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Linking a distal ejecta with its source crater: a probabilistic approach applied to tektites

Pierre Rochette *, [a], **David Baratoux** [b, c], **Regis Braucher** [a], **Jean Cornec** [d], **Vinciane Debaille** [e], **Bertrand Devouard** [a], **Jerome Gattacceca** [a], **Matthieu Gounelle** [f], **Fred Jourdan** [g], **Fabien Moustard** [a] **and Sébastien Nomade** [h]

[a] Aix-Marseille Univ, CNRS, IRD, INRAE, UM 34 CEREGE, Aix-en-Provence, France

[b] Géosciences Environnement Toulouse, UMR5563, Université Toulouse III, CNRS & IRD, 31400, Toulouse, France

[c] Université Félix Houphouët Boigny, UFR Sciences de la Terre et des Ressources Minières, Abidjan, Côte d'Ivoire

[d] Geologist, Denver, Colorado, USA

[e] Laboratoire G-Time, Université Libre de Bruxelles, Brussels, Belgium

[f] Muséum National d'Histoire Naturelle, Sorbonne Universités, CNRS, IMPMC – UMR CNRS 7590, 57 rue Cuvier, 75005 Paris, France

[g] School of Earth and Planetary Sciences, Curtin University, Perth, Western Australia, Australia

[h] LSCE, CEA, UVSQ et Université Paris-Saclay, Gif-sur-Yvette, France

E-mails: rochette@cerege.fr (P. Rochette), david.baratoux@gmail.com (D. Baratoux), braucher@cerege.fr (R. Braucher), jcornec13a@gmail.com (J. Cornec), Vinciane.Debaille@ulb.be (V. Debaille), devouard@cerege.fr (B. Devouard), gattacceca@cerege.fr (J. Gattacceca), matthieu.gounelle@mnhn.fr (M. Gounelle), F.Jourdan@exchange.curtin.edu.au (F. Jourdan), fabien.moustard@hotmail.fr (F. Moustard), sebastien.nomade@lsce.ipsl.fr (S. Nomade)

Abstract. We propose a probabilistic approach to gauge the plausibility of a genetic link between a distal ejecta and a known impact structure, considering the only possible alternative that the distal ejecta could originate from an unknown impact site. We exemplify this approach in the case of three tektite strewn fields related to three known impact structures—the belizites, related to Pantasma (Nicaragua), the ivorites, related to Bosumtwi (Ghana), the moldavites, related to Ries (Germany), as well as on Manson crater ejecta. The computed probability for the unknown meteoritic impact is about 1% or less for these four cases studies.

Keywords. Impact craters, Distal ejecta, Probability, Bosumtwi, Manson, Pantasma, Ries.

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[*] Corresponding author.

1. Introduction

Ejecta generated by hypervelocity impacts of asteroids or comets on Earth have drawn the attention of planetary and Earth scientists for more than a century [e.g. Suess, 1900, Lacroix, 1935, Osinski et al., 2011]. The exploration of the solar system has made impact science a proper scientific discipline. Ejecta are important objects that are studied for the understanding of the impact processes as well as for deciphering the flux of extraterrestrial matter on Earth [Glass and Simonson, 2013]. Ejecta deposits may contain:

- glass derived from the melted target surface, allowing to define the chemical composition of the target as well as to date the impact;
- rock fragments and minerals grains transformed by the high pressure and temperature reached as the shock wave propagates into the geological media, allowing both an estimate of P–T paths and petrography of the target;
- extraterrestrial matter allowing to prove the impact origin and constrain the nature of the extraterrestrial impactor [e.g., the iridium K–Pg peak; Alvarez et al., 1980].

