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FLANGES OF AUSTRALITES (TEKTITES).

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Plates I-III.

Introduction

Flanges of australites are equatorial projections between the posterior and anterior surfaces (Fig. 1) ; they are broad and thick compared to the rims of some specimens, and they usually curve towards the posterior surface. Incipient flanges are called rims.

The literature of australites, which has been listed by Fenner (1938) and by Barnes (1940), contains few details of structural features of flanges. Dunn (1912 b) figured thin sections showing flow lines in the glass of which they are composed; he attributed australites to "blebs" on glass bubbles escaping from volcanoes, the flanges being part of adjacent walls of the bubbles. Fenner (1938) reviewed theories of origin and gave reasons for considering that australites are glassy meteorites and that the flanges result from flow of molten material during transit through the atmosphere; these theories are generally accepted.

The following observations are based on study of 137 flange fragments, 9 complete detached flanges, 72 fragments of australites and several complete examples. Most of the material came from the Port Campbell district, Victoria. Many thin sections were prepared.

Australites are grouped according to shape. Most of them are shaped like buttons, ovals, dumb-bells, lenses, discs, boats, tear-drops, canoes and cores, but there are also aberrant forms such as "air bombs" and "crinkly tops" (Fenner, 1934).

Few flange fragments can be assigned to australites of shapes other than buttons, since few are sufficiently large to indicate the shape of the australites of which they formed a part. The majority are assumed to come from buttons because buttons are by far the most abundant type. Oval fragments are rare.

Some flanges are complete, others are imperfect owing to loss of a portion during flight or subsequently. Flanges completely encircling australites are commonly found on buttons and more rarely on dumb-bells, ovals and boats, but flanges on dumb-bells are usually restricted to the waist and those on boats and ovals to the sides. On canoes, flanges when present are confined to the two ends, and on teardrops to the narrow end and half way along the sides. Unabraded lenses have small, sharply defined rims (Fig. 2 b) which may be considered incipient flanges. Air bombs, large cores (Baker, 1940 b) and aberrant forms are flangeless. Complete circular flanges from buttons and fragments of elongated flanges from ovals are occasionally found unattached to cores. One circular flange has been figured by Dunn (1912 a) and another by Hodge Smith (1939). On the posterior surfaces of some australites smooth bands 2 mm. to 2·5 mm. wide mark the positions from which flanges have broken away.

Fig. 1 illustrates the various parts of an australite. The chin is the rounded inner edge of the flange; the neck is the surface of the flange below the chin and facing the core, and the seat is the

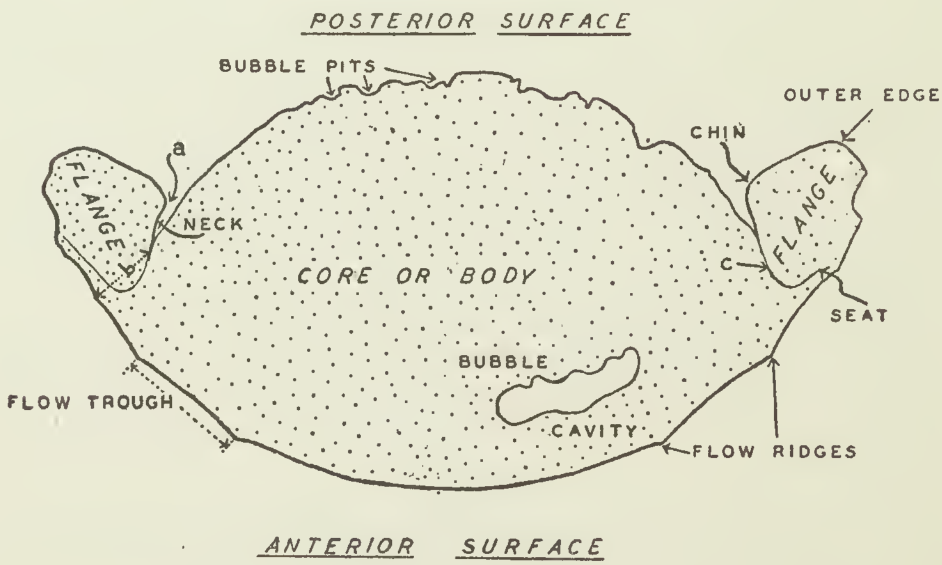

FIG. 1.

Radial Section of an Australite.

part of the core on which the flange rests. Flow ridges are ridges on the anterior surface of the core, and the spaces separating adjacent flow ridges are the flow troughs. The gap between flange and core is marked *a*; the thickness of glass between the bottom of *a* and the anterior surface, *b*; and the junction of flange and core, *c*.

External Features

The width of flanges (distance from chin to outer edge) usually ranges from 1 mm. to 6 mm., but Hodge Smith (1939) has recorded a button-shaped australite from Mt. Cameron, Tasmania, with a 9 mm. flange. In circular and oval plate-shaped australites (Fig. 2 w and x, and Pl. I, 8 and 10) the flange forms the greater part of the specimens; those from 8 mm. to 12 mm. across have flanges 3 mm. to 5 mm. wide. Flanges are constant in width (Pl. III, 3) unless their outer edges are wavy (Pl. III, 2).

