

*Micro-forms of hay-silica glass and of volcanic glass*

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*Summary.* In view of recently reported microtektites in deep-sea sediments north-west, south-west, and south of Australia, attention is drawn to the occurrence of minute forms of hay-silica glass among the products of incineration of opal-bearing vegetation in haystacks, and to the minute forms of volcanic glass ejected in lava fountains. These terrestrial micro-forms of glass have properties within the range of those for the fossil glassy bodies named 'microtektites'. It is possible that the fusion of opal contained in silica-accumulator plants during fierce, prehistoric forest, bush, and grass fires in Australia generated micro-forms of glass that became readily airborne and drifted away in up-currents. Carried by the south-east Trades, they would ultimately descend over the Wharton Basin in the Indian Ocean. Strong to violent northerlies and north-easterlies (Brickfielder Winds) would carry them over the ocean south and south-west of Australia. Thus they could contribute to the deposits of bodies of glass regarded as microtektites in deep-sea sediments. Many microbodies of glass in the Wharton Basin could have had their origin in the Javanese volcanic eruptions.

THE purpose of this article is to show that micro-bodies of glass similar to those described as 'microtektites' from deep-sea sediments have been generated by fusing opal contained in silica-accumulator plants, fusion being facilitated by fluxes in the plants. Others have been noted as micro-forms cooled from the molten spray ejected in the lava fountains of basic volcanoes. These are of a size, shape, and density that makes them become readily airborne for long-distance transport. Since the burning vegetation frequently produces plant-silica glass such as hay, straw, wood, and grain-silica glass, and since plants have secreted silica during past geological periods (Baker, 1960), it is likely that past forest, bush, and grass fires produced micro-forms of silica glass from the opal phytoliths precipitated in the cell structures of plants (Baker, 1961*a* and *b*, and earlier references therein).

*Silica glass from a haystack.* The burning to the ground of approximately 325 tons of meadow hay in the parish of Gnarkeet, near Lismore, Western Victoria, on 7 March 1961, yielded an estimated 15.8 tons of hay-silica glass; this is about 5 per cent of the material constituting the

original haystacks. The bulk of the glass was formed into various shapes of macro-size (Baker and Baker, 1964), but micro-beads averaging 1 mm in diameter were observed attached to larger pieces and as free entities in the fine ash at the site of the fire. An unknown quantity of micro-forms could have been removed from the site, during the fire by drifting away in hot ascending gases, and after the fire by wind transportation.

A detailed search for the smaller forms of hay-silica glass among the fine constituents in material collected at the time of inspection of the haystack fire residues at Gnarkeet has revealed numerous micro-shapes (figs. 1 and 2), principally spherical and spheroidal forms, with fewer elongated forms; a few of them are hollow. Rare, nearly black, micro-forms are sufficiently magnetic to be attracted to a strong Alnico hand magnet, but other black forms are non-magnetic and consist of carbon-discoloured glass.

The main constituent plants (*Hordeum maritimum* and *Lolium perenne*) of the haystacks are relatively avid silica-accumulators when grown on soils having readily available silica, like the Newer Basaltic soil at Gnarkeet. The glass was produced by melting and fusion of opal phytoliths in the presence of such fluxes as CaO, MgO, K<sub>2</sub>O, and Na<sub>2</sub>O in the ash from gramineous and other plant species; these fluxing constituents make up 29 % of the hay-silica glass (Baker and Baker, 1964).

Micro-forms that spiralled up and away from the seat of the fire in hot gases rising from the conflagration would tend to become clarified of many of the micro-bubbles and carbon particles, and their forms would become more regularly shaped than those of many that remained at the site of the fire. An analogy is provided by the 'smoke-bombs' ('slag-bombs') that spiral up in the hot gases from the funnels of coal-burning locomotives.

*Nature of the micro-forms of hay-silica glass.* The micro-bodies of glass formed in the haystack fire (figs. 1 and 2) include spheres, spheroids, discs, ovoids, ellipsoids, dumb-bells, teardrops, pear-shaped, flask-shaped, canoe-shaped, and aberrant forms, distorted and nondescript shapes, and irregular fragments. They are of brittle glass that breaks with a conchoidal fracture. Spherical and spheroidal forms exceed elongated forms in the ratio of approximately 8 or 9 to 1.

