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An empirical model for the Australasian tektite field

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The Australasian strewn-field contains a radial sequence of tektite shapes ranging from unmodified impactite (Muong Nong type), through dumb-bells and discs (thailandites, indochinites), and spheres (phillipinites, billitonites, and javanites) to ablated button shapes (australites). This sequence extends from a suspected impact area in northeast Kampuchea following an approximate southeasterly bearing to southeastern Australia and Tasmania. The possible impact area appears to be surrounded by Neogene basalts, which are younger than the tektites, and may have been generated by the impact event.

Key words: atypical impact, fragment size, impact-generated basalts, shape variation, South-East Asia, tektites.

INTRODUCTION

Since the first scientific description of an Australasian tektite by Charles Darwin (1844) there has been considerable speculation on their origin. The argument was initially clouded by the fortuitous occurrence of moldavites in Europe and glass at Mt Darwin, Tasmania, along approximately the same great circle, leading David *et al* (1927) to propose an extra-terrestrial source to account for this distribution. This led ultimately to the appellation of 'glassy meteorites' for tektites and speculation on a possible lunar source.

However, with the availability of analytical data and ages for lunar rocks, no good case could be made for a lunar source; indeed, as pointed out by Urey (1971) and King (1977) a terrestrial source had already been well-established by Schwarcz (1962), Taylor (1969) and Taylor and Kaye (1969).

The correlation of tektites with source craters (Faul 1966) — e.g. Ivory Coast tektites with Lake Bosumtwi (Schnetzler *et al* 1966) — moldavites with the Ries crater (Storzer & Gentner 1970) and Irghzites with Zhamanshin crater (Boŭska *et al* 1981), together with the presence of coesite (Walther 1965; Glass *et al* 1986), is good evidence for terrestrial, impact origins of tektites.

The Australasian strewn-field, which is by far the largest identified so far, is about 0.709 Ma old (Gentner *et al* 1969) and remarkable for the variety of tektite shapes represented. The analytical data (Table 1) indicate a consistency in major components for all localities which, despite their wide geographical distribution, suggest a common source. Both Taylor (1969) and the present author have noted a general increase in the specimen size from southern Australia, through Indonesia to South-East Asia in tektites housed at the National Museum of Natural History, Smithsonian Institution, Washington DC, USA. Tektites from Tasmania are rarely greater than 10 mm in diameter; the largest from Hampton Station, Kalgoorlie, WA (Cleverly 1986), where approximately 22 000 were collected, was about 35 mm; and a large Muong Nong Tektite (lodged at the Department of Mineral Resources, Bangkok, Thailand) has a diameter of about 0.3 m and weighs several kilograms.

EMPIRICAL MODEL

A model for the Australasian tektite field must incorporate explanations for Muong Nong types, discs, dumb-bells, spheres, tear-drops and australite buttons.

On the basis of chemical composition, Muong Nong tektites belong to the Australasian tektite field but have many features apparently foreign to other members of the group. They were first recognized by Lacroix (1935) and are characterized by extreme irregularity of shape and size (up to several kilograms) with no apparent aerodynamic modifications, as well as having coarse flow structures and flutings, numerous lateritic inclusions (probably incorporated by

