COMMENTARY

The Australasian tektite source crater: Found at last?

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In PNAS, Sieh et al. (1) present the best candidate yet for the long-sought source crater of the Australasian tektite strewn field. Unlike the other 4 or so tektite strewn fields, each of which can be traced back to a large impact crater, the Australasian field's source has yet to be definitively located. While this proposal does not fully prove the case, it offers strong evidence implicating a ~15-km-diameter impact crater in Laos that has been hiding in plain sight beneath a mass of younger volcanic rocks. From here, it is clear that the next step in proving its parentage must be drilling through the volcanic rocks into the putative impact rocks below.

Tektites are centimeter-scale black or green blobs of glass that have long fascinated humans (2). Moldavites, an Eastern European variety, were found interred with the much more famous Venus of Willendorf, dating back to 30,000 BCE, possibly reflecting our ancestors' interest in unusual rocks as well as female deities. Individual tektites occur in widely strewn fields of which about 4 are currently known (there are other candidate strewn fields). Each of these fields, which extend over hundreds to thousands of kilometers, is associated with a meteorite impact crater—except one, the biggest of them all, the Australasian strewn field. It ranges south from Southeast Asia, across Australia then south of Tasmania to East Antarctica, with a western extension that crosses over Madagascar and an eastern extension into the western Pacific Ocean, covering about 10% of Earth's surface. The tektites in this enormous field have been intensively studied using modern analytical methods. They are divided into a number of distinct types, ranging from meter-scale irregular masses of black glass called Muong Nong tektites, found in Laos, Vietnam, and Thailand, to submillimeter-scale microtektites that abound in deep-sea cores within the limits of the field. Some far-flung types exhibit distinctive flanges that suggest melting during reentry at high speed. Others enclose apparent bubbles that contain only vacuum and a few rare gases (3), the low-pressure gas evidently frozen into the body of the tektite while it was in flight high above Earth's surface. The time at which all of these objects were melted is well established at about 790,000 y.

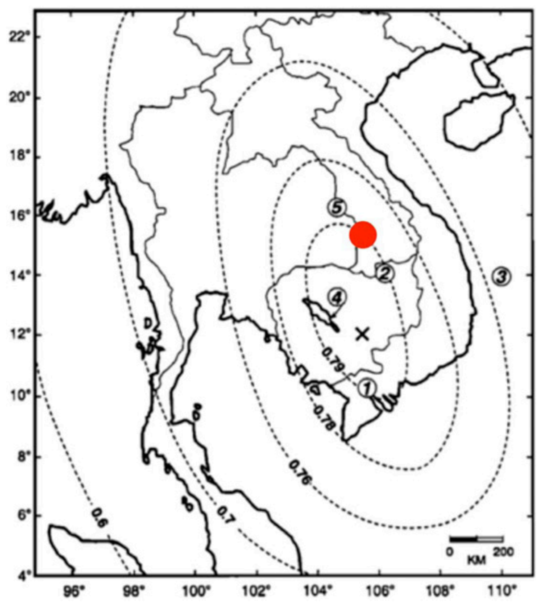

Fig. 1. The location of the Bolaven volcanic field is shown as a red dot overlain on a plot from Glass and Pizzuto (ref. 5; figure 2) that contours the correlation coefficient of fits to the density distribution of microtektites. The numbers indicate the centers of other proposals for the source of the Australasian strewn field. The Bolaven field lies just to the edge of the highest probability ellipse. Adapted with permission from ref. 5.

The major mystery of the Australasian strewn field is the lack of any apparent source crater (4). The ability of large terrestrial impacts to melt and eject glassy material at high speed is now reasonably well understood, and the Australasian tektites do not seem markedly different from those in other strewn fields for which a source crater is known. Much effort has been invested into mapping the size and abundance of microtektites from ocean floor sediments (5) with the aim of zeroing in on the source (Fig. 1). The large size and only partial melting of the Muong Nong types suggest they originated not far from where they are found. However, despite an extensive hunt by a legion

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Author contributions: H.J.M. wrote the paper.

The author declares no competing interest.

See companion article on page 1346.

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First published January 6, 2020.

of scientific sleuths, to date no candidate crater has been found. The potential source area includes a large lake, Tonlé Sap in Cambodia (number 4 on Fig. 1), now recognized as a volcanic feature. Many other candidates, including underwater burial under the Gulf of Tonkin (number 3 on Fig. 1), have been suggested and discarded. Diameter estimates of the source crater range from a few tens of kilometers up to more than 100 km. Other investigators, such as John Wasson (6), suggested a distribution of many small craters plus a contribution from airburst heating produced the Muong Nong field. Boslough and Crawford (7) suggested that there was never any crater at all and that the Muong Nong field was created by an intense airburst that, like the 1908 Tunguska impactor, never reached the ground while still releasing many megatons of radiant energy above the surface. This hypothesis begs the question of how such a different origin has produced tektites that closely resemble those found near undisputed impact craters.

