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Perspective

Remote sensing studies of impact craters: how to be sure?

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After previous studies on impact craters in the eastern Sahara, particularly in Chad [2,15] and Libya [1], the paper by Paillou et al. [11] provides a good opportunity to discuss some important aspects of impact craters. They are a dominant landform on our Moon, and on other atmosphereless bodies (including planets and the satellites of planets) in our solar system. On the Earth, impact craters are far less obvious, and only about 170 structures have so far been confirmed to have been formed by hypervelocity impact. The diameters of these terrestrial impact craters range from less than 100 m to about 200 km; a couple of these structures have originally been even larger, probably about 250 to 300 km in diameter. The reason why we do not see more obvious impact craters on the surface is the Earth is intimately connected to the reason why it is such a suitable place for life: the Earth is a geologically active planet. The forces that shape our planet – for example, tectonics, volcanism, erosion, water, and weather – are those that obliterate the traces of even large-scale and devastating impact scars after geologically short time scales. This is probably one of the reasons why it took geologists so long to accept the reality of impact craters on Earth.

A clear hiatus in the history of impact-related studies was the realization, around 1980, that Cretaceous-Tertiary (K/T) boundary rocks bear unambiguous evidence for a large-scale catastrophic impact event; this was followed in the early 1990s by the discovery of the ca. 200-km-diameter Chicxulub impact structure, Mexico, as the source of the world-wide impact ejecta. While the details of the relation of this largest documented impact event in the recent geological history of our planet and the K/T mass extinction are still being investigated, it is clear that these studies, over the past 20 years, have finally led to a more general realization that impact cratering has been of profound importance for the biological and geological evolution of our planet (e.g., [6,12–14]).

This brings us to the topic of how to recognize an impact crater. On the Moon and other planetary bodies that lack an appreciable atmosphere, impact craters can commonly be recognized from morphological characteristics, but on Earth complications arise as a consequence of the obliteration, deformation, or burial of impact craters. This problem made it necessary to develop diagnostic criteria for the identification and confirmation of impact structures on Earth (e.g., [3,10]). The most important of these characteristics are: (a) crater morphology; (b) geophysical anomalies; (c) evidence for shock metamorphism; and (d) the presence of meteorites or geochemical evidence for traces of the meteoritic projectile. Morphological and geophysical observations are important in providing supplementary (or initial) information. Geological structures with a circular outline that are located in places with no other obvious mechanism for producing near-circular features may be of impact origin and at least deserve further attention. Geophysical methods are also useful for identifying promising structures for further studies, especially in the case of subsurface features. In complex craters the central uplift usually consists of dense basement rocks and usually contains severely shocked material. This uplift is often more resistant to erosion than the rest of

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the crater, and, thus, in old eroded structures, the central uplift may be the only remnant of the crater that can be identified. Geophysical characteristics of impact craters include gravity, magnetic properties, reflection and refraction seismics, electrical resistivity, and others [5].

Of the criteria mentioned above, only the presence of diagnostic shock metamorphic effects and, in some cases, the discovery of meteorites, or traces thereof, are generally accepted to provide unambiguous evidence for an impact origin [3,10]. Shock deformation can be expressed in macroscopic form (shatter cones) or in microscopic form. The same two criteria apply to distal impact ejecta layers and allow one to confirm that material found in such layers originated in an impact event at a possibly still unknown location. The 170 terrestrial impact structures mentioned above have been identified on Earth based on these criteria.

The study of Paillou et al. [11] highlights an important problem. Many structures exist on Earth that superficially might resemble (eroded) impact craters. Better remote sensing studies, with better resolution and more spectral information, help to weed out structures that are clearly not of impact origin. Morphological and structural criteria can be applied to high-resolution images taken from space. More and more dedicated satellites for such work are now available. A retarding factor, especially for academic work, is still the high price of acquiring and processing satellite images. Paillou et al. have used a combination of optical, infrared, and radar images to detect a possible double impact crater in southern Libya. This work requires not only the acquisition of high-resolution images, but also the dedicated search and evaluation of these images.

There is potential for such studies to be automated [9], but there are limitations. Firstly, criteria have to be found that allow for the automatic distinction between impact features and other circular geological features. Secondly, about one third of the impact craters known on Earth today do not have a surface expression – they are buried features. Thirdly, not all regions on Earth are equally suited for remote sensing studies – deserts are clearly preferable because of lack of obscuring vegetation. And finally, nothing replaces a site visit and the study of the actual rocks. Remote sensing is a great tool, but it does not allow (so far) the detection of impact-characteristic shock features, or traces of meteoritic matter – so far the only really unique and unambiguous criteria for the confirmation of the impact origin of geological structures.