Table 1 Chemical analyses of Australasian tektites.*

wt%	Muong Nong Type (2)		Indochinites (52)		Billitonites (14)		Philippinites (21)		Australites (32)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	72.97	72.44–73.50	73.68	70.58–81.36	71.32	68.30–76.40	70.87	68.90–72.10	73.06	68.91–79.51
TiO_2	0.75	0.74–0.76	0.82	0.47–1.03	0.78	tr–1.10	0.83	0.63–1.04	0.68	0.08–0.90
Al_2O_3	12.97	12.59–13.34	12.47	8.87–14.39	12.04	9.86–13.50	13.48	12.08–15.23	12.23	9.36–15.42
Fe_2O_3	0.35	0.29–0.41	0.32	0.03–0.82	0.77	0.06–2.25	0.79	0.50–2.03	0.60	0.23–1.48
FeO	4.16	4.03–4.20	4.52	2.81–5.63	5.10	3.17–6.81	4.30	3.03–5.32	4.14	3.11–5.30
MnO	0.10	0.09–0.10	0.11	0.06–0.32	0.14	0.08–0.32	0.09	0.08–0.16	0.12	tr–2.42
MgO	1.97	1.93–2.00	2.05	1.11–2.93	3.18	2.38–4.96	2.67	2.23–3.65	2.04	1.35–2.49
CaO	2.16	2.16–2.16	2.17	1.00–3.48	2.95	2.22–3.92	3.14	2.50–3.97	3.38	1.48–5.10
Na_2O	1.60	1.58–1.61	1.42	0.90–2.00	1.55	0.77–2.46	1.41	1.18–1.76	1.27	0.91–1.84
K_2O	2.47	2.45–2.48	2.39	1.84–3.16	2.19	1.57–2.76	2.31	1.69–2.56	2.20	1.25–2.56
Total	99.50		99.95		100.02		99.89		99.72	

*Data from Barnes and Pitakpaivan (1962) and Barnes (1967).

impact of soft glass on a lateritic substrate) and containing relatively coarse remnant vesicles similar to a medium vesicular basalt. Muong Nong tektites have surface features like Darwin glass (Fig. 1), an impactite glass scattered asymmetrically about Darwin crater, Tasmania (Fudali & Ford 1979).

Field work in eastern Thailand has confirmed that the tektites lie on the surface of a laterite layer below the normal soil profile (Barnes & Pitakpaivan 1962; Fontaine & Workman 1978; E. Gangadaram pers. comm. 1986). Muong Nong tektites were collected from east Thailand near the centres of Ubon Ratchathani and Yasathon. Smaller fragments were found near Chaiyaphum to the west indicating a distribution of fragments of decreasing size in that direction (Fig. 2). Muong Nong tektites collected from Hainan Island (housed at the Geology Department, University of Malaya, and inspected by courtesy of Dr E. Gangadaram) are

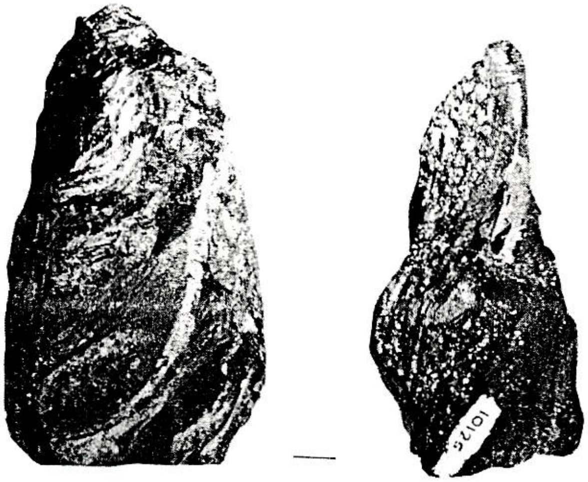


Fig. 1 Darwin glass (left) and Muong Nong tektite (right) showing the similarity of the coarse twisted flow structure and vesicles. Specimens Nos 10142 and 10125 housed in the Geology Department, University of Tasmania. Bar scale = 10 mm.

