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Report

Obsidian and mafic volcanic glasses from the Philippines and Vietnam found in the Paris Museum Australasian tektite collection

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Abstract–During the systematic magnetic susceptibility survey of the Paris Museum Australasian tektite collection, we identified three previously overlooked occurrences of volcanic glass that resembles tektites, based on anomalous magnetic properties, high water content, the presence of microcrystals, and anomalous chemical composition. These occurrences are from the Phu Yen province in south-central Vietnam (two rhyolitic glass fragments) and from the Philippines: one from northern Luzon Island (a basaltic rounded etched glass), one from Santa Mesa near Manilla (a dozen small rounded rhyolitic gravels). The two occurrences in the Philippines are quite similar to previously described volcanic glasses from the nearby Pagudpod and Nagcarlan localities, respectively. The rhyolitic glass specimens from the Phu Yen province are the first documentation of a geological occurrence of obsidian in Vietnam. This work is a warning note that glass samples with anomalous properties found among tektite collections may correspond to volcanic pseudotektites instead of real tektites with anomalous composition. The basaltic glass sample from the Philippines locally shows microcrystalline quench textures previously unknown in natural samples. These findings may also be of interest for archeologists involved in glass artifacts sourcing.

INTRODUCTION

Various natural processes can produce macroscopic masses of silicate glass (Glass, 2016), among which the most recurrent is volcanism. Other processes related to surface material heating can be extraterrestrial impact (Dressler & Reimold, 2001), lightning (Essene & Fisher, 1986), and coal or vegetation burning (Roperch et al., 2017). Glassy ballistic impact ejecta can be found at large distances from their source crater, in particular a specific type of macroscopic pure and vesicle poor glass called tektite. Macroscopic tektite samples can be found at a distance from 200 to 5000 km from their source crater (Glass, 1990). Only a few tektite strewn fields are known, with four classic fields—Australasian tektites in SE Asia and Australia, ivorites in West Africa, moldavites in Central Europe, and bediasites–georgiaites in North America—and a newly proposed one, belizites in Central America (Rochette et al., 2021). The source impact crater of the largest tektite strewn field, the Australasian one, extending from China to Australia, is not yet formally identified but proposed to be located in Indochina based on various arguments (Glass &

[Correction added on 14 Jun 2022, after first online publication: The copyright line was changed.]

Koeberl, 2006; Sieh et al., 2020). Note that, in the definition of the geographic extent of the abovementioned strewn fields, we did not include microtektites which would expand, for example, the Australasian strewn field to Antarctica (Folco et al., 2009). Volcanic glasses may also occur as centimeter-sized fragments, rounded by fluvial transport and alteration within soil, and can be visually confused with tektites. They may be widely dispersed and be misleadingly proposed as new tektite occurrences, thus the term "pseudotektite" (see recent discussion of such an occurrence, named the Cali glass strewn field in Colombia by Ferrière et al., 2021). Other such "pseudotektite strewn fields" are known in many volcanic areas around the world although not always published as such (but see examples from the Philippines and Patagonia in Koomans [1938]; macusanite from Peru by Martin & De Sitter-Koomans [1956] and Craig et al. [2010]; from Central America in Mrazova & Gadas [2011]; from western USA in La Paz [1948] or Rochette et al. [2015]). The dispersion of volcanic glass pebbles or fragments away from their source volcanic formation may be due to erosion (with river transport over tens of kilometers) or human transport. Indeed, obsidian, the most common massive volcanic glass, has been strongly praised as a cutting material since prehistory, with long distance trading (Craig et al., 2010; Tykot, 2021).

In the present contribution, we will address the specific case of volcanic pseudotektites found among a large historic tektite collection from the Natural History Museum in Paris, mostly built by the pioneering work of Alfred Lacroix (Caillet-Komokorowski, 2006; Lacroix, 1931, 1935). Indeed, while finding material resembling tektite in an area far from known tektite strewn fields naturally generates further investigation to determine their origin, pseudotektites of volcanic origin can be incidentally collected in a known tektite strewn field and remain unnoticed.

Procedures to distinguish tektites and impact glasses from volcanic glasses have been reviewed and exemplified by various authors (e.g., Ferrière et al., 2021; Koeberl, 1994; Rochette, Alaç, et al., 2019). The following criteria have been proposed:

- Very low water content, below 300 ppm for tektite, while it is usually above 1000 ppm for volcanic glass (Beran & Koeberl, 1997);
- Presence of microcrystalline inclusions in volcanic glass, while crystalline inclusions in tektites are absent or extremely rare and never with well-shaped growth forms;
- Distinct geochemistry with in particular lower abundance of alkali (Na_2O and K_2O) relative to silica in tektites;
- Greater compositional homogeneity in tektites;
- Reduced oxidation state of Fe, with an essentially Fe^{2+} state in tektites (Giuli et al., 2002), while volcanic glasses often contain a mixture of Fe^{2+} and Fe^{3+}.

