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NIRRANDA STREWNFIELD AUSTRALITES, SOUTH-EAST OF WARRNAMBOOL, WESTERN VICTORIA

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List of Contents

Foreword

The Nirranda Strewnfield australites have been discovered at a time when much additional knowledge of the location, concentration density, fragmentation, etching propensities, specific gravity, shape and size variation, sculpture patterns, &c., of south-western Victorian australites has been accumulated, and can thus be applied to the study of this latest discovery, which embraces a considerable number of different forms of australites from a relatively small concentration centre in the vast Australian tektite strewnfield.

Much of the propounded theory of tektite origin is, of necessity, based largely upon conjecture and supposition. After some 150 years of the study of tektites by renowned scientists in various parts of the world, the tektite question as a whole is still remote from an entirely satisfactory solution. It is with this long background of accumulated fact and theory to hand, associated with an awareness of the important recent advances that have been made in the realm of the aerodynamics of high-speed flow, that the writer feels justified in indicating the need for a detailed study of the geometry of the remarkably symmetrical australite varieties of tektites, and in suggesting that their typical secondary shapes as derived from primary forms can be explained in terms of gas dynamics. It is possible that such an approach may help to take the tektite problem a step further towards an ultimate solution, and at the same time perhaps add something more to the growing field of knowledge relating to the aerodynamics of high-speed flow produced at far greater than ordinary supersonic speeds.

It is the writer's opinion that too much stress has been laid in the past on the idea that australites must have rotated through the earth's atmosphere about an axis, the position of which was parallel to the direction of propagation through the atmosphere. Although rotation is obviously necessary for the initial development of all except the spheres among the primary forms from which the secondary shapes of australites were produced, the likelihood is considered herein that a spinning motion need not have been maintained during the atmospheric phase of earthward flight, i.e. during a phase when the secondary shapes now possessed by australites were impressed upon the original primary shapes.

Introduction

Three hundred and sixty-six australites, which are Australian tektites of late Recent age, were found in January, 1953, along a narrow strip of the south-west Victorian coastline, extending from Childers Cove south-east of Warrnambool, to the Bay of Islands north-west of Peterborough (text figure 1). These australites are registered in the National Museum Rock Collection, Melbourne, as E707 to E1056 and E1099 to E1114.

The strewnfield in which the australites were located, is hereafter referred to as the Nirranda Strewnfield, the name being derived from the post office nearest to the site on which the greatest numbers of australites were found in the district. Nirranda is situated on lat. 38 deg. 30 min. S., and long. 142 deg. 45 min. E., approximately 3 miles inland from the coastline of south-western Victoria, and 18 miles south-east of the City of Warrnambool (text figure 1).