Colour ranges from colourless through grey, pale smoky-brown grey, brownish, yellowish-green, and less commonly dark grey to black according to micro-bubble content, carbon in a sub-microparticulate state, and iron content. The grey colour in reflected light is mostly due to light reflections from included micro-bubbles, since the glass itself is mostly

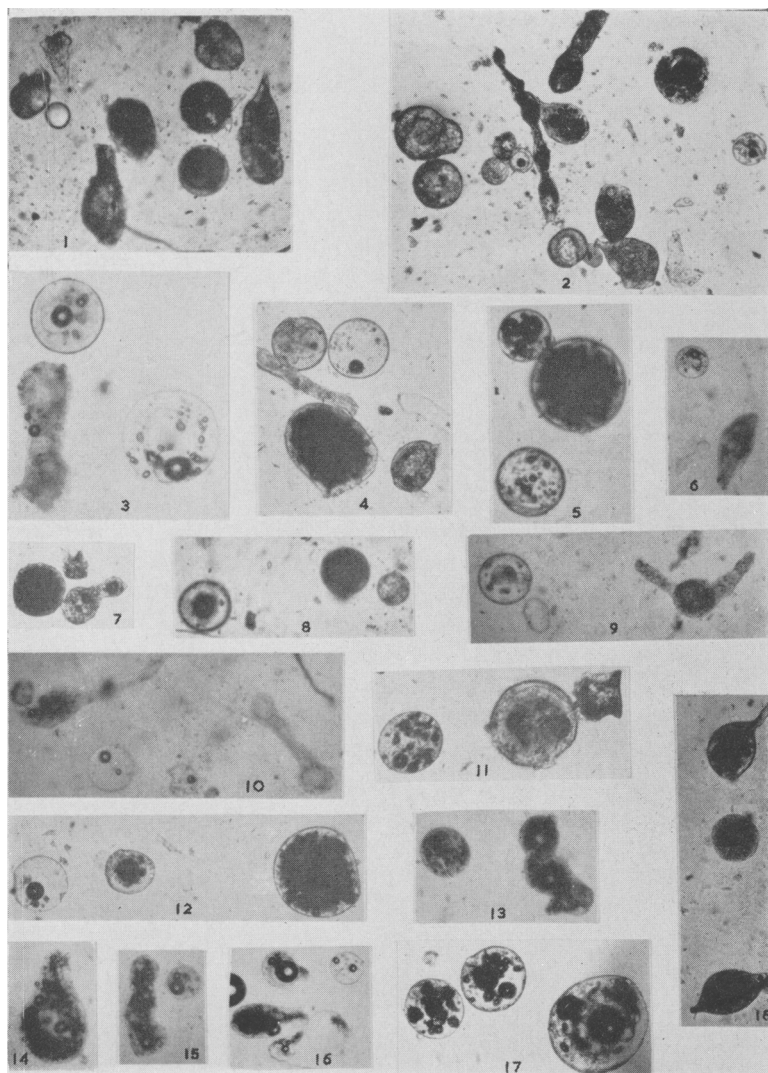


FIG. 1. Groups of micro-forms of hay-silica glass, Gnarkeet, Victoria. Nos. 1-18 ( $\times 40$ ) photographed completely embedded in Canada balsam, in ordinary light under the petrological microscope. (Photographs by T. H. Donnelly and G. Pietsch.)