Ejecta are classified into proximal and distal types. Proximal ejecta form more or less continuous deposits extending outward from the crater rim. On Earth, due to erosion, only relatively recent craters have preserved proximal ejecta layers [Kenkmann, 2021]. In contrast, distal ejecta form layers or deposits, continuous or not, that are observed several hundreds or thousands of kilometers from the impact structure, and can be buried and preserved within a stratigraphic layer. Distal ejecta are useful stratigraphic markers, as demonstrated by the worldwide K–Pg layer originating from the Chixculub impact in Yucatan at 66 Ma [e.g. Schulte et al., 2010], the Australasian tektite and microtektite field at 0.8 Ma, extending over more than 10,000 km from the putative source impact region [Folco et al., 2009], or the various spherules layers identified in the Archean and Proterozoic periods [Simonson and Glass, 2004, Glass and Simonson, 2013]. Tektites and microtektites are pure glass with splash forms, specific to Cenozoic distal ejecta [Glass, 1990, Koeberl, 1994].

Distal ejecta also occur on other solar system bodies, and they may blur the connection between regolith composition and local rock composition on heavily cratered bodies such as Mars, Mercury and Moon [Lorenz, 2000, Wrobel and Schulz, 2004, Zellner, 2019]. Their study is therefore a significant task in planetology.

By their allochthonous nature, ejecta cannot be obviously connected to a given impact structure, contrary to e.g. *in situ* shatter cones or melt sheets. In the case of proximal ejecta, the proximity is taken as a proof of genetic link, given the rarity of impact craters and ejecta materials. This proximity criterion suffers however from some exceptions in the impact literature: (1) although the occurrence of meteorites near a small impact crater is generally taken as a proof of the meteoritic impact [e.g. the Kamil crater case; Folco et al., 2011], the fall of a few meteorites found in the proximity of a crater may appear to be separated in time from the cratering event. For example, an LL6 chondrite fell about 70 ka ago near the Aouelloul crater, formed 3.1 Ma ago [Fudali and Cressy, 1976]. The occurrence of shatter cones together with the constraints that it places on the size and age of the Agoudal structure appear also difficult to reconcile with the recent fall of an iron meteorite [Chennaoui Aoudjehane et al., 2016, El Kerni et al., 2019]. In fact, tens of meteorite falls/finds may be reported within 5 radii of impact structures, without any genetic link [Chennaoui Aoudjehane et al., 2016]. (2) In the case of the Darwin glass, of admitted meteoritic impact origin, the presence near the center of the circa 30 km wide strewn field of a crater-like circular depression [Howard and Haines, 2007] has not been taken as a proof that this candidate crater is indeed of impact origin. The absence of the Darwin crater among the list of confirmed impact structures [e.g. Quintero et al., 2021] is at odds with a few other impact entries that are mainly confirmed based on the presence of impact glass proximal ejecta [e.g. Monturaqui and Zhamanshin: Crósta et al., 2019, Masaitis, 1999].

For distal ejecta, usually found at more than 100 km from their source crater and spread over much larger scale, the proximity criterion is not relevant anymore. Once it has been independently proven that the distal ejecta and the candidate source crater were generated by an impact, how can a genetic relationship be proven? According to Glass and Simonson [2013], the hypothesis that distal ejecta is launched from a given impact site must be submitted to a number of tests, by order of importance:

(a) the absolute ages obtained on the distal ejecta and impact structure should be undistinguishable within uncertainties;
(b) the distance between the impact site and strewn field as well as the size of the impact structure should match current knowledge based on previously known associations;
(c) the elemental and isotopic composition of ejecta material should be similar to the surface target rocks of the impact structure, within the variability observed in both materials;
(d) in case of a sufficiently large strewn field, the ejecta characteristics should fit a ballistic relationship with the crater: e.g. ejecta thickness, or density of microtektites, should decrease with distance to crater;
(e) if an extraterrestrial component is identified in both the ejecta and the crater [e.g., Koeberl, 2014], they should derive from the same type of impactor;
(f) mineral inclusions or relict material found in the glass ejecta should match the mineralogy of the surface or sub-surface rocks at the impact site.