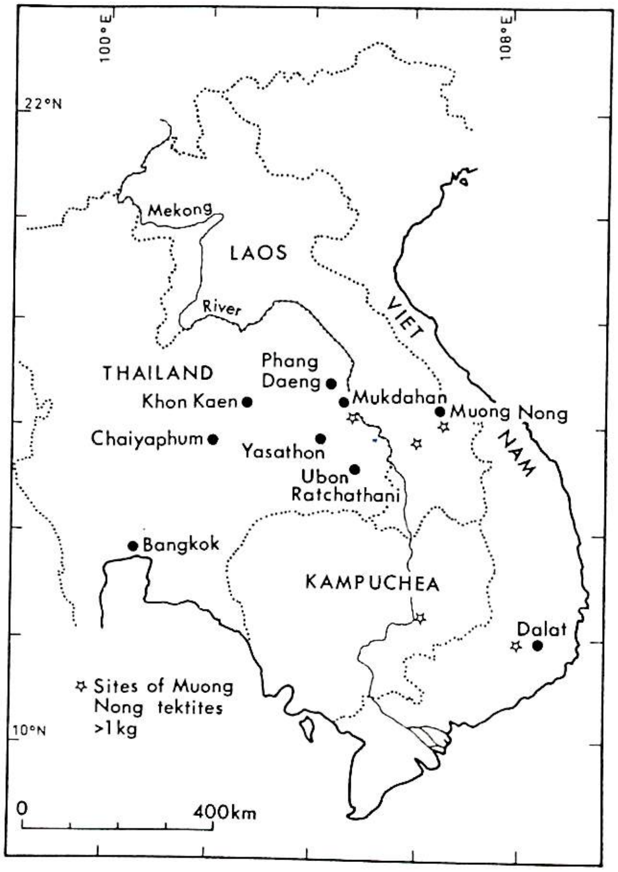


Fig. 2 Locality map of South-East Asia showing sites of reliably known finds of large Muong Nong tektites.

also small (a few centimetres in diameter). When compared with the large Muong Nong types from the type locality and elsewhere in Laos (Lacroix 1935), near Dalat in Vietnam (Fontaine 1966), and near Mukdahan in Thailand (K. Pitakpaivan pers. comm. 1986), there is an apparent radial variation of fragment size of Muong Nong tektites about an area in northeast Kampuchea near the Laotian border. There is a similar variation in size of fragments of Darwin glass impactite around Darwin Crater (Fudali & Ford 1979). On this basis, Muong Nong tektites represent impactite, scattered around a collision site, with no great aerodynamic modification.

The more normal tektite forms, predominantly dumb-bells and discs, are found in Thailand and Kampuchea. Some of these may be deformed in ways showing they had not solidified before impact (Fig. 3); plastically deformed dumb-bells and discs were also reported by Nininger and Huss (1967). Flow lines on a disc (Fig. 4a) are parallel to the circumference and of circular to spiral form on the face of the disc (Fig. 4b), and there is also a tendency for some thickening towards the periphery of the disc. These features are consistent with a fragment of molten glass spinning about an axis normal to the direction of flight of the object through the atmosphere.

The dumb-bells cannot be modelled as simply, but probably represent fragments rotating about an axis oriented parallel to the flight direction. Where present, the flow lines appear to cross the long axis of the tektite diagonally.

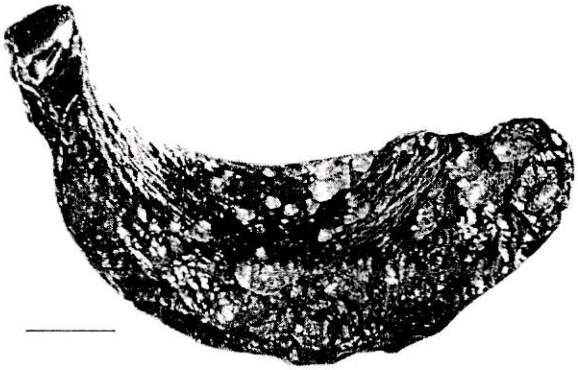


Fig. 3 A plastically deformed thailandite from South-East Asia. Specimen No. 1014 housed in the Geology Department, University of Tasmania. Bar scale = 10 mm.

In summary, tektites from the mainland of South-East Asia have shapes derived from uncongealed spinning glassy fragments passing through the atmosphere.

