Mernoirs of the National Museurn of Victoria 11 March 1968

https://doi.org/10.24199/j.rnrnv.1968.28.06

6

AUSTRALITES FROM PRINCETOWN, VICTORIA

By George Baker

Abstract

Seven australites recently discovered along a new road N. of Princetown township on the S. coast of Western Victoria serve to extend the area of distribution of tektites in the Moonlight Head-Port Campbell-Peterborough concentration centres of the Australian strewnfield.

The state of preservation of the specimens is such that they still reveal some of the features arising from the effects of the secondary process of aerodynamic heating and ablation generated during hypersonic transit through the earth's atmosphere. Tertiary processes such as natural solution etching in soils and terrestrial exfoliation that have occurred during the few thousand years the specimens have lain on the earth's surface have somewhat modified the original primary (extraterrestrial) and the secondary (aerodynamic) surfaces.

Introduction

Seven australites from a new branch road six miles N. of Princetown (Fig. 1) on the S. coast of Western Victoria were collected by Mr Eric Franks of Coburg Victoria, in January 1965. They reveal a state of preservation comparable with that of (a) many of the australites collected in larger numbers (over 2100) during the past 30 years in the Port Campbell district (Baker 1937, 1955) a few miles to the west, and (b) the australites (approximately 20) found in the Moonlight Head -Rivernook area nine miles to the SE. (Baker 1950). They have not been as severely weathered as the several hundred specimens found in the Stanhope's Bay-Childers Cove district (Baker 1956) 26 miles W. of Princetown, where abrasion as well as solution-etching has been effective. The specimens were donated to the National Museum of Victoria (Nos. E3958 to E3964) by Mr Franks in January 1965, and were submitted for examination and description per courtesy of the Assistant Director Mr E. D. Gill.

The discovery of these australites followed the opening up for closer settlement of the bush country N. and NW. of Princetown, where new access roads were constructed. The specimens were found on areas of grey sandy loam freed from vegetation by bulldozing on the new access roads. Some of the blocks of weathered rock exposed by these operations are Paleocene sedimentary types (sandstones to fine conglomerates). The area is $3\frac{1}{2}$ to 4 miles E. of the E. limit of the Port Campbell concentration centre. Princetown township is 10-12 miles ESE. of Port Campbell township.

The only two other australites have been found in the area around Princetown, (1) a worn core portion of button from which the flange has been completely lost by erosion. It was located on a hardened soil surface exposed by sand-winnowing in the Recent sand dunes, approximately three-quarters of a mile E. of the mouth of the Gellibrand River and half a mile inland from the coast (Fig. 1). The site is about 8 miles S. of that of the australites collected by Mr Franks, and the specimen is also in the collection of the National Museum of Victoria (donated Mr T. Scott 2/1/63 reg. no. 2797), (2) a better preserved lens-shaped australite of specific gravity 2·463 from one mile NW. of Princetown township found on the side of the Great Ocean Road by a local resident and presented to the National Museum (reg. no. 2786) by Mr W. A. J. Saunders 12/12/62.

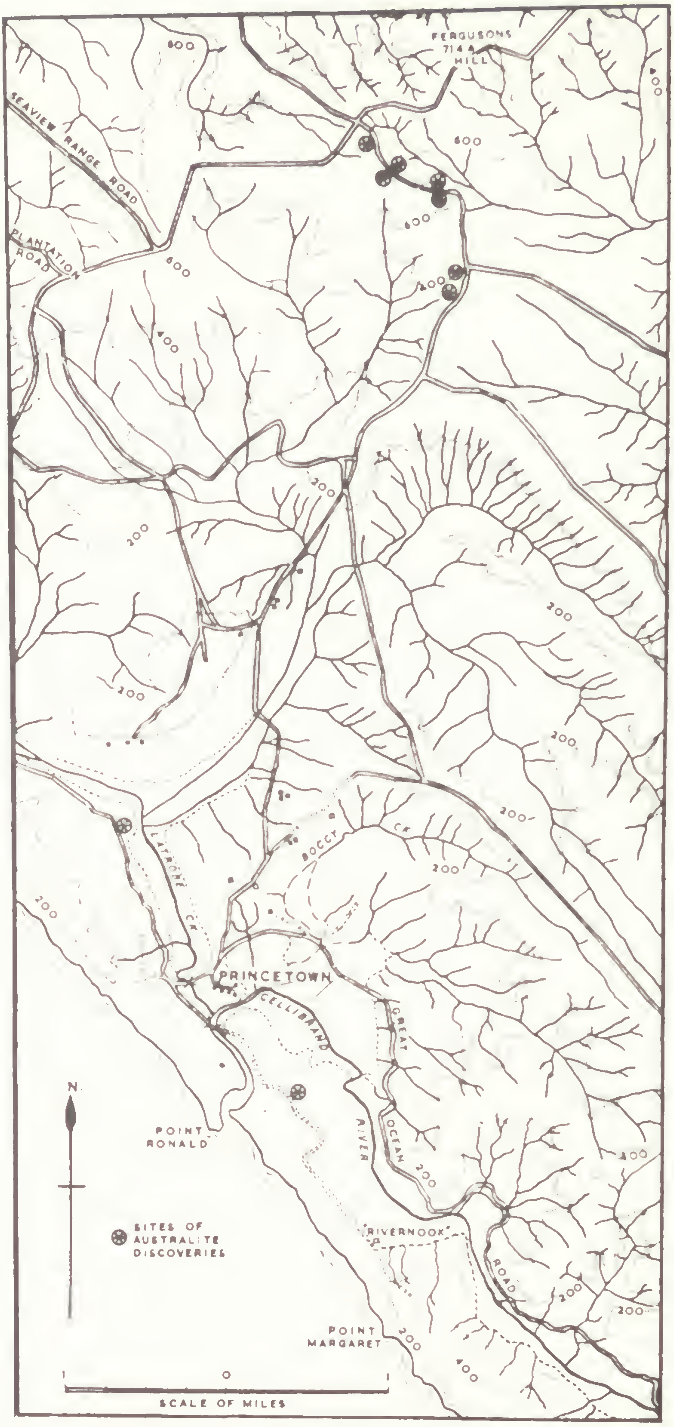


Fig. 1—Sketch map of Princetown area where australites were discovered (based on 1 : 31,680 Standard Series State Aerial Survey, Victoria. 933A—Princetown.)