If all these tests are positive, or at least the most stringent ones a-b-c, the association is deemed plausible. Glass and Simonson [2013] list eight of such plausible distal ejecta and crater couples (Table 1), including three tektite strewn fields: the ivorites (Ivory Coast), connected to lake Bosumtwi, the moldavites (Central Europe), connected to the Ries crater, and the North American strewn field (bediasites–georgiaites), connected to the Chesapeake impact structure.

Non-tektite distal ejecta have been identified as originating from a number of pre-Cenozoic craters, with the exception of Popigai, of Eocene age (Table 1). From this table, it is clear that distal ejecta is a characteristic of large craters (all craters listed are >25 km diameter except Bosumtwi). According to impact modeling [e.g., Collins et al., 2005, Osinski et al., 2011, Johnson and Melosh, 2014] and taking into account atmospheric drag, distal ejecta should be observed on all terrestrial craters large enough to launch an ejecta above the atmosphere, allowing a long-distance ballistic flight. Therefore, there is still a number of distal ejecta to be discovered, as well as impact structures to connect robustly to known distal ejecta, whose source crater is only putative or unknown [Glass and Simonson, 2013, Schmieder and Kring, 2020]. In the case of the atacamaite glass strewn field, extending over 50 km [Gattacceca et al., 2021], finding the source crater would allow to place it among the distal or proximal categories.

To transform a plausible connection into a demonstrated causal link, one has to consider alternative ejecta sources, which could be either a known or an unknown impact structure. In case of an alternative known impact site whose age is compatible with the ejecta, it has to pass the other tests to the same or higher level of satisfaction, otherwise the initially proposed impact crater remains the most plausible source. This was the case for the North American strewn field for which alternative source craters have been proposed based on age and relative proximity matches: Mistastin and Popigai. However, they were not considered as plausible alternative to Chesapeake based on a number of criteria [see discussion in Assis Fernandes et al., 2019, Deutsch and Koeberl, 2006]. If no other known crater passes the tests, there is still the alternative hypothesis of an unknown impact structure as the source. This hypothesis was not considered in the previously mentioned proposed ejecta-crater couples.

Recently a new tektite strewn field has been identified in Central America [Rochette et al., 2021, Koeberl et al., 2022]. Based on coincidental ages, at 804 ± 9 ka, as well as consistent elemental compositions and isotopic ratio, the new tektite field was proposed to be connected with the Pantasma impact crater [Rochette et al., 2019, 2021]. However, Koeberl et al. [2022] expressed skepticism on this proposed genetic link, implicitly invoking the unknown crater hypothesis. This raises the question: should we also consider this hypothesis for genetic links previously considered as established (Table 1) based on similar criteria?

The plausibility of the unknown crater hypothesis has to be evaluated in terms of probability that such an impact occurred. Until now, this question has been addressed qualitatively, with no appropriate mathematical treatment of the available information. The present contribution aims at providing a

Table 1. List of terrestrial impact structures with a genetically related distal ejecta layers, according to Glass and Simonson [2013]

Impact structure	Bosumtwi	Ries	Chesapeake	Popigai	Chixculub	Manson	Acraman	Sudbury
Age (Ma)	1.1	14.8	34.9	36.6	66.0	75.9	540–635	1849
Diameter (km)	10.5	26	40–85	100	180	36	40–90	200
Distal ejecta range (km)	250–2500	200–500	350–2800	Worldwide	Worldwide	250–500	300–500	500–900
Type	T, ET	T, SM	T	S, ET, SM	S, ET, SM	SM	E, ET, SM	S, ET, SM

Ages and diameters are updated following Schmieder and Kring [2020]. Distance from crater to distal ejecta sites includes microscopic material. Type of material identified in the ejecta: tektites and microtektites (T), glass spherules (S), shocked minerals (SM), extraterrestrial matter (ET). Shocked minerals in Ries ejecta were reported by Holm-Alwmark et al. [2021].