Now, Sieh et al. (1) propose a very plausible solution to the mystery. The geology of Southeast Asia is not well known, largely due to its cover of dense jungle and lack of roads and exposures. Sieh et al., however, recognized a large plateau, the Bolaven volcanic field in Southern Laos, which is roughly circular and about the right size to conceal a potential source crater. Of course, any lavas that conceal an impact crater must postdate it, and so it was essential for this group to show that the lavas are younger than the 790-ky date of the tektite melting event. Using ^{40}Ar–^{39}Ar dating, they found that eruptions in this region began about 16 My before present, but the most recent flows are dated to be younger than the tektites. In effect, they propose that the impact occurred right on top of an active volcanic center, consistent with the finding of a basaltic component in the geochemistry of the tektites. Other tests, including the gravity signature indicating a deficit of density under the surface lavas and a finding of grains of apparently shocked quartz in brecciated material that may be proximal ejecta, are also consistent with an impact.

The main cause for concern about this proposal is the small size of the putative crater. The gravity deficit suggests an elliptical crater, measuring about 13 × 17 km, implying a highly oblique impact at an angle of about 10° from the horizontal. Most previous estimates of the Australasian source crater size suppose that the largest strewn field must originate from the largest crater. The European Moldavites originated from the ∼24-km-diameter Ries crater, the North American Bediasites and Georgiaites originated in the Chesapeake Bay, whose inner basin is about 40 km in diameter, and the Ivory Coast tektites were expelled from the 10-km-diameter Bosumtwi crater in Ghana. All of these source craters are circular, indicating oblique impacts at angles of about 30° or steeper. In the case of the Australasian field, perhaps a combination of a porous sandstone target, highly susceptible to melting,

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and a very oblique impact, suggested by the tektite distribution, resulted in a smallish crater despite the impact of a large asteroid.

If Sieh et al. turn out to be correct, and the crater is buried under a pile of young lavas, this will inevitably raise the old claim that impacts initiate volcanic eruptions (8), an idea dating back to the 1960s when it was observed that lunar lava plains generally occupy large impact basins (9). However, our current understanding of impact cratering argues strongly against a direct connection (10). In the case of the Bolaven volcanics, eruptions were evidently occurring well before the impact event, so we may have a case [one dismissed as unlikely by Ivanov and Melosh (10)] of an impact onto an already active volcanic center. In this case, it may not be surprising that the disturbance caused by a large impact could have stimulated further eruptions that ultimately obscured the crater.

Not all readers will find it plausible that the Australasian source crater lies beneath the Bolaven volcanic plateau. Indeed, one of my impact-savvy colleagues read the paper and was unconvinced. As with all possible impact craters, proof will rest on finding shock-metamorphosed rocks (11), minerals, and melt. Given that the putative crater lies under a pile of basalt about 300 m thick, access to the crater interior will require drilling through the basalt and retrieval of samples of the underlying rock units. Coring in this remote tropical jungle will not be cheap or easy, but it is probably the only way in which the reality of a buried crater will be either proven or rejected. Until that happens, the Bolaven plateau must nevertheless be regarded as a strong candidate for the source of the Australasian tektite field.

1 K. Sieh *et al.*, Australasian impact crater buried under the Bolaven volcanic field, Southern Laos. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 1346–1353 (2020).

2 J. A. O'Keefe, *Tektites and Their Origin* (Elsevier, New York, 1976).

3 J. A. O'Keefe, P. D. J. Lowman Jr, K. L. Dunning, Gases in tektite bubbles. *Science* **137**, 228 (1962).

4 A. J. Cavosie, The enduring mystery of Australasian tektites. *Elements* **14**, 212–213 (2018).

5 B. P. Glass, J. E. Pizzuto, Geographic variation in Australasian microtektite concentrations: Implications concerning the location and size of the source crater. *J. Geophys. Res.* **99**, 19075 (1994).

6 J. T. Wasson, Layered tektites: A multiple impact origin for the Australasian tektites. *Earth Planet. Sci. Lett.* **102**, 95–109 (1991).

7 M. B. E. Boslough, D. A. Crawford, Low-altitude airbursts and the impact threat. *Int. J. Impact Eng.* **35**, 1441–1448 (2008).

8 A. P. Jones *et al.*, Impact induced melting and the development of large igneous provinces. *Earth Planet. Sci. Lett.* **202**, 551–561 (2002).

9 L. B. Ronca, Meteoritic impact and volcanism. *Icarus* **5**, 515–520 (1966).

10 B. A. Ivanov, H. J. Melosh, Impacts do not initiate volcanic eruptions: Eruptions close to the crater. *Geology* **31**, 869–872 (2003).

11 B. M. French, C. Koeberl, The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why. *Earth Sci. Rev.* **98**, 123–170 (2010).