Based on the latter two criteria, Rochette et al. (2015) showed that tektites are characterized by a paramagnetic behavior due to Fe^{2+} in glass, with a low value of magnetic susceptibility (χ) and a narrow dispersion of χ values for a given strewn field, while volcanic glasses (as well as impact glasses other than tektites) may show variable ferromagnetic grain content and thus variable χ. Volcanic glasses may be more magnetic than tektites due to the presence of magnetite inclusions or less magnetic due to low content of iron. Based on the nondestructive character, rapidity, and portability of χ determination, we undertook systematic measurements on large collections of tektites. The initial aim of such surveys was the detection of rare excursions of the abovementioned χ characteristics linked to the exceptional presence of ferromagnetic inclusions such as magnetite or metallic iron, as previously identified in Australasian tektites by Chao et al. (1964) or Kleinmann (1969). Indeed, the survey of about 4000 belizite samples yielded 30 anomalous samples (χ higher than two times the mean, see Rochette, Bezaeva, et al., 2019) that were identified as tektite samples bearing granular magnetite inclusions inherited from the volcanic target rocks (Rochette et al., 2021). Measurements of Australasian tektite collections from China (662 samples) or from Leyden Natural History museum (472 samples) failed to reveal anomalies, apart from those due to the presence of magnetic soil incrustations, identified by a back to normal value after thorough surface cleaning (Rochette, Bezaeva, et al., 2019). In Paris, we recently measured nearly 8000 individual Australasian tektite specimens. General results of this survey, allowing the detection of both anomalous tektites and pseudotektites of volcanic origin, will be presented in a companion paper. It was also easy to confirm visually during the survey a few other nontektite samples that corresponded to other types of rocks (chert, basalt, schist, etc.) or bottle glass.

Here, we present a detailed characterization of three occurrences of volcanic glasses among the Paris tektite collection, one from Vietnam (catalog number 524) and two from the Philippines (catalog numbers 2191 and 2196–2200).

Sample Description

Macroscopic images are shown in Fig. 1. Label of reference 524 indicates provenance from a South Vietnamese locality named Phuoc Thuan plateau, from the coastal Phu Yen province northeast of Dalat (approximate lat 13°N, lon 109°E; Dalat is known as a major site for tektite collection). This locality is mentioned in Lacroix (1935). Unfortunately, several localities with such a name are known today in Vietnam

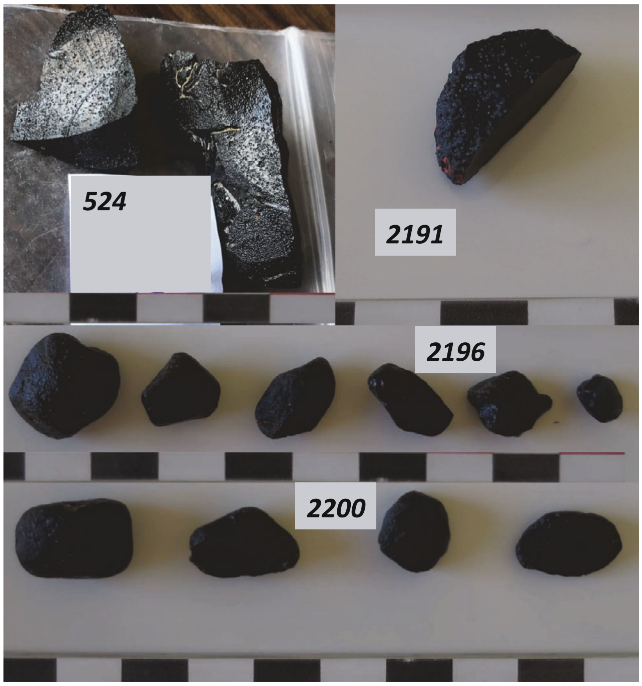

Fig. 1. Pictures of studied samples with a 1 cm scale. (Color figure can be viewed at wileyonlinelibrary.com.)

(none in the present Phu Yen province). It consists of two nontranslucent fragments totaling 13.3 g with angular shapes. Smoothed surfaces suggest a significant stay in soil after fragmentation. The shine is not typical of tektite, suggesting the presence of micro-inclusions. Few vesicles are observed.

Reference 2191 label reads “Selga, Pasuquin, Ilocos Norte.” Selga is not a locality but the name of the local provider, mentioned in Lacroix (1931, 1935). Pasuquin is a locality of Ilocos Norte province (approximate lat 18°20′N, lon 120°39′E). Specimen 2191 consists of a single black subspherical half cut sample of 6.6 g. Its aspects are perfectly tektite-like with a shiny pitted surface, showing a few small spherical vesicles. On close scrutiny, rare globular dull gray inclusions, circa 0.5 mm diameter, can be observed under the binocular microscope.

References 2196 and 2200 come from Santa Mesa, Manilla, the Philippines (lat 14°38′N, lon 120°0′E). They consist of eight and five fragments, totaling 11.7 and 9.4 g, respectively. They correspond to translucent rounded gravels with grayish color in transparency. Their surficial aspect is typical of fluvial abrasion. It appears likely that all fragments are of the same material.

METHODS

To measure χ inside the collection in Paris, we used an SM150 susceptibility meter by ZHinstruments, operating with a field of 320 A m^{-1} at 1 kHz frequency. This instrument can process very large collections by measuring susceptibility and mass simultaneously. Using a sample mass above 5 g can produce a noise level less than a few 10^{-9} m^3 kg^{-1}, after correcting for holder mass and susceptibility. This target minimum mass was often obtained by pooling several specimens in a single measurement, to reach a mass of the order of 20 g. The largest mass measurable with the instrument is around 50 g (depending on sample geometry). Based on previous experience (Rochette et al., 2015; Rochette, Bezaeva, et al., 2019), we set the limits to sort anomalous samples at <70 or >130 x 10^{-9} m^3 kg^{-1}. When anomalous measurements were obtained on pooled samples, the pool was split and remeasured until the anomalous specimen was identified. Anomalous samples were borrowed from the Museum, cleaned, and remeasured at the CEREGE rock magnetic laboratory using an Agico MFK1 bridge (1 kHz alternating field of 200 A m^{-1}). Hysteresis data were obtained on a Princeton Micromag vibrating sample magnetometer (VSM) with maximum field of 1 T. High-field susceptibility (χ_{hf} of mostly paramagnetic origin) was computed from the above 0.7 T part of the cycle. Saturation remanences at 3 T and eventually in a back field of 0.3 T were measured with a 2G Enterprises superconducting magnetometer.