Table 2. Characteristics of the three impact structures and associated tektite strewn fields discussed here (see Table 1 and text for references)

Crater	Diameter (km)	Distance to strewn field	Age (Ma)	Δt (ka)	p (‰)	F	p' (‰)
Pantasma	14	500	0.80	32.6	1.0	0.16	<0.16
Bosumtwi	10.5	300	1.07	230	7.0	0.25	<1.7
Ries	26	200–500	14.8	260	7.9	0.42	<3.3

The reported distances to the strewn fields do not take into account microtektites. Δt is the time interval for the coeval hypothesis, p represents the probability that the crater is not the source of its associated strewn field, p' represents the same probability considering the fraction F of target rocks that matched the composition of tektites within the search radius (1000 km).

method to quantify this probability. We first expose the method, and then apply it to the proposed tektite-impact structure couples (Pantasma, Bosumtwi, and Ries see Table 2). The Chesapeake-North American tektites couple, with a much larger diameter for the impact structure (85 km) and a maximum distance to the strewn field of 2000 km, as well very large strewn field extension, is less relevant to our purpose and more complex to evaluate, and therefore will not be examined further.

2. Probabilistic approach

2.1. *Probability for another impact in a time window compatible with the tektite strewn field age*

The present approach corresponds to statistical quantification of matching of the first three tests mentioned in introduction. Searching for the source of a tektite strewn field, the choice is limited to two possibilities: the source of tektite is either a known or an unknown impact structure. We assume that tektite production is limited to impact structures larger than 10 km in diameter, based on the smallest impact crater associated with a tektite strewn field (Bosumtwi). The recurrence time t_r of such an event on Earth has been estimated to be about 0.2 Ma [Bland, 2005]. Therefore, there should be five impact craters larger than 10 km per Ma over the whole Earth surface. However, the source crater cannot be at any arbitrary distance of the tektite strewn field, and the search surface should be limited to a fraction of the Earth surface. The maximum plausible distance between an impact structure and the tektite strewn field may be conservatively set to a maximum of 1000 km, based on our three examples (see Figure 1 and Table 2).

The corresponding surface S (spherical cap, 1000 km in radius) is 3.08×10^6 km^2. Based on an Earth surface S_e of 510×10^6 km^2, the recurrence time of a >10 km crater on S is thus 33.1 Ma ($t_r * S_e / S$).

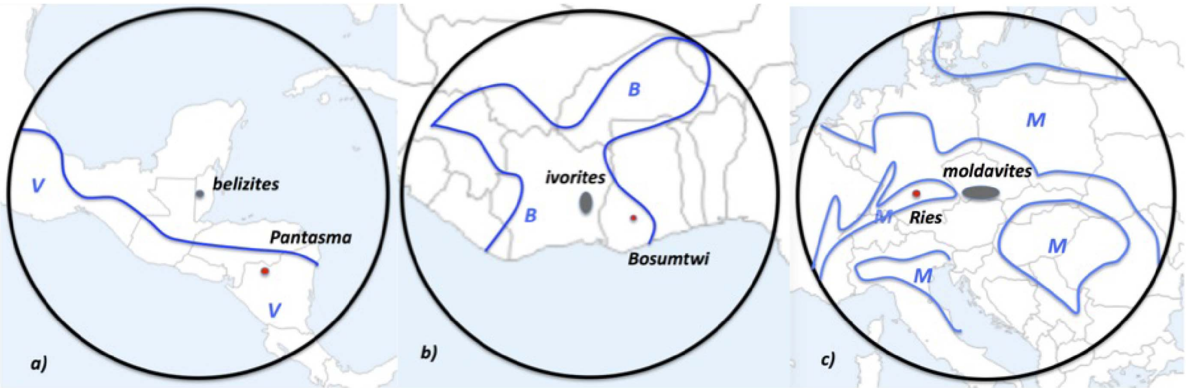

Figure 1. Maps centered on the discussed tektite strewn fields (gray ellipse) with a surrounding 1000 km radius circle, indicating putative source crater position (red dot) and the area where geologically likely target can be found (outlined by blue line): (a) belizite, with the northern limit of the Tertiary to present day volcanic arc (V); (b) ivorites with the limit of Birimian formations (metasediments and granites, B); (c) moldavites with Miocene and post-Miocene continental basins (indicated with a M). Information derived from the Geological Map of the World (https://ccgm.org/ geological limits are schematized), Rochette et al. [2021], Koeberl et al. [1997] and Skála et al. [2016]. Only the major strewn fields with high density of finds are outlined.