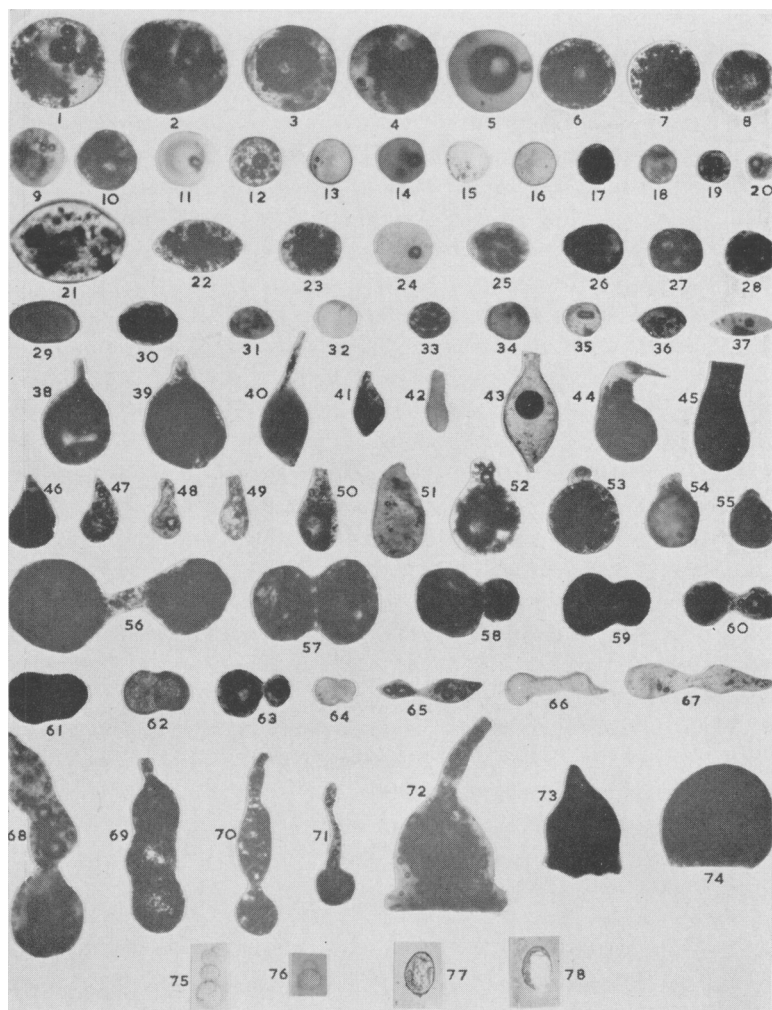


FIG. 2. Micro-forms of hay-silica glass, Gnarkeet, Victoria. Nos. 1-78 ( $\times 40$ ) photographed completely embedded in Canada balsam. Nos. 1-77 taken in ordinary light, no. 78 taken in polarized light to reveal quartz particle enclosed in oval-shaped rim of opal. (Photographs by T. H. Donnelly and G. Pietsch.)

colourless. In Canada balsam mounts, many micro-forms are crystal-clear and colourless (e.g. fig. 1, nos. 1, 3, 4, 10, 12; fig. 2, nos. 5, 11, 13, 15, 16, 24, 32, 42, 64, 66, 75, 76) and these have a highly vitreous lustre in reflected light (viewed in air).

Spherical forms range from 10 to 320  $\mu$  in the microscope preparations. Several contain numerous micro-bubbles, others are completely free. Between these two extremes, they show a continuous range in micro-bubble content. One colourless sphere, for example, which measured 0.189 mm across, contained only two spherical micro-bubbles measuring 0.010 mm and 0.042 mm respectively.

Ovoidal and ellipsoidal forms (fig. 2, nos. 21–37) range in size from 0.075 by 0.052 mm to 0.357 by 0.252 mm, and show a range in micro-bubble content like the spherical forms.

The dumb-bells (fig. 2, nos. 56–64) are from 0.100 mm to 0.750 mm long, and their widths vary from 0.020 mm to 0.320 mm for the gibbosities, and 0.010 mm to 0.250 mm for the waists. Some dumb-bells have gibbosities of approximately the same size (fig. 1, nos. 3, 10; fig. 2, no. 57) but many are of unequal size (fig. 2, nos. 56, 58–64) with variable waist widths. In examples with thin, attenuated waists, the dumb-bell-shaped forms are usually distorted (fig. 3, no. 71). Aberrant examples reveal three or more gibbosities (fig. 1, no. 2 (centre), 13 (right-hand side); fig. 2, nos. 68, 69, 75). Micro-bubbles are as common in the dumb-bell-shaped as in other micro-forms.

The size range of the teardrops, flask-shaped, and pear-shaped forms (fig. 1, no. 14; fig. 2, nos. 38–55) is from 0.160 by 0.084 mm to 0.357 by 0.230 mm for the gibbosity, and 0.020 mm to 0.063 mm for the width of the neck or attenuated tail. Some are symmetrical but others have short recurved necks (fig. 2, nos. 46, 47) or recurved attenuated tails (fig. 2, nos. 40, 44). Several are highly charged with micro-bubbles (fig. 2, nos. 52, 53).