A further zone including the Philippines and Indonesia contains groups referred to as phillipinites, javanites and billitonites. These are dominated by spherical and tear-drop forms (O'Keefe 1967; E. Gangadaram pers. comm. 1986; S. Darsoprajitno pers. comm. 1987), but also include some ablated fragments (Stauffer 1978). These shapes have formed from soft (fluid) fragments, the trajectories and velocities of which have taken them into a zero gravity environment where surface tension becomes the dominant force, spheres are produced, and most fragments congeal. A proportion of these fall

why?

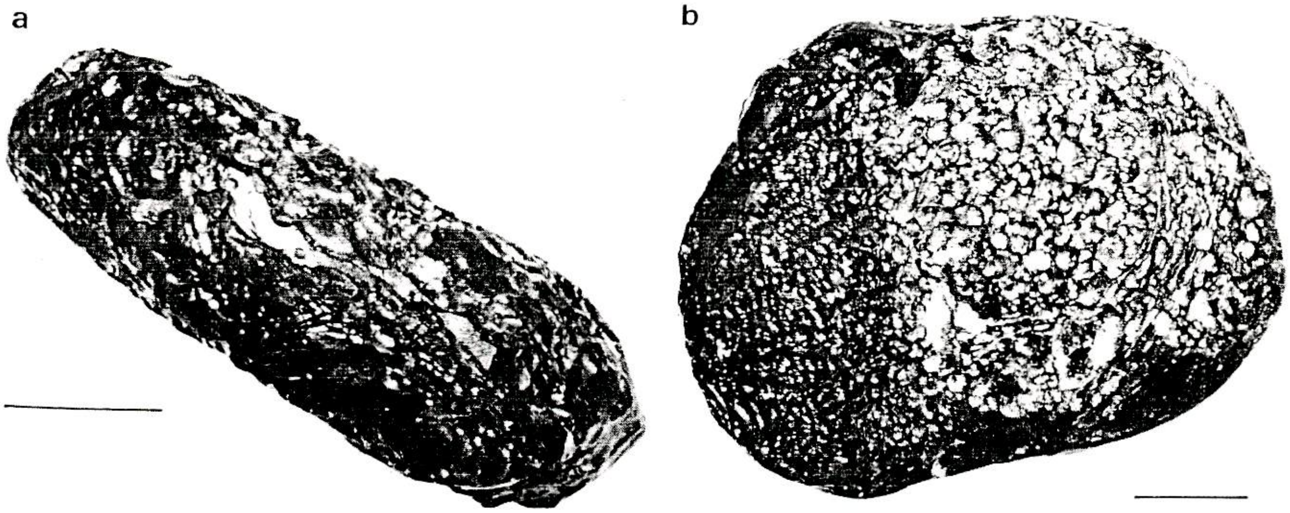


Fig. 4 (a) Flow lines around the circumference of a disc-shaped thailandite. (b) Circular and spiral flow lines on the face of the disc. The form of the flow lines is consistent with that of a disc of molten glass spinning perpendicular to its direction of propagation. The circumference of the disc is thicker, also suggesting a spinning disc. Specimen No. 10143 housed at the Geology Department, University of Tasmania. Bar scale = 10 mm.

back to Earth and some may still be soft, producing the familiar spheres and tear-drops indicative of relatively short re-entry paths and resulting in minimal further modification by interaction with the atmosphere. Barnes (1967) drew attention to the predominantly spherical shapes of bubbles in phillipinites, javanites and australites in contrast to the more elliptical shapes in the indochinites and Muong Nong types. Spherical bubbles are indicative of higher temperatures, and are much less abundant in australites. On the basis of contamination of a heated tektite glass sample, Reynolds (1960) concluded that the initial gas content was very low, which could be the result of efficient out-gassing in a low pressure environment. All of these features are consistent with the more evolved tektites having been at a higher initial temperature and longer in a low gravity environment. The zone in which spheroidal tektites are dominant extends from about 1000–3000 km from the inferred impact area, with some australite ablation forms appearing towards the southeastern limit of this zone.