Finally, to estimate the probability of the existence of the unknown impact event, one has also to define a time window on which such an event could have occurred. In fact, this time window should be set to the time uncertainty Δt between the impact and tektites, i.e. their age difference plus the two age uncertainties. This time window corresponds to the uncertainty on the coeval hypothesis between the impact event and the tektites strewn field. The probability p represents the probability that another impact occurred in a time window compatible with the tektite strewn field:

$$p = \frac{\Delta t * S}{t_r * S_E} \tag{1}$$

Pantasma crater and belizites have been dated by ^{40}Ar/^{39}Ar at 792.1 ± 9.2 and 809.1 ± 6.4 ka, respectively [Rochette et al., 2021]. Using the eight ^{40}Ar/^{39}Ar plateau ages returns a χ^2 test p-value of 0.081 which is concordant, indicating our data is compatible with a single event. Bosumtwi crater and ivorites have been dated by ^{40}Ar/^{39}Ar at 1.03 ± 0.11 and 1.1 ± 0.05 Ma, respectively [Koeberl et al., 1997] corresponding to a p-value of 0.25. Ries crater and moldavites have been dated at 14.75 ± 0.16 and 14.81 ± 0.04 Ma, respectively [Schmieder et al., 2018] corresponding to a p-value of 0.47. The corresponding Δt for the three craters are thus 33, 230, and 260 ka, respectively. Using Equation (1), the alternative unknown crater hypothesis probability p ranges from 1 to 7.9‰ (Table 2).

2.2. *Probability inferred from geochemical coherence between potential target and tektites*

Based on geochemical inferences on the potential targets able to produce the considered tektites, it is then possible to reduce further the probability (p') that the known impact is not the source of the considered tektites:

$$p' = F * p \tag{2}$$

where F is the fraction of the continental surface in a spherical cap of 1000 km in radius with geochemical properties consistent with the tektites.

In the case of belizites, based on an andesitic to dacitic composition, as well as specific elemental and isotopic Sr and Nd compositions, both Rochette et al. [2021], Koeberl et al. [2022] concluded that the source target material was composed of volcanic arc rocks. We will evaluate further the specific match with Pantasma in the discussion. In Figure 1a, the northern limit of the volcanic arc front since the Oligocene is indicated. We set up an upper limit for the adequate surface for the unknown impact in between this geological limit and the ocean. Not all corresponding areas are adequate potential targets for belizites, because outcropping of the *ad hoc* lithology is discontinuous. It leads to a potential target maximum surface equal to 16% of the search circle ($F = 0.16$). Therefore, the corresponding probability p' for the unknown crater is below 0.16‰.

Geochemical studies of ivorites point toward the target being a mixture of Birimian metasediments and granitoids, as found in the Bosumtwi area [Koeberl et al., 1998]. Such lithologies crop out over a large area (Figure 1b) that can be estimated to be about 25% of the search circle. Therefore, the corresponding probability p' for the unknown crater is below 1.7‰.

Geochemical studies of moldavites [Zak et al., 2016] point toward the target being the Miocene quartz-rich freshwater molasse, as found in the Ries area. Therefore, any Miocene to present-day fluvial or lacustrine basin bearing sandy layers may be an adequate target. The area englobing thick enough Miocene to recent continental sediments is highlighted in Figure 1c, and amounts roughly to 42% of the whole target circle. The corresponding probability p' for the unknown crater is thus about 3.3‰.