The seven australites from the site six miles N. of Princetown township have been attacked by natural etchants (cf. Baker 1963a, pp. 4-6), some rather more extensively than others. A few have been subjected to processes of exfoliation (cf. Baker 1963b), more particularly the specimens listed in Table 1 as numbers 3, 7 (see Pl. 1, fig. J-L, S-U), evidently as a consequence of the effects of diurnal temperature changes accompanied by the effects of such processes as (a) differential expansion and contraction and (b) terrestrial solution etching along certain (often random) directions in the glass. None of the specimens, however, reveals signs of wear by abrasion, and in as much as certain aerodynamically produced features (Baker 1958) are still relatively well-preserved, no allowance can be made for a previous period of abrasion followed by subsequent terrestrial etching. Hence natural attrition by rolling during a period of transportation or by sand blasting during wind erosion can be eliminated from their history.

Even though there are only seven specimens in the collection made by Mr Franks, they nevertheless represent approximately 60% of the usual australite shapes found in other centres of greater numbers.

Dimensions, Weights and Specific Gravity Values

The dimensions, weights and specific gravity values of the seven specimens are listed in Table 1. These values do not apply to complete specimens, as can be judged from inspection of Pl. 1, hence the values for some of the dimensions and for all of the weights are lower than their original dimensions and weights at the time of earth landing. Fig. D-F on Pl. 1 represent the specimen nearest to a complete form. The shape types represented and the medium to small sizes are characteristic of the general run of specimens from the Moonlight Head-Port Campbell-Peterborough region.

The total weight of the seven specimens is 24·827 gms. For a range in weight of 0·658 gms to 13·272 gms shown in Table 1, the arithmetic average weight is 3·547 gms.

The specific gravity range is from 2·372 for the partially exfoliated flanged button to 2·467 for the round core, using deionized water at a temperature of 21·2°C. This range gives an average specific gravity value of 2·411, the same as that for 15 determinations of australites found nine miles SE. in the Moonlight Head district (Baker 1950, p. 35), and a little greater than the average (2·409) for 366 specimens from the Nirranda district to the W. (Baker 1956, p. 85). The average is higher than that for 555 specimens (2·397) from the Port Campbell region (Baker and Forster 1943) a few miles W. The differences between these average specific gravity values, and also the range in individual values, are within the compass of the figures obtained for over 1000 determinations (Baker 1956, Table VI, p. 90) from the spread of australites along the S. coast of Western Victoria. This covers a coastal strip from Moonlight Head at the E. end of the known area of distribution (Baker 1956, fig. 1) through Port Campbell, Peterborough, Flaxman's Hill and Stanhope's Bay, to Childers Cove nearly 40 miles W.

Usually flange fragments have a somewhat lower specific gravity than the core portions of australites, as seen from a large number of determinations for cores and flange fragments found separately and not known to have come from any one particular specimen in its more complete state (Baker and Forster 1943, p. 384, Baker 1944, p. 17). The same applies to a few specimens for which the specific gravity of the flange and core from the same specimen have been separately deter-

TABLE 1

Dimensions, weights and specific gravity values of australites from Princetown, Western Victoria

No.	Plate I, figure	Shape type	Diameter (mm)	Depth (mm)	Flange width (mm)	Length (mm)	Width (mm)	Weight (gms)		Specific gravity‡	
1	G to I	Small button with attached flange remnant*	11·0 (ex-flange)	6·5	4·7	—	—	Core	0·894	2·404	2·405
								Detached* flange fragment	0·357	2·405	
									1·251		
2	A to C	Small button with attached flange remnant	Core portion = 14·0	7·5	4·0	—	—	1·621		2·419	
3	J to L	Partially exfoliated flanged button	Core portion = 12·5; core plus flange = 20·0	10·1	3·5	—	—	2·152		2·372	
4	D to F	Flanged oval button with chipped flange†	—	9·0	4·0	23·5	20·6	Core with attached flange remnant	3·492	2·405	2·405
								First detached† flange fragment	0·553	2·402	
								Second detached† flange fragment	0·411	2·404	
									4·455		
5	M to O	Small oval	—	5·6	—	12·7	10·6	0·658		2·395	
6	P to R	Boat with attached flange remnant	—	6·0	4·3	Core portion = 17·2	Core portion = 10·8	1·419		2·418	
7	S to U	Round core	22·5	19·3	—	—	—	13·272		2·467	

* flange fragment became detached while cleaning specimen by ultrasonic techniques;
† one fragment of the flange became detached on cleaning, the other was detached when received for examination;
‡ $T_{H_2O} = 21 \cdot 2\,^{\circ}C$.

mined (Baker and Forster 1943, p. 401). Less commonly, the specific gravity value of a flange can be greater than that of a core from which it was detached (Baker 1956, p. 85). Furthermore, as seen from Table 1, there is no significant difference in the specific gravity values for flange and core respectively of one and the same specimen for two of the examples listed (nos. 1, 4, Table 1). The same has been noted for a flanged australite button fragment from Nirranda, Western Victoria (Baker 1956, p. 86).

Such departures as these are not in accord with the earlier concept that flanges have lower specific gravity values than cores because of the loss of some of the heavier, more volatile constituents during aerodynamic ablation and the accompanying process of circumferential flange construction (cf. Baker 1956, p. 154). Evidently a process of differential volatilization during the phase of aerodynamic heating is not always responsible for producing flange glass of different specific gravity to that of the non-secondarily heated, primary core glass.

Descriptions of Specimens

In the following descriptions, the term 'anterior surface' refers to the surface that was directed forward down the flight path during hypersonic entry, and the term 'posterior surface' refers to the back surface that remained facing back along the flight path during high speed atmospheric transit (cf. Baker 1958, fig. 3, p. 379).