Helmet-like forms (fig. 2, nos. 72, 73) resemble one figured by Glass (1967, fig. 2), being approximately the same size and glassy, although one (fig. 2, no. 72) has a much longer attenuated peak and contains abundant micro-bubbles.

Hollow forms are represented among the various shape types. Hollow spheres are shown in fig. 2, nos. 3 and 5. A hollow dumb-bell has internal cavities of generally comparable size for each gibbosity. Forms with relatively large bubbles compared with the size of the containing micro-bodies of glass are also shown in fig. 1, no. 16 and fig. 2, nos. 12, 43, 60, 63. Often the glass walls of these minute hollow shells are riddled with

tiny spherical bubbles ranging down to  $3\ \mu$  in diameter, but sometimes the glass walls carry only one or two micro-bubbles (e.g. fig. 2, no. 5).

Whereas many of the hollow micro-forms are complete entities in themselves, several are 'punctured' and some collapsed, so that aberrant forms arise such as three-quarter spheres (fig. 2, no. 74), half-spheres, and various, narrow, curved segments often crescentic in outline and like some types of glass shards.

The micro-bubbles arise from reactions causing intumescence and the release of gases. The heat of the conflagration and the presence of fluxing materials contained in the vegetation in the haystacks resulted in melting and fusion of the opal phytoliths precipitated in the plants during their life cycle. The melting process drove off the combined water, which in the hyaline opal ( $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ ) constituting the phytoliths ranges up to approximately 15 to 20 %. Other microparticulate matter in the haystack, such as small soil and dust particles mechanically entrained during mowing and stacking of the meadow hay, is small in amount and of no significance in hay-silica glass formation. Melting and fusion of the opal phytoliths in the presence of fluxes was carried to completion in parts of the haystack fire, clarifying some micro-forms of their original micro-bubble content (e.g. small spheres in fig. 1, no. 1; fig. 2, nos. 16, 32, 42, 64, 66, 75, 76), but the process was not quite complete where the micro-forms still retain one, two, or three micro-bubbles (fig. 1, nos. 3, 10, 12, 16; fig. 2, nos. 11, 13, 15, 18, 24, 43). The clarification process was far from complete where the micro-forms are in a tumid state and where they are packed with micro-bubbles but still relatively symmetrical (fig. 1, nos. 5, 7, 11, 15, 17; fig. 2, nos. 1-4, 6-8, 21-23, 52, 68, 72).

One or two of the lenticular forms show an apparent equatorial bulge or girdle, but this structure does not warrant classification as a flange structure as applied to tektites, for it was not produced in the same manner and is not the same shape as the circumferential flanges on such tektites as the australites (cf. Baker, 1957).

Some micro-forms show tapering ends, as on the spindle-like examples (e.g. fig. 1, no. 18 (bottom)); occasionally these ends are turned back in alate fashion (fig. 1, right-hand side of no. 9); sometimes they represent the proximal ends of long, drawn-out, filamentous glass that connected one lenticular form with another.

*Chemical composition, specific gravity, and refractive index of hay-silica glass and its micro-forms.* The micro-forms of hay-silica glass from Gnarkeet have not been chemically analysed, but larger pieces of hay-silica glass with which they are associated gave:  $\text{SiO}_2$  61.7 %,  $\text{TiO}_2$  0.19,

$\text{Al}_2\text{O}_3$  1.16,  $\text{Fe}_2\text{O}_3$  0.83,  $\text{FeO}$  0.28,  $\text{MgO}$  4.88,  $\text{MnO}$  0.30,  $\text{CaO}$  6.77,  $\text{Na}_2\text{O}$  8.73,  $\text{K}_2\text{O}$  8.53,  $\text{P}_2\text{O}_5$  5.66,  $\text{CO}_2$  nil,  $\text{SO}_3$  tr.,  $\text{Cl}$  0.08,  $\text{H}_2\text{O} + 0.20$ ,  $\text{H}_2\text{O} - 0.12$ ,  $\text{C}$ , 0.25, total (less  $\text{O} \equiv \text{Cl}$ ) 99.66 % (Baker and Baker, 1964). Some concept of the composition of the micro-forms can be obtained by comparison of their refractive index values with that of larger pieces.

In contrast, a wood-silica glass from Stawell contains 20 % more silica and a little more alumina, iron, and lime, but is much poorer in magnesia, potash, soda, manganese oxide, and phosphorus pentoxide. Its somewhat greater content of ferrous iron is a pointer to more of the yellowish-green varieties of micro-forms being expected from burnt timber than from burnt meadow grasses and associated plants.