We point out that in the above reasoning we considered the present continental surface above sea level. We should have added the continental shelf area, on which a distal ejecta producing impact could occur (e.g. the Chicxulub case). However, the surface increase corresponding to moldavites and belizite (Figure 1) is minor and negligible in the case of ivorites as the continental shelf is reduced along the West African coast. A significant marine carbonate contribution should also be detected geochemically, limiting the likelihood of shelf impact.

2.3. *Other matching criteria for tektites*

The approach followed so far corresponds to a probabilistic analysis of the first three tests mentioned in introduction: age, distance and target geochemistry. Concerning the ejecta thickness variation test, the three considered tektite strewn fields, limited to a few hundreds of km at most do not allow such evaluation. On the other hand, the Ivory Coast strewn field also exhibits microtektites [Glass et al., 1991] in the ocean SW of Bosumtwi at distances up to 3000 km. The gradient of microtektite density points toward Bosumtwi, but equally so toward any potential site from Figure 1b. Therefore, this test is not useful in our cases.

Concerning the extraterrestrial component matching, an ordinary chondrite component has been identified based on Cr isotopes in both belizites and Pantasma crater glass [Rochette et al., 2019, 2021]. This matching observation only slightly decreases the computed probability of the unknown crater hypothesis, as the proportion of ordinary chondrite impactor identified in large craters is large [Koeberl, 2014]. In Bosumtwi and Ries cases no such evidence exists.

Finally, concerning the inclusion tests, the most abundant inclusion found in the three tektites strewn fields is lechatelierite, likely pointing toward quartz grains with size higher than 100 μm being present in the target. This brings no further constrains on the Bosumtwi and Ries cases as quartz is ubiquitous in the considered Birimian or Miocene continental sediments target formations. For Pantasma, the presence of quartz-bearing dacite and rhyolite is attested in the local Miocene to Oligocene volcanic pile. This may not be the case in all the volcanic area highlighted in Figure 1c. In belizites and Pantasma glasses, rare inclusion of titanomagnetite were identified [Rochette et al., 2021]. They point toward the presence of this mineral in large enough crystals in the target. This is the case in most volcanic rocks.

2.4. *Application to a non-tektite producing ejecta*

As an example of further application of our method, we offer a preliminary probability estimate for the case of the Manson ejecta located in Iowa (USA) [Table 1; Katongo et al., 2004; reviewed in Glass and Simonson, 2013]. The structure age is 75.9 ± 0.1 Ma [recalculated in Schmieder and Kring, 2020]. The ejecta layer, traced from 250 to 500 km from the structure, has been stratigraphically dated at the same age. However, stratigraphic ages in late Cretaceous shallow marine sediments determined three decades ago have an absolute uncertainty likely larger than 0.1 Myr. Therefore, we tentatively use a Δt value of 0.2 to 0.5 Myr, leading to a probability p of the unknown crater in between 6 and 15‰.

Variants of the present probabilistic approach could be applied to other contexts such as the Agoudal meteorites versus crater conundrum (were the Agoudal meteorites genetically related to the crater or not?), or the Darwin crater eligibility as a proven impact (is the crater unrelated to the proximal glassy ejecta found around it?).

3. Discussion

One may challenge our choice to base our approach on the putative case of an unknown >10 km in diameter crater, situated within 1000 km of the studied ejecta strewn field. Impact craters with larger diameters may be associated with larger maximum distances between a tektite location and the crater source, but the recurrence time increases with crater size. For instance, a 2000 km radius may be considered based on the case of bediasites, but the recurrence time of a >80 km in diameter (Chesapeake is 85 km in diameter) on a 2000 km search radius would increase to 125 Ma. This is 3.8 times longer than our 10/1000 km test case. Therefore, the additional probability brought by considering the 80/2000 km case is marginal. For the australasite event case, tektites are spread over 5000 km, but the recurrence time of the source crater cannot be estimated in the absence of a known source crater. The discovery of tektites only at large distance and not closer to impact site is viewed as highly unlikely, though it cannot be quantified. The same reasoning can be applied to a Chicxulub size event. Considering both the increase of recurrence time associated with larger craters and the unlikely finding of tektites exclusively at large distance of the crater source, the case of a crater larger than 10 km and a search surface of 1000 km in radius can be considered to provide a conservative probability estimate. We emphasize that the proposed method to obtain probability estimates is crude and provide an order of magnitude rather than precise values, and is likely overestimated.

