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BROAD OVAL AUSTRALITE CORE FROM MUNTADGIN, WESTERN AUSTRALIA

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ABSTRACT

The combination of unusually large size and relatively unweathered condition of an australite from Muntadgin, Western Australia has made possible an assessment of the form, dimensions and mass of the primary body from which it was developed. The primary body approximated to a triaxial ellipsoid of dimensions *c.* 77 x 62½ x 40 mm and mass *c.* 245 grams. The retention of a small part of the aerothermal stress shell on the anterior surface of flight of the australite is suspected.

INTRODUCTION

An unusually large australite (Australian tektite), registered no. 13 396 in the Western Australian Museum collection, was presented by Mr W.J. Hooper, who found it in early January 1977, at the northern roadside adjoining Avon Loc. 19 196, 6 km east of the railway line at Muntadgin. A nearby borrow pit may have been the source of gravel used on the road and containing the specimen. The site of find has co-ordinates 118°37′E, 31°46′S.

Muntadgin is approximately 260 km north of east from Perth and is within the western of two recognised belts of occurrence of unusually large australites (Cleverly & Scrymgour, 1978); the largest and heaviest of all known australites was recovered near Notting, only 85 km distant (Cleverly, 1974).

DESCRIPTION OF AUSTRALITE

The specimen is a core, the remnant shape after loss of frontal glass by ablation stripping during oriented, hypersonic velocity encounter with the

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earth's atmosphere, and subsequent loss by spalling of the aerothermal stress shell. Terrestrial weathering processes have been responsible for losses represented by a variety of shallow sculptural features, but it is uncertain whether terrestrial processes have also been responsible for the major losses from the anterior surface which resulted in its asymmetrical shape (**Fig. 1**). If those losses were terrestrial, they must have occurred on impact with the earth's surface or shortly afterwards because the scars are as abundantly and deeply etched as other parts of the australite surface. The shape of the specimen is oval in plan view (i.e. when looking down the line of flight) — **Fig. 1A.** The line of flight is taken to be normal to the plane of the rim which defines the posterior limit of the discarded stress shell. The sense of movement is abundantly demonstrated by such features as the flow swirls characteristic of primary surface (the protected posterior surface during atmospheric flight), and the abundance of grooves of U-shaped cross section characterising surface exposed by loss of the frontal aerothermal stress shell. The elongation, defined as length/width, is 1.23; the shape is therefore broad oval in the definition of Fenner (1940).

The dimensions are 69.9 x 56.9 x 35.2 mm measured in the conventional manner with length and width in directions normal to the line of flight and thickness parallel to it.

The rim is generally sharp and it undulates only very gently. An equatorial zone of average width 12 mm is present along one side of the core between the rim and a rather rounded anterior shoulder (**Fig. 1B** and **1C**); the equatorial zone has been eliminated elsewhere by the major losses responsible for the asymmetry of the anterior surface.

The specimen weighs 167.98 g: only 18 heavier australites have been recorded (Cleverly 1974; Cleverly & Scrymgour, 1978; Scrymgour, 1978). The specific gravity, measured by loss of weight in toluene at 20.3°C, is 2.428; this is a typical value for large australites from south-western Australia, for which the specific gravities of 25 previously reported specimens are in the range 2.420-2.439 and the weighted mean is 2.427 (Cleverly *op. cit.*).

Minor sculpture has been extensively developed on the australite surface by etchants in the soil water, and is of considerable variety. The more notable features are as follows. The posterior surface of flight is dominated by an etched, slightly eccentric, ovoid flow swirl (35 x 28 mm). Between that swirl and the rim, there is a small elongate flow swirl (28 x 6 mm) and portions of two others in an area of complex flow lines. The schlieren defining these flow lines have been etched to the extent that a few of them are shallow grooves of U-shaped cross section (U-grooves). The short existing length of equatorial zone carries deeply etched 'flake scars', the sites of detachment of the petaloid portion of the stress shell. Short U-grooves are extensively developed on the anterior surface. When present in the vicinity of the rim, U-grooves have their typical orientation approximately at right angles to it.

A puzzling and quite unusual feature of the anterior surface is a relatively smooth and slightly raised, plateau-like area *c.* 26 x 27 mm, almost completely fringed by short U-grooves (**Fig. 1D**). This relationship of the grooves to a raised area is like their relationship to posterior surface at a rim, and it suggests that the 'plateau' could be a small undiscarded remnant of the stress shell. A large undescribed australite core from Babakin, W.A. (WAM 13 364) supports this interpretation by illustrating the manner in which a fringe of U-grooves may faithfully outline stress shell (**Fig. 2C**).

