Regmaglypts on clasts from the Puerto Mínguez ejecta, Azuara multiple impact event (Spain)

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1 Introduction

Regmaglypts (or thumbprints) are a relief commonly reported for the surface of some meteorites (Fig. 1). The depressions originate from dynamic air pressure and from selective erosion by material melting (ablation) off the surface of the meteorite on its passage through the atmosphere (Svetsov 2003, and others). The relief may show polygonal, spherical, rounded or elliptical shape, and a pattern like fingers over wet clay is frequent.

Source: Cascadia Meteorite Laboratory, Portland State University

Fig. 1. Regmaglypted Gibeon meteorite.

The find of very similar ablation features on clasts from impact ejecta has been reported by Ernstson (2004). Here, we present an extended article on this subject.

Fig. 2. Typical aspects of the Puerto Mínguez impact ejecta hosting regmaglypted limestone clasts.

The ejecta under discussion (Puerto Mínguez ejecta) belong to the mid-Tertiary large Azuara/Rubielos de Cérida impact crater chain in Spain (Ernstson et al. 2002, 2003; Web 1, 2). The unconsolidated, badly sorted ejecta material (Fig.2) is to a large extent composed of carbonate clasts (angular to slightly rounded pebbles, cobbles and boulders) which without exception display prominent plastic deformations in the form of striae, polish, deep imprints and faceted sculpture (Claudin et al. 2001, Ernstson et al. 2002; Web 3, 4). The abundant regmaglyptic clasts among these plastically deformed components look amazingly similar to regmaglyptic meteorites (Fig. 3) suggesting similar formation processes.

Fig. 3. Amazingly similar: Regmaglypts on the surface of the Tabor meteorite and on a limestone clast from the Puerto Mínguez impact ejecta.

2 Shape and surface of the regmaglyptic limestone clasts

Fig. 4 shows various limestone clasts which have been sampled from these Azuara/Rubielos de la Cérida ejecta and which display the peculiar regmaglypts.

Fig. 4. Regmaglypted carbonate clasts from the Puerto Mínguez ejecta. Counterparts of the regmaglyptic surfaces as shown in the images are easily found in meteorite collections.

Frequently, the regmaglyptic samples are flat and roughly conically to pyramidally shaped as can be seen in forward-facing and side-facing views (Fig. 5). The base of these conical and pyramidal clasts in general lacks distinct regmaglypts, an observation that is made also with regmaglypted meteorites and may be explained by a very stable flight during the ablation process. On the other hand, limestone clast that are regmaglyptic all around, can likewise be sampled from the ejecta.

Fig. 5. Forward-facing and side-facing views of conically to pyramidally shaped regmaglyptic clasts.

In a few cases, the ablation process has not only produced superficial regmaglypts but has also eaten deeply into the clast (Fig. 6) reminding of similar distinct ablation features of some meteorites (Fig. 7).

Fig. 6. A regmaglyptic limestone clast from the Puerto Mínguez ejecta exhibits prominent ablation reaching deeply inside into the limestone clast. For comparison see the meteoritic ablation features in Fig. 7.

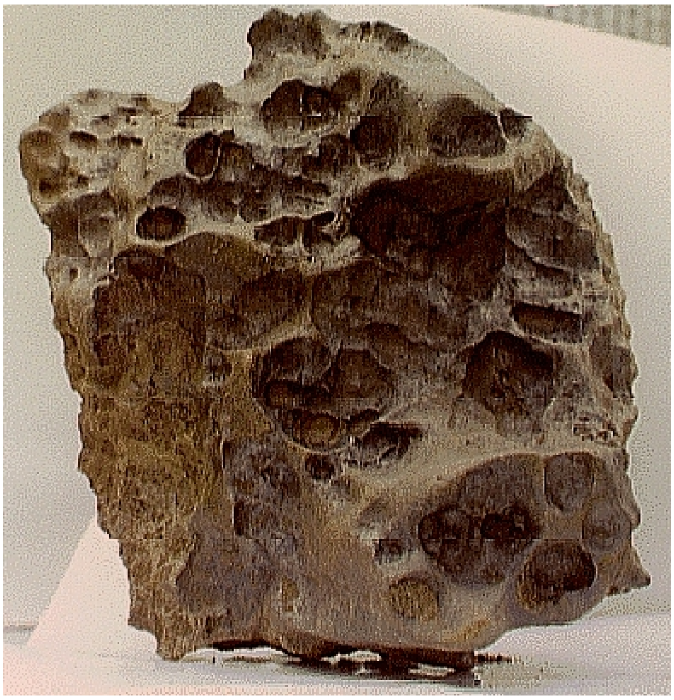

Fig. 7. The Derrick Peak, Antarctica, meteorite. Image courtesy of NASA.