The previous data interpretation and logical reasoning made it clear that the currently admitted tektite-crater couples (ivorite-Bosumtwi and moldavite-Ries) could be challenged by the unknown crater hypothesis, with a circa ten to twenty times larger probability than for the belizite-Pantasma couple. In any case, the probabilities involved for all three tektite-crater couples, of the order of a few ‰ or less, make the alternative crater hypothesis not credible. Therefore, we propose that in the three tektite cases, as well as for Manson ejecta, the unknown crater hypothesis can be rejected beyond reasonable doubt. To obtain in the studied cases a probability of the order of 10%, making the unknown crater hypothesis more likely, one would need either to invoke a crater of circa 1 km diameter, at odds with current knowledge on distal ejecta, or have an age uncertainty over 3 Ma.

Our method has been applied to relatively recent impacts (two Quaternary, one Miocene, one Cretaceous). In the case of much older craters, one should also take into account the higher probability for the unknown crater hypothesis due to its possible destruction or concealment of the evidence by erosion, burial, and plate tectonic processes. On the other hand, for Quaternary impacts such as Bosumtwi and Pantasma, the expected well expressed crater depression makes the non-detection of the putative unknown crater further unlikely, although one may acknowledge the case of the missing australasite source crater.

The case of Pantasma-belizite connection, challenged by Koeberl et al. [2022] based on geochemical arguments, deserves further discussion. Rochette et al. [2021] advocated that rocks, proximal impact glasses and soils from Pantasma fit the composition of belizites. Belizites are somewhat depleted in Na, K, Cu, Zn, Rb, but this depletion is typical of the volatilization effect observed in tektites, and/or of the effect of hydrothermalism and weathering on the target rocks. Indeed, comparing fresh volcanic arc rocks [as done by Koeberl et al., 2022] with tektite composition, is not sufficient as the surface exposed at the time of the impact was covered with soil and altered rocks. To question the Pantasma hypothesis Koeberl et al. [2022] insist on the fact that trace elements and isotopic data of belizites give a better fit when compared with the active volcanic arc data from Guatemala and Honduras rather than from Nicaragua [Patino et al., 1997]. However, Patino et al. [1997] data comes from the active coastal volcanic range, with ages likely all younger than 100 ka. This young fresh rock dataset is thus not the most relevant one to describe a volcanic target that must be at least 800 ka old [note that the volcanic source is older than 5 Ma in the Pantasma hypothesis; Rochette et al., 2021]. Isotopic and elemental

