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Morphology of a remarkably well preserved australite found near Ravensthorpe, Western Australia

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Abstract

An australite (Australian tektite) found near Ravensthorpe, Western Australia, is unweathered except for a complex pattern of lines etched on the posterior surface of flight. Other australites from the area show various degrees of weathering and abrasion. A double rim and obtuse ridges on the anterior surface are minor by-products of the loss of the stress shell which have survived because of the insignificant degree of weathering. The surface flaking of the two retained areas of stress shell could be artificial. Enclosure within clayey soil may have minimised water circulation and restricted weathering.

Introduction

In June 1985 Mr A.C. Anderton took an australite (Australian tektite) which he had found on his property near Ravensthorpe to the Albany Branch of the Western Australian Museum for identification and report. Subsequently he donated it to the Western Australian Museum (registration number G13 655). It is remarkable for the almost complete absence of weathering and hence the survival of minor features which have not been reported previously on an australite.

Mr Anderton found the specimen while clearing stones from cultivated ground near the north-east corner of Oldfield Location 850, 11 km west of Ravensthorpe, at *c.* 119°56′E, 33°35′S. It was at the edge of a stone pile on a low ridge of soil turned up by the plough and thus exposed to rain wash.

Description

Australite G13 655 is a round "indicator" in the sense of Fenner (1935, Fig. 1, 1940, p. 316), i.e. a round core from which the aerothermal stress shell has been incompletely discarded. The dimensions are (40.5-42.2) mm diameter x 33.4 mm thick, weight 73.87 g, specific gravity 2.431. Morphological details are described below in sequence from the posterior surface of flight to the anterior surface.

The posterior surface of flight, a remnant of the surface of the primary body, is shiny but with some deep scratches. A test cut in the edge made by the finder with a grinding wheel resulted in a minor loss ~ 0.05 g. Close inspection in oblique

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light shows the presence of three dark clear areas with circumferential bands, and outside them, a matte surface. One of the round clear areas is 10.3 mm diameter and near the edge of the posterior surface (the rim): the other, *c.* 16.4 mm diameter, is truncated by the rim (Figure 1A) and has a less regular, poorly defined feature with etched centres and complex structure tangential to it. A poorly defined, ovoid feature ajoins and is truncated by the rim. It has a clear central area about 10 mm long (incomplete) and up to 4 mm wide. All of these structures appear to be flow swirls at a very early stage of delineation by etching.

Microscopic examination reveals complex patterns of very finely etched lines surrounding the clear areas and responsible for the matte appearance. The types of pattern (Figure 2) tend to progress outward from the central clear area through parallel lines to braided lines, braided cells, cells, and complex patterns of cells in sheaves or other arrangements, but with some reversals and omissions. There are generally 20-50 lines per millimetre of width. At the opposed ends of a diameter of the smaller round clear area, the following were observed outward using the type letters of Figure 2, width in millimetres and estimated number of lines or cells per millimetre in brackets.

(i) A 10.31 mm, B a single line, A 0.05 mm, B 0.69 mm (25), C 1.03 mm (50), B 0.92 mm (40), E 1 mm plus (20).
(ii) A 10.31 mm, B 0.88 mm (40), C 1.17 mm (50), D 1.68 mm (50), E 2 mm plus (35).

For the ends of a diameter of the larger clear round area, the following were observed outward:-

(i) A 16.37 mm, B a single line, A 0.15 mm B 0.06 mm (80), D 0.91 mm (30), E 0.87 mm (30), F 2 mm plus.
(ii) A 16.37 mm, B two lines, A 0.16 mm, B 0.14 mm (57), C 0.90 mm (40), E 3.6 mm plus (25).

The above figures are approximate, partly because the observations are of an unprepared and strongly curved surface, partly because boundaries between types may be transitional as shown somewhat diagrammatically in Figure 2. It may be seen by comparing the ends of a traverse line that there are considerable differences arising from the lensing out of pattern types. The traverses should not be regarded as necessarily typical. Two additional traverses outward from the larger round clear area gave results which are yet further variations on the general theme.

The rim of the australite is sharp and regular but missing along two diametrically opposed lengths of 17 mm and 35 mm respectively where there are extensive areas of conchoidal flaking (Figures 1B and 1C). Close inspection shows that the rim is double, a second gently convex ridge being present on an average 1 mm beneath the overhang (i.e. to the anterior) of the main rim, somewhat in the mannner of a double chin (Figures 1D and 1E).