The rare feature of the Muntadgin australite which justifies its individual description, is the form of the transverse posterior profile, which is quite evidently not the arc of a circle but flatly elliptical (**Fig. 1C**). The specimen is so large that it could be immediately confirmed with a lens measure of 2 cm span that there is increasing curvature in each direction outward from the posterior pole towards the rim.

It is usual to regard oval australites as derivatives of prolate spheroids (which are circular in the transverse section), but such attributions arise from default. The longitudinal posterior profile of many oval australites is quite clearly elliptical, but the transverse profile is shorter, and especially upon small and weathered specimens, its divergence from the arc of a circle is difficult, if not impossible to detect. The simplifying assumption is therefore usually made that the primary body was a prolate spheroid. The shapes of rotating primary masses of melt were determined by an equilibirum between surface tension and centrifugal force, but the centrifugal force acted not only toward the ends of the body but also in the transverse direction, and for that matter, in all other intermediate directions at right angles to the axis of rotation (the vertical axis in **Fig. 1B** & **1C** and **Fig. 2B**). It must be suspected therefore that the transverse section of most australite primary bodies was never closer than approximately circular, i.e. that the so-called prolate spheroids were in reality triaxial, though the fact can seldom be demonstrated from the weathered remnant of profile available. The Muntadgin australite has an exceptional length of transverse profile (nearly 7 cm) and the posterior surface is less weathered than on

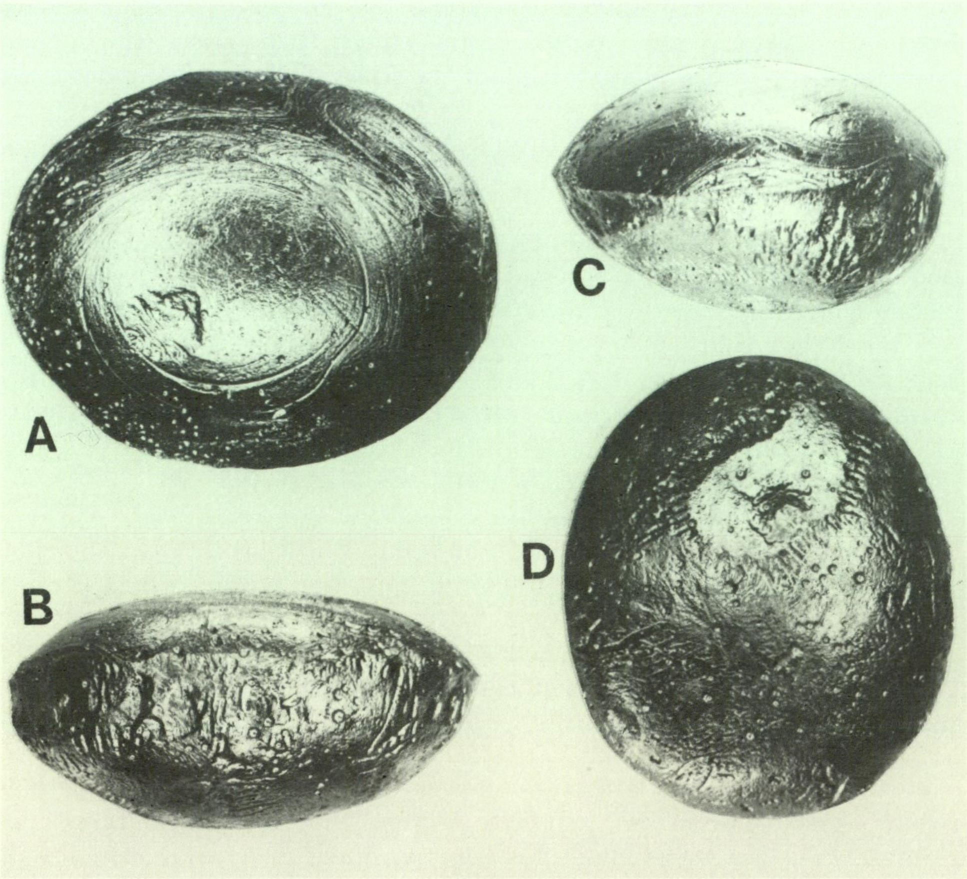

FIG. 1

Broad oval australite core from Muntadgin, W.A. (WAM 13 396)