Posterior surfaces of flanges on buttons and ovals have fine, concentric flow lines in the chin region; those on most plate-shaped australites have radial flow lines. Circular or nearly circular bubble-pits and craters rarely interrupt the general smoothness of the posterior surfaces of flanges, although common on the posterior surfaces of cores. They are due to the bursting of gas bubbles at the surface as evidenced by the presence of a small blister about ready to burst on one of the flange fragments examined. Walcott (1898) suggested that the impact of small foreign bodies on semi-plastic australites caused the pits; had this been so, remnants of such postulated foreign bodies, of which there is actually no evidence, should be found embedded in the pits.

The anterior surfaces of flanges are continuous in curvature with the anterior surfaces of the cores (Fig. 1). Characteristic features are the flow ridges which are concentric or spiral (clockwise or anti-clockwise) on the cores but wrinkled on some flanges, resulting in wavy outer edges unlike the smooth inner edges of flanges. Fine, radial flow lines are most marked in the troughs of the flow waves, and they also cut through some flow ridges. Bubble-pits on anterior surfaces differ from those on posterior surfaces in being often tube-like and parallel to the radial flow lines. In some instances, they emerge from beneath flow ridges situated near the junction of flange and core. Rare circular bubble-pits on anterior surfaces consist of a crater with a small cone-shaped elevation of glass at the bottom (Pl. I, 4) suggestive of collapse under air pressure rather than of bursting by expansion.

In plan the shape of flanges corresponds with that of the australites on which they are developed, but in cross section they display considerable diversity of form (Fig. 2) and internal structure (Pl. I, 1). Fenner (1935) considered that no two

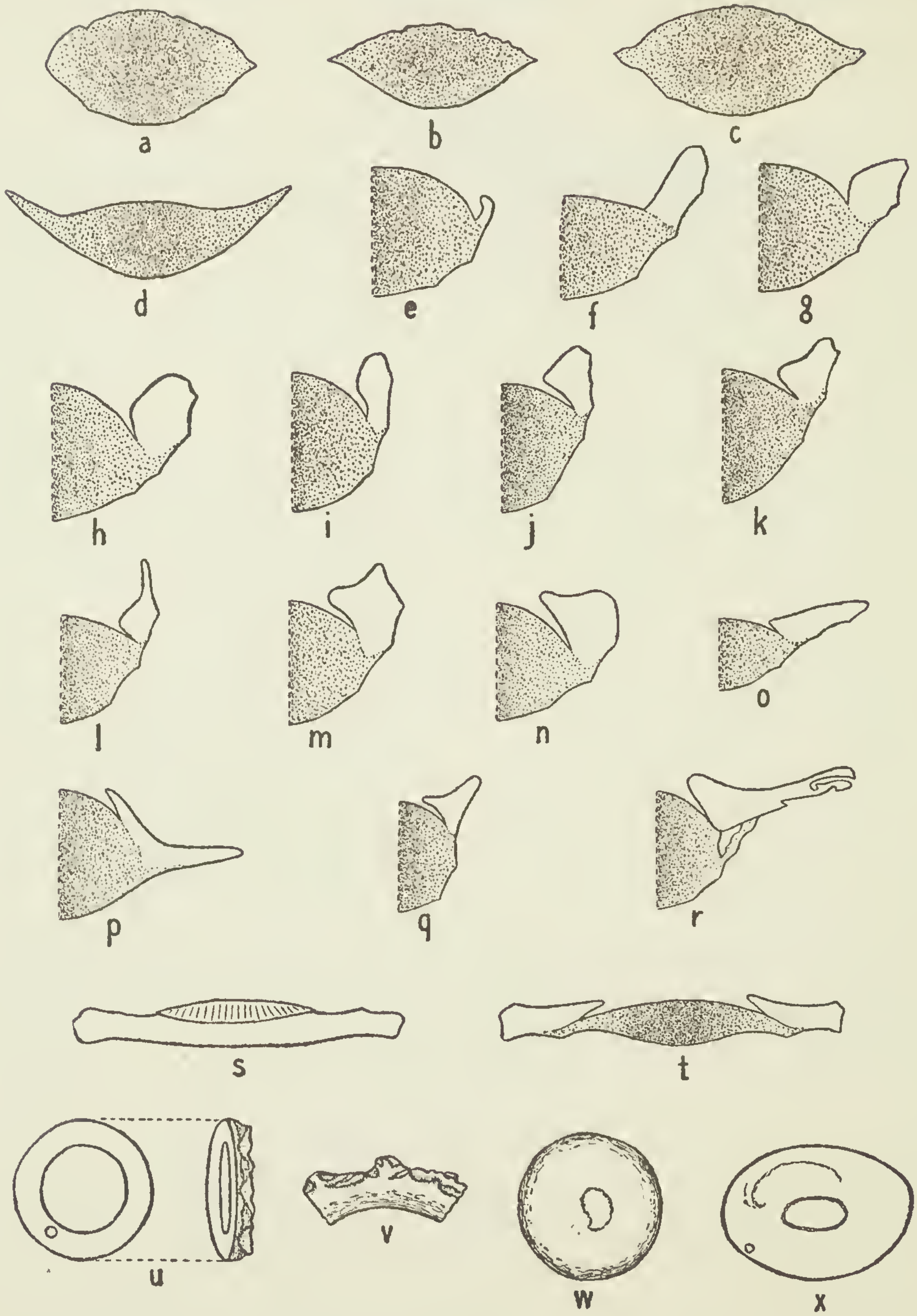

FIG. 2.