Consequently the primary form from which the classical button-shaped australite evolved, is available. In reaching zero gravity conditions the tektites were effectively in orbit, but apparently had insufficient energy to complete an Earth orbit; hence re-entry began in the region between Indonesia and Australia on an approximately southeasterly bearing (Fig. 5).

On re-entry to the denser atmosphere at supersonic velocity, surface frictional ablation of the solid spheres began, with the amount of ablation being related to the distance travelled, and the typical button-shaped australites were produced, eventually landing on the Australian continent and Tasmania. The longer the journey through the atmosphere, the smaller and flatter the australite. This model, proposed by Baker (1958), has been demonstrated to be plausible by Chapman (1971). The more irregularly shaped tektites were derived from fragments which had solidified before entering a zero gravity regime.

Adams and Huffaker (1964) claimed that it is impossible to put fragments into orbit from a meteoritic impact, but the geological evidence suggests otherwise. They also stated that, for orbital flight, such projectiles must be propelled by some mechanism in addition to that of the impact. If the impact took place during the wet season in South-East Asia, with the concomitant production of superheated steam contributing to their ejection, dispersion of the tektites may

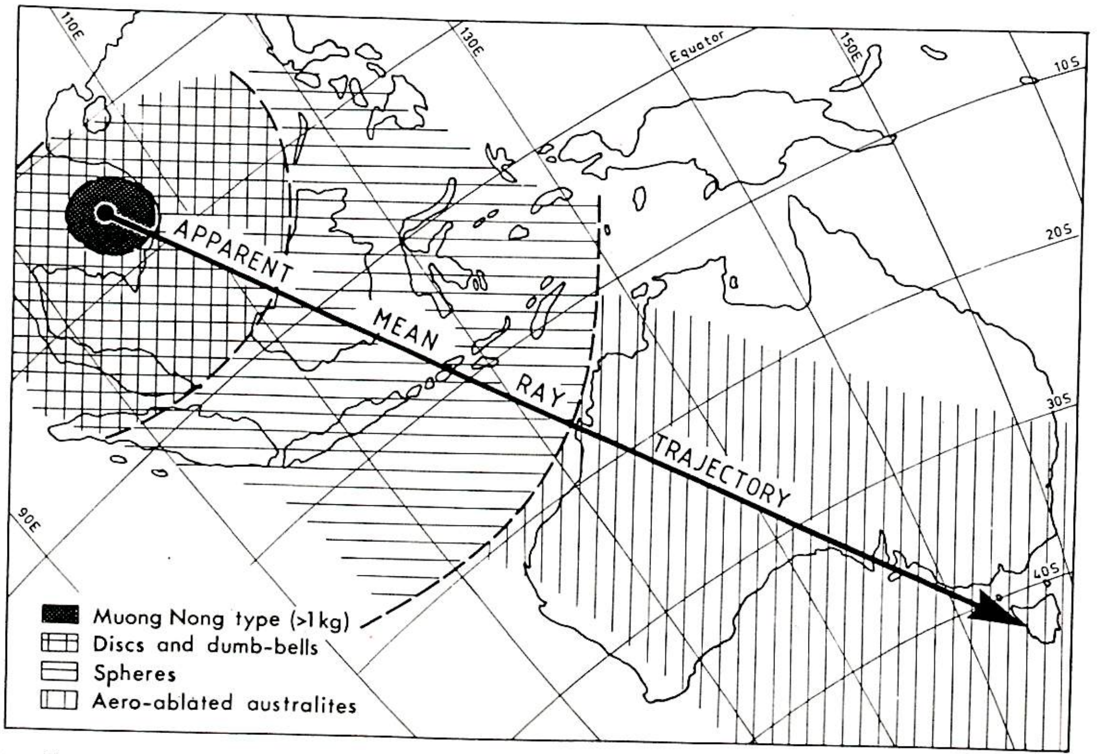


Fig. 5 Locality map showing distribution of the main tektite forms on an axis between Kampuchea and Tasmania.