Double-polished sections were prepared from three glass samples in order to determine water content through transmission measurements. Samples were polished using SiC disks under ethanol until they were optically thin through the spectral range of interest. Their thickness was measured using a Mitutoyo Digimatic micrometer. Water content was determined using Fourier transform infrared (FT-IR) transmission microscopy with a VERTEX V70 spectrometer coupled to a Hyperion 3000 infrared microscope (calibration described in Rochette, Alaç, et al., 2019).

Major and trace element analyses were performed at the Laboratoire G-Time at the Université Libre de Bruxelles. For three samples (524, 2191, and 2196), approximately 50 mg of crushed material was dissolved by alkaline fusion using ultrapure (>99.999%) lithium metaborate. Major elements were measured using a Thermo Scientific ICaP inductively coupled plasma atomic emission spectroscopy (ICP-AES). International standards BCR-2, BHVO-2, AGV-2, and BIR-1 were used for monitoring accuracy. The relative difference between the accepted and measured values was lower than 5% for individual elements and lower than 2% for the total wt%. Loss on ignition (LOI) was measured after 1 h at 1000 °C and corrected for Fe content. For trace elements, the concentrations were measured on an Agilent 7700 quadrupole ICP-mass spectrometer. External reproducibility based on natural duplicate analyses is generally lower than 10% (2 relative standard deviation [RSD]), except for Cr, Ni, and Cu (<20% 2 RSD). International standards BCR-2, AGV-2, and BHVO-2 were used to monitor accuracy and yielded results within the accepted range.

Microscopic investigation of polished sections was carried out using a microanalytical scanning electron microscope FEI QUANTA 450 ESEM-FEG equipped with energy-dispersive system (EDS) Bruker XFlash Detector 6-10 at the Centro per la Integrazione della Strumentazione Scientifica—Università di Pisa, Italy.

Further microanalyses were obtained by electron microprobe analysis using a CAMECA SX-100 at the Centre de Microanalyse de Paris VI (CAMPARIS).

RESULTS

Geochemistry

Water content (Table 1) varies from 1065 to 6650 ppm. These high concentration values exclude tektites and are typical of volcanic glass (Beran & Koeberl, 1997). LOI is compatible with these values for 524 and 2191 (Table 2). In the Na_2O+K_2O versus SiO_2 plot, specimen 2191 shows a basaltic composition, while 524 and 2196–2200 are typical of rhyolitic obsidian (Fig. 2). The three samples are far away from the Australasian tektite range. Note that major elements were also determined using an electron microprobe, showing rather consistent values with ICP-AES, with a lower SiO_2 eventually due to the avoidance of crystalline inclusions. This allows verifying that composition of 2200 is very close to that of 2196.

Full major and trace element results are given in Tables 2 and 3 for the three samples, respectively. Totals significantly larger than 100% may suggest that Fe is largely in Fe^{2+} state (Fe is reported as Fe_2O_3).

The rare earth element (REE) pattern (Fig. 3) for 2191 is flat, typical for mafic mantle-derived magmas, with no Eu anomaly and limited enrichment in light REE. Patterns of 524 and 2196 rhyolites are more similar to the ones of Australasian tektite, but with a stronger Eu anomaly for 2196 and a larger enrichment of heavy REE for 524.

Magnetic Properties

The high-field susceptibility measurements (χ_{hf}) compared to FeO content as well as intensity of ferromagnetic contribution (M_s and M_{rs}) indicate that paramagnetism dominates in 2191 and the lower susceptibility fragments of 2191–2196 (down to 40×10^{-9} m^3 kg^{-1}; see Table 1). Low-field susceptibility is mainly due to ferromagnetic inclusions of likely FeTi oxides in 524 (with an estimated oxide content of 1‰) and in the most magnetic samples of 2196–2200 (with estimated maximum amounts of about 100 ppm, in case of titanomagnetite). The high coercivities observed in 2196–2200 (with B_{cr} > 100 mT and S ratio of 0.82 and 0.92), clearly point toward titanohematite, eventually mixed with titanomagnetite. This high oxidation state of iron is another argument against a tektite origin (Giuli et al., 2002; Rochette et al., 2015).

Electron Microscopy

We note that lechatelierite, the most common inclusion in tektites, made of SiO_2 glass, was not observed in any of the three sections. 524 and 2196 rhyolitic obsidian samples show flow textures with oriented microcrystals typical of obsidian (Figs. 4a–d), with FeTi-bearing oxides as expected from magnetic properties. The platelet aspect of the oxide grains in 2196 is compatible with titanohematite, as suggested by magnetic coercivity. Observed silicate crystals are likely plagioclase (in 524) and biotite (in 2196). We note that optical observation of 524 slice used for water content determination shows compositional banding while 2196 and 2200 do not.

The area of the 2191 basaltic glass investigated under the field emission scanning electron microscope (FESEM) is virtually devoid of visible crystals, similar to classic tektite. However, a couple of large rosettes formed by dendritic to feather-like crystals of clinopyroxene were observed (Figs. 5a–c; diameter of the order of 0.5 mm). At the center of the rosette, rare micrometer-sized grains with high *Z*-contrast in backscattered imaging may correspond to FeTi oxides, serving as seeds for the rosette growth (Fig. 5c).

DISCUSSION

There is no doubt that the presently described anomalous glasses found among the Australasian tektite collection of the Paris Museum are of volcanic origin, based on the various geochemical and petrological observations reported here: high water content, odd geochemistry, presence of microcrystals, lack of lechatelierite, and high iron oxidation state. These pseudotektites were collected as tektites about 90 yr ago and remained unnoticed until our magnetic susceptibility survey.