Since the micro-forms generally have a lower refractive index than larger pieces of hay-silica glass, they are expected to have a rather higher silica content. The refractive index of crushed colourless micro-forms of the Gnarkeet hay-silica glass was determined by the immersion method as  $n_{\text{Na}} 1.510 \pm 0.001$ , while that of the larger pieces was mostly  $n_{\text{Na}} 1.520 \pm 0.001$ , sometimes a little greater.

These values fall at the lower end of the range ( $n$  1.50 to 1.604) given by Glass (1967) for the 'microtektites'.

All of the micro-forms of hay-silica glass were isotropic under crossed nicols, except one (fig. 2, no. 78), which consisted of an angular fragment of quartz armoured about with glass formed by the fusion of opal in such a way as to produce a small ellipsoidal form (fig. 2, no. 77). The other micro-forms revealed no crystal fraction whatsoever, and the quartz inclusion was evidently adventitiously derived. Very few forms revealed occasional schlieren indicating slight compositional variations within one and the same micro-form; this indicates that mixing of the constituents forming the hay-silica glass micro-bodies was largely thorough.

As adjudged from the Becke line test, the smoky and pale yellowish-green micro-forms possessed refractive indices just below that of the mounting medium (Canada balsam with  $n$  1.54), whereas the colourless micro-forms had significantly lower refractive indices ( $n_{\text{Na}} 1.510$ ). Hence these coloured varieties would be somewhat less siliceous than the colourless micro-forms. At the site of the haystack fire, the micro-forms did not include many yellowish-green examples; from the nature of the plant material that was burned, this is to be expected. On the other hand, when sawdust from milling timber at the mill of J. Terret Bros. was burned in a brick incinerator at Benalla, north-eastern Victoria, pieces of wood-silica glass a few inches across, formed among residues in the incinerator, were bright green and in this respect rather similar to a thick

piece of a moldavite (Czechoslovakian tektite). The green wood-silica glass contained sporadically distributed micro-bubbles up to 0.25 mm in diameter; spectro-chemical qualitative analysis revealed ferrous iron that was evidently responsible for the emerald green colouration of the glass. The specific gravity was 2.850 (average value of two determinations on separate pieces weighing 4.4185 g and 1.8790 g), significantly greater than that of moldavites (sp. gr. 2.30 to 2.39). The refractive index of the fresh green wood-silica glass is  $n_{\text{Na}} 1.602 \pm 0.001$ , also significantly greater than that of moldavites ( $n$  1.48 to 1.496). Its fresh appearance and highly vitreous lustre contrasts markedly with the duller lustre and less vivid green colour of a small piece (approximately half to three quarters of an inch across) of glass found in bush country south of Norseman, Western Australia by W. Hattow, in April 1963; this duller green glass, lustre sub-vitreous to vitreous, is weathered and has evidently lain exposed in the bush country for a considerable time. Apparently it was developed from burning timber containing silica during a bushfire. It is free from micro-bubbles, has a specific gravity of 2.868 and a variable refractive index ( $n_{\text{Na}}$  1.570 to 1.580) as a consequence of weathering.

The specific gravity of the hay-silica glass from Gnarkeet is 2.53 for larger pieces of the glass having  $n_{\text{Na}} 1.520 \pm 0.001$ . That of the micro-forms of hay-silica glass having  $n_{\text{Na}} 1.510 \pm 0.001$  would be rather less than 2.53 and that of complete micro-forms that are hollow or contain abundant micro-bubbles would be even lower.

*Nature of the micro-forms of volcanic glass.* Forms of terrestrial volcanic glass that reveal primary shapes comparable with those of some of the 'microtektites' are the Hawaiian Pele's tears (peleite = basaltic glass or tachylyte). These are small tear-shaped droplets and dumb-bell-shaped forms ejected as fluid basalt in the form of spray in lava fountains, cooled in the atmosphere to form shapes measuring up to a few millimetres in length, brown in colour, and containing micro-bubbles of gas. From the illustration of Pele's hair in Williams, Turner, and Gilbert's 'Petrography' (1954, p. 150, fig. 47c), the teardrop-shaped and dumb-bell-like micro-forms of basaltic glass are calculated to measure from 0.122 to 0.410 mm in length; this range falls within the size range given by Glass (1967) for the 'microtektites' (0.038 mm to nearly 1 mm).