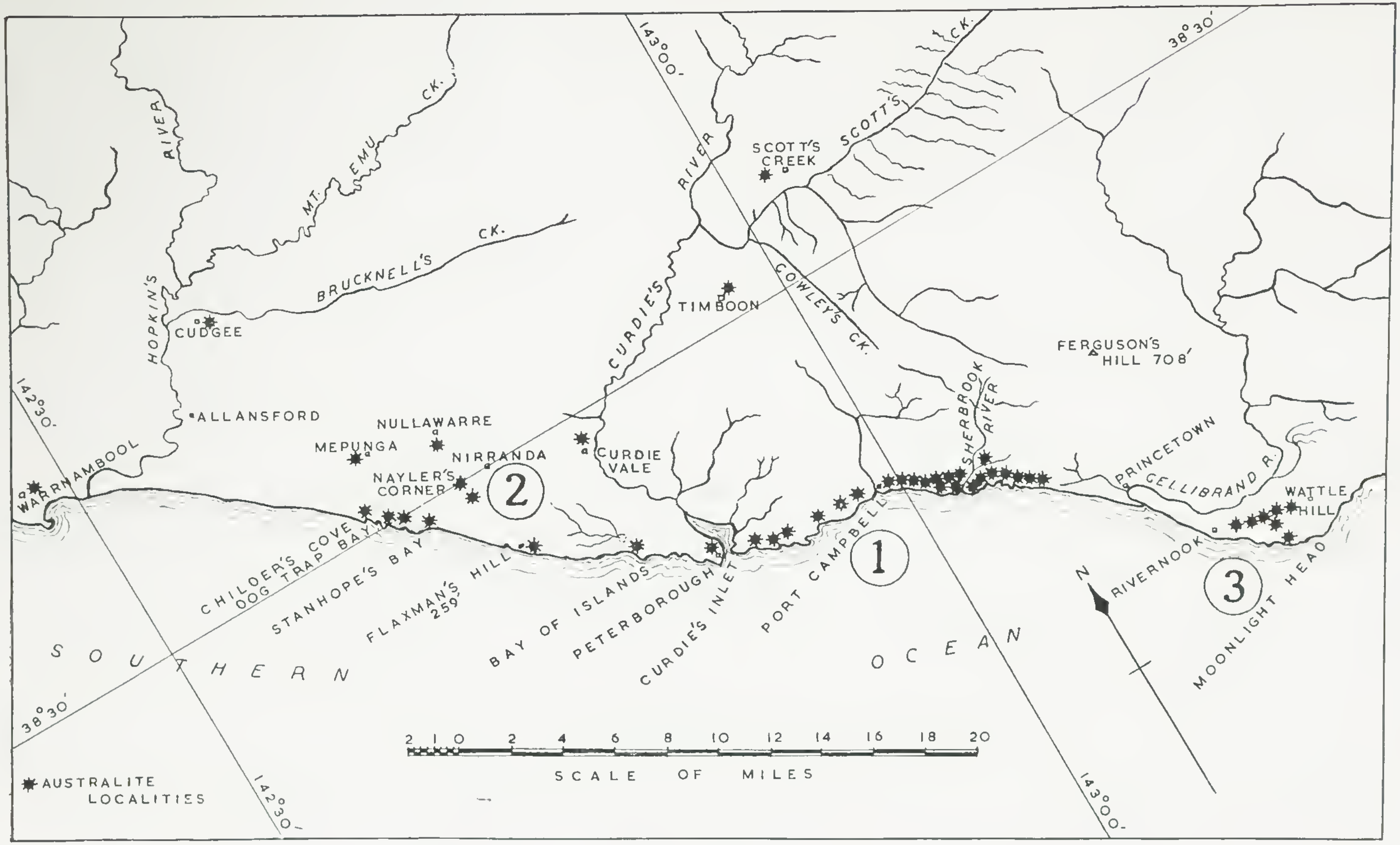

FIGURE 1.

Sketch map of part of the coast of south-western Victoria, extending from Warrnambool in the north-west to Moonlight Head in the south-east.

The asterisks denote different sites from which varying numbers of australites have been obtained.

The three principal strewnfields in this region are indicated by the large figures. No. 1 is the Port Campbell Strewnfield, No. 2 the Nirranda Strewnfield, and No. 3 the Moonlight Head Strewnfield.

Most of the australites from these three strewnfields were located on areas facilitating discovery—areas such as old roads, borrow pits and cliff edges, all relatively free of vegetation, and on areas consisting of naturally bared patches that have been subjected to frequent coastal showers and strong winds, and so are much rain-washed and wind-swept.

