IMPACT METAMORPHISM – WHAT TO LOOK FOR IN THE CASE OF SMALL IMPACT STRUCTURES. L. Ferrière, Natural History Museum, Burgring 7, A-1010 Vienna, Austria (ludovic.ferriere@nhm-wien.ac.at).

Introduction: A requirement for the recognition and confirmation of meteorite impact structures is the presence of specific impact-related phenomena, such as shock metamorphic indicators, either megascopic (e.g., shatter cones) or microscopic (e.g., planar deformation features in minerals), high-pressure polymorphs (e.g., coesite and stishovite) and/or siderophile element (e.g., iridium) or isotopic (osmium) anomalies in specific geological settings (see e.g. [1]; and references therein). In some rare cases, the occurrence of meteorite(s) within or in proximity to a circular or elliptical structure can also be used as an evidence for an impact origin. Crater morphology alone is not a sufficient argument, because a variety of circular features can be formed by completely different geological processes (e.g., volcanism or salt diapirism).

In the present contribution, the main criteria that need to be searched for in the case of small impact structures (i.e., from a few meters large and up to less than a few kilometers in diameter) are reviewed and discussed.

Review & Discussion: The term "impact metamorphism" covers all types of shock-induced changes, such as the formation of planar microstructures and phase transformations (i.e., so called "shock effects") and it also encompasses the melting, decomposition and vaporization of target rocks (see e.g., [2]). A great diversity of these irreversible changes in rocks and minerals are known and have been abundantly described, mostly for quartz and to some extent for feldspar, olivine, pyroxene, and zircon grains; Less is known about the shock effects in other minerals.

Shatter cones are the only distinctive shock-deformation feature that can be seen with the naked eye. Occurrence of these meso- to macro-scale features have been reported to date for more than half of the currently confirmed impact structures, but not (or questionable) in impact craters less than 1-2 km in diameter (Therefore this type of shock-deformation feature will not be further discussed here).

Upon shock compression, minerals develops irregular fractures (which are not diagnostic shock effects) and, if the involved pressure is strong enough, planar microstructures (most of them generally crystallographically controlled) may form. Another type of microstructures are also formed in some minerals, the so-called "deformation bands" (i.e., kink bands and mechanical twins). However, these microstructures and also the planar fractures and feather features that are discussed in the next paragraph are thought to form at somewhat lower pressures and, alone, are not regarded as unambiguous evidence of impact metamorphism.

Planar microstructures include: 1) planar fractures (PFs; by definition planar, parallel, thin open fissures, generally greater than 3 µm wide and spaced more than 15–20 µm apart), 2) feather features (thinly spaced, short, parallel to subparallel lamellae that branch off of PFs), and 3) planar deformation features (PDFs; narrow, individual planes of amorphous material that are less than 2 µm thick, comprising straight, parallel sets spaced 2–10 µm apart and generally occurring as multiple sets per grain; Fig. 1a).

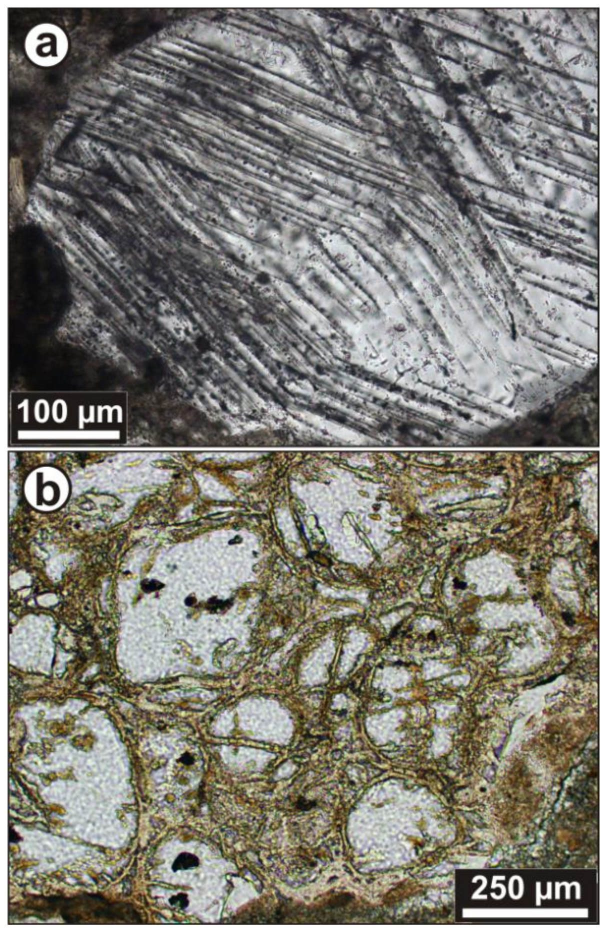

Fig. 1. Microphotographs (plane-polarized light) of impact metamorphism features in quartz grains. a) Quartz grain with two PDF sets. b) Diaplectic quartz glass in a shocked sandstone. Note the occurrence of coesite (and some alteration products) within and between the idiomorphic quartz grains.

In many of the confirmed and relatively small impact structures, unequivocal PDFs are generally rare (e.g., at the Barringer Crater) or "missing" (e.g., at Henbury and at Wabar) either because the shock pressures involved were not strong enough and/or because of the properties of the target (e.g., unconsolidated sedimentary materials in the case of Henbury and Wabar).

Mosaicism and also a number of alterations to the optical properties of the minerals, such as the refractivity and birefringence, are also generally observed in minerals that were subjected to impact metamorphism, but are not further discussed here because of limited space and as they cannot be used alone to fully confirm the impact origin of a suspected structure.

At high-pressure regimes, with shock pressures greater than ~35 GPa for quartz in the case of dense non-porous crystalline rocks and at somewhat lower shock pressures, between 28 and 35 GPa, for An-rich feldspar, diaplectic glass starts to form (generally from framework minerals, such as quartz or feldspar). However, in sandstones, diaplectic quartz glass starts to form at pressures as low as ~5.5 GPa, and between ~10 and 20 GPa, almost complete conversion of quartz to diaplectic glass has been observed in some cases. Melting of individual minerals starts at around 50 GPa and at around 60 GPa for the whole-rock in the case of non-porous crystalline rocks, while for sandstones, melting of individual quartz grains starts at pressures as low as ~20 GPa and whole-rock melting occurs above ~30–35 GPa. However the formation of glasses or melts do not necessarily require high shock pressures and can be formed through non-impact processes, e.g., in the case of fulgurites or in the process of smelting ore, etc. Impact glasses and melts are frequently described in the case of relatively small impact structures (such as in Barringer Crater and Wabar; Fig. 2) and in most cases chemical and or isotopic analyses were used to confirm the occurence of traces of the impacting projectile and thus the impact origin of these glasses/melts.

Fig. 2. Photograph of a typical vesicular impact-melt glass fragment from Wabar with partially fused clasts (whitish) of the target material (NHM-Vienna sample L4401).

High-pressure phases, for example, coesite (Fig. 1b) and stishovite (from quartz), are rarely reported in impactites from small impact structures. In only a few examples of craters, that were formed in sedimentary rocks (in which coesite is known to form at pressures as low as ~5-6 GPa), coesite has been characterized, e.g., in impactites from Barringer Crater and Wabar (at Barringer Crater stishovite was also detected).

Interestingly, many of the relatively small and young craters, such as the Barringer Crater, Henbury, Wabar, Whitecourt, Kamil, etc., have been detected and/or confirmed to be of impact origin after the discovery of preserved meteorites spatially associated with them. In addition, in extremely few cases, such as for the Sikhote Alin and Carancas craters, the confirmation of the impact origin of these craters is only based on the presence of meteorites as no products of shock metamorphism were formed/recovered. Identification of an impact structure based on the presence of meteorite fragments requires extremely young craters that are formed by iron meteorites projectiles, as other types of meteorites are rapidly altered within a short timeframe.

Conclusion: It is important to note that because minerals subjected to impact metamorphism occur in different petrographic assemblages and in different rock types, the full spectrum of the diagnostic features described in this paper may not necessarily be present in all (small) impact structures and is strongly dependant on the lithology and other properties of the target rock(s), and is a function of the magnitude of the (hypervelocity) impact and of the level of erosion of the crater.

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References: [1] French B.M. & Koeberl C. (2010) *Earth-Science Reviews, 98,* 123–170. [2] Stöffler D. & Grieve R.A.F. (2007) Chapter 2.11. In: Fettes D. and Desmons J. (eds.) *Metamorphic rocks,* pp. 82–92.