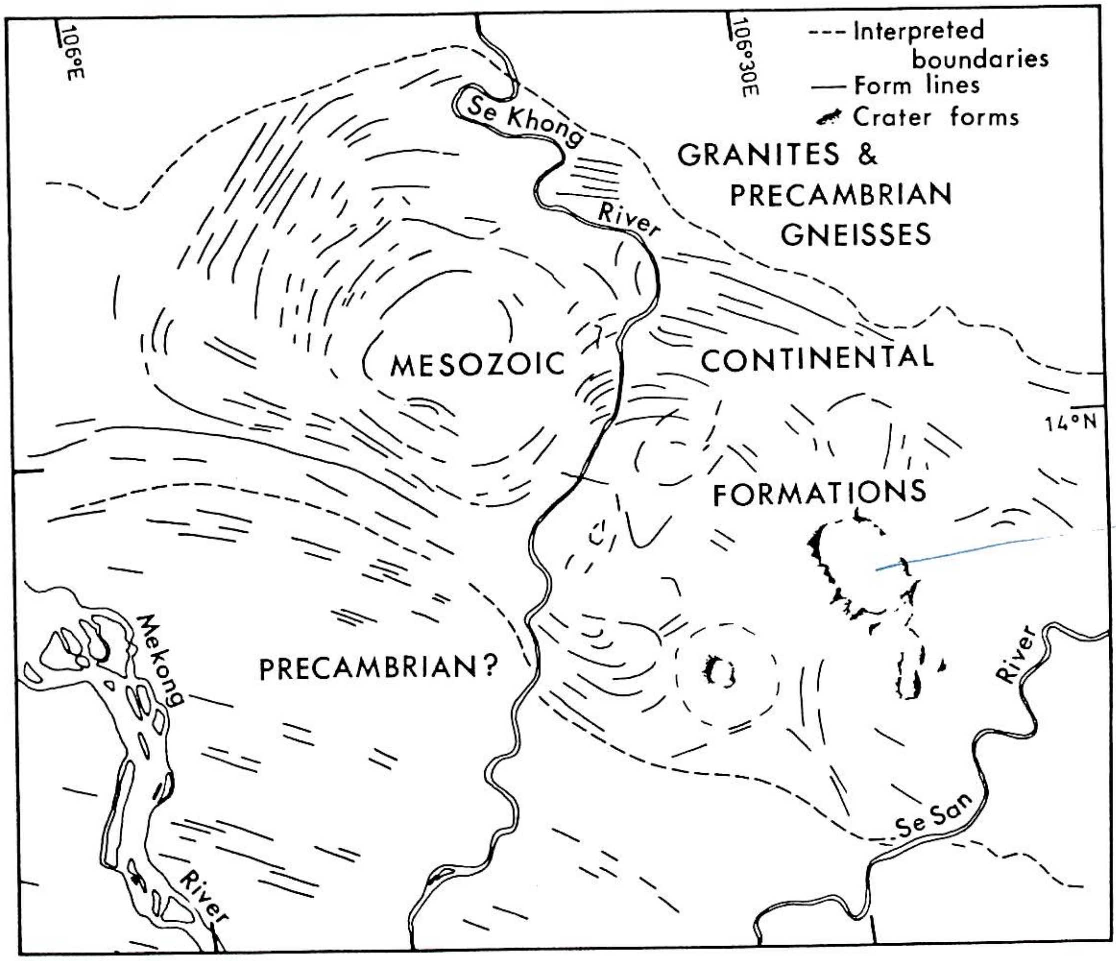
have been enhanced. As tektites are not associated with all large craters there must be special factors, beyond that of a simple impact model, governing their formation. The nature of the distribution of tektites related to known sources is invariably asymmetrical, suggesting a momentum change model involving the oblique impact of the meteorite. Consequently molten rock producing the tektite is probably derived from near the surface of the impact area. Where source relationships have been established, the parent craters maintain their circularity.