In the Nirranda Strewnfield, the majority of the australites were found on such rain-washed and wind-swept patches situated very close to cliff edges. Vegetation, recent soils and the fine to medium size mineral particles have been removed from these patches by wind and by surface run-off of rainwater leaving a veneer of coarser sand in some parts, and a buckshot gravel sprinkled hardened crust in others. Resting upon this hardened crust and coarser sand, which in parts of the strewnfield represents the topmost portion of a former soil horizon, australites have been found in varying numbers, sometimes associated with occasional rounded, partially chipped rocks and numerous flakes of rocks alien to the bedrock of the area. The greater part of the bedrock hereabouts, is Miocene limestone, capped in places with Pleistocene dune limestone. Most of the rock flakes appear to be rejected chips from the process of aboriginal stone implement manufacture. Shell fragments from molluscs used as food by the aborigines, are also a feature of some of the australite-bearing patches. All the geological evidence points to a late Recent age for the australites, substantiating Fenner's (1935, p. 140) belief that australites are "geologically Recent, but historically remote." The precise age is not yet known, but it would not be much more than a few thousand years since the Nirranda Strewnfield australites first arrived upon the surface of the earth. In both the Nirranda and the Port Campbell Strewnfields, the australites occur above an old soil horizon, and in parts of the Port Campbell Strewnfield, a few australites have been unearthed from the top 6 inches of recent soils.

Forty-two per cent. of the australites recently found in the Nirranda Strewnfield are complete or nearly complete forms. Of the remainder, 54 per cent. are composed largely of fragments that can be specifically recognized as coming from the body portions of australites, and among this total are a few nondescript fragments; 4 per cent. of the total are flange fragments. None of the fragments fitted one another, hence each fragment is considered to represent a portion of a different individual australite. The percentage of complete or nearly complete australites that were found with their anterior surfaces facing upwards, is approximately nine times as great as the percentage found to have the posterior surface upwards. The anterior surfaces pointed earthwards during the atmospheric phase of flight, and since 87·5 per cent. were found on the ground with the anterior surfaces facing away from the earth, it is apparent that the stable position of rest of australites upon the earth's surface is the reverse to their stable position of propagation through the earth's atmosphere.

On the whole, the Nirranda Strewnfield australites are considerably more abraded than the majority from the Port Campbell Strewnfield, and moreover, they are not quite as well preserved as most of the Moonlight Head Strewnfield australites. As a consequence of their worn character, it is possible that some of the australite fragments in the Nirranda Strewnfield may have come from the same original complete form, but having been fragmented a long time ago, they are now largely too abraded and etched to be matched with any degree of certainty. The fact that some of these australites and some of the fragments have a fresher appearance than others is due to their having been buried longer under a protective cover of surface soil, while others have been exposed for longer periods to the abrasive action of wind-borne sand and other erosive agents.

This article deals as comprehensively as has been possible under present circumstances, with the location, distribution, concentration density, physical properties, optical properties, chemical composition, sculpture, shapes, symmetry, statistics and ultra-supersonic flight effects of the recently collected Nirranda Strewnfield australites. Many of these attributes are compared and contrasted with those that have been described for the Port Campbell and Moonlight Head Strewnfields in south-western Victoria, and with those for the Charlotte Waters Strewnfield in Central Australia, and the Nullarbor Plain Strewnfield extending east and west across the southern border between South Australia and Western Australia. The statistics of the Nirranda collection of australites, involving such factors as numbers, dimensions, specific gravities, weights and radii of curvature, are herein presented as frequency polygons and scatter diagrams in order to obviate the use of many cumbersome tables.

Distribution and Concentration

The numbers of australites recovered from various localities in the Nirranda Strewnfield are as follows:—

Locality	Number
Childers Cove	8
Nayler's Corner, Nirranda	3
North-east end of Bay of Islands, Peterborough	3
Half a mile south-east of Flaxman's Hill	11
North-west corner of Dog Trap Bay ..	1
Middle of Dog Trap Bay	2
North-east corner of Dog Trap Bay ..	5
Three-quarters of a mile south-east of Nayler's Corner	1
"Errawallun" homestead, 1 mile south of Nullawarre P.O. (donated by Mrs. A. Mathieson)	1
North-east corner of Stanhope's Bay ..	331
Total	366

Earlier discoveries of a small number of australites from other localities in this region are known from specimens in the National Museum Collection, Melbourne. One is from Cudgee, one from Narrarnhuddut, Scott's Creek, and one from Warrnambool. Three others from the Warrnambool District, formerly in the Warrnambool Museum Collection, are now lodged in the collection of the South Australian Museum, Adelaide. Another one was recorded from Mepunga by Dunn (1912, p. 12). One collected from Curdie's Inlet some years ago has been chemically analysed (Summers, 1913, p. 190). A few others known to have been collected in recent years include two from Timboon and two from Curdie Vale.