A: Posterior surface of flight showing large flow swirl defined by etched schlieren and U-grooves, small elongated swirl at upper right and zone of pitting extending around periphery of lower left quadrant. B: Side elevation (upper edge of A) with direction of flight towards bottom of page, showing longitudinal posterior profile, rim, anterior shoulder (left profile only) and part of equatorial zone. Two deeply etched flake scars are visible on the equatorial zone (centre and left of centre) and a few U-grooves are oriented approximately normal to the rim. C: End elevation (right hand end of A) with direction of flight towards bottom of page, showing transverse posterior profile and sharp rim. Anterior shoulder and equatorial zone present only to right side of centre. Portion of the 'plateau' featured in D is visible on the highly asymmetrical anterior surface below at middle of anterior profile. D: Anterior surface viewed somewhat obliquely to line of flight showing the relatively smooth and highly reflecting 'plateau' suspected as remnant of stress shell with surrounding fringe of U-grooves. Upper end of this view is the underside of the right hand end of A. Scales differ slightly but all views are close to natural size.

almost any other large Western Australian australite. This fortunate combination provides a rare opportunity to attempt the reconstruction of a triaxial primary body.

RECONSTRUCTION OF PRIMARY BODY

The reconstruction of a primary (parental) body is made possible by the existence upon an australite of a portion of the primary surface — the protected posterior surface during oriented atmospheric flight. The quality of the reconstruction is necessarily limited by the extent to which terrestrial destructive processes have affected that surface.

The reconstruction of a primary body which approximated to a prolate spheroid is relatively simple because the radius of curvature of the transverse posterior profile is also the semi-minor axis of the elliptical longitudinal profile. The origin of the axes on a longitudinal section (**Fig. 2A**) can be located by first describing an arc with the transverse radius of curvature centred upon the mid-point of the profile, and then drawing a tangent to it parallel to the rim; the semi-minor axis, drawn as a perpendicular from the mid-point of the profile, completes the construction. By substituting the co-ordinates of a point on the best preserved part of the profile in the general equation of the ellipse, the length of the semi-major axis and thence the locations of the foci can be calculated, and an ellipse drawn to test its fit to the profile. Some trial and error may be necessary for reasons explained below.

A modified procedure was used for the Muntadgin specimen, taking advantage of two points: first, that the vertical semi-minor axis is common to both longitudinal and transverse elliptical sections; second, that the elongation (length/width) did not change as the result of secondary (aerodynamic) processes including loss of stress shell, provided that the body was ideally oriented in flight. (Stable orientation in hypersonic velocity flight through the atmosphere requires that the aerodynamic centre — the point towards which the total normal pressure vectors on each half of the anterior surface are convergent — should be on the line of flight and posterior to the centre of mass. This could be achieved by a triaxial ellipsoid if the two longer axes were in a plane normal to the line of flight and the shortest axis was in the line of flight.) When an ellipsoid, whether biaxial or triaxial, was affected by aerodynamic losses posterior to the mid-plane, both length and width were reduced, but it may be readily shown from the equations of the circle and ellipse that the length/width ratio was unaffected. A preliminary indication of ideal orientation is that the halves of each of the longitudinal and transverse posterior profiles are symmetrical about their point of intersection. Reconstruction will subsequently demonstrate whether the vertical axis was indeed the shortest axis or not.

Enlarged longitudinal and transverse profiles of the australite with common mid-point and the rim levels parallel (**Fig. 2B**) were prepared from readings made with a travelling vernier microscope. The ends of the profiles were extended in what appeared to be natural curves to their points of inflexion at the mid-plane of the body, at the same time observing that elongation, which is here the ratio of the semi-major axis of the longitudinal section to the semi-major axis of the transverse section, should be about 1.23. A trial horizontal axis was then drawn at the average level of the points of inflexion and parallel to rim levels. The common semi-minor axis was drawn as a perpendicular from the mid-point of the profiles to locate the origin of the axes. Proceeding then as for the prolate spheroid, trial ellipses were drawn. The first trials were found to fit the profiles with departure (on true scale) of no more than a fraction of a millimetre at any point except along a length of about 1 cm at one end of each of the profiles where the australite surface is closely and deeply pitted.

It would be expected that a small number of trials with different locations of the horizontal axis or slight angular adjustments of the axis for each profile would usually be necessary to achieve a reasonable fit, but no attempt was made to refine the initial result in this instance. Firstly, because although the posterior surface is fairly well preserved, it is not of a quality which justifies fine distinctions. Secondly, and more importantly, because the true shapes of the primary bodies were not simple ellipsoids but far more complex. They closely parallel the series of shapes shown by minute glass bodies in lunar 'soil'. The general equation for the shapes of those bodies, in which surface tension and centrifugal force are related to viscosity, angular velocity and surface curvature, has been discussed by Bastin & French (1970) and by Fulchignoni *et al.* (1971). For bodies with appropriate degrees of elongation, ellipses can approximate closely to the profiles, and the imperfect weathered surfaces of australites do not encourage the mathematical fitting of more highly complex curves.