Sample 524 is apparently the first rhyolitic obsidian reported in Vietnam as a geological occurrence. We found in Briles et al. (2019; citing Phu et al., 2017) a short mention of obsidian flakes recovered within a Neolithic site in Quan Lan Island (lat 20.9°N, lon 107.7°E). In the area around sample 524's putative location (Fig. 6a), Quaternary volcanic rocks are abundant but composed exclusively of basalts (Hoang et al., 2016). Rhyolitic flows

Table 1. Major bulk properties of the studied specimens. Chemical compositions were obtained using an electron microprobe.

Sample	H_2O	SiO_2	Na_2O+K_2O	FeO	χ	χ_{hf}	M_{rs}	M_s	M_{rs}/M_s	B_c	B_{cr}
Unit	(ppm)	(wt%)			(10^{-9} m^3 kg^{-1})		mAm^2 kg^{-1}			mT	
524	1065	75.1	6.2	3.2	396–421	92	3.78	77.1	0.07	9	36
2191	5145	50.5	3.8	11.1	268	206	0.06	2.5	0.15	8	n.d.
2196	6550	75.2	8.3	1.3	36–101	31	0.23–1.51	11.5	0.15	28	101
2200	n.d.	74.8	8.3	1.4	41–57	24	0.08–1.84	6.5	0.13	46	117

Table 2. Whole-rock geochemistry of major elements in wt% using ICP-AES in this study, compared to SEM-EDS data from Reepmeyer et al. (2011) on the Philippines glasses from Pagudpod and Nagcarlan.

	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	Total
524	11.76	1.72	3.50	2.49	0.10	0.09	4.30	0.01	76.50	0.23	0.11	100.79
2196	12.55	0.83	1.58	4.61	0.04	0.06	3.65	0.01	78.67	0.09	0.00	102.09
2191	15.38	8.08	13.20	0.31	6.83	0.16	3.55	0.09	51.75	1.37	0.51	101.26
Pagudpod	15.30	7.80	10.78	0.40	5.90	0.10	3.60	0.10	53.70	1.60		99.28
Nagcarlan	13.80	0.80	1.33	4.70	0.20	0.20	4.40	0.01	73.70	0.10		99.24

LOI, loss on ignition.

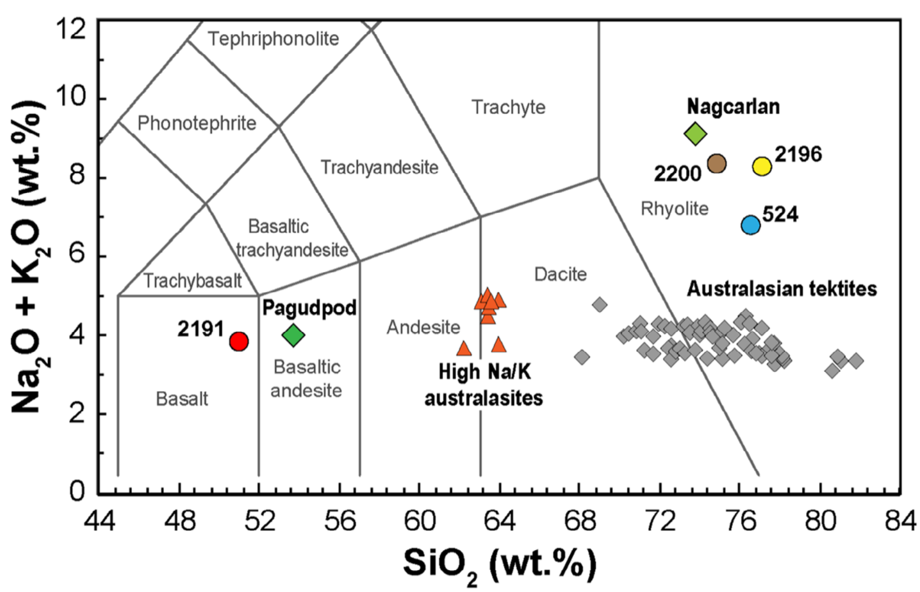

Fig. 2. Total alkali silica (TAS) diagram (after Le Maitre, 2002) for pseudotektites (circles) based on ICP-AES (or electron micro-probe analyzer for sample 2200; see Tables 1 and 2), and for geological references for the Philippine glasses after Reepmeyer et al. (2011; green diamonds). Data for the Australasian tektites (black diamonds; both Muong Nong and splash form types) from the literature (Amare & Koeberl, 2006; Chapman & Schreiber, 1969; Masotta et al., 2020; Mizera et al., 2016; Son & Koeberl, 2005; Žak et al., 2019), as well as high Na/K australites (red triangles after Chapman & Schreiber, 1969) are shown for comparison. (Color figure can be viewed at wileyonlinelibrary.com.)

of Cretaceous age are also abundant in the Phu Yen province and named Nha Trang formation (Hennig-Breitfeld et al., 2021). We, therefore, hypothesize that our 524 pseudotektite specimen may come from these Cretaceous acidic lava flows.

The Philippines, in particular the northern Luzon island from which our samples come, are essentially made of volcanic and associated plutonic rocks. Two "obsidian" outcrops, Pagudpod and Nagcarlan, have been reported in Luzon (Neri, 2007; Neri et al., 2015) (Fig. 6b). Their major and trace element compositions have been reported by Reepmeyer et al. (2011) using SEM-EDS for major elements and ICP-MS for trace elements, respectively. Tables 2 and 3 report these

Table 3. Trace element analyses in ppm using ICP-MS in this study and Reepmeyer et al. (2011).