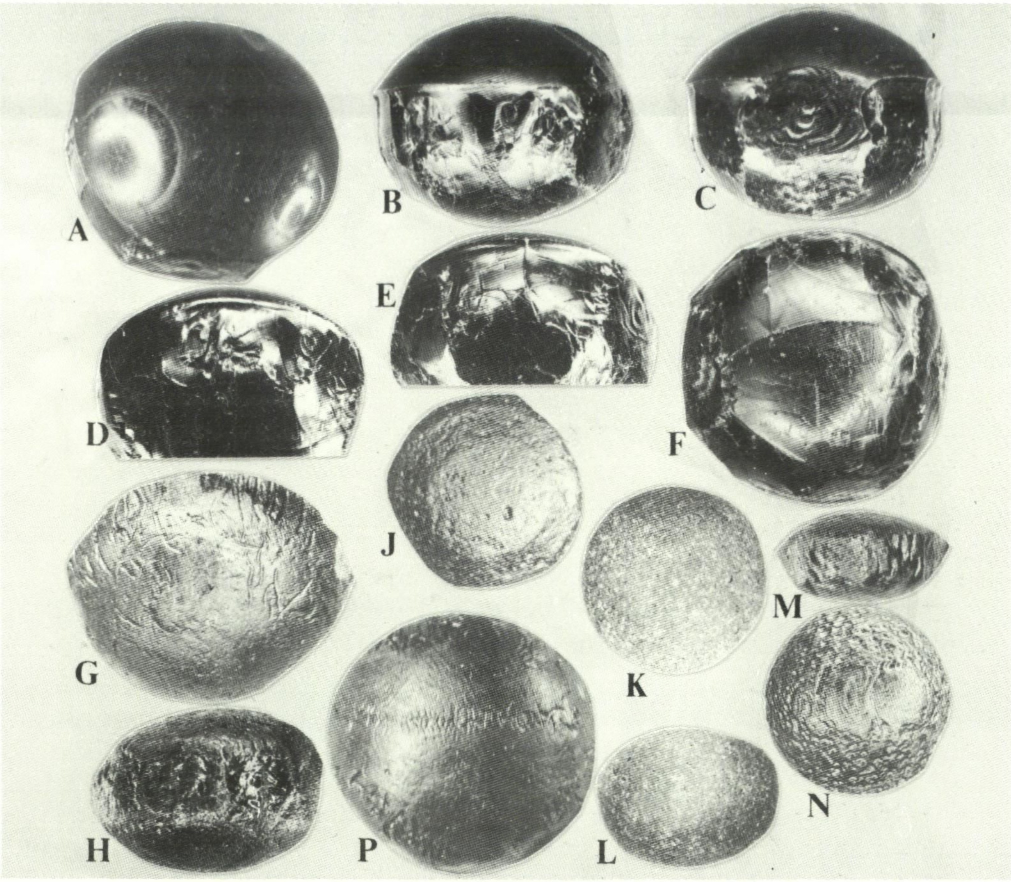

Figure 1 Australites from Western Australia, natural size unless otherwise stated. In elevational views, direction of flight is towards bottom of page. A-F. Round indicator G13 655 from west of Ravensthorpe. A. Oblique view of posterior surface, highlighted to show the circumferential bands of the two round smooth areas. B. Elevation with flake scars centre and left and the wider of the two flaked areas at extreme right. C. Elevation with narrower conchoidally flaked area central and showing point of percussion. D. Posterior half of australite viewed obliquely upward towards the double rim. E. Another view upward toward the double rim with an obtuse ridge sub-dividing the field of view. F. Anterior surface with narrow and wide flaked plateaus to left and right and obtuse ridges elsewhere. G. Obliquely upward view of anterior surface and equatorial zone of broad oval core from west of Ravensthorpe. H. Side veiw of round core from west of Ravensthorpe. J. Anterior surface of button core from west of Ravensthorpe showing two flow ridges (one near the edge and incomplete). x 2. K. and L. Posterior surface and elevation of severely abraded round core from west of Ravensthorpe. M. Elevation of round core from west of Ravensthorpe. N. Posterior surface of round core from Mount Madden showing group of flow swirls in deeply bubble pitted surround. P. Anterior surface of round core G13 654 from Gnowellen.