The primary body had approximate dimensions 77 x 62½ x 40 mm and volume about 101 cm^3 calculated as a triaxial ellipsoid. Assuming that the primary body had the same specific gravity as the remnant core, its mass was *c.* 245 grams. Loss of mass (or volume) from the primary body as the result of secondary and terrestrial processes has therefore been 31%, and the thickness has been reduced by 12%.

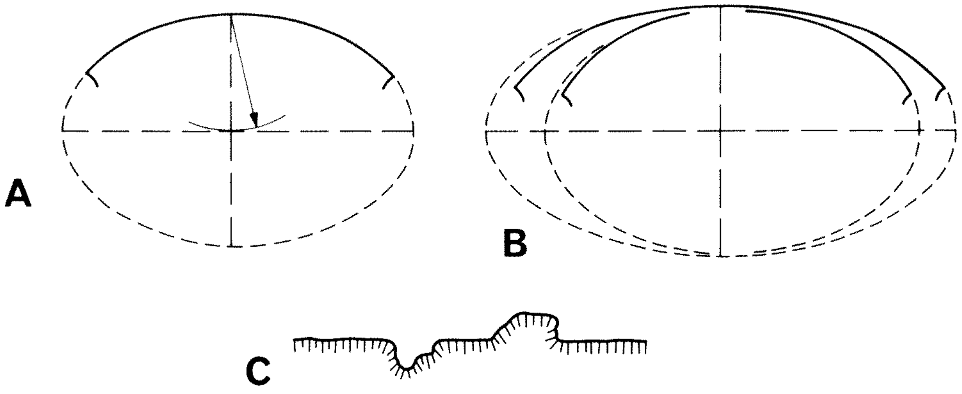

FIG. 2

A: Longitudinal posterior profile of an australite core and notches at rim level (firm line) with reconstruction of longitudinal section of prolate spheroid primary body (for method see text). **B**: Longitudinal and transverse posterior profiles of australite core from Muntadgin (WAM 13 396) and reconstruction of longitudinal and transverse sections of primary body. The misfit of the ellipses has been somewhat exaggerated. About natural size. **C**: 'Unrolled' rim of australite WAM 13 364 from Babakin (heavier line) showing tongue of retained stress shell anterior to general level of rim (pointed towards bottom of page) and shallow embayment of detached glass posterior to general level of rim, with fringe of short U-grooves. Semi-diagrammatic.

DISCUSSION

The loss figures are rather low, even when compared with the primary bodies of 19 other large cores from the same region, which averaged only 46% mass loss and 29% thickness loss (Cleverly, 1974; Table 2). However, when a markedly triaxial body was ideally oriented in flight, it had a larger ratio of frontal area to mass than more closely spherical bodies. It would be more rapidly decelerated and would lose a relatively thin layer of glass as the result of ablation stripping. If the small 'plateau' rising about a millimetre above the general level of the anterior surface is indeed a remnant of stress shell, the shell was likewise unusually thin.

The elongation of the reconstructed primary body is 1.23 as in the australite, but this must be regarded — in spite of the method used — as to some extent fortuitous. For 12 prolate spheroid primary bodies (Cleverly *op. cit.*), the average disagreement between the elongations of the reconstructed primary bodies and of the australites is 4.7%; however, those specimens were generally more weathered than the Muntadgin core.

The primary body of the Muntadgin australite was less massive than the largest representatives of other basic shapes for which I have been able to make estimates with reasonable confidence (**Table 1**). Larger triaxial bodies certainly existed, as for example the primary body of a 195 g australite core from Narrogin or Narembeen (WAM 12 992), but the state of preservation of that specimen precludes calculation as a triaxial body. Opportunities such as that provided by the large and relatively well preserved australite core from Muntadgin rarely arise.

TABLE 1

Masses and dimensions of large australite primary bodies

Shape	**Mass** g	**Dimensions** cm	**Reference**
Sphere	*c.* 380	6.7 diam.	Cleverly (1974)
Oblate spheroid	*c.* 320	7 x 7 x 5.1	Cleverly (1974)
Prolate spheroid	*c.* 910	10.2 x 8.4 x 8.4	Cleverly (1974)
Triaxial ellipsoid	*c.* 245	7.7 x 6.2 x 4.0	This paper
Boat primary body	*c.* 300	9.1 x 4.5 x 4.5	*
Dumbbell primary body	*c.* 300	10.4 x 4.6(4.0) diam.	*

* Estimates for boat and dumbbell bodies calculated from data and illustrations of Baker (1969) and Baker (1966) respectively.

ACKNOWLEDGEMENTS

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