For comparison with these numbers in the Nirranda Strewnfield, the numbers are given for neighbouring strewnfields. Thus twenty australites have been discovered west and south-west of Wattle Hill in the Moonlight Head Strewnfield (15 described by Baker, 1950, p. 35), and 1,487 australites are known from the stretch of coast extending from 1 mile south-east of Curdie's Inlet, through Port Campbell township to 3 miles south-east of the Sherbrook River in the Port Campbell Strewnfield (Baker, 1937, 1940*a*, 1944, 1946, and Baker and Forster, 1943).

Since the initial discovery of 331 australites at Stanhope's Bay, a further 223 specimens comprising complete forms and fragments of australites, have been collected from this site, and donated to the National Museum of Victoria over the past year and a half, by Colin Drake of Warrnambool and Brian Mansbridge of Allansford, Victoria.

The Nirranda Strewnfield has its greatest concentration of australites near Stanhope's Bay, where 91 per cent. of the total for the field were discovered. Three hundred and thirty-one australites, including complete forms, nearly complete forms and separate fragments were found on a small area approximately 350 yards by 200 yards in size. This represents the most densely populated australite centre so far known in south-western Victoria and, for that matter, is probably also the most densely concentrated centre in the whole of Australia. Three hundred and ten of the 331 australites from this site near Stanhope's Bay were the outcome of four hours searching by E. D. Gill (59), A. E. Gill (108), M. Gill (8), M. K. Baker (55) and G. Baker (80) in January, 1953. The remaining 21 from this small area were subsequently collected by R. T. M. Pescott (9) and E. D. Gill (12).

Comparison with Concentrations in Other Australian Strewnfields.

Some idea of the comparative population density of australites in various parts of Australia can be obtained by combining the Moonlight Head–Port Campbell–Nirranda Strewnfields, and comparing the result with that of two other areas—Charlotte Waters and the Nullarbor Plain—from which large collections have been made over extensive tracts of territory. The areas of distribution, numbers found and concentration densities for these three major strewnfields, are compared in Table I.

TABLE I.

—	Moonlight Head Port Campbell Nirranda Strewnfields.	Charlotte Waters Strewnfield.	Nullarbor Plain Strewnfield.
Area embracing discovery sites	150 square miles ..	8,000 to 9,000 square miles	30,000 square miles
Numbers found	1,877	7,184	3,920
Concentration density	12·5 per square mile	0·8 per square mile	0·13 per square mile

Outlying areas at Scott's Creek, Timboon, Cudgee and Warrnambool have been excluded from the calculations for the Moonlight Head–Port Campbell–Nirranda Strewnfields, and the area considered is thus a strip of coast 50 miles long by 3 miles wide. The specimens comprise the Baker Collection of 1,352 Port Campbell australites and 20 Moonlight Head australites, 83 from Port Campbell in the Melbourne University Geological Collection, 366 Nirranda Strewnfield australites in the National Museum Collection, Melbourne, and a few in private collections.

The Charlotte Waters Strewnfield australites comprise the Kennett Collection described by Fenner (1940, p. 305) and the Nullarbor Plain Strewnfield australites comprise the Shaw Collection also described by Fenner (1934, p. 62).

The comparative values shown in Table I for these three major strewnfields indicate that the greater concentration of australites per square mile is in south-western Victoria. Smaller centres within this region are even more densely populated than is indicated by the overall figures in column 1, Table I, for example, the occurrence of 331 australites over an area 350 yards by 200 yards in extent at the Stanhope's Bay tektite site. This observation relating to the density concentration of australites has even greater significance when it is considered that opportunities for successful searching in the relatively well-vegetated region of south-western Victoria are not as great as in the sparsely vegetated gibber regions and dry plains of the other two strewnfields included in this comparison.