	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Ba
524	9.02	1.80	2.64	0.75	3.67	10.73	131.06	62.03	94.49	99.04	442.92	51.54	551.27
2196	4.14	1.19	18.38	0.71	3.75	13.15	38.64	174.80	44.94	34.04	127.86	11.34	231.80
2191	23.99	218.44	211.98	52.87	204.44	103.98	99.73	6.45	176.16	21.96	59.96	7.48	51.91
Pagudpod	20.7	145	194	37		96		8.2	196	15.9	80.7	9.3	82
Nagcarlan	6.1	0.7	1.4	0.4		4.8		144	68	31	161	11	571

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
524	60.89	125.89	18.50	71.05	14.48	2.91	17.23	2.58	17.07	3.53	10.57	1.58	10.43
2196	34.00	64.40	7.30	26.76	5.20	0.39	5.22	0.78	5.37	1.11	3.53	0.55	3.91
2191	6.16	13.11	1.78	8.73	2.90	1.08	3.85	0.62	4.05	0.80	2.31	0.31	2.15
Pagudpod	6.1	12.7	1.68	7.7	2.6	1.05	3.2	0.5	3.2		1.66	0.23	1.5
Nagcarlan	24	49	5.5	19.9	4.7	0.63	4.6	0.74	5.1		3.41	0.51	3.74

	Lu	Hf	Ta	Pb	Th	U
524	1.48	12.70	2.31	5.26	7.06	2.16
2196	0.53	4.87	bdl	22.52	19.81	5.86
2191	0.29	1.96	0.28	1.26	0.72	0.19
Pagudpod	0.21		0.5	0.7	0.9	0.2
Nagcarlan	0.57					

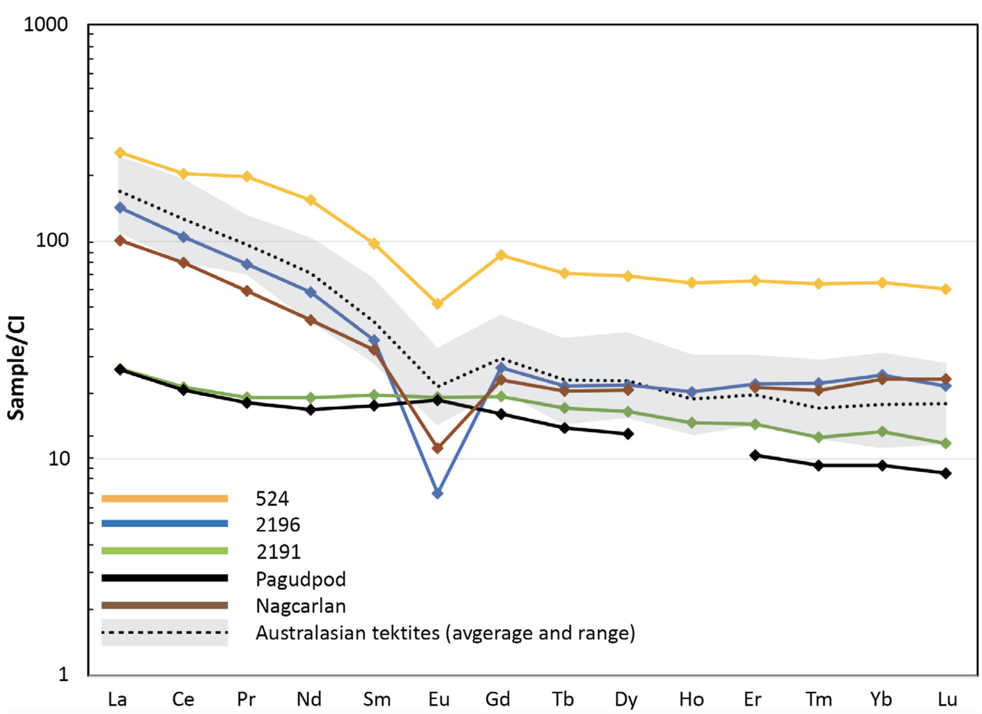

Fig. 3. Normalized to chondrite REE patterns of our pseudotektites, compared to volcanic glass identified by Neri (2007, data after Reepmeyer et al., 2011), and to Australasian tektites (range appears as shaded area). CI values for normalization are from McDonough and Sun (1995) and data for Australasian tektites are from Amare and Koeberl (2006), Son and Koeberl (2005), Žak et al. (2019), Mizera et al. (2016), and Goderis et al. (2017). (Color figure can be viewed at wileyonlinelibrary.com.)

results. Nagcarlan is a rhyolitic obsidian (Fig. 2), whose composition in major elements and REE shows reasonable match with specimen 2196 (Tables 2 and 3; Figs. 2 and 3). The Nagcarlan source may thus eventually be related to our 2196–2200 lithology as it outcrops 70 km SE of the reported finding of 2196–