Positions and Shapes of Rims and Flanges. Posterior surfaces are shown uppermost, in a to t; u to x are sketches of posterior surfaces.

flanges are quite alike, a statement substantiated by this investigation.

Typical cross sections of flanges are indicated in Fig. 2, c to x, and a few examples were figured by Dunn (1912 b) and by Baker (1937). In Fig. 2, sketches a to n are arranged in an order which the author thinks may represent stages in development from rims of lenses (Fig. 2, a and b) through more common shapes to rare types (Fig. 2, o to t).

Fig. 2 a is a radial section of a lens with rim well marked on one side only, and Fig. 2 b a radial section of a lens with a sharply marked equatorial rim. In Fig. 2 c, a longitudinal section of an oval, the projection is intermediate between a rim and a flange. In Fig. 2 d, a longitudinal section of a canoe, the flange-like structure is further drawn out and commencing to curve posteriorly. Fig. 2 e, an oval, has a small flange partially curved towards the posterior surface of the core. The rare type illustrated in Fig. 2 f occurs on a few flat-topped buttons and on several dumb-bells and teardrops; it has a smooth rounded outer edge and marked flow ridges, and is inclined at 60° to the central core. Fig. 2 g, a cross section of the flange of a button, has a vertical neck and a flat posterior surface inclined at 20° from the horizontal and the gap (*a* in Fig. 1) is becoming conspicuous; button-shaped australites from Mulka, South Australia, commonly have flanges of this type, but at Port Campbell only certain boat-shaped specimens have such flanges.

Fig. 2, h and i, flanges of buttons, illustrate convex posterior surfaces partially overlapping towards the core, and Fig. 2, j to r, show further stages of rearward curvature but may not represent a definite series of stages. Overlapping may reach a stage where the contact between flange and core is completely obscured from above.

Fig. 2 s, a radial section of an oval, plate-shaped australite (plan like that of Fig. 2 x) shows a thin, flat horizontal flange with shallow depressions between the centre and the outer edges of the anterior surface. In Fig. 2 t, a radial section of a flat, disc-shaped australite (plan like that of Fig. 2 w), the flange overlaps a thin central core. Fig. 2 u, plan and side aspect of a detached flange, shows that the width of the flange is considerably less than the diameter of the area once occupied by the core. Fig. 2 v is a flange fragment with a smooth inner edge and adjacent flow lines, and a crenulate outer edge. In Fig. 2 w, a disc, the flange is broad in proportion to the core and has concentric flow lines near its outer edge. In Fig. 2 x, the posterior surface of an oval, plate-shaped australite, the flange is broad, and carries few flow lines and one bubble-pit.

On an oval, bowl-shaped australite figured by Baker (1940 a) a rare type of flange forms the sides and the small core the base of the bowl. In this specimen, probably a flat and thin flange was pushed backwards while plastic by atmospheric pressure.

Internal Structures

Internal structures of flanges and cores are intimately associated. They are best seen in thin plates, although distinct on weathered surfaces of fractured specimens and on artificially polished surfaces etched with a mixture of strong sulphuric and hydrofluoric acids. In thin plates the Becké line effect clearly reveals the complexity of the flow patterns.

After australites arrived at the earth's surface, internal cracks (probably resulting from stresses set up during cooling) were infilled with ferruginous clay containing occasional grains of quartz (Pl. I, 2); similar material sometimes also infills the gap *a* and some bubble-pits. The cracks may traverse both flange and central core, sometimes cutting across the surface of union *c* from the gap *a* and bifurcating in the base of the flange (Pl. III, 1 and 4). They cut across internal structures without offsetting them.

The refractive indices of the flange glass of two australites from Port Campbell, of specific gravity 2·409 and 2·410, were found by the immersion method to be 1·510 and between 1·505 and 1·510 respectively. The glass is isotropic except for occasional bands of higher refractive index (1·535) which sometimes exhibit strain polarization. Such bands are especially noticeable near the junction of flange and core and in contorted structures of flanges. Optical figures for these strained areas are too indefinite for accurate determination, although some appear to be biaxial. Strained areas are often colourless, the remainder of the glass being pale yellowish-green in thin plates except where colour banding imparts a deeper brownish colour (Pl. II, 1 and 9).

Inclusions

The only inclusions in flanges and central cores are gas bubbles and minute glassy particles (Fig. 3).

The bubbles are frequently circular, but may be elliptical along flow directions. All bubbles in flanges are minute, but in the central cores they may be larger and segmented (Pl. I, 12) or may even occupy the bulk of the interior, as in a hollow sphere from Hamilton, Victoria, described and figured by Dunn (1912 b). In thin plates, all the smaller bubbles have dark borders. Barnes (1940) regarded similar spherical bubbles in tektites (bediasites) from Texas, U.S.A., as formed later than flow structures; but in australites elongated bubbles and flow structures bending round spherical bubbles indicate that bubbles were formed prior to flow. It is therefore likely that bubbles continued to form throughout the development of australites, and that bubbles with dark borders are primary. Small secondary cavities lacking dark borders are confined to posterior surface regions of the core near its union with the flange; they were originally pits, but some are either infilled with or partly enclosed by glass from the flange (Pl. II, 8 and 11, and Pl. III, 5 and 7). In thin plates such infilled cavities are delimited by differences between the refractive index of the walls and that of the infilling glass. Infilled cavities are sometimes tubular with rounded bases and with openings to the posterior surfaces of the cores, as shown by some of the dark areas (infilled with ferruginous clay) in Pl. II, 5.