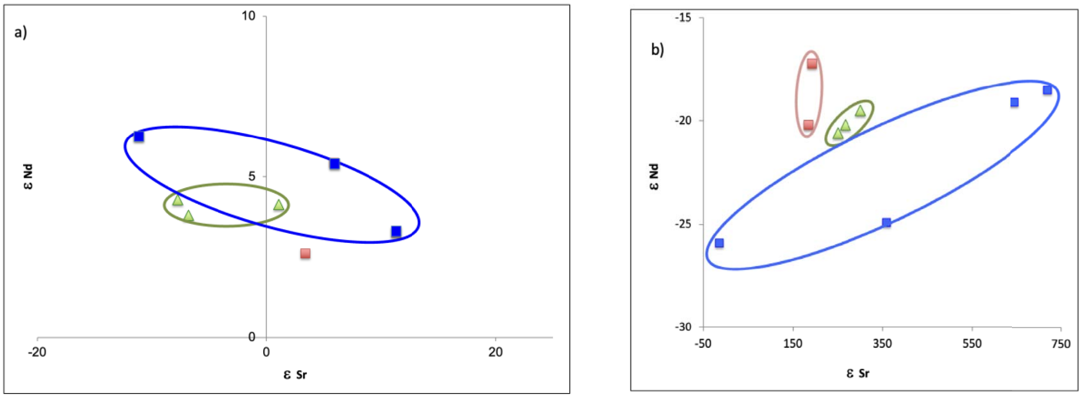

Figure 2. Isotopic ratio of Nd and Sr expressed as epsilon values for both tektite (green triangles) and source crater material (blue and red squares for rock/soil and glass/suevite, respectively) for (a) Pantasma versus belizite, (b) Bosumtwi versus ivorite; after Rochette et al. [2021] and Koeberl et al. [1998], respectively.

compositions on a given volcanic arc vary not only along the trench, but also with time and distance to the trench. Moreover, while Pantasma is at the Honduras border 200 km away from the ocean, the sampling sites of Patino et al. [1997] in Nicaragua are along the coast and due south with respect to Pantasma (see Figure 1a). So Pantasma should better compare to Patino et al. [1997] data from Honduras than from Nicaragua. Therefore, disqualifying Pantasma as a potential target based on these geochemical arguments alone is not justified. What has to be considered is the actual geochemical data obtained on Pantasma material, which derives from Oligocene to Miocene volcanics. In terms of Sr and Nd isotope ratios the Pantasma data brackets well the belizite data (Figure 2a).

While Koeberl et al. [2022] describe our isotopic data on Pantasma material as “widely scattered”, the larger dispersion of the Pantasma data with respect to belizite data, mostly on Sr ratio, is actually easily accounted for by the fact that we purposely measured altered rocks and soils. Indeed, Sr is a mobile element and Sr isotope ratios are thus sensitive to alteration [e.g. Clauer et al., 1982, Innocent et al., 1997]. However, we may point out that our data is much less dispersed than the Bosumtwi rock data used to support the identification of Bosumtwi as the ivorites source crater [Figure 2b after Koeberl et al., 1998]. Therefore, although it is obvious that the potential target for the belizite producing impact could be anywhere in the Central American volcanic arc, the Pantasma site is not only a valid plausible source but a robust one, based solely on geochemical arguments.

Admitting the belizite-Pantasma connection brings an important interpretative change for the ^{10}Be data obtained on belizites by both Rochette et al. [2021] and Koeberl et al. [2022]. Koeberl et al. [2022] claim that the average ^{10}Be content cannot be used to demonstrate a near surface origin for the belizites, as was done for australasites and ivorites, and argued for belizites by Rochette et al. [2021], based on the fact that arc magmas can have similar ^{10}Be concentrations due to their contamination by subducted marine sediments [Reagan et al., 1994]. However, this argument fails to take into account that the impacted volcanics are not 0.8 Ma old (age of belizites), but more than 5 Ma and more likely in the 15–30 Ma range in the case of Pantasma [Rochette et al., 2019]. Any subduction-related ^{10}Be should have mostly disintegrated at the time of impact [by 92% for the 5 Ma younger limit using half-life of 1.388 Ma; Chmeleff et al., 2010].

4. Conclusion

We have elaborated a probabilistic approach to test the likelihood of a genetic link between a distal ejecta and a known impact structure, with the only possible alternative being that the distal ejecta could originate from an unknown impact structure. This approach was applied and discussed on three tektite strewnfields, the couples belizites-Pantasma, moldavites-Ries, and ivorites-Bosumtwi, as well as on the Manson crater ejecta. For each of these cases, the genetic link is considered to be confirmed, since the probability of the unknown crater hypothesis is extremely low.

Conflicts of interest

Authors have no conflict of interest to declare.

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