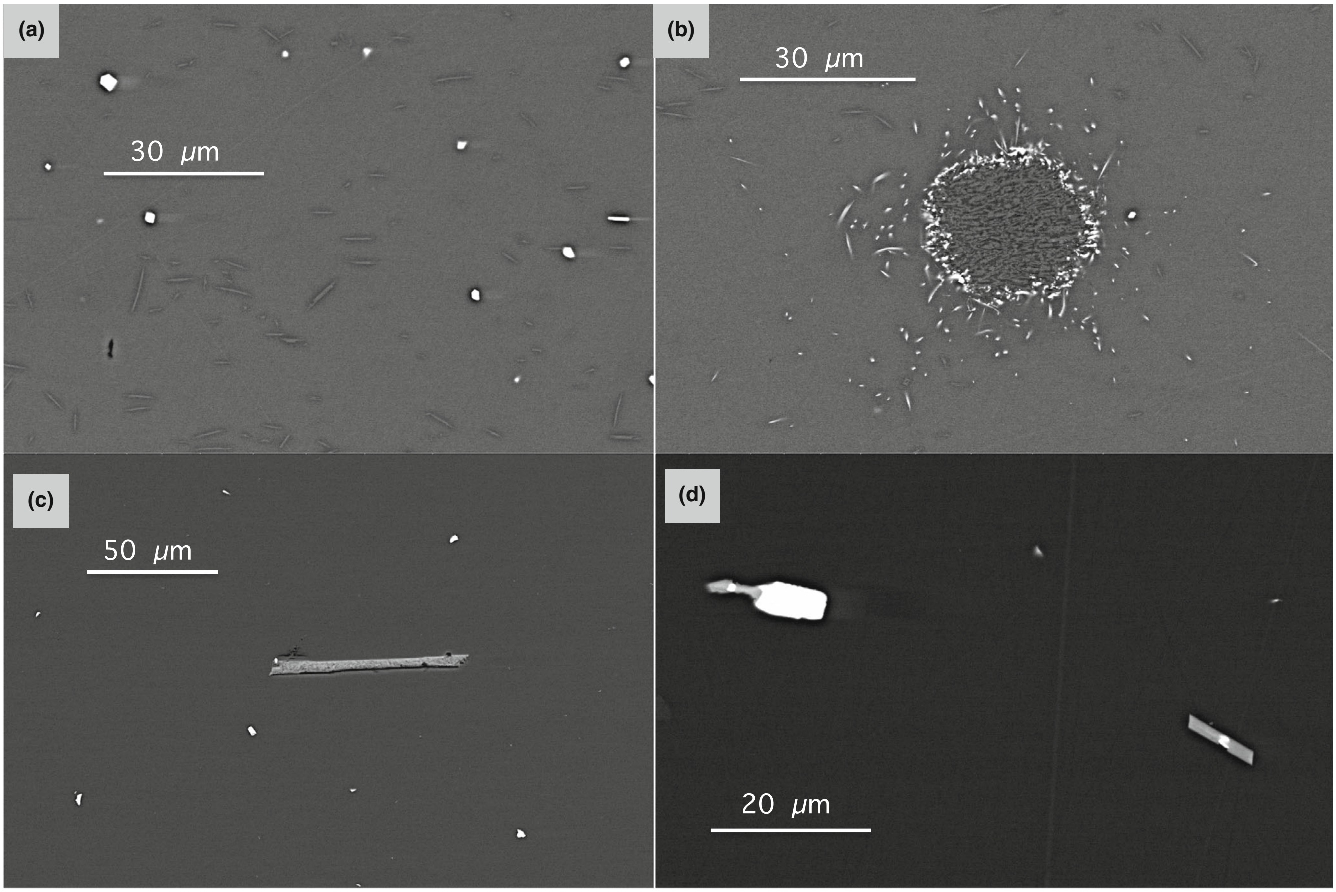

Fig. 4. Field emission gun scanning electron microscope (FEG-SEM) pictures from specimen 524: (a) with feldspar and FeTi oxide microlites; (b) with a dentritic rounded inclusion surrounded by oxide microlites; and specimen 2196: (c) one biotite inclusion surrounded by several FeTi oxide inclusions; (d) cocrystallization of oxides and biotite.

2200. It is probable that Nagcarlan outcrop is not directly at the origin of our gravel samples as fluvial transport is unlikely to have overpassed the 40 km large lake separating the two. Therefore, a nearby source similar to Nagcarlan may be proposed. However, the actual site of recovery of 2196–2200 pseudotektites may not be precisely located.

Both the Pagudpod “obsidian” outcrop and the Pasuquin locality of 2191 are located in Ilocos Norte Province. Moreover, the chemical composition of Pagudpod is basaltic (Fig. 2; Table 2) and thus does not qualify as a real obsidian but as a basaltic glass. Its composition, in particular REE pattern, fits well with the 2191 pseudotektite. The two localities are about 35 km apart, but the exact finding locations are unknown. Moreover, the Pagudpod glass locality is a fluvial or colluvial deposit, so it may not point exactly to the source outcrops.

Further geochemical arguments for the proposed correspondence with known sites in the Philippines can be derived from the Zr versus Sr trace elements plot often used to discriminate among obsidian artifacts (Fig. 7) (e.g., Neri, 2007). Moreover, our three pseudotektite samples are well discriminated with respect to Australasian tektites in this plot.

The occurrence in specimen 2191 of rosette structures formed by dendritic to feather-like microcrystals of clinopyroxene and embedded in a glassy matrix testifies to a rapid cooling of the basaltic melt from a temperature above the liquidus. The formation of dendritic clinopyroxene arranged in radial structures around crystals of titanomagnetite has been experimentally observed in basaltic melts rapidly cooled from superliquidus and re-equilibrated at high degrees of undercooling ($\Delta T > 120$ °C; Griffiths et al., 2020; Pontesilli et al., 2019). Crystallization under such a regime is, however, unlikely to occur in basaltic magmas. A rapid cooling mechanism (most likely quenching) of the basaltic melt must be therefore invoked to explain the formation of the rosettes in the 2191 pseudotektite. One may invoke emplacement in water. To our knowledge, this is the first time such crystallization is observed in natural basaltic glass samples.