there's only two craters

SOURCE

On the assumption that Muong Nong tektites are unmodified impactites it can be expected that larger fragments would be scattered proximally to their source. The reliable known occurrences of large Muong Nong tektites >1 kg mass are given in Fig. 2 and the area examined by means of Landsat imagery. Near the centre of the area delineated there are at least five pseudo-circular structures, the most prominent of which is of elliptical plan, and centred at 106°34′E, 13°55′N, just within the northeastern border of Kampuchea (Fig. 6). This would indicate a multiple impact event, but the interpretation of these structures is not simple.

This area has been studied by Hartung and Rivolo (1979) who gave the dimensions of the elliptical feature as 10 × 6 km with an axial ratio of about 1.66. Baldwin (1949) had previously considered elliptical structures more akin to terrestrial calderas in which axial ratios approximate 1.5. Morphometric models proposed by Baldwin (1963) and Pike (1974) do not recognize elliptical forms as typical of meteorite craters. It is impossible to obtain all of the morphometric data for the best appraisal of a crater-form (Baldwin 1963), but a value of 0.56 for the circularity index of the structure lies outside the range of terrestrial impact craters. On the other hand, the rim-width seems too



"most prominent"

Fig. 6 The geology of the area about the possible impact area interpreted from Landsat imagery and the map compilation of Fontaine and Workman (1978).

narrow for a volcanic form with the rim-width/diameter ratio in the range 0.11–0.20, compared with 0.14–0.30 for terrestrial meteorite craters. An apparent peak and ring structure at 106°25′E, 13°52′N may be the remains of a central peak in an original crater, but the rim, which should be preserved, is absent. Other structures have raised rims but also possess atypical ridges. All of these structures are adjacent to a Mesozoic basin, the form lines of which are traceable towards the crater forms, but these lines become somewhat diffuse in the suspect area. The Mesozoic rocks, consisting of sandstone and shale with some calcareous sandstone, are compatible with the source rock types suggested by Taylor (1969) and Taylor and Kaye (1969). Collection of suitable samples from the area would test the proposed association. Derivation from adjacent Precambrian rocks would also be consistent with the isotopic data of Shaw and Wasserburg (1982).

The distribution of microtektites (Cassidy *et al* 1969; Stauffer 1978), including a restricted pattern of distribution on the Malay peninsula (E. Gangadaram pers. comm. 1986), is indicative of a ray pattern within South-East Asia. Chapman (1971) has also demonstrated an apparent ray pattern based in compositional differences within the australites. Though poorly defined, their traces are consistent with the proposed impact area.

If the impact took place in this area, it may have triggered a volcanic event which obliterated the original crater and superimposed upon it the more volcanic-like forms observed above. Existing geological maps of South-East Asia indicate Neogene basalts, younger than the tektites, having an approximately circular disposition about the suspected impact site (Fig. 7). According to Fontaine and Workman (1978) these basalts overlie the laterite surface with its associated tektites and clearly postdate them.