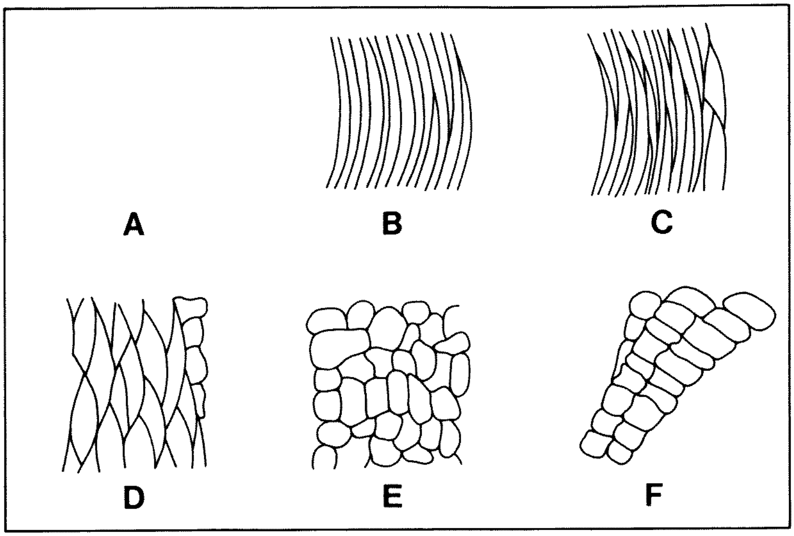

Figure 2 Types of etched pattern on the posterior surface of the australite G13 655 from west of Ravensthorpe. A. Clear. B. Lined. C. Braided. D. Braided cellular. E. Cellular. F. Complex cellular.

The equatorial zone is 13-14 mm wide. Where undamaged, it shows some so-called "flake" scars (Baker 1940) separated by low obtuse ridges. The two conchoidally flaked areas mentioned above are also centred on this zone and extend beyond it to affect in the one direction the rim and posterior surface and in the other the anterior surface (Figures 1B and IC). In spite of their flake losses, these two areas stand up as low plateaus ~ 1 mm above the adjacent equatorial zone (Figure 1F). There are centres of percussion upon each (Figure 1C).

The obtuse ridges between the "flake" scars of the equatorial zone extend out over the anterior surface created by loss of the stress shell and are the dominant feature there, sub-dividing the surface into several blocks (Figure 1F). Sprays of fine lines such as occur on australite artefacts are related to the rim and to these low ridges. Similar fine lines are also abundantly present on the two conchoidally flaked areas.

A traversing vernier microscope was used to determine the form of the posterior surface of the australite along two profiles through the posterior pole approximately 90° apart. Both profiles are closely arcs of circles. The first has radius of curvature 24.9-25.1 mm and the second 24.6-25.0 mm. The mean of these ranges is 24.9 mm and the primary body has been calculated as a sphere of that radius. The primary sphere had volume nearly 65 cm^3 and mass *c.* 157 g, on the assumption that it had the same specific gravity as the remnant australite. In forming the indicator, the primary body lost rather more than half of its volume (or mass) and one-third of its thickness. These losses are within usual ranges.

The site of find

The site of find is close to the concealed boundary between gneiss and a complex unit of metamorphosed sediments and igneous rocks (Sofoulis 1958). Most boulders on the stone pile appear to be of acid gneiss but some could be arenaceous metasediment. The soil contains a full range of sizes from coarse angular quartz of centimetre size down to silt and clay. It appears to have formed *in situ.* The silt and clay fraction is evidently prominent because water from earlier rain and the light rain falling at the time of inspection was lying on the surface of the ground. The soil at the site of find had been treated with superphosphate and cropped several times but a sample could be taken for chemical testing from about 2 m distant beneath the shallow stone pile, thus reducing the chance of contamination by fertilizer.

Other australites from the same general area

It is pertinent to investigate whether the state of preservation of the australite G13 655 is unique or usual amongst australites of the district.

The only australite known to the writer from the Ravensthorpe area prior to Mr Anderton's find is a rather weathered, plano-convex form in the E.S. Simpson collection held by the Western Australian Museum. However, enquiries at properties neighbouring Location 850 yielded several additional specimens for inspection and comparison with G13 655.

A large broad oval core from the gravel pit 11 km west-south-west of Location 850 shows considerable chemical weathering in the etching of schlieren on the posterior surface and abundant development of U-grooves (Figure 1G).

Three australites from Location 65 to the immediate south of Location 850 comprise: a round core with "irregular base" (Chapman 1964; p. 851 and Fig. 11) and severely etched "flake" scars (Figure 1H); a somewhat weathered button core, on the anterior surface of which two flow ridges are still discernible (Figure 1J); a round core which is severely abraded, showing occasional round percussion scars and innumerable lunate remnants of such scars, having evidently travelled a considerable distance down the Phillips River (Figure 1K and L).

A round core from the bank of Annabel Creek 7 km east-north-east of Location 850 has the "black enamel" appearance resulting from rapid chemical dissolution of glass. Chemical attack has accentuated schlieren on the posterior surface, developed U-grooves and modified the "flake" scars (Figure 1M).

No australites were available from immediately north of Location 850 but two were examined from the Mount Madden area about 30 km north-north-west. They are a round core with a group of three flow swirls accentuated by etching of the deeply bubble-pitted posterior surface (Figure 1N) and a specimen which has lost flakes, been worn smooth and since further modified by chemical action.

Thus eight australites from points around Location 850 show variously an imperfection of form, mild to severe degrees of chemical etching, mild abrasion, and in one instance, severe abrasion; none shows the perfection of form and high degree of preservation of G13 655.

Discussion and conclusions

The australite shows rare and possibly unique features – the double rim, the obtuse rim, the obtuse ridges, the etched patterns of the posterior surface and the flaked remnants of stress shell. It is conceivable that the minor features were once present on many australites and that they are remarkable here only because they have survived.

The second small rim and the obtuse ridges are on surface created by loss of the aerothermal "strained zone" (Baker 1963) or "stress shell" (Chapman 1964). The following mechanism is proposed to account for the loss of the stress shell and the creation of a rim (or rims), the so-called "flake" scars of the equatorial zone and the obtuse ridges on the anterior surface. The heated and expanded anterior shell exerted pressure on the protected and relatively cold posterior shell during ablation flight. Frontal air pressure assisted the compression. The anterior shell tended to override the posterior surface on a shear which steepened towards free surface in the manner of a thrust fault. The pressure thus established a sheared weakness which was utilised by the subsequent tensile forces of contraction to detach the stress shell in that vicinity and form the rim. The smoothly curved underside and regular nature of many rims is in keeping with a pattern of failure initiated by compression. Tension in rapidly cooling and brittle glass would be exprected to result in ragged and irregular fractures. It is a matter of further conjecture whether the site of the shear would migrate posteriorly as ablation stripping continued from the anterior surface to result in two or even a series of shears: in that manner there might arise a double rim as on the Ravensthorpe australite.

The even size and spacing of the "flake" scars (Baker 1940) on many cores points to an origin related to the thermal history of the symmetrical form as a whole in steady flight orientation. It is suggested that a mechanism similar to rim formation operated where the expanded anterior shell had its greatest circumference, causing it to ride up at regular circumferential intervals now marked by the obtuse ridges of the equatorial zone. Subsequent to being heated and expanded, the stress shell shrank through a petaloid form, each "petal" detaching from the rim fracture and from its neighbours to curve up somewhat in the manner of drying and shrinking mud flakes, leaving a concave surface, the so-called "flake" scar, and an obtuse ridge between the up-curved "petals". Small remnants of a "petal" persist occasionally within the scar and are separated from the main body by an incomplete concave fracture. The size of the australite and the range of heating would dictate the number of ridges and "petals" necessary to detach the stress shell with minimal expenditure of work. If flaking of the kind envisaged by Baker (1940) were possible once it would surely have been possible again, yet overlapping scars have never been reported. Further, it would be necessary for all "flakes" to be lost simultaneously or at least in some symmetrical manner if stable flight orientation were to be maintained while the balance of "flakes" were lost.

Detachment of the remainder of the stress shell may have been less systematic. On the well preserved Ravensthorpe specimen the obtuse ridges of the equatorial zone extend out over the anterior surface sub-dividing it into a number of areas from which individual plates of stress shell were detached in mud-flake style as the cooling surface contracted before the hotter interior. Sprays of fine lines related to these low ridges and to the rim such as are present on australite artefacts indicate that the ridges are sites of fracture and parting of the stress shell.

The only other examples of obtuse ridges known to the writer are on two specimens from Finke, NT (SA Museum T. 1375), but a distinctly different feature with the same pattern is often developed on anterior surfaces by weathering. The pattern consists of rows of short transverse U-grooves like a minute ladder (Figure 1P). Several rows with various degrees of development and orientation may be present. These rows of transverse grooves on cores lacking obtuse ridges may mark former plate boundaries with various degrees of residual strain in the glass underlying the stress shell. The grooves would thus be analogous to those developed elsewhere on surface created by loss of stress shell — those normal to the rim in equatorial zones, as a "beard" around remnants of stress shell (Cleverly 1979) or as longer meandrine grooves on anterior surfaces (Chapman 1964 Fig. 6).

Retention of parts of the stress shell on australites as large as G13 655 is not usual but occurs occasionally even on specimens of twice the size (Cleverly 1979). The centres of percussion present on each remnant of stress shell and their opposed relationship suggest the possibility that the australite was struck severely on some anvil but Mr Anderton knows of no such incident. Another possibility is that it became firmly clamped by its most upstanding parts in a piece of machinery during clearing of the land or on one of the several later occasions when the land was ploughed and cropped.

The etched patterns are confined to the posterior (primary) surface. The etching was presumably done by soil water, and as with most other types of minor surface sculpture, reflects "built-in" weaknesses such as residual strains or variations in chemical composition arising from earlier events. The relationship here is to primary events because the etch pattern conforms to the boundaries of various round and ovoid features, two of which are truncated by the rim and must therefore have pre-dated secondary events. The only known features of posterior surfaces having centimetre dimensions are flow swirls, and bubble craters. Those present are evidently flow swirls, but seen at a very early stage of delineation. Baker (1972) has described flow swirls on the posterior surface of a large australite from Victoria as "just detectable", but that is because etched schlieren have been partially removed by abrasion until barely visible. The Victorian specimen is very badly weathered and abraded relative to the Ravensthorpe australite.

The up-welling of melt during the brief and violent primary period of australite genesis is generally held responsible for the clear pools central to flow swirls, but would hardly appear adequate to provide complex surrounding patterns of tens of linear compositional bands per millimetre suited ultimately to differential etching. Nor are the bubble pits of posterior surfaces (Figure 1N) likely to have any relationship to the cellular patterns. They are generally one or two orders of size larger than the etched cells.

The etch pattern tends to change outward from purely circumferential through increasing degrees of obliquity to the cellular with random orientation of individual lines or with complex clustering of cells. It is suggested that this pattern arose from tension in a surface skin of glass, the tension becoming decreasingly radial and increasingly random outward from the flow swirls and having its origin in the drag by down-turn of the liquid currents. The etched lines would then have close analogy with the macroscopic V-grooves of australites, which look like tension cracks and occupy the expected locations of tension cracks, but are produced by preferential solution of glass which has residual strain, thus allowing the crack to gape open and the surface to spread. At greater distance from an individual swirl, the surface would come under the conflicting influence of other swirls, resulting in complex patterns. The thin layer of glass susceptible to etching in this way has probably been removed long since by weathering from the surface of most australites.

Considerations of specific gravity make it unlikely that G13 655 differs significantly in its chemistry from other australites found in the general area in spite of considerable differences in their states of weathering. Nor is there any major difference in the form or relationship to the primary body. Thus the remarkably well preserved condition of G13 655 is not likely to have resulted from any property of its own but from those of its environment since arrival on the earth's surface.

It is suggested that the australite G13 655 fell onto and was embedded in a soil through which water circulation was minimal and that it remained there until brought up during clearing of the land or preparation of the soil for cropping some time during the last 15 years. Etching by soil water prior to disinterment produced the complex patterns of the posterior surface, possibly guided by the in-built "memory" of some primary event. Weathering has been insufficient to eliminate the double rim or the low obtuse ridges of the anterior surface. Some artificial damage has occurred.

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