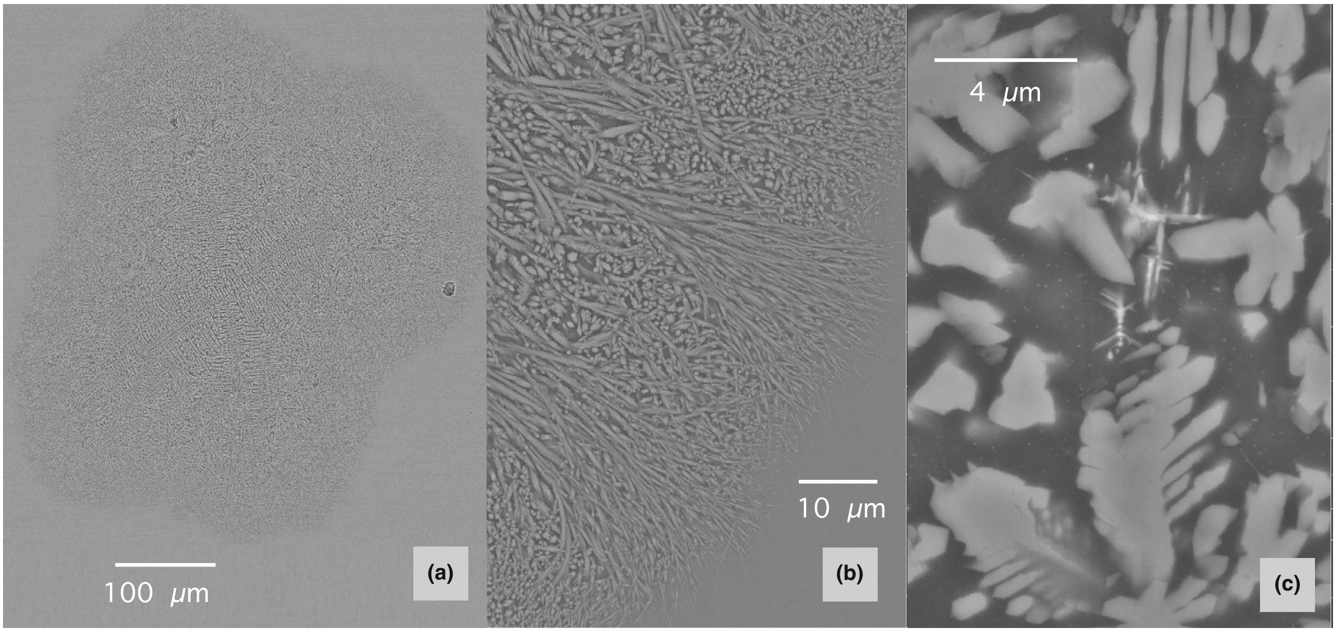

Fig. 5. FEG-SEM backscattered electron images from specimen 2191. a) Full view of a dendritic pyroxene rosette within pure glass. b) Details of feather-like crystallization at the border of the rosette. c) Close-up on the center of the rosette showing pyroxene crystallization as well as dendritic microcrystals of FeTi oxides.

It is worth noting that the volcanic pseudotektites from the Philippines described by Koomans (1938), and coming from Santa Mesa and "NW Luzon," yield chemical compositions close to the Nagcarlan and Pagudpod glasses.

This study raises a number of perspectives. As tektites and volcanic glasses can be easily confused, care must be taken not only for new possible tektite occurrences outside known strewn fields but also for the collection of volcanic pseudotektites within recognized tektite strewn fields (e.g., Baker, 1956). Visual examination may not be sufficient to detect these pseudotektites, as exemplified by specimen 2191 whose aspects are perfectly tektite-like. When finding oddities among tektite collections, one must first check this possible confusion before claiming the discovery of an odd type of tektite. As an example, we may point out the high Na/K "australites": These rare glasses were identified in a few sites from south-central Australia by their distinctive density and chemical composition (Chapman & Schreiber, 1969) (Fig. 2). They yield ages consistently older than the Australasian event (Bottomley & Koeberl, 1999). Implicitly, the high Na/K glasses were considered to form another tektite or impact glass strewn field, despite the lack of a detailed study able to exclude a volcanic origin. In fact, the documented occurrence of volcanic glasses in Australia (e.g., Bonetti et al., 1998; Smith, 1996) has been overlooked. Volcanic glasses could have been dispersed naturally or by Aboriginal Australians in the tektite strewn field. Such problem may also occur in impact glass strewn fields, as exemplified in the Pantasma crater case (Rochette, Alaç, et al., 2019), where both impact and obsidian glasses are found in the same places and cannot easily be distinguished visually. Similar cases may thus be encountered in other tektite and impact glass collections. For example, we have found some volcanic glasses among our collection of atacamaites (Gattacceca et al., 2021).

CONCLUSIONS

The present study describes the discovery of three independent occurrences of volcanic glass that were collected in Vietnam and the Philippines and part of the Australasian tektite inventory of the Paris Natural History Museum. These pseudotektite specimens were detected thanks to a systematic magnetic susceptibility survey of this large collection, based on the normally restricted range of magnetic susceptibility in Australasian tektites. They constitute less than one per mil of the total collection. A combination of high water content, and geochemical and petrographic features leaves no doubt that these are not tektites with an anomalous composition, but volcanic glasses. This conclusion is further grounded for the two glasses found in the Philippines, based on the match with two known volcanic glass outcrops nearby the pseudotektite find sites, Nagcarlan and Pagudpod. In