There is another danger of remote sensing studies: overinterpretation. A case in point is the BP impact structure, also in Libya. Early studies noted that the structure comprises three ‘rings’, at about 0.6, 2, and 2.8-km diameter (e.g., [4]). More recently, Shuttle radar images revealed an even wider circular feature, of about 3.2 km, which was interpreted as the crater diameter [8]. However, in a very recent field study it became obvious that the cited crater diameter of 2.8 or 3.2 km, for the outer ring, does not represent the actual crater diameter, as the ‘middle ring’ represents the actual crater rim (clearly identified from structural criteria) with a diameter of about 2 km [7]. This is also the advantage of working on Earth: ground truth is not only necessary, but also possible. Paillou et al. [11] did the right thing: they checked out their suspect feature in the field, and came up with some evidence supporting an impact origin. It is to be hoped that these authors will publish their full petrographic and mineralogical studies, and maybe return to the field for more structural work. Each impact crater on Earth has its very own and unique features, and helps us understand impact processes and their importance.

References

[1] B. Abate, C. Koeberl, F.J. Kruger, J.R. Underwood, BP and Oasis impact structures, Libya, and their relation to Libyan Desert Glass, in: B.O. Dressler, V.L. Sharpton (Eds.), Large Meteorite Impacts and Planetary Evolution II, Geol. Soc. Am., Spec. Pap. 339 (1999) 177–192.

[2] J.-F. Becq-Giraudon, O. Rouzeau, E. Goachet, S. Solages, Impact hypervéloce d’une météorite géante à l’origine de la dépression circulaire d’Aorounga au Tchad (Afrique), C. R. Acad. Sci. Paris, Ser. II 315 (1992) 83–88.

[3] B.M. French, Traces of catastrophe: a handbook of shock-metamorphic effects in terrestrial meteorite impact structures, in: LPI Contribution, vol. 954, Lunar and Planetary Institute, Houston, 1998, p. 120.

[4] B.M. French, J.R. Underwood Jr, E.P. Fisk, Shock metamorphic features in two meteorite impact structures, Southeastern Libya, Geol. Soc. Am. Bull. 85 (1974) 1425–1428.

[5] R.A.F. Grieve, M. Pilkington, The signature of terrestrial impacts, AGSO J. Aust. Geol. Geophys. 16 (1996) 399–420.

[6] C. Koeberl, K. MacLeod (Eds.), Catastrophic events and mass extinctions: impacts and beyond, Geol. Soc. Am., Spec. Pap. 356 (2002) 746.

[7] C. Koeberl, W.U. Reimold, J. Plescia, BP and Oasis impact structures, Libya: remote sensing and field studies, in: H. Henkel, C. Koeberl (Eds.), Impact Tectonism, Impact Studies, vol. 6, Springer, Heidelberg (in press).

[8] J.F. McHone, R. Greeley, K.K. Williams, D.G. Blumberg, R.O. Kuzmin, Space shuttle observations of terrestrial impact structures using SIR-C and X-SAR radars, Meteorit. Planet. Sci. 37 (2002) 407–420.

[9] G.G. Michael, Coordinate registration by automated crater recognition, Planet. Space Sci. 51 (2003) 563–568.

[10] A. Montanari, C. Koeberl, Impact stratigraphy: the Italian record, in: Lecture Notes in Earth Sciences, vol. 93, Springer Verlag, Heidelberg, 2000, 364 p.

[11] P. Paillou, A. Rosenqvist, J.-M. Malezieux, B. Reynard, T. Farr, E. Heggy, Discovery of a double impact crater in Libya: the astrobleme of Arkenu, C. R. Geoscience 335 (2003) 1059–1069.

[12] G. Ryder, D. Fastovsky, S. Gartner (Eds.), The Cretaceous–Tertiary event other catastrophes in Earth history, Geol. Soc. Am., Spec. Pap. 307 (1996) 576.

[13] V.L. Sharpton, P.D. Ward (Eds.), Global catastrophes in Earth history, Geol. Soc. Am., Spec. Pap. 247 (1990) 631.

[14] L.T. Silver, P.H. Schultz (Eds.), Geological implications of impacts of large asteroids and comets on the Earth, Geol. Soc. Am., Spec. Pap. 190 (1982) 528.

[15] P.M. Vincent, A. Beauvilain, Découverte d’un nouveau cratère d’impact météoritique en Afrique : l’astroblème de Gweni-Fada (Ennedi, Sahara du Tchad), C. R. Acad. Sci. Paris, Ser. IIa 323 (1996) 977–987.