No. 1 (Table 1, Pl. 1, fig. G, H, I) is a small australite button with an attached flange remnant. The posterior surface of the core portion shows a rather vaguely defined flow swirl structure covering the greater part of the surface, and a few small, shallow pits up to 0·5 mm in diameter on the remainder of the surface. A little under one half of the flange remains on the specimen, and its posterior surface lies in an almost horizontal plane (cf. Baker 1944, fig. 2t) relative to the flight position (Pl. 1, fig. H), i.e. approximately normal to the flight direction. The posterior surface of the flange is slightly concave down the flight path, and minor amounts of terrestrial solution etching have brought out a series of concentric flow lines paralleling the inner and outer edges of the circumferential flange. The flange is relatively broad (4·7 mm wide as measured across the posterior surface) compared with the diameter (nearly 8 mm) of the posterior surface of the core exposed between the inner edges of the flange. The broken ends of the flange (see Pl. 1, fig. H) have been naturally etched to reveal the toroidal character and planar spiral arrangement of the internal schlieren (cf. Baker 1944, Pl. 1-3).

On the anterior surface, the first flow ridge (i.e. the ridge nearest the stagnation point in the front polar regions) is concentric in the ring-wave pattern and slightly oval in outline, measuring 7·5 mm by 8·5 mm across. Outwards from the first flow ridge, the second and third ridges are incomplete in continuity in the sense that they overstep one another in a radial direction (see top of photograph, Pl. 1, fig. 1), and hence they tend to be incipiently spiral in character. A shallow lunate depression 2 mm across which is slightly deeper towards the stagnation point side, occurs within the confines of the first flow ridge on the anterior surface, and is barely discernible in the right-central portion of the photograph (Pl. 1, fig. 1). It is situated half way between the front pole of the specimen and the first flow ridge, and is comparable with the dimple occurring in a similar position on a complete, oval-shaped, flanged australite from the Port Campbell district (Baker 1960, Fig. 1 B, C, p. 50, Pl. IX B). This is interpreted as a remnant of a small internal bubble that became exposed and modified in shape by the progressive ablation and thin-film-melting of front surface tektite glass during the aerodynamic heating phase.

Several fine, radial flow lines trend across the anterior surface from near the stagnation point region to the equatorial regions of the specimen, being most pronounced where crossing the surfaces of the flow troughs in the ring-wave pattern (some of these flow lines are just detectible in Pl. 1, fig. 1). Their presence does not break the overall continuity of trend of the relatively sharp-crested flow ridges. Minute shallow pits averaging just under 0·25 mm across on the anterior surface, and situated more commonly in the area between the stagnation point and the first flow ridge, are a result of terrestrial solution etching.

No. 2 (Table 1, Pl. 1, fig. A, B, C) is an australite button with a small remnant of the flange still attached to the core portion. The posterior surface of the core reveals a relatively regular scatter of shallow pits that are evidently largely due to the effects of natural solution etching. These pits vary in diameter from approximately 0·25 mm to 1·0 mm. Few occur as isolated pits with regular, sharply defined edges. Most lie in close proximity to each other and are more irregular in outline and separated by slightly lower wall edges along their contacts. The posterior surface of the core shows no evidence of flow lines nor flow swirl structures as in specimen 1. About one-eighth of the circumferential flange remains attached to the central core portion (Pl. 1, fig. A). It shows the characteristic fracture pattern developed when a flange is detached in segments from the core by weathering agents. Fine concentric flow lines are discernible on its posterior surface by means of a X10 hand lens.

The contrasting anterior surface is virtually free from pits. It reveals a generally smoother surface surmounted by sharply defined elevations forming flow ridges, with the intervening flow troughs 1·5 mm to 2 mm wide. The first flow ridge outwards from the stagnation region is concentric, slightly oval in outline, and measures 8 mm by 9 mm across. The second flow ridge measures 12 mm by 12·5 mm, and its trend on the curved anterior surface is clockwise spiral (Pl. 1, fig. C). The ridges and troughs constitute the ring-wave patterns of aerodynamic origin which are so well displayed on the better preserved specimens. Finely sculptured flow lines pass radially outwards from the front polar regions, cross the surfaces of the flow troughs (Pl. 1, fig. C), and terminate at the broken edges of the specimen in the equatorial regions. Compared with specimen 1, the flange is narrower (4 mm wide) relative to the diameter of the core surface (12 mm) exposed within the inner edges of the (reconstructed) circumferential flange.

No. 3 (Table 1, Pl. 1, fig. J. K, L). This is a partially exfoliated flanged button that was evidently originally round in plan aspect but is now oval in outline (Pl. 1, fig. J, L) due to approximately equivalent amounts of spallation of the glass from two diametrically opposed sides of the specimen. The posterior surface reveals a number of etch pits in places, but elsewhere, such as on lower levels arising from removal of thin flakes by exfoliation, subsequent terrestrial solution etching has accentuated the complex pattern of internal schlieren in the sub-surface regions of the glass. The etch pits average 0·3 mm to 0·4 mm in diameter.

Approximately one-fifth to one-quarter of the circumferential flange remains attached to the core of the australite as two separate portions on diametrically opposed parts of the circumference of the specimen (Pl. 1, fig. J, K). Natural etching of the broken surfaces of the flange, as viewed in side aspect (Pl. 1, fig. K) has accentuated the remarkably well-developed toroidal character of the inrolled schlieren in the glass constituting this secondary, aerodynamically produced structural feature. In the chin regions (cf. Baker 1944, p. 8) of the flange, the schlieren reveal some contortion and puckering which were evidently due to the jamming of warmer against cooler glass during a phase of flange construction. As exposed on the posterior surface of the flange, the flow lines constituting the toroidal schlieren outcrop (on natural etching) as a series of fine concentric flow lines. The flange is somewhat narrower (3·5 mm wide) relative to the diameter of the core surface (12·5 mm) exposed between the inner edges of the circumferential flange, in comparison with specimens 1 and 2. The relationships of flange width to core diameter for specimens 1 to 3 are shown in Table 2.