In the three south-western Victorian strewnfields, the present stream patterns (cf. text figure 1) bear little or no relationship to australite distribution, and there is no evidence to indicate spreading or concentration by former streams. In the main, it is considered that the majority of the australites were recovered from more or less the positions where they originally fell as extra-terrestrial bodies. However, it cannot be assessed how much the Australian aborigines, nor how much native birds such as emus and bush turkeys have been concerned in australite distribution in these parts. Australites were utilized for various purposes by the aborigines, and have been found in the gizzards of emus and bush turkeys. There is evidence of the continued use of australites by living tribes of Australian aborigines. A verbal communication from Mr. H. R. Balfour of Toorak, Victoria, discloses that the aborigines of the Woomera region in Central Australia call australites "emu-stones," by virtue of the purpose for which they are employed. Mr. Balfour states that the australites are wrapped up in balls of feathers by the aborigines, and these are then thrown towards flocks of emus. Being especially endowed with a natural inquisitiveness, the emus approach these objects for closer inspection. While absorbed in their investigation, they are speared by the aborigines. Their gizzards often contain a number of stones, usually black in colour, a large proportion of which are frequently australites. This practice has been a feature of aboriginal food-hunting for many years past, and it therefore seems possible that occasional small concentrations of worn and broken australites could well have been brought about by some such, or allied aboriginal custom, particularly when it is recalled that aboriginal chipped flints and shell-food remnants are common associates of the australite-sprinkled areas along the coastline of south-western Victoria. The worn character of these australites is also partly due to minor amounts of sand-blasting where exposed on the wind-swept patches, while some of the wear on some of the australites may have been due to "carry polish" during utilization by the aborigines.

On a barren patch of ground near Childers Cove, from which eight australites were recovered, are numerous shell fragments and chipped flints testifying to previous occupation by the aborigines. At Nayler's Corner, 2 miles inland from the coast, where three australites were found, there was no evidence to indicate aboriginal occupation. This site is a small triangular patch of ground at a road junction, and the area has evidently been bared by road-making activities and stripped of the top few inches of soil, thus exposing the australites. At several of the other sites where australites were discovered, namely near Flaxman's Hill, Dog Trap Bay and the Bay of Islands near Peterborough, there is further evidence in the form of occasional chipped flints and shell fragments that these coastal areas were within the region of aboriginal middens and camping grounds.

Forms of Australites Represented

The collection of australites from the Nirranda Strewnfield contains a generally representative variety of the usual australite shapes recovered from other strewnfields in Australia, but shows minor variations in some respects from the Port Campbell and Moonlight Head Strewnfields further to the south-east. The collection contains a greater percentage of fragments of hollow forms of australites (cf. Plate II) than so far encountered in either the Port Campbell or the Moonlight Head Strewnfields, and also a greater percentage of lens-shaped forms (cf. Plate I figures 3 and 7). Like the Moonlight Head Strewnfield australites, those from the Nirranda Strewnfield show a complete absence of small forms such as flat circular discs, bowl-shaped forms and oval plate-like forms (forms that were especially searched for); this is in contrast to the Port Campbell Strewnfield from which a number of these particular shapes have been recovered (cf. Baker, 1937, 1940*a*, 1946). Aberrant forms (cf. Baker, 1946) are also wanting in the Nirranda, as in the Moonlight Head Strewnfield.

External features shown by the australites from the Nirranda Strewnfield are typical in consisting of bubble-pitted posterior (back) surfaces (see Plates I to IV) and of flow-ridged, flow-lined anterior (front) surfaces carrying few bubble pits and etch marks (see Plates I, II and IV). Some of the forms are flanged (see Plates I and II).

The