Most bubble-pits are semi-circular in section (Pl. I, 1 and 12, and Pl. III, 7), but a few are tube-like or funnel-shaped. In sections of cores numerous bubble-pits in close proximity give rise to jagged outlines in sections through the posterior surface (Pl. I, 7).

Bubble-pits are rarer on anterior than on posterior surfaces. Many pits on anterior surfaces are wider at the base than at the opening, and they may have a central pyramid of glass (Pl. I, 4); some of the larger pits are irregular in shape (Pl. I, 5).

The minute glassy particles (Fig. 3) are microscopic in size, pale pink where embedded in glass, but colourless where protruding, and their refractive index (1·460) is lower than that of the surrounding glass (1·510). They are numerous in those parts of flanges contorted by flow structures, but are also common along line of union *c*; infrequent in central cores and scarce in the less disturbed regions of flanges. They form rounded or irregularly-shaped blebs, granules, elongated threads, and ribbons. Ribbon and thread-like particles may be coiled and contorted (Fig. 3, A, B and L), some only slightly (Fig. 3, C and K), others in complex fashion like examples from bediasites figured by Barnes (1940). Some associated with flow directions are elongated, others are neither distorted nor elongated. Occasional bleb-like particles are hooked (Fig. 3 E), curled (Fig. 3 G) or bean-shaped (Fig. 3 F), and some are lens-shaped particles with tapered plane spiral processes (Fig. 3 I). Some granular particles

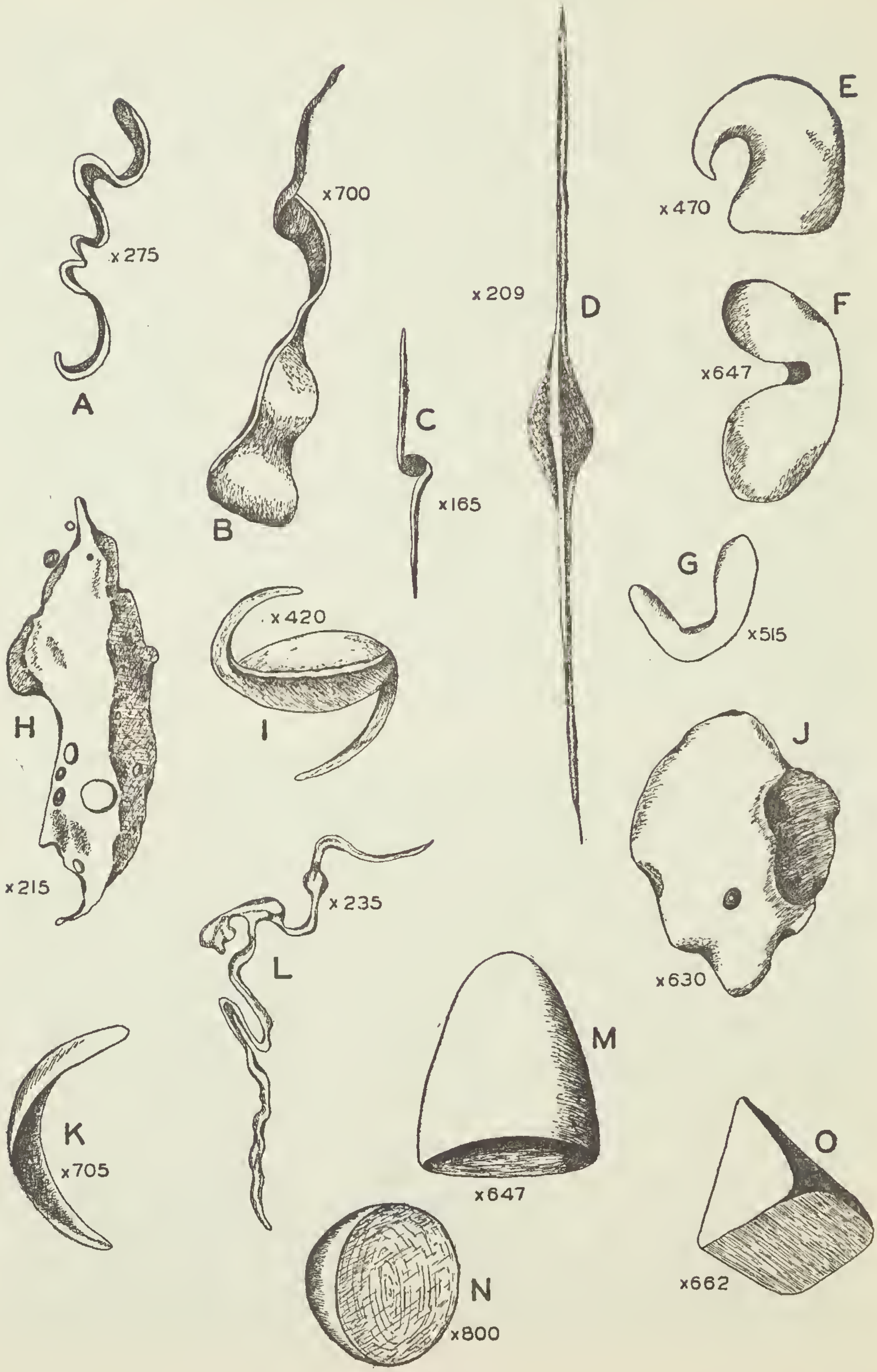

FIG. 3.
Glass Inclusions.
(All observed in radial sections of flanges except M.)

have facetted surfaces (Fig. 3 O). Irregular flint-like particles (Fig. 3, H and J) are often associated with gas bubbles within their own substance and in the surrounding glass. Many bubbles were probably released during the formation of these particles. Other particles are ellipsoidal, some with flattened bases (Fig. 3 M). The majority of those along the surface of union *c* are hemispherical (Fig. 3 N); they are embedded in the cores, and have their flat bases in contact with and parallel to *c*.