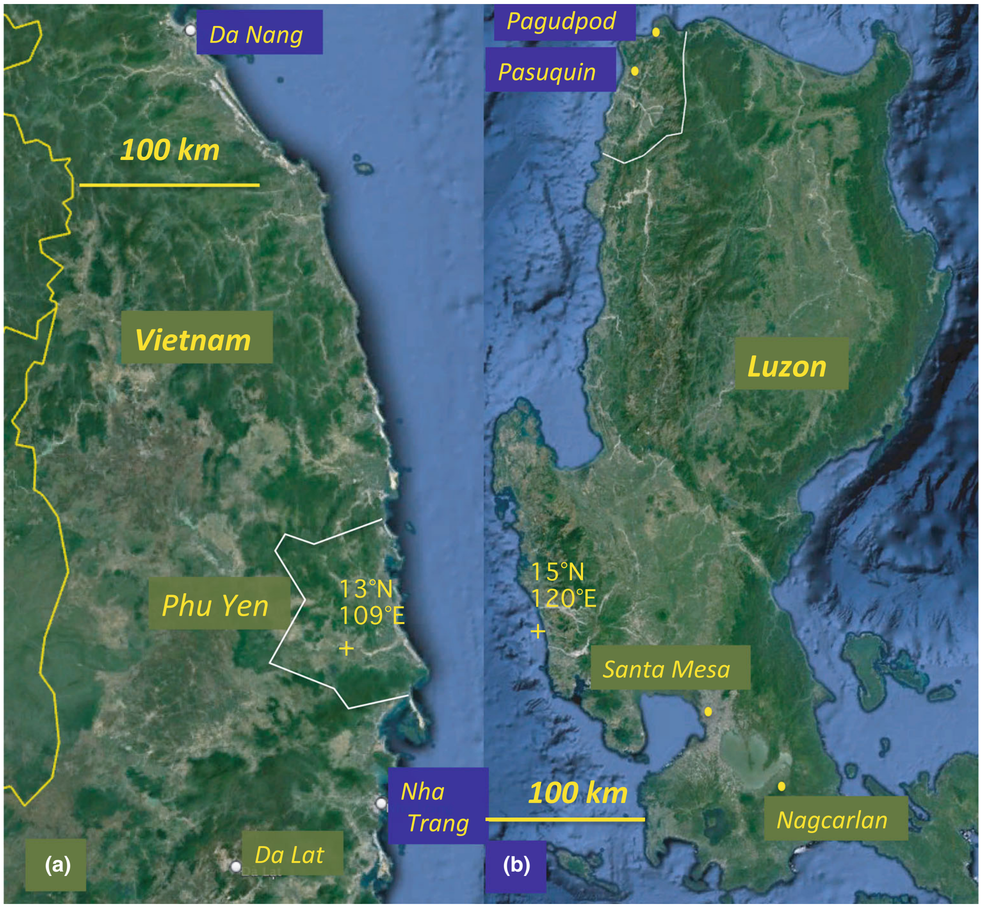

Fig. 6. a) Map of south-central Vietnam with Phu Yen province highlighted in white. b) Map of Luzon island indicating the pseudotektite localities (Ilocos Norte province shown as white contour), and the obsidian sources of Neri (2007). (Color figure can be viewed at wileyonlinelibrary.com.)

Vietnam, specimen 524 may be the first natural occurrence of obsidian described in this country. However, based on the shape of the fragments, we cannot exclude that they are prehistoric artifacts.

The anomalous magnetic properties of the studied samples are due to iron oxide crystalline inclusions in the rhyolitic obsidians (524 and 2196–2200) and to high total iron in the mostly paramagnetic basaltic glass 2191.

The peculiar microcrystalline rosettes found in basaltic glass 2191 are unique features never observed before in natural basaltic glasses and may trigger new volcanologic implications.

Our pseudotektite findings may also improve the knowledge of volcanic glass occurrences in Vietnam and the Philippines, in particular in the context of glassy archeological artifacts. Indeed, the sourcing of obsidian artifacts is often used in a Neolithic context to discuss trade routes, but this needs an exhaustive database of the regionally available sources. It would also be useful for archeologists engaged in such sourcing studies in SE Asia to consider the possibility that some of their artifacts may be made from tektites rather than volcanic glass. We suggest reconsidering the volcanic glass alternative for other odd tektite occurrences, such as the high Na/K "australites."

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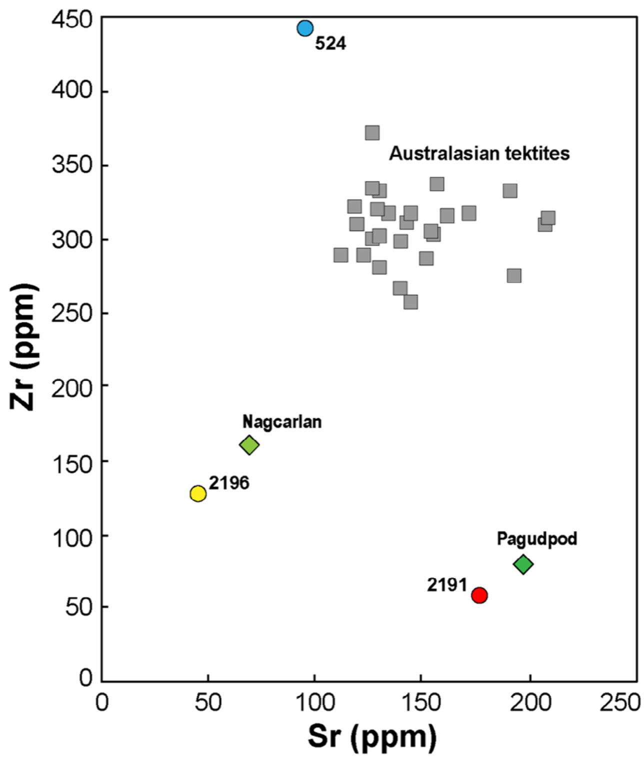

Fig. 7. Zr versus Sr plot for the studied pseudotektites (circles) as well as reference outcrops from the Philippines (diamonds; see Table 3); data for the Australasian tektites (black squares; both Muong Nong and splash form types) from the literature (Amare & Koeberl, 2006; Chapman & Schreiber, 1969; Masotta et al., 2020; Mizera et al., 2016; Son & Koeberl, 2005; Žak et al., 2019) are shown for comparison. (Color figure can be viewed at wileyonlinelibrary.com.)

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Data Availability Statement—All the data that support the findings of this study are available in the paper.

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