Larger pieces of basaltic glass (tachylyte), sometimes mistaken for fragments of tektites (Baker, 1956) have specific gravity and refractive index values within the upper ranges of the values given by Glass (1967) for 'microtektites', and the micro-forms of basaltic glass, such as



Pele's tears and hair, would have comparable properties and generally similar chemical compositions.

*Conclusions.* It is questionable whether the glass micro-bodies referred to as 'microtektites' from deep-sea sediments (Glass, 1967) belong to the group of the 'tektites' *sensu stricto*, because it can be shown that micro-bodies of glass with comparable properties have been produced by terrestrial processes from terrestrial materials without the agency of 'cosmic encounters with the Earth'.

Such micro-forms of glass are unlikely to have survived hypersonic transit through the Earth's atmosphere, if they are advocated as resulting from cosmic encounters on the surface of the Moon. They do not have comparable shapes to those of the aerodynamically modified forms so well shown by the Australian tektites (australites). At the outset, the forms of the micro-bodies of glass from the deep-sea sediments 1250 miles north-west, 800 to 1000 miles south-west, and 800 miles south of Australia are fundamentally primary shapes and accidental modifications and distortions of such shapes. They lack the true secondary modifications of primary shapes that arise from a second (and partial) melting phase brought about by aerodynamic ablation and sculpturing at hypersonic velocities, as present on the best-preserved examples of australites (Baker, 1957).

Processes by which the forms of the 'microtektites' could be generated on Earth, without resorting to cosmic encounters with either the Earth or the Moon, include fusion of opal phytoliths in silica-accumulator plants during prehistoric forest, bush, and grass fires, and ejection as fine spray in the lava fountains of terrestrial volcanoes. The micro-forms from both of these processes are small enough (0.010 mm to nearly 1 mm in size) to become airborne and carried away from their source of origin.

The properties of size, shape, colour, brittleness, conchoidal fracture, micro-bubble content, lustre, specific gravity, refractive index, and other optical properties are similar for 'microtektites', micro-forms of plant-silica glass, and micro-forms of basaltic (tachylytic) glass.

The micro-forms of hay-silica glass figured herein have a specific gravity within the range of specific gravities (2.37 to 2.80) given by Glass (1967, table I) for the 'microtektites'. It is apparent that hollow micro-forms that persisted as complete, 'non-punctured' entities, and also the micro-forms packed with numerous micro-bubbles, will have specific gravity values significantly lower than that of the bubble-free hay-silica glass, and thus will range across the lower limits of the 'microtektite' specific gravity range of 2.37-2.80. A trend of this nature is shown among

the australites, for hollow forms are known of this tektite glass that have specific gravity values of: 1.050, 1.357, 1.509, 1.809, 1.900, 2.072, 2.120, 2.157, 2.255, 2.259, 2.286, and 2.347 (Baker, 1966).

The higher specific gravity values in the 2.37–2.80 range given by Glass (1967) match those of pieces of tachylite (basaltic glass) and hence, by deduction, those of the micro-forms of basaltic glass with teardrop and dumb-bell shapes.

The colours of the 'microtektites' from deep-sea sediments (Glass, 1967, p. 373) are represented among those given herein for the tachylite, for the micro-forms of tachylitic glass, and for the micro-forms of hay-silica glass.

The refractive index values are also comparable. The range for the 'microtektites' is given as 1.50 to 1.604 (Glass, 1967, p. 373), that for the hay-silica glass from Gnarkeet is from just under  $1.510 \pm 0.001$  to just over  $1.520 \pm 0.001$ , and pieces of tachylite from south-west Victoria average 1.575 (Baker, 1956). Like the 'microtektites', the micro-forms of hay-silica glass and the pieces of tachylitic glass are isotropic, with the tachylite sometimes showing birefringent areas with low-order polarization colours. Glass (1967, p. 373) has recorded that some of the 'microtektites' show polarization colours of low-order grey. The true tektites of macro-size reveal low-order polarization colours only in areas of strain and in the aerothermal stressed zones; such areas of strain have not been referred to in the 'microtektites' and have not so far been observed in the glassy microforms of either the hay-silica glass or the tachylitic glass.

Suffice to say that micro-forms of glass comparable with the recently described 'microtektites' are known to have been produced on the Earth's surface by more commonplace terrestrial processes, and without invoking 'cosmic encounters' (cf. Glass and Heezen, 1967). It is evident that such processes can have occurred during the geological past, not only during several periods of Earth history, but for protracted lengths of time in each period. But glass tends to devitrify with geological time, and as a consequence of aging processes, small glassy bodies like 'microtektites', micro-forms of silica glass and of tachylitic glass are not likely to survive as recognizable entities in other than geologically relatively young horizons. The deep-sea sediments in which Glass (1967) records 'microtektites' south of Australia and Sumatra are geologically relatively young, hence it is to be expected that any microbodies of glass incorporated in them would still retain the characteristic of glass.

Glass and Heezen (1967, p. 372) record the 'microtektites' as being dispersed through a sediment zone 30–60 cm thick and representing

$4 \times 10^4$  to  $10^5$  years of deposition. They regard the tektite fall as probably being instantaneous, and overcome the problem of dispersal through 30–60 cm of sediment and hence a spread over at least 40 000 years of time by mixing the ‘microtektites’ upwards through later deposited sediments by the agency of bottom currents and vertebrate burrowers. Another way of viewing the problem is to consider the facts that volcanicity has occurred in this region before, during, and after the deposition of the deep-sea sediments containing the ‘microtektites’ and that micro-forms of tachylytic glass can be produced by volcanic action, while forest fires, bush fires, and grass fires are not limited to man’s short span of observational history, and can yield other types of micro-forms of glass by fusion and melting of opal phytoliths precipitated in plant structures. Volcanic activity and the occurrence of natural conflagrations of plant materials are spasmodic and not perpetual events, they could have occurred at various intervals during the period of sedimentation of the deep-sea sediments containing ‘microtektites’, and thus explain their distribution.

Well-developed basaltic volcanoes occur in Java, 300 miles or so north-east of the ‘microtektite’-bearing deep-sea sediment sampled from the northern part of the Wharton Basin, and also in Sumatra. The chain of volcanoes extending from one end of Java to the other and those in Sumatra form part of a volcanic arc initiated in late Tertiary or early Pleistocene times and still active in parts today. Enormous calderas in parts of Java have resulted from catastrophic eruptions, and these could well have been the source of the ‘microtektites’ recorded from the Wharton Basin as having specific gravity values of  $2.80 \pm 0.021$ . These higher specific gravity ‘microtektites’ were not recorded by Glass (1967) from the Australian Basin approximately 2500 miles to the south. In terms of their generation by a ‘cosmic encounter’ with the Earth, their limited distribution is not easy to explain. In terms of origin from a nearby volcanic source, the occurrence of the higher gravity ‘microtektites’ is more readily explicable, more especially as a dispersing medium is at hand in the form of the ‘sumatras’ of this region, these being violent local storms that occur in the Malacca Straits during the east monsoon.

Forest, bush, and grass fires occur extensively in the Australasian region, particularly in Australia and Tasmania. It is known that some of the timbers carry up to 10 % or so of silica, and some of the harsher grasses approximately 5 %. It is also known that the silica present is largely in the form of hyaline opal, and that the conflagration or gradual incineration of silica-accumulator plants produces plant-silica glass from

fusion of the opal content in the presence of fluxing materials in the plants. That shaped micro-forms of the plant-silica glass can be generated is demonstrated in this paper; the specific gravity, micro-size, and shapes of these minute bodies of glass make them amenable to becoming readily airborne and transported from their sources of origin. That this has been accomplished in the past is evidenced by the glass shards found in soils, many of which in non-volcanic soils are remote from the effects of volcanicity and the weathering of volcanic rocks. Any prehistoric forest, bush, and grass fires in the Australian and New Guinea region are likely to have produced many micro-forms of plant-silica glass. A means of their dispersal to the Indian Ocean region is provided by the south-east Trade Winds, while dispersal towards the south-west and south over the Australian Basin, where the lower gravity 'microtektites' are the more abundant and where the higher gravity 'microtektites' are not recorded by Glass (1967), could readily be achieved by the winds of the time, like such present day winds as the Brickfielder Winds, which are strong to violent winds that blow from the north and north-east.

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