The remaining 22 polygonal craters were typical Martian simple craters, often with flat floors due to sedimentary infilling. There certainly are some simple craters in the study area larger than 7 km, but their contribution to rim strike distribution is regarded insignificant compared to the substantially larger number of complex craters.

The results of the rim strike studies are intriguing. Instead of the expected differing strike patterns, we could not detect any statistically significant difference between simple and complex craters' rim strike distributions. As previously shown [e.g. 5, 8 and references therein], in a regional study the influence of illumination geometry is insignificant, although it notably affects the apparent polygonality of any single crater. Thus, the similar straight rim segment strike patterns in simple and complex craters can be regarded as real. This contradicts the expectations based on the existing PIC formation models [6].

Size distribution of PICs: If no observational bias occurs, and the formation of PICs favors no particular size range, then the size distributions of polygonal and non-polygonal craters should be similar. We have studied this aspect with data from Argyre region in Mars (10ºW–74ºW, 26ºS–58ºS), from the whole globe of Venus using Magellan SAR-data (synthetic aperture radar images; craters D>12 km, see 9 for details), and from highlands of the Moon (10ºW–40ºE, 10ºN–50ºS; craters D>10 km, at the moment very preliminary data) using photographs from the Consolidated Lunar Atlas. The size distributions of PICs and "normal" craters are somewhat different. It appears that there are "too many" PICs in some size classes compared to the well-defined size distribution of ordinary circular craters. When the sizes are normalized using the average simple/complex transition diameters (D_t=7 km for Mars, modeled D_t=4 km for Venus, and D_t=15 km for the Moon), all the discrepancies in the size distribution curves are roughly at the same D/D_t-ratio: PIC formation appears to "favor" a size range of about $2D_t$ – $5D_t$. Further studies are underway to find out if this truly is a real phenomenon, and not caused by any observational bias. However, at least for Venus the diameter–polygonality -dependence seems quite robust [9]. Also the fact that similar trend can be seen on three different heavenly bodies (although the lunar data is very preliminary) studied with different types of datasets, implies a real preference to a specific size range.

Another PIC formation mechanism? Current models state that in complex PICs, the crater expands preferentially in a direction perpendicular to the strike of fractures, whereas in simple PICs this enhanced expansion takes place in a direction parallel to their strike. This is because simple PICs should form in the excavation stage, when the excavation flow progresses more easily in a direction parallel to the strike of the fractures. Complex PICs, on the other hand, should form in the modification stage, when the rim collapses along normal (listric) faults that utilize the pre-existing planes of weakness [6]. The rim strike data from northern Argyre region is in stark contrast to this idea.

Detailed studies in the few well-preserved terrestrial craters, both simple (e.g. Meteor Crater [1, 2] and Tswaing [10]) and complex (Bosumtwi [11]), clearly indicate the importance of thrusting related to the excavation stage. Therefore it does not seem too far-fetched to think that perhaps this thrusting takes place utilizing pre-existing structures [5]. With this mechanism, straight rim segments would parallel the orientations of regional pre-existing fractures. This mechanism could work in simple PICs, as well as in small and medium sized complex PICs. In larger complex PICs that have gone through more substantial collapse in the modification stage [12], collapse along the pre-existing structures might well be more important mechanism to create polygonality. The suggested size range (small to mid-sized complex craters) of this thrusting model for PIC formation is also approximately the size range where PICs seem to be "too abundant" compared to non-polygonal craters.

The importance of PICs: Polygonal craters are not merely an interesting detail of impact cratering. In addition to increasing our understanding of the most common geologic process in the Solar System, their study has also other benefits. They have been effectively applied in the tectonic studies of various cratered surfaces [reviewed in 5]. Especially useful they are in studying the tectonic history of highly cratered areas with very few other indications of tectonism [7 and references therein]. This aspect is further emphasized by the fact that degradation does not change the strike distribution of straight rim segments [8]. Another aspect favoring their study is that they can be utilized in inferring the general rheological properties of small Solar System bodies: bodies with PICs must have a crust rigid enough for relatively long-lasting fractures to form. As some of these bodies might become an impact hazard, knowing their structure is vital in case there will be a need to try to protect the humankind from their impacts.

Summary and conclusions: Polygonal impact craters, formed by the interaction of pre-existing target structures and the cratering process, are ubiquitous throughout the Solar System. Their current formation models [6] of structurally controlled excavation and slumping predict different straight rim segment strike patterns for simple and complex polygonal craters, respectively. However, we have observed no such difference in simple and complex PICs north from Argyre basin, Mars. Based on our studies of Martian, Venusian and lunar PICs it also appears that there is a preferred size range, where PICs have a higher tendency to form. This size range seems to be roughly around 2–5 times the simple/complex transition diameter. These observations have led us to propose an additional PIC formation mechanism, namely thrusting of the crater rim in the excavation stage utilizing pre-existing planes of weakness. This mechanism would explain the varied results obtained in cratering experiments in fractured targets [3, 4], and it is in concert with observations of major thrusting on the rims of both simple [e.g. 1, 2, 10] and complex [11] terrestrial craters.

Further understanding of PIC formation – complementary to remote sensing and field studies – could be obtained from cratering experiments in fractured targets, including a detailed analysis of pre- and post-impact fractures with respect to the crater rim shape. Another approach would be 3D modeling of the cratering process. Involving relatively small-scale structural discontinuities in the numerical model, however, increases the required computing power substantially.

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