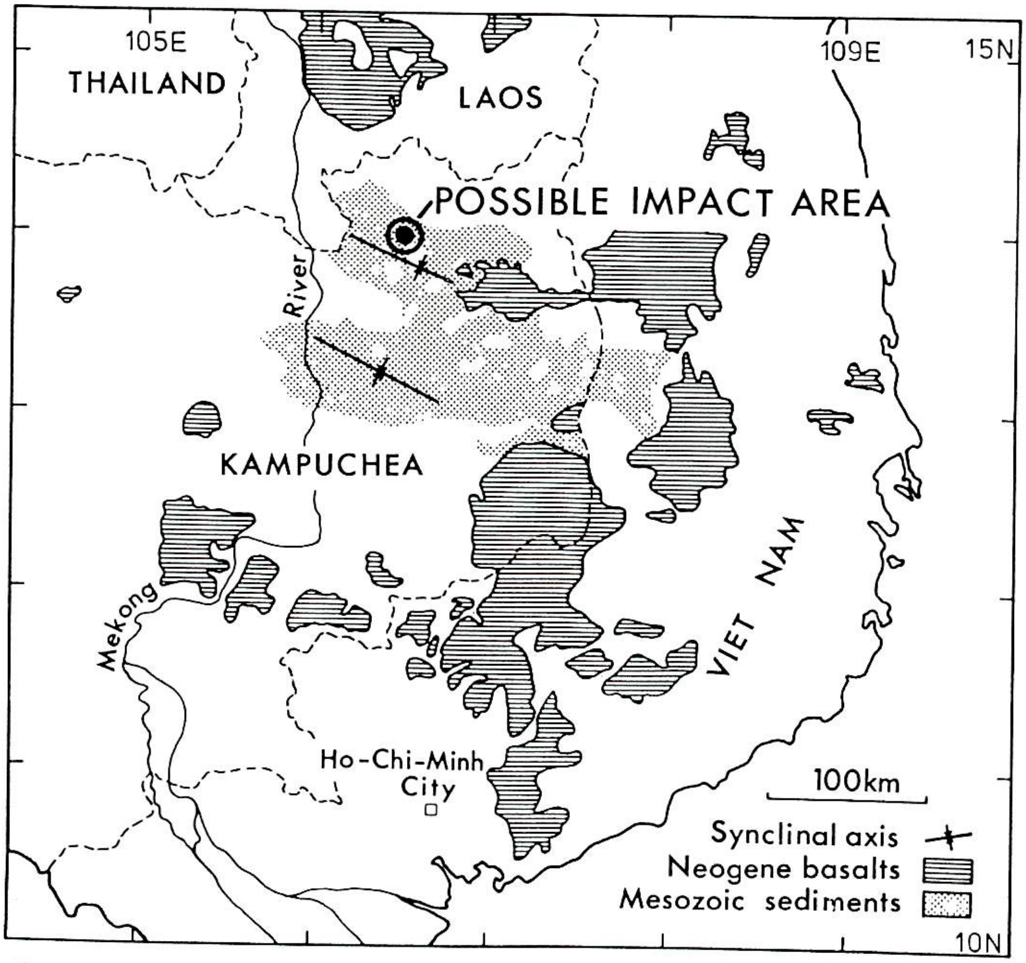


Fig. 7 The distribution of Neogene basalts around Kampuchea from the compilation of Fontaine and Workman (1978).

CONCLUSIONS

An empirical model has been proposed whereby the variation in shapes of tektites from the Australasian strewn-field may be explained by the interaction of molten glass with the atmosphere and beyond due to high velocity ejection from a possible impact in northeast Kampuchea. The Muong Nong group of tektites is comparable to relatively unmodified impactites like Darwin glass, Aouelloul glass, and Wabar glass occurring close to their source craters.

An event comparable with that responsible for the South-East Asian strewn-field must have a characteristic set of fragment trajectories. In the first 400 km from impact there are large Muong Nong tektites; between 400 and 1000 km there are disc and dumb-bell shapes (e.g. thailandites, indochinites); between 1000 and 3000 km, spherical and tear-drop shaped phillipinites, billitonites and javanites occur; and at distances greater than 3000 km ablated tektites (australites) would be most abundant.

The button form of australites is unique to the Australian strewn-field and is produced by travelling more than 3000 km from the source. Tektites from other strewn-fields not exhibiting ablated australite forms are within 3000 km of their source on the basis of the proposed model.

The age, stratigraphy and geographical distribution of the Neogene basalts in the area are not inconsistent with their being related to the impact event.

Hence, there is a potential source of South-East Asian tektites in northeast Kampuchea.

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