Most of these particles are isotropic, but occasional irregularly-shaped examples (Fig. 3 H) are birefringent and give polarization colours of a low order but no axial figures; some such particles are surrounded by a halo of glass with a refractive index intermediate between that of the normal glass and that of the particles; these haloes are usually isotropic, but a few are birefringent and give low polarization colours.

Barnes (1940) regarded similar inclusions in bediasites (Texas) and other tektites as lechatelierite, i.e., re-fused quartz akin to the material of fulgurites; he suggested that they indicate either limited liquid miscibility or, more probably, incompletely mixed re-fused quartz grains of the material from which the tektites were formed. For this reason he suggested that tektites may be of fulguritic origin; but similar inclusions have been observed by the author in Pelée's Hair from Kilauea, in Darwin Glass from Tasmania, and more rarely in fulgurites from Macquarie Harbour, New South Wales.

The origin of these particles may be the key to that of tektites.

Flow Structures

Internal flow structures in cores and flanges are very pronounced (Pl. I to III). Many near the posterior surfaces lead to the bases of bubble-pits (Pl. II, 6 and 8), suggesting directions of internal gas streaming, but elsewhere they are associated with streaks of glass showing strain polarization, differences in refractive index, or both, and with elongated partially resorbed glassy inclusions. It therefore appears that flow lines result partly from escape of gas through the posterior surfaces and partly from flowage of molten glass. Directions of streaming are more readily determined in flanges than in cores. In flanges the spiral and elliptical structures are seen to best advantage on fractured surfaces (Baker, 1937, Figs. 1-7) and in radial sections (Pl. I, 8 and 10, and Pl. II). In equatorial sections of flanges these structures are concentric (Pl III, 3 and 6), but within cores most of them are complex, their major directional trends being sometimes towards posterior surfaces (Pl. I, 6) but more frequently along anterior surfaces towards equatorial regions. Some main flow lines well within the body are parallel to its exterior surfaces (Pl. I, 9), others are radial (Pl. I, 1). Those near anterior surfaces arise in all positions from the front pole almost to the flange junction, *c*, numerous short flow lines originating within the body at depths below the surface of from 0·5 mm. at the junction *c*, up to 3 mm. near the front pole; these unite and form streaks trending more or less parallel to the anterior surface. Near and parallel to the posterior surfaces main sets of flow lines are rare (Pl. I, 5), and they seldom trend from both anterior and posterior surfaces towards equatorial regions (Pl. I, 3). Flow lines close to anterior surfaces are generally truncated in flow troughs, but are parallel with those in flow ridges (Pl. III, 1); this indicates some loss of glass in such regions, probably caused by ablation during flight.

Oblique sections across the line of union *c* (Pl. III, 5) also show internal flow lines in the core trending mainly flange-wards, but made complex by fold-like structures. Most of the complex flow lines within cores were probably formed at an earlier stage.

Union Between Flange and Core

Surfaces of attachment between flanges and central cores (*c*, Fig. 1) can be seen on detached flanges free from adhering portions of core. Tracks of bubbles and aggregations of bubble-pits indicate accumulation of gas in this region; this must weaken the attachment of flange to core and it accounts for the occurrence of detached complete flanges.

The surface of the neck often carries concentric flow lines parallel to similar lines on the chin.

In thin section *c* is invariably a sharp, dark line; and, as already remarked, small bubble-pits tend to assemble at or near it (Pl. II, 8 and 11, and Pl. III, 7). Before reaching the anterior surface, *c* usually swings round parallel to the anterior surface (Pl. II, 3), ultimately passing into the flange as flow lines; it thus marks off the seat (Fig. 1), a narrow, shelf-like part of the core upon which the flange rests. Flow structures in the base of the flange are parallel to those of the seat (Pl. II, 4). The seat may be small (Pl. II, 8 and 10) or almost wanting (Pl. II, 1 and 9), probably as a result of ablation during flight. The width of glass at *b* (Fig. 1) ranges from 2 mm. to 6 mm. At the wider end of the seat the glass is from 0·5 to 1 mm. thick.

Australites with small seats associated with plentiful bubbles would lose their flanges more readily than would other forms.

Specific Gravity and Composition

The specific gravities of 107 flange fragments and three complete detached flanges from Port Campbell range from 2·31 to 2·44, the average being 2·385; the average for cores is 2·426, range 2·34 to 2·49 (Baker and Forster, 1943). The difference in the mean values, 0·04, suggests that flanges are more acidic than central cores, since the specific gravities of australites rise as their silica content decreases. This is borne out by specific gravity determinations of the powders of flange and core of two australites from Port Campbell; the specific gravity of the core of a boat-shaped specimen is 2·34, that of its flange is 2·29; for a button-shaped specimen, the specific gravity of the core is 2·33, that of its flange 2·29.