From Figs. 8, 9 and 10 it is evident that the strong plastic deformations exhibited by the clasts throughout the Puerto Mínguez ejecta (Claudin et al., Ernstson et al. www.) have affected also the regmaglyptic components. It is also evident that the deformation features (breccia dike implantation in Fig. 8, a rotated fracture in Fig. 9, prominent striations in Fig. 10) are not overprinted by the regmaglypts and, therefore, are younger.

Fig. 8. Moderately regmaglypted limestone clast cross-cut by polymictic breccia dikes.

Moreover, SEM images of the polished regmaglypts reveal a surface pockmarked by abundant micro-craters (Fig. 11). In a thin-section cut across a regmaglyptic clast (Fig. 12), a superficial calcite grain coarsening can be observed suggesting enhanced temperatures which is substantiated by a whitish discoloring of many clasts pointing to superficial decarbonization (Fig. 9).

Fig. 9. Regmaglyptic limestone cobble (upper) displaying a distinct rotated fracture and prominent striations (lower, close-up). The whitish discoloring possibly originates from decarbonization upon enhanced temperatures.

Fig. 10. Striations and polish on the regmaglyptic surface of the right-hand sample in Fig. 5. The field is 10 mm wide.

Fig. 11. SEM image of a regmaglyptic surface that is pockmarked by microcraters. The microcratering obviously preceded the polish and the formation of the striation (in the middle, NNE - SSW trending).

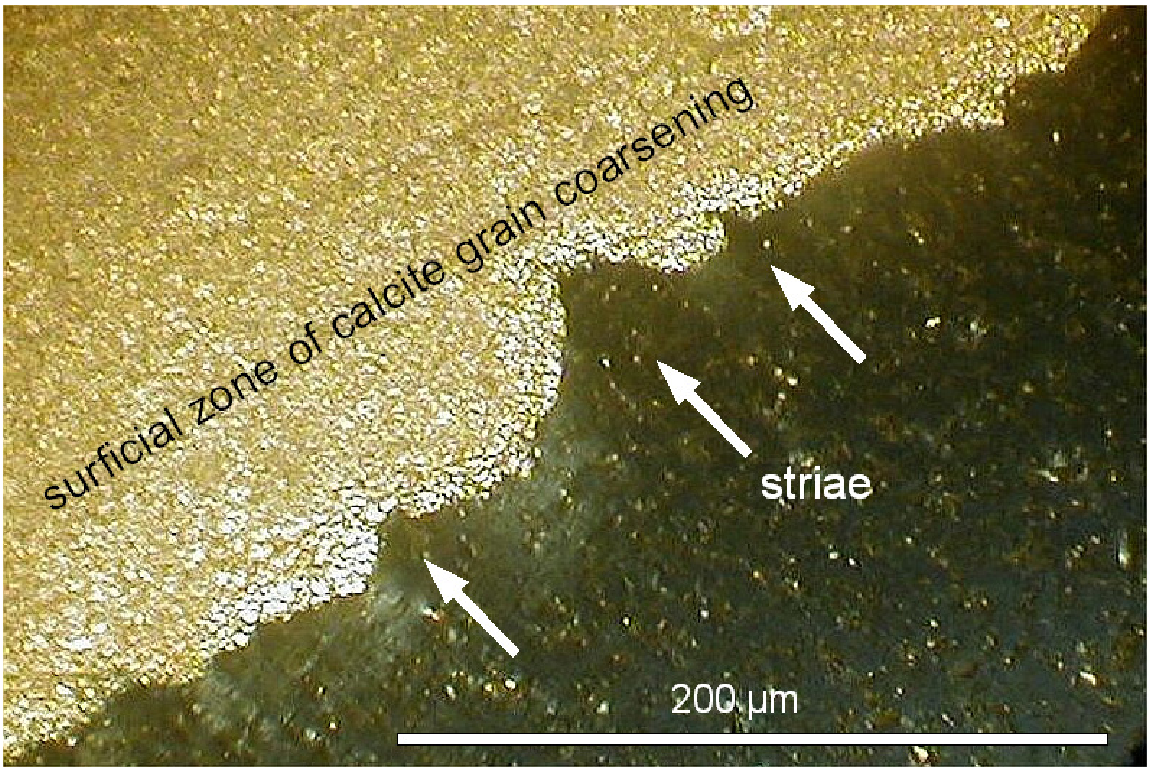

Fig. 12. Photomicrograph (xx polarizers) of a cut across the regmaglyptic surface of the right-hand sample in Fig. 5.

3 Discussion: Possible confusion with lapiés (karren) features?

Of course, the regmaglyptic depressions in a way remind of lapiés (karren) features on surfaces of exposed limestones (Figs. 13, 14). Lapiés consist of shallow, straight grooves or runnels incised into the limestone by solution.

Theoretically, there are two possibilities that the regmaglyptic clasts in the Puerto Mínguez ejecta are confused with lapiés grooves:

-- the "lapiés" depressions formed after the deposition of the ejecta by dissolution

-- the "lapiés" depressions are an "inherited" original feature that survived clast excavation, ejection and emplacement.

Fig. 13. Lapiés pattern on limestones (Monasterio de Gombrèn, Ripollès, Catalunya).

Fig. 14. Lapiés (karren) features on Jurassic limestones in close-up.

Fig. 15. Grove-like regmaglypts on all faces of a limestone clast. Note that the surrounding clasts lack any thumbprint features. The upper image shows the clast deeply embedded in the matrix of the Puerto Mínguez ejecta from which it was dug up for taking a photo (lower).

Fig. 16. Front and rear of a regmaglyptic limestone clast from the Puerto Mínguez ejecta. The regmaglypts all around exclude a "lapiés" formation before excavation and ejection.

Both possibilities are not compatible with the observations. Because of the striae and polish on the regmaglyptic surfaces (Figs. 9, 10, 11) and because the regmaglyptic clasts are embedded as individuals in the ejecta matrix (Fig. 15), an *in situ* formation as lapiés can clearly be excluded.

Alternatively, the "lapiés" depressions existed already before the impact and survived fracturing of larger limestone complexes, excavation, ejection and emplacement of the ejecta. In this case, we have to explain the abundant clasts within the ejecta that are regmaglyptic all around (Figs. 15, 16), which is absolutely incompatible with an ordinary lapiés formation by precipitation and dissolution.

Anyway, the in part very similar morphology of lapiés (karren) and regmaglypts on limestone surfaces expresses a typical example of convergence in science that is quite different processes may lead to nearly identical features.

4 Conclusions

From the observations and the above discussion, we conclude that the thumbprints displayed on the clasts from the Azuara/Rubielos de la Cérida ejecta (Puerto Mínguez ejecta) are true ablation features (regmaglypts) that formed in the ejection process by heating and partial melting of the limestone. The heating is substantiated by the recrystallization observed on regmaglyptic surfaces (Fig. 12) and by evidence of decarbonization (Fig. 9).

Partial melting of limestones requires pressures > 100 bars and temperatures > 1,500 K (Tyburczy & Ahrens 1986). These conditions are assumed to be reached during atmospheric re-entry of the ejecta (Schultz & Gault 1982) or when the expanding vapor plume passes through the ejecta curtain (Vickery1986). As the regmaglyptic clasts in the Azuara/Rubielos de la Cérida ejecta are found near the crater rim and, therefore, hardly escaped from the atmosphere, a partial melting in an expanding vapor plume seems more probable than a partial melting during atmospheric re-entry.

Summarizing the most intriguing observations, the following scenario of events is suggested: Jurassic and Cretaceous limestone clasts, excavated and ejected from the impact target, entered the expanding vapor plume, where they experienced decarbonization, partial melting and the formation of regmaglypts and, in a few cases, also deep-reaching ablation features as shown in Fig. 6. During the ejection, the collision with faint dust particles from the vapor plume and the ejected material resulted in the formation of micro-craters (Fig. 11) that could survive when the ablation process came to standstill. Upon the highly energetic emplacement of the ejecta, the components and among them the regmaglyptic clasts experienced the plastic deformations (polish, striations, rotated fractures, breccia dike implantation etc) partly or completely overprinting the regmaglypts. Enhanced temperatures in the deposited ejecta and annealing of the carbonate clasts enabled a final surficial recrystallization (Fig. 12).

Plastic deformations like striae, polish and penetration marks have been reported (Ocampo et al. 1998, Marshall et al. (1998) also for carbonate clasts in the Chicxulub impact ejecta in Belize, and they are proposed (Ocampo et al. 1998) to have partly originated from ablation in the before-mentioned processes. Therefore, it is suggested that also in the Belize ejecta deposits true regmaglyptic clasts may exist, although different from the Chicxulub plastically deformed clasts, the polish and the striations on the regmaglyptic surfaces (Figs. 10, 11) are assumed not to result from ablation but to have formed upon emplacement of the ejecta (Ernstson et al. 2002, Claudin et al. 2001). It is further suggested that regmaglypts are considered an additional clast-texture criterion for the recognition of impact deposits the importance of which has been pointed out, e.g., by Marshall et al. (1998).

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Web4: http://www.impact-structures.com/spain/rubie/ejecta.html