TABLE 2

Relationships of flange width to diameter of core exposed between the inner edges of the flange for three round australites from Princetown

No. in Table 1	Flange width (mm)	Core diameter (mm)	Ratio flange width: core diameter
1	4·7	8·0	0·59
2	4·0	12·0	0·33
3	3·5	12·5	0·28

The trend in Table 2 is for the ratio of the flange width to the core diameter to decrease in value with increase in size of the specimen. This is evidently a reflection of the relative amount of flange glass re-frozen in the equatorial regions of secondary forms produced by aerodynamic ablation of small spheres of tektite glass with originally somewhat different radius, giving a generally broader flange from originally smaller spheres. Unlike specimen 1, the posterior surface of the flange in specimen 3 is somewhat rounded down the flight path (Pl. 1, fig. K) and dips inwards at an angle of just under 10° to the horizontal plane of the specimen (cf. Baker 1944, fig. 2g, h). The flange posterior surface in specimen 2 likewise dips inwards (Pl. 1, fig. B) in contrast with that of specimen 1. The reasons for this variation in angle and curvature of the flange posterior surface have yet to be interpreted in detail in terms of the aerodynamic turbulence which moulds the flange glass into its toroidal, circumferential form.

The flow ridges on the anterior surface of specimen 3 are somewhat irregular in trend, but are generally counterclockwise spiral in character (Pl. 1, fig. L). The first ridge measures 8·5 mm by 10 mm across. The degree of vitreous lustre of the anterior surface is somewhat higher than on the other six specimens in this collection of australites from N. of Princetown. In view of the presence of finely marked radial flow lines trending outwards on the anterior surface from the stagnation region to the periphery of the specimen, and the probability that such flow lines become accentuated by terrestrial solution etching, it is considered that the highly vitreous lustre of the anterior surface is not so much indicative of preservation of the outermost layer of aerodynamically heated glass as an expression of the effects of etching. No doubt a fraction of a millimetre of such glass has been removed by sub-aerial agencies since the time the specimen landed on earth a few thousand years ago. A few minute etch pits on the anterior surface (Pl. 1, fig. L) average between 0·1 mm and 0·2 mm in diameter, while a larger, shallow etched-out 'crater' measuring 3 mm by 2 mm in size is located between the first and second flow ridge. The floor of this 'crater' is covered with micro-etch pits.

Examination of the naturally etched exfoliation surfaces in side aspects of the specimen (e.g. Pl. 1, fig. K) reveals that the thickness of the sub-surface shell of aerodynamically heated glass on the anterior surface of the tektite ranges from 1·9 mm in the stagnation region (i.e. at the front pole of the specimen at the bottom of Fig. K in Pl 1) to 2·7 mm at the contact between the central body portion and the circumferential flange in the equatorial regions of the specimen (i.e. left-hand and right-hand portions of Fig. K, Pl. 1). The surfaces exposed by exfoliation have been significantly affected by terrestrial solution etching, and they now reveal the intricate internal flow line pattern of the core glass and of the glass constituting the aerodynamically heated outer shell. The line of contact between the heated shell of glass on the anterior surface and the inner core regions to which heating did not effectively penetrate, is relatively well defined in Pl. 1, fig. K. The rather irregular nature of the line of contact is principally, if not entirely, an outcome of slight variability in the degree of attack of subsequent terrestrial etching processes. Further spallation and etching subaerially of a weathered specimen such as that represented by Pl. 1, fig. J, K, L, ultimately leads to complete removal of the flange glass and of the anterior surface heated shell glass, leaving the more stable core portion which usually is of conical shape and reveals a flaked equatorial zone like that depicted in Pl. 1, fig. T.

No. 4 (Table 1, Pl. 1, fig. D, E, F), is a flanged oval-shaped australite in plan aspect with a slightly chipped circumferential flange. It is the best preserved specimen in the collection. Although oval and having the longer diameter 3 mm greater than the shorter diameter (cf. Pl. 1, fig. D, F), the flange width remains constant at 4 mm, apart from minor irregularities around the outer edge of the specimen.

The posterior surface of the core is covered with minute pits averaging 0·2 mm to 0·3 mm across and ranging in outline from sub-circular to elliptical, and occasional indistinct grooves where etch pits have merged into one another. The posterior surface of the flange is in marked contrast to that of the core, being generally smooth and revealing only a few shallow micro-pits mostly under 0·1 mm across and one larger pit nearly 1 mm in diameter (Pl. 1, fig. D, left side). This larger pit is evidently a small bubble that burst at a late stage of the atmospheric phase of the australite, or else its thin upper wall has been penetrated during weathering while the specimen rested on the earth's surface. The bulged up glass extending circumferentially around the pit opening for nearly 0·5 mm around its edge, indicates conclusively that this is truly a bubble remnant and not due entirely to subsequent terrestrial solution etching. A number of similar, small, burst bubbles have been noted previously on the posterior surfaces of australite flanges (Baker 1944, p. 9), but very few remain unburst. One such bubble has been figured adjacent to a burst bubble (Baker 1946, Pl. XII, fig. 15) on a flange fragment from the Port Campbell district. The pressure and composition of the gas in such small bubbles is unknown. In view of the circumferential flange structure on australites being generated as a secondary feature from aerodynamic heating during hypersonic transit through the earth's atmosphere, any gas included in such small bubbles is likely to be either entrapped air, or vapours outgassed from melting tektite glass, or both. The inner walls of the pit reveal glass with a higher degree of vitreous lustre than the surrounding glass, but because of some initial attack by terrestrial etchants which have had access to the pit, the lustre is not as brilliant as shown by the 'hot polish' (cf. Baker 1959a, Pl. XIV, fig. 2) of the interior of newly opened tektite bubbles (hollow tektites). Fine concentric flow lines trending parallel with the outer and inner edges of the circumferential flange are in places interrupted by the micro-etch pits on the posterior surface.

The first flow ridge on the smoother anterior surface of the specimen is oval, concentric, and measures 10 mm by 12 mm across. The subsequent flow ridge is counterclockwise spiral (Pl. 1, fig. F). Fine radial flow lines extend from the stagnation point region outwards to the equatorial edges of the specimen. They are mostly too fine to be readily detectible at the magnifications of Pl. 1, fig. F. Where these flow lines encounter a cavity 1·5 mm across at the edge of the first flow-ridge (Pl. 1, fig. F, right side), they are arranged in an anticlinal (saddle-like) pattern with the apex of the anticline directed towards the stagnation region of the specimen. Although this cavity, which is round in plan, may have been a little overdeepened and broadened by slight terrestrial solution etching, its origin seems to be fundamentally one of exposure of an internal bubble at the particular level reached during the final stages of ablation-reduction of the forwardly directed surface during atmospheric flight. It is slightly deeper towards the stagnation region and the 'anticlinal' appearance of the adjacent flow lines indicates streaming of non-homogeneous glass around the internal bubble in the primary phase of tektite formation.

Another pit 1·25 mm in diameter on the anterior surface is located towards the other end of the specimen between the first and second flow ridges. It is unusual in containing a small pyramid of tektite glass, broader at the base and projecting up from the bottom of the pit almost to the level of the lip of the pit opening. This pyramidal or conical projection of glass measures approximately 0·3 mm across at its summit, the surface of which is slightly concave and hence 'crater-like'. The origin of this feature is uncertain, and although its present overall appearance may have been modified somewhat by the tertiary process of terrestrial solution etching, there is nothing evident to disprove an origin during the primary and/or secondary phases (cf. Baker 1963a) of formation. A similar pit with a central core of glass is shown in a thin section of a flanged button from Port Campbell (Baker 1944, Pl. 1, fig. 4).

Very few micro-pits under 0·1 mm diameter occur on the otherwise smooth anterior surface, and a few occur on the walls of the small bubble cavity exposed by ablation. The lip of this cavity, on the side remote from the stagnation region, is interrupted by five small pits of circular outline and approximately 0·1 mm across, while a string of four smaller pits, closely spaced and in line, lead away from the edge of the cavity and trend across the surface of the flow trough situated on the side of the cavity nearer the periphery of the specimen. These are probably micro-etch pits and due to the tertiary process of terrestrial erosion.

No. 5 (Table 1, Pl. 1, fig. M, N, O) is a small oval from which the flange has been completely removed by erosion and the flange band, which is approximately 2 mm wide, has been corroded by soil etchants. The flange band is usually smooth-surfaced on relatively recent exposure and it represents the circumferential plane of contact between the flange and the core in the complete flanged australites (Baker 1944, p. 8; 1959b, p. 76). The oval shape of the specimen is rather accentuated by the way it has weathered (Pl. 1, fig. O), but its original outline in plan is confirmed as oval from the measurements (7·5 mm by 9 mm) of the core surface within the confines of the etched flange band (Pl. 1, fig. M). The posterior surface of the core is minutely pitted and roughened from terrestrial solution-etching, whereas the flange-band shows a somewhat different etch pattern due to the presence of short, shallow, but rather ill-defined solution grooves (Pl. 1, fig. M, right end) and a few larger, shallow pits.

A few micro-pits averaging 0·2 mm across occur on the otherwise smooth anterior surface which has a counterclockwise spiral flow ridge. A relatively large concave, shallow facet (just distinguishable on fig. N, O, Pl. 1) on one side of the anterior surface, evidently marks the site of an internal bubble which became exposed and nearly obliterated by the process of aerodynamic ablation. The concave facet measures up to 5 mm across and 4 mm deep. It is slightly deeper and narrower (3 mm across) nearest the stagnation point where it tends to be lunate in outline. From this region it flattens and broadens (to 5 mm across) at its edge remote from the stagnation point. Since it lies across the ring-wave pattern of flow ridge and flow troughs on the convexly curved anterior surface, it has caused the flow ridge to pass from a rather poorly-defined 'initial hump' 4 mm in diameter in the stagnation point region, to a counterclockwise spiral, relatively sharp-crested flow ridge. This flow ridge descends around the curved anterior surface from near the top edge of the facet to the periphery of the specimen where it forms the broader edge of the facet. Radial flow lines cross the ring wave pattern and extend from the stagnation point in the front polar region outwards to the equatorial edge of the specimen.

The specimen reveals a marked difference between the arcs of curvature of the posterior and anterior surfaces respectively (see 5, Table 3). As seen in side aspect, the posterior surface has a much larger radius of curvature and hence is much flatter than the anterior surface which is rather steeply curved (lower surface of fig. N, Pl. 1) for a relatively small specimen. Since the curvature of the posterior surface is more or less that of the original australite spheroid, while the anterior surface is a product of the secondary process of aerodynamic ablation, the indication is that for its size this specimen suffered rather more ablation than other primary australite spheroids (cf. 4, 5, 6, Table 3).

No. 6 (Table 1, Pl. 1, fig. P, Q, R) is a small boat-shaped australite with portion of the circumferential flange preserved as an attached remnant along one side of the specimen; the remainder of the flange has been lost by terrestrial weathering. The sculpture pattern of the posterior surface of the core of the specimen is dominated by closely crowded pits 0·15 mm to 0·5 mm across. The pits cover all but the central portion of the core surface, while the central portion is constituted of a small flow swirl 3·5 mm by 4 mm in area. This swirl (Pl. 1, fig. P) is a somewhat smoother, slightly oval patch on the surface marked by partially etched-out flow lines. Immediately adjacent to the swirl, terrestrial solution-etching has overdeepened the neighbouring pits, causing this part of the surface to become ragged in appearance and more roughened (see black area surrounding the flow swirl in fig. P, Pl. 1). In marked contrast, the posterior surface of the attached remnant of the circumferential flange is considerably smoother (Pl. 1, fig. P) and reveals only a few shallow, minute pits and occasional flow lines. In cross-sectional aspect, the weathered broken ends of the attached flange remnant show the toroidally inrolled character of its internal schlieren pattern.

On the diametrically opposite side to the attached flange remnant, and also at each end of this elongated australite, a relatively smooth-surfaced flange band (just visible above the rim of the specimen in Pl. 1, fig. Q) marks the original position of attachment of the circumferential flange to the core. The flange band measures 1·0 mm to 1·5 mm in width. The fact that its surface is little etched and dulled in lustre, indicates that the missing portions of the circumferential flange have not been detached for any length of time compared with other australites on which the flange-band surface is more weathered. The smoother anterior surface is marked by a pattern of radial flow lines (Pl. 1, fig. R), one incompletely preserved concentric flow ridge, a few micro-pits, a crater-like pit 2 mm across which was evidently caused by overdeepening on terrestrial solution-etching, and a pit at one end (left-hand side of fig. R, Pl. 1) measuring 1·0 mm by 1·5 mm across which is regarded as a small internal bubble exposed as a pit on the forwardly directed surface of the specimen by progressive thin film ablation.

No. 7 (Table 1, Pl. 1, fig. S, T, U) is the largest specimen in the collection and is designated a round core. The posterior surface reveals two large excellently developed flow swirl structures in the sculpture pattern, and a few micro-pits ranging from 0·1 mm to 0·75 mm across. These swirls measure 11 mm by 16 mm and 9 mm by 19 mm across, but the larger swirl is transected at the edge of the specimen as a consequence of terrestrial erosion. Smaller flow-swirled areas adjacent to the two larger swirls are less defined and show more complexly folded flow line trends. Each swirl structure is constituted of patches of glass with numerous fine flow lines arranged in crudely concentric to complexly contorted (fold-like) fashion. They have been accentuated by a small degree of differential solution etching. This has produced the effect of some schlieren being represented by long, narrow ridges slightly raised above the general surface of the glass, while others are long, narrow grooves depressed below the general level of the swirl structures. These fine grooves are seldom as deeply etched-out as the majority of the micro-pits. Some of the micro-pits lie athwart the trends of the miniature ridges and grooves in the flow-swirled areas, without offsetting their trends in any way, while others occur on the smoother (less flow-lined) parts of the flow-swirl structures.

A feature seldom noted on flow swirl patterns generally is that in addition to such positive and negative features as the elevations forming micro-ridges and the elongated depressions forming micro-grooves, the micro-pits also have a counterpart in the form of slightly elevated, sub-circular to oval-shaped micro-mounds. One such micro-mound measuring 0·5 mm by 0·75 mm occurs on the surface of the larger of the two biggest flow swirls. Another approximately 0·2 mm across occurs on the surface of one of the smaller flow swirls. Two others of rather irregular shape occur on the surfaces of other flow swirls. A few appear on the etched anterior surface while rare examples are noted on the etched surface of the flaked equatorial zone shown in Pl. 1, fig. T. These are evidently small nodes of different composition in the flow line pattern. They have remained rather more resistant to terrestrial etchants than the surrounding glass and that in the micro-ridges, while all of these three features are evidently constituted of tektite glass that is significantly more resistant to etching than that of the micro-grooves and micro-etch pits. There is no observable colour difference between these features in the hand specimen, but thin section studies indicate that chemically significant differences occur, the positive features such as the micro-ridges and micro-mounds being evidently richer in silica and slightly more resistant to soil etchants.

The anterior surface of this core reveals no remnants of the secondarily developed aerodynamic sculpture pattern so conspicuous on more completely preserved australites. This is because the thin outer zones of aerodynamically heated glass have been removed by terrestrial erosion. The specimen reveals an excellent pattern of complexly contorted flow lines because solution-etching has exposed and accentuated the internal schlieren in the sub-surface regions of the australite. Cutting across and sometimes parallel with the flow line trends are a number of solution gutters (Pl. 1, fig. U) which are much deeper and wider than any of the micro-grooves in the flow-swirl patterns appearing on the posterior surface. Exfoliation of glass from the anterior surface of this core has been most pronounced in the perimeter regions of the specimen. This is a consequence of terrestrial erosion and has resulted in the development of a marked circumferential flaked equatorial zone that is 11 mm to 12 mm deep and strongly etched to reveal the complicated nature of internal schlieren in the sub-surface glass of the core.

Curvature of posterior and anterior surfaces

The curvatures of the posterior and anterior surfaces of the specimens have been determined graphically from magnified silhouettes (Baker 1955, 1956). The radii of curvature determinations for the round forms of australites from north of Princetown, and for directions normal to the long axes of the elongated specimens, are set out in Table 3. From this table it can be seen that the largest round specimen (7) in the collection resulted from the aerodynamic ablation of the largest primary sphere (3·7 cm diameter) while the average size primary sphere for the remaining round forms (1-3, Table 3) was approximately 1·6 cm in diameter.

TABLE 3

Radii of curvature determinations, Princetown australites

No. (cf. Table 1)	R_B (mm)	R_F (mm)	Diameter of primary sphere (mm)
Round Forms			
1	8·8	7·6	17·6
2	7·7	8·9	15·4
3	7·4	10·9	14·8
7	18·6	14·2*	37·2
No. (cf. Table 1)	**R_B (mm)**	**R_F (mm)**	**Diameter of primary ellipsoid (mm.)**
Elongated Forms†			
4	12·6	11·6	25·2
5	9·4	5·9	18·8
6	6·3	7·2	12·6

* Anterior surface significantly modified by terrestrial exfoliation and solution-etching.

† Determinations made across shorter diameter.

Sculpture Patterns arising from Natural Solution Etching

In as much as the australites from N. of Princetown reveal a variety of well-developed sculptural elements arising from the attack to different degrees by soil etchants, the results of the etching process are summarized below and subsequently further elaborated:

1. Accentuation and/or development of small surficial pits on the posterior surfaces of the body portions of many of the specimens (Pl. 1, fig. A, D, G, M, P), and of the schlieren constituting flow swirls on others (Pl. 1, fig. P, S).
2. Exposure of the generally concentrically trending flow lines on the posterior surfaces of the circumferential flanges but with the concomitant development of very few micro-etch pits compared with their frequency on the posterior surface of the core.
3. Accentuation of the internal inrolled schlieren in toroidal flanges generally broken across in more or less radial directions (Pl. 1, fig. H).

4. Exposure of the complex internal flow line patterns within central body portions as a consequence of attack by terrestrial etchants on surfaces exposed by terrestrial exfoliation (Pl. 1, fig. K, T).
5. The development of deeper grooves as gutter-like structures trending largely across the patterns of schlieren on etched surfaces exposed by exfoliation, more especially on the anterior surface of the australite round core specimen (Pl. 1, fig. U) which is larger than any of the other forms.
6. The production of circular pits and accentuation of the complex internal flow line pattern on the spalled surfaces of the flaked equatorial zone of the core specimen (Pl. 1, fig. T).
7. The formation of low micro-ridges and micro-mounds of rather less readily etchable glass as infrequent features (seen only in the core specimen 7).

Furthermore, the exfoliation processes have assisted in the spallation and shedding of segments of outer zone glass from some specimens (cf. Pl. 1, fig. J, L) as evidenced by specimen 4 (Table 1) which shows narrow 'crack-like' features (cf. Baker 1944, p. 12) that cut across the posterior surface of the circumferential flange in three places (Pl. 1, fig. D). Before this specimen (4, Table 1) was cleaned by ultrasonic techniques to remove soil particles, the narrow, 'crack-like' features contained partially cemented soil constituents and possibly some residual alteration products formed during dissolution of the glass from the 'cracks'. The removal of the terrestrial materials by ultrasonic vibration in 1 : 1 cold HCl resulted in segments of the flange parting from the equatorial edges of the central body portion of the specimen. Inspection of the cleaned walls of the 'cracks' under low power lenses of a binocular microscope revealed that differential natural solution-etching had advanced to such a degree as to bring out the toroidal character of the internal schlieren in the circumferential flange. The detached portions fitted together relatively well (Pl. 1, fig. D-F), but in places, open 'cracks' (grooves and gutters) remained where some of the glass had been completely removed by solutions.

It is still unknown as to precisely how such 'cracks' were initiated and what controlled the directions they followed on the curved surfaces and into the interior of the australites. On the circumferential flanges they usually cut normally to or obliquely across (i.e. more or less radially) the external and internal structures of the flanges (see Pl. 1, fig. A, G, J, P). On the cores of the australites they wander over the curved surfaces and sometimes penetrate deeply into the interior zones of the glass objects, frequently following quite random directions. Elsewhere in the literature, comparable but generally shallower features have been referred to as 'saw-marks' and 'saw-cuts' (cf. Baker 1959, p. 40), and deeper structures as gutters or gouttières (Baker 1959, p. 39).

In view of the major rôle played by natural (terrestrial) solution etching in destroying the primary (extraterrestrial) and secondary (aerodynamically produced) features of australites, the crack-like structures are not to be regarded as true 'cracks' in the sense of being contraction cracks or impact-induced cracks. Rather are they to be explained as narrow, sometimes shallow, sometimes deep, solution grooves developed as a consequence of the biochemical reactions occurring in soils. The concept is that the 'crack-like' features were initiated after the specimens landed on the earth's surface. They are certainly not primary features because they occur on the secondarily produced aerodynamic structures. Neither were they formed as aerodynamic features during earthward flight, because they show no relationship to the established aerodynamically produced features on the anterior surfaces of australites; they often cut randomly across all features such as the flow ridges and flow troughs constituting the ring-wave pattern, as well as across the circumferential flanges. After landing on the earth's surface, terrestrial erosion principally affected the strained tektite glass constituting the aerodynamically formed anterior surface zone and the circumferential flange (cf. Baker 1963a, fig. 1), but in several specimens the process of dissolution continued beyond the strained zones into the primary core glass. In view of the fact that the specimens occurred within the root zone of the soils from which they were recovered, emphasis must be placed on the rôle of the soil biota and the roots of grasses and other vegetation in etching and dissolving tektite glass. The potency of the biochemical reactions arising from such an association is paralleled by the effects that lichens and mosses have in the etching and weathering of the exposed surfaces of many and varied types of rocks. The trends of the solution gutters in australites showing these features may well be controlled by the directions of rootlets growing around them. In substantiation of this concept is the observation that soil constituents occupy the gutters in specimens recently released from soils, and that two of the specimens recently collected north of Princetown and another from the Port Campbell district contained rootlets in the soil constituents occupying the gap region near the core-flange boundary and in the soil continuing down into the deep gutters. In course of time the soil constituents may ultimately become partially cemented to the walls of both deep and shallow gutters (cf. Baker 1944, Pl. 1, fig. 2, 4), and are then no longer suited to root access. The process of glass dissolution continued gradually during over-deepening of the initially shallower etched out gutters, accompanied by progressive infiltration of soil constituents.

Following cementation of soil constituents in the 'cracks' (gutters) and exposure of some australites in areas subject to minor amounts of soil deflation, it is apparent that differential expansion and contraction between the walls of the gutters and the contained soil constituents, would (as a consequence of diurnal temperature changes) contribute substantially to the disintegration of such australites. Fragments of australites have been found with soil constituents still firmly attached by cementation to one or other of the gutter-walls. The nature of the cementing medium varies with locality and degree of soil leaching. In some areas the cement is dominantly ferruginous (limonitic), elsewhere it is siliceous. In some the matrix is largely argillaceous, relatively well compacted, and ranges in colour from brown to white. Sub-angular and sub-rounded to rounded grains of quartz are commonly embedded in the fine-grained matrix.

References

BAKER, G., 1937. Tektites from the Sherbrook River district, east of Port Campbell. *Proc. Roy. Soc. Vict.* 49: 165-177.

————, 1944. Flanges of australites (tektites). *Mem. Nat. Mus. Vict.* 14 (1): 7-22.

————, 1946. Some unusual shapes and features of australites (tektites). *Mem. Nat. Mus. Vict.* 14 (2): 47-51.

————, 1950. Geology and physiography of the Moonlight Head district, Victoria. *Proc. Roy. Soc. Vict.* 60: 17-43.

————, 1955. Curvature-size relationships of Port Campbell australites. *Proc. Roy. Soc. Vict.* 67: 165-219.

————, 1956. Nirranda strewnfield australites, south-east of Warrnambool, Western Victoria. *Mem. Nat. Mus. Vict.* 20: 59-172.

————, 1958. The rôle of aerodynamical phenomena in shaping and sculpturing Australian tektites. *Amer. J. Sci.* 256: 369-383.

———, 1959a. Tektites. *Mem. Nat. Mus. Vict.* 23: 5-313.

———, 1959b. Australites from Kanagulk, Telangatuk East and Toolondo, Western Victoria. *Mem. Nat. Mus. Vict.* 24: 69-89.

———, 1960. A complete oval australite. *Proc. Roy. Soc. Vict.* 74: 47-54.

———, 1963a. Form and Sculpture of Tektites. Chapter 1 (pp. 1 to 24, 11 pls.) of 'Tektites' edited by John O'Keefe. University of Chicago Press.

———, 1963b. Exfoliation from the anterior surface of a flanged australite button, Port Campbell, Victoria, Australia. *Chemie der Erde* 23 (2): 152-165.

———, and Forster, H. C., 1943. The specific gravity relationships of australites. *Amer. J. Sci.* 241: 377-406.

Description of Plate

Plate 8

Australites from N. of Princetown, Western Victoria. A-U × 2. (In all photographs of side aspects, the posterior surface is at the top.)

A-C. Small button with flange remnant. A—posterior surface. B—side aspect. C—anterior surface showing first flow ridge concentric and subsequent flow ridge clockwise spiral; flow lines radial.

D-F. Flanged oval form. D—posterior surface showing pitted core and smoother circumferential flange with pit representing a burst bubble at left-hand end. E—side aspect showing flow ridges on anterior surface. F—anterior surface showing first flow ridge concentric and interrupted (right side) by an exposed internal bubble pit; subsequent flow ridge counterclockwise spiral (in E the core does not appear above the edge of the flange).

G-I. Small button with nearly half of flange preserved. G—posterior surface showing pitted to flow lined core and smoother circumferential flange. H—side aspect showing toroidal incoiling of internal flow lines of flange brought out by weathering of the fracture surfaces. I—anterior surface showing concentric flow ridges.

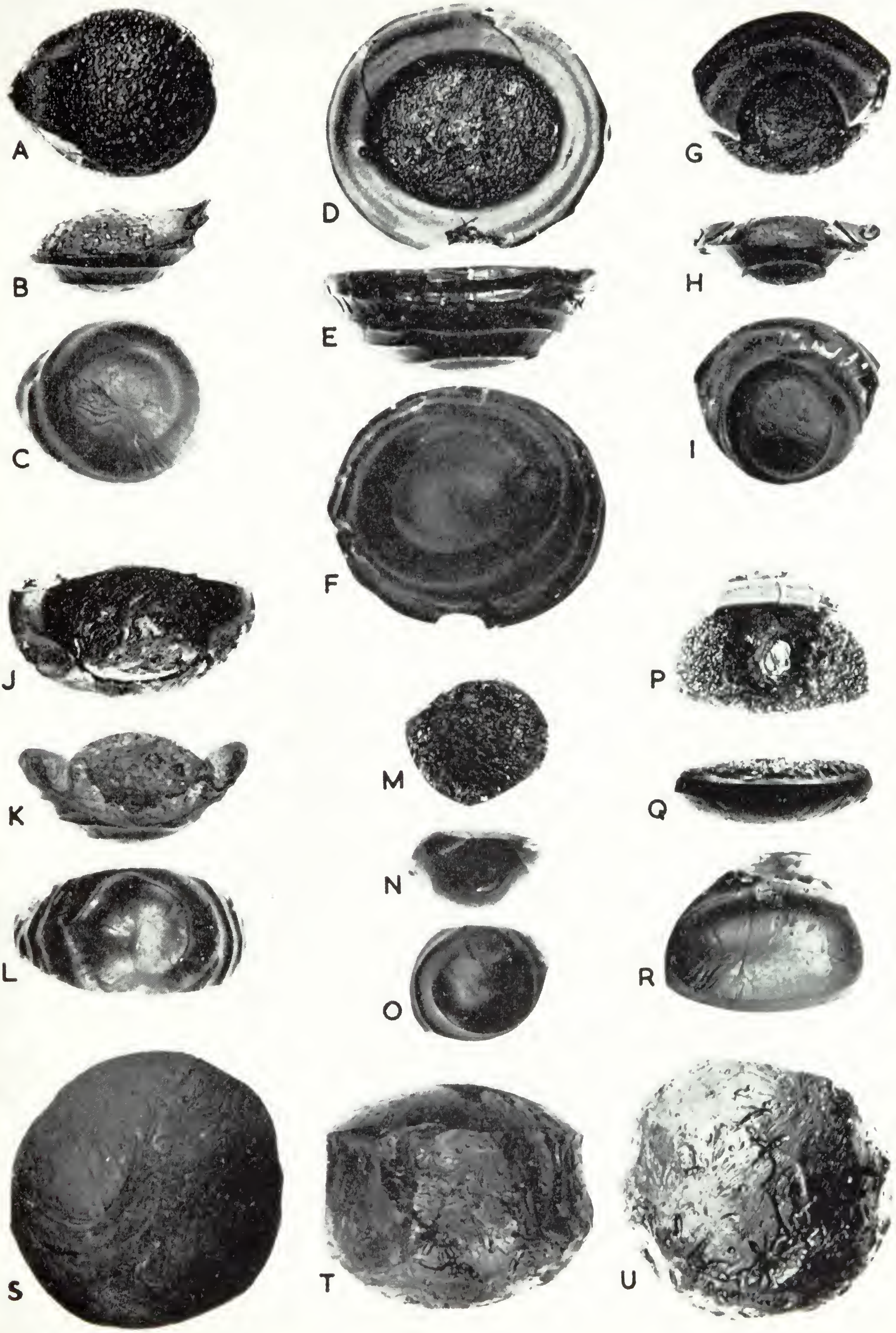
J-L. Partially exfoliated flanged button. J—posterior surface with core showing etch pattern of flow lines and occasional pits. K—side aspect showing central core marked off by spallation from the aerodynamically strained front surface glass (bottom of photograph). L—anterior surface with counterclockwise spiral flow ridge and radial flow lines.

M-O. Small oval without flange. M—posterior surface much pitted from (terrestrial) solution-etching. N—side aspect. O—anterior surface with counterclockwise spiral flow ridge and facet (top of photograph).

P-R. Boat-shaped form with attached flange remnant on one side (top of photograph P). P—posterior surface showing etch-pitted core and remnant of flow swirl structure (in central portion of photograph), flange relatively smooth. Q—side aspect showing smoother 'flange band' representing position from which the flange was detached during a late stage of weathering. R—anterior surface with concentric flow ridge and radial flow lines.

S-U. Round core with flaked equatorial zone. S—posterior surface showing pattern of flow swirls. T—side aspect showing nature of flaked equatorial zone (11-12 mm wide); flow lines common, few pits. U—anterior surface with flow lines, pits, and short gutters; no flow ridges are shown on this form because exfoliation of the outer zone of the anterior surface has occurred.

(Photographs by Mr R. K. Blair)


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U