Variation in composition within some flanges is also indicated by colour banding and by differences in refractive index. Bands coloured deep brown in thin sections are evidently richer in iron than the surrounding pale green glass.

Origin of Shapes and Structures

According to Dunn's bubble hypothesis (1912 b), the glass of australites flowed downwards from the top (posterior) towards the bottom (anterior) surface. It is now, however, generally accepted that the movement of molten glass was from the anterior surface towards the equatorial region (Fenner, 1934).

Dunn thought that the flanges were not sufficiently hot to coalesce with the cores along the junction *c* (Fig. 1). In some instances, they must, however, have been sufficiently hot because (a) some bubble-pits on the posterior surface of the core have been re-enclosed by the glass of the flange, and (b) in "crinkly-top" types (Fenner, 1934) melted glass spread over portions of posterior surfaces. In general, the material of the flange solidified before coming into complete contact with the glass of posterior surfaces of cores, leaving the gap *a* (Fig. 1).

According to the hypothis of meteoric origin, the front surface in australites was melted by heat generated by friction of the air (note by Suess, in Fenner, 1935) or was already molten when shed from a burning light-metal meteorite. Under pressure by the atmosphere this molten glass flowed towards the equatorial region and formed the flange; some molten glass was lost during flight, however, as evidenced by truncated flow lines in the flow troughs. The congealing glass of the flange was forced back by pressure and frictional drag, and was partially rolled in upon itself, and the flow structures frequently indicate spiral coiling of the flange glass.

The complex flow patterns in flanges result from the movement of cooling glass from the outer edge towards still cooler glass in and below the chin. The major flow structures result from flowage from the anterior surface of successive streams of molten glass; see Plates I to III.

The shapes of australites are not those considered as streamlined by physicists, but no other tektites approach a similar degree of symmetry, a fact suggesting that these tektites differed from australites in physical condition during transit through the atmosphere.

If australites traversed our atmosphere at speeds greater than that of sound, the adjacent layers of air in which all frictional effects took place would be thin. Since the coefficient of heat conductivity in australite glass is low (somewhere between that of artificial glass, 0·0005, and that of Darwin Glass, 0·0002), the rate of heat transference is slow. Little time was available while the australites traversed the atmosphere for diffusion of heat to the interior and to rear surfaces. To become plastic the glass must be raised to temperatures of 800°C. or higher. In the wake of fast-moving australites there would be a region of "dead air" where pressures and temperatures were low, and the rear regions of the objects would therefore remain cold.

It has been shown experimentally that no frictional forces operate at the poles of a sphere falling through a fluid, that pressure is greatest at the front and least at the rear pole, and that frictional forces are greatest at the equator. It is therefore probable that, during flight, pressure on the anterior surfaces of australites caused plastic glass to form ridges which moved towards their equators, where these ridges would be crinkled by frictional drag developed by turbulences in the adjacent layer of air. Flow lines would therefore be contorted or puckered near the outer edge of the flange (Pl. I, 12, and Pl. II, 3 and 7). On reaching the outer edge of the flange, some of the plastic glass was swept towards the posterior surface, probably by eddy currents which exerted a smoothing effect, as indicated by the smooth posterior surfaces of flanges. Complexities in internal structures of flanges, then, resulted from variations in direction of eddy currents and in the rate of cooling of successive layers of molten glass. The first supplies of glass to a growing flange would cool while more fluid glass was flowing in from the heated front surface.

Velocity of flight probably controlled the limiting height of flow ridges on forward surfaces; in the final phase of flight, these heights were at a maximum of 1 mm., and the distances between the ridges reached a maximum of 3 mm. to 4 mm. nearest the front pole.

Only translatory motion is here considered, since rotary movements must greatly complicate motions in the boundary layers of air and their effects.

At supersonic speeds, if the motion of the solid is purely translatory, a disturbance of a permanent type would be set up in the shock waves of air ahead of the australites. Such shock waves are considered as sheets in which there is discontinuity of velocity and they travel in front of the body producing them at the same speed and in the same direction as that body (Durand, 1935). At all other points the shock waves move obliquely to the direction of flight (cf. bullet in motion, illustrated by Durand, 1935). Wavelets are formed in the air layer in contact with the australite wherever there are irregularities (e.g., flow ridges perhaps) upon the curved forward surface. Pressure increases in such regions during separation of the main air-stream from boundary layers, i.e., between points of origin of the shock wavelets, causing within these areas differential dragging of small amounts of plastic glass with the result that flow lines are truncated in the flow troughs.

Reverse and secondary reverse flows in the boundary layers of air caused whirlpools or vortices about the equatorial regions, where the main flow of air diverged from the bodies. These vortices generated stresses that caused complex puckering of surface structures in thin films of plastic glass. The stretching, bending and twisting of glassy particles in the flanges resulted from (a) turbulency in the plastic glass moving back under pressure to form the flange and (b) jamming during the development of the flow structures in the glass.

The total drag on forward surfaces is set up both by pressure and by friction; these are functions of the shape and surface areas of the bodies. Conversion of mechanical energy into heat is due to the viscosity and conductivity of the air; viscosity and conductivity are also regarded as maintaining shock waves of a permanent type (Durand, 1935). The concentric flow ridges on forward surfaces of certain australites are in keeping with such shock waves and wavelets; and since these can be caused only by non-rotating bodies, the inference is that australites with concentric flow ridges did not rotate during flight through the atmosphere.

