The tektite problem.[1]

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THE natural glasses, found as small corroded pieces scattered on the earth's surface and in alluvial deposits in a few limited areas, have long presented a puzzling problem; and many theories have been propounded to explain their origin. They have been known in southern Bohemia and western Moravia since before 1787; and similar material has since been found in the Dutch East Indies, Malay States, Australia, Tasmania, French Indo-China, south China, Philippine Islands, and quite recently in the Ivory Coast in West Africa [M.A. **6**-106]. These glasses are distinct in chemical composition from volcanic glass (obsidian), and there are no volcanoes in the districts where they are found. They have been given the names moldavites, billitonites, australites, Darwin glass, indochinites, rizalites [M.A. **4**-422; **6**-403], &c.

In 1900, Professor F. E. Suess of Vienna included all these under the term tektites, and he put forward the theory that they are of meteoritic origin. This theory has found general acceptance, but as a matter of fact there is no direct evidence for its support. None of the glasses has been seen to fall from the sky; and they are quite different in chemical composition and structure from any meteorite (siderite or stone) actually observed to fall. Differing from all known terrestrial materials (except those quite recently recognized around meteorite craters) and being found under strange circumstances, it is perhaps natural to assume that they have simply fallen from the sky. Professor Suess's main argument that they are of cosmic origin was based on a certain similarity in the surface sculp-

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turing to that seen on meteoritic stones; and he assumed that this was produced by friction and corrosion in the earth's atmosphere. But similar surfaces are shown by weathered rocks (especially limestone), and it is now generally admitted that the peculiar types of sculpturing shown by tektites are due to chemical corrosion by humic acids in the soil [M.A. **3**–98; **5**–303; **6**–18, 107].

The peculiar forms of australites (' blackfellows' buttons ') cannot, however, be explained in this way. These were produced no doubt by the spinning of a viscous mass [M.A. **6**–18]. It has therefore been assumed that the glass was melted by the heat developed by friction in the earth's atmosphere. It is well known that the surface of meteorites is fused during their rapid passage through the atmosphere. But it is evident that this fused material must be wiped off (ablated) as quickly as it is formed, so producing the fiery trail of fireballs. When meteorites reach the ground they are seen to be covered with a thin skin of glassy material (the fused crust), which rarely exceeds a millimetre in thickness. It is evident that meteorites that reach the ground are only a fraction of their size when they entered the earth's atmosphere; and it is only really big ones that have a chance of getting through. A blob of molten material travelling at a high velocity would not hold together. Rain does not come down in lumps.

The suggestion was made by H. Michel in 1925 [M.A. **3**–97], and more recently supported by A. Lacroix [M.A. **5**–303] and F. E. Suess [M.A. **6**–108], that tektites have been formed in a molten condition in the earth's atmosphere by the burning of meteoritic masses of the element silicon (Si) with some metallic aluminium, calcium, potassium, &c. But such a burning would surely cause the dispersal of the matter in a fiery trail.

Further, as recently pointed out by Fletcher Watson, Jr., in a letter to 'Nature' (London, 1935, vol. 136, p. 105) [M.A. **6**–209], time is required for the conduction of heat into a solid body. Even with the higher degree of conductivity of siderites, the heating zone, shown by the transformation of α-iron to γ-iron (which takes place at a temperature of 850° C.), extends to a depth of only a few millimetres [Min. Mag. **24**–17]. This fact indicates that the molten material is wiped off the surface in the rush of air as quickly as heat is conducted into the interior of the mass. Meteoritic stones also show only a very slight heating effect beyond the fused glassy crust.

It is thus clearly impossible that tektites could have been completely fused during their brief flight through the earth's atmosphere. Dr. Charles Fenner has recently (1935) [M.A. **6**–208] suggested that the peculiar button shape of australites has been formed by ablation from a sphere of solid glass entering the atmosphere.

Tektites contain from 70 % to 80 % of silica and are an impure form of silica-glass. In recent years the presence of silica-glass in large quantities has been recognized around the undoubted meteorite craters at Canyon Diablo in Arizona [M.A. **5**–16], Wabar in Arabia, and Henbury in Central Australia [Min. Mag. **23**–387]. It has here been formed by the melting of sandstone or desert sand in the intense heat generated by the impact of a really large mass of meteoritic iron. The air resistance is proportional to the square of the radius of the body, while the momentum is proportional to the cube of the radius. Hence a large mass will reach the earth's surface with a greater velocity. The kinetic energy, measured by $\frac{1}{2}mv^2$, will be suddenly transformed into heat, giving rise to a violent gaseous explosion and the formation of a crater [M.A. **5**–301]. The material from Wabar affords ample evidence of extremely high temperatures. The molten silica not only boiled, but was vaporized; and the meteoritic iron also was vaporized and came down again as a fine rain [Min. Mag. **23**–399].

The Darwin glass from Tasmania, which has been classed with the tektites, compares exactly in its form and chemical composition with the silica-glass from Wabar [M.A. **6**–106, 407]. It covers a wide area in glacial deposits, but no trace of meteoritic iron or of meteorite craters has been found there. However, the iron would soon be destroyed by weathering, and the craters obliterated by glacial action and denudation. Silica-glass is very resistant to chemical action, and also, on account of its very low coefficient of thermal expansion, it is not broken by changes of temperature. It therefore has remained to tell the tale.

This meteorite-crater theory of the origin of tektites, which I first advanced in 1933 (Nature, London, vol. 131, p. 117; Compt. Rend. Acad. Sci. Paris, vol. 196, p. 710) [M.A. **5**–304], has been criticized [M.A. **6**–407] on the ground that tektites are found over a much wider area than that occupied by meteorite craters, and that they are not always found in the neighbourhood of the right kind of rocks to yield such a fused product. The local distribution of tektites must, however, be considered in connexion with not only recent but also ancient systems of drainage, and perhaps also (as in Tasmania) with glacial action. And further, it must be remembered that silica-glass is a material that will survive for a long period. But I must admit that the peculiar forms and the very wide distribution of australites present a difficulty. Still we have for this theory some scraps of positive evidence, whereas the meteoritic theory is based only on negative evidence.

Closely allied to tektites, and no doubt to be classed with them, are the lumps (of weights up to 16 pounds) of almost pure silica-glass (SiO_2 97½ %) recently found in the Sand Sea of the Libyan Desert [Min. Mag. **23**–501]. This material is clear, with a yellowish-green colour, and is suitable for cutting as gemstones. It presented such a strange problem that I was glad to have the privilege of joining a special expedition of the Survey of Egypt to investigate the matter in December, 1934. The glass was found sparingly scattered over an area of 85 by 35 miles with the largest amount at our Camp 7, lat. 25° 17′ 54″ N., long. 25° 34′ 0″ E. Unfortunately we were not able to trace the material to any source, and no trace of meteorites or of meteorite craters could be found amongst high sand-dunes. It seemed easier to assume that it had simply fallen from the sky! But the problem still remains unsolved.