Spiral flow ridges were probably caused by combined rotary and translatory motions; these involve complications far beyond the scope of this article.

Acknowledgments

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References

Baker, G., 1937. Tektites from the Sherbrook River District, East of Port Campbell. Pr. R. Soc. Vict., 49 (n.s.), pt. 2, pp. 165-77, 2 figs.

1940a. An Unusual Australite Form. *Ibid.,* 52 (n.s.), pt. 2, pp. 312-14, 1 fig.

1940b. Some Australite Structures and their Origin. Min. Mag., 25, pp. 487-94, 1 fig., 1 pl.

Baker, G., and H. C. Forster, 1943. The Specific Gravity Relationships of Australites. Amer. Journ. Science, 241, pp. 377-406, 9 figs.

Barnes, V. E., 1940. North American Tektites. University of Texas Publication No. 3945, pp. 477-656, 17 figs., 5 pl.

Dunn, E. J., 1912a. Pebbles. Robertson & Co., Melbourne, pp. 30, 34, 45, 63 and 64, pl. 57 and 58.

1912b. Australites. Bull. Geol. Surv. Vict., 27, pp. 21, 17 pl.

1916. Additional Notes on Australites. Pr. R. Soc. Vict., 28 (n.s.), pt. 2, pp. 223-27, 1 pl.

Durand, F. W., 1935. Aerodynamic Theory, vol. 3. Julius Springer, Berlin, pp. 212-243, figs. 26-31.

Fenner, C., 1934. Australites, Part 1. Classification of the W. H. C. Shaw Collection. Tr. R. Soc. S. Aust., 58, pp. 62-79, 4 figs., 6 pl.

1935. Australites, Part 2. Numbers, Forms, Distribution and Origin. *Ibid.,* 59, pp. 125-140, 3 figs.

1938. Australites, Part 3. A Contribution to the Problem of the Origin of Tektites. *Ibid.,* 62, pt. 2, pp. 192-216, 3 figs., 2 pl.

Smith, T. Hodge, 1939. Australian Meteorites. Mem. Aust. Museum, Sydney, 7, pp. 65-70, pl. 19.

Walcott, R. H., 1898. The Occurrence of so-called Obsidian Bombs in Australia. Pr. R. Soc. Vict., 11 (n.s.), pt. 1, pp. 23-53, 2 pl.

Explanation of Plates

Plate I

Fig. 1. Radial section of button-shaped australite showing turbulent flow patterns in the core and variations in pattern in the two portions of the flange. Flow lines from anterior surface of core pass upwards into flange.

2. Radial section of button-shaped australite. The dark irregular bands are cracks infilled by ferruginous clay containing quartz grains.

3. Cross section of boat-shaped australite with well-marked rim. Internal flow lines near anterior surface truncated in flow troughs at right hand end.
4. Tangential section of button-shaped australite; ferruginous clay (black) fills the gap *a*. A bubble crater on anterior surface has a central pyramid of glass. Neck of flange vertical.
5. Longitudinal section of oval australite. Flow lines parallel to posterior surface. Remnants of former flange (top right). Flow lines trending from both posterior and anterior surface regions into a new flange. Irregular bubble cavity on anterior surface.
6. Radial section of lens-shaped australite showing directions of major flow lines trending from anterior to posterior surfaces. Rim poorly developed.
7. Radial section of lens-shaped australite with bubble crater on anterior surface; jagged outline of posterior surface due to numerous bubble-pits. Flow pattern complex but flow lines in equatorial regions trend towards rim.
8. Cross section of oval, plate-like australite showing spiral flow lines in flange. Flange and core separated by well-marked line of union *c* from which bubbles are nearly absent. Complex flow pattern in core. Truncation of flow lines in left hand portion of flange probably due to ablation.
9. Longitudinal section of boat-shaped australite showing flow lines partially parallel to its length. Rim pronounced at left hand end; abrupt termination of structures at other side probably due to loss by ablation.
10. Cross section of oval, plate-like australite with spirally coiled flow lines in flange. Small bubbles (dark areas) along the line of union *c*.
11. Longitudinal section of canoe-shaped australite showing flange-like ends curving away from anterior surface, and flow lines trending from the body into this structure.
12. Cross section of button-shaped or oval australite showing segmented bubble cavity. A crack passes from posterior almost to anterior surface. Internal flow lines truncated in flow waves on anterior surface. In flange, flow lines in posterior surface regions are contorted in concertina fashion.

Plate II

Radial sections of flanges.

Fig. 1. Line of union *c* sharply defined. Colour bands (darker areas in the chin region) parallel with the flow lines. Seat wanting.

2. Line of union *c* short, seat separated from base of flange. Flow lines in anterior surface regions of core continuous with those in seat. Flow groove in outer edge of flange.
3. Line of union *c* well marked; flow troughs well defined on anterior surface of flange; seat continued well up the flange. Concertina-like flow lines in chin regions of flange.
4. Flow lines near outer edge of flange coiled into a plane spiral, those in chin regions normal to outer surface. Accumulations of bubbles at line of union *c* shown by dark areas on core side. Flow lines of seat truncated in flow trough.

5. Gap *a* filled with ferruginous clay (dark area). Bubble tubes (black areas) along line of union *c* continuous with flow lines in core.
6. Flow lines parallel in seat, folded towards posterior side of flange and contorted in vortical region (dark). Neck inclined; posterior surface of flange flat.
7. Flow lines in seat continuous with those in anterior surface regions of core; those in flange deeply folded on posterior side of the vortical region. Flow lines in core normal to posterior surface.
8. Re-enclosed bubble-pits in core occur along the line of union *c*. Flow lines in core have marked trend towards bases of bubble-pits opening on its posterior surface. On flange, vortical region of spirally coiled flow lines lacking, probably removed by ablation.
9. Sharp line of union *c* without bubbles. Seat structure ill-defined. Colour banding represented by darker regions in chin and along line of union *c*. Posterior surface of flange concave.
10. Seat small. Line of union *c* clearly defined, not associated with bubbles. Flow lines normal to surface in chin, line of union *c*, and base of flange. Flow lines spirally coiled in outer edge regions; vortical portion of coiling clearly marked.
11. Re-enclosed bubble-pits along line of union *c*; seat sharply terminated at lowest flow ridge in flange; ferruginous clay infilling gap *a*. Posterior surface of flange concave with outer edge reduced in thickness by ablation.

Plate III

Fig. 1. Enlarged portion of Fig. 4 (this Plate). Spiral coiling in vortical region (black area) obscured by crowding. Flow lines of anterior surface truncated in the flow troughs. Tubes of glass of different refractive index occur in core near line of union *c*.

2. Equatorial section of flange fragment. Outer edge crenulate, inner edge smooth. Flow lines in chin region concentric and parallel with the inner edge; in other parts crowded and confused.
3. Equatorial section of half a flange. Both inner and outer edges relatively smooth. Flow lines locally complex, but major trends parallel with the outer and inner edges.
4. Radial section of flange on button-shaped australite, showing bifurcating crack infilled with ferruginous clay extending from gap *a* into base of flange. Flow lines pass from anterior surface regions of core into seat and coil spirally near outer edge.
5. Oblique section through junction of flange and core of button-shaped australite. Re-enclosed bubble-pits along line of union *c*. General direction of flow lines in flange parallel to *c*.
6. Equatorial section of disc-shaped australite (cross section as in Plate I, Fig. 8) showing broad flange with concentric flow structures and small core with bubble cavity and complex flow pattern.
7. Equatorial section of button-shaped australite with remnants of flange, showing re-enclosed bubble-pits along line of union *c* and complex flow pattern in core.

Flanges of Australites

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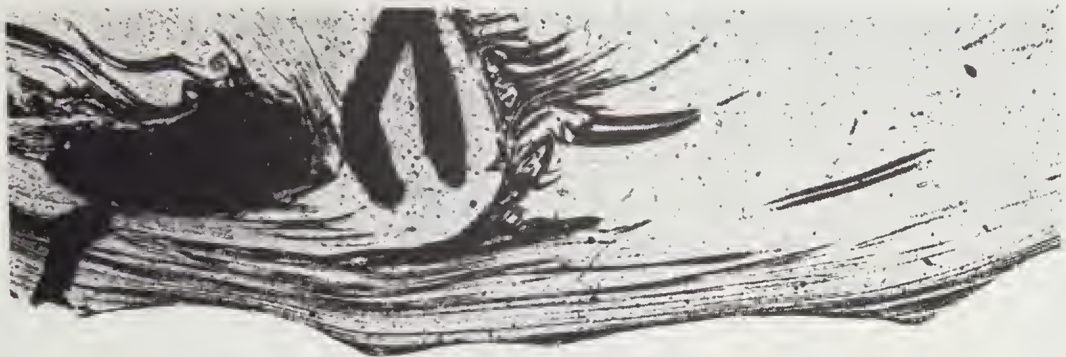
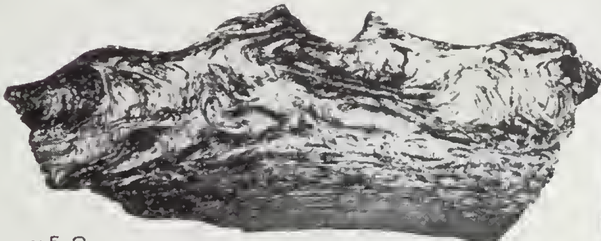


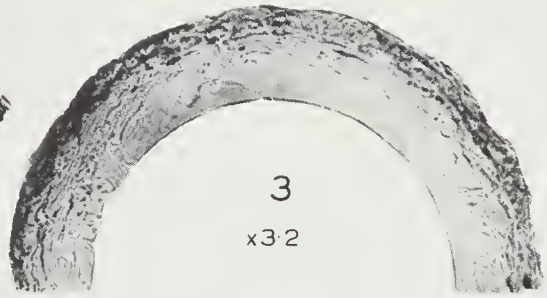
x15·5

1



x5·2

2

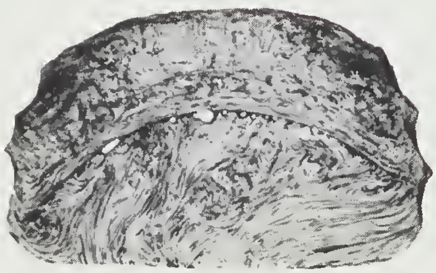


3

x3·2

x9

4



5 x3·2

x5·2

6

x3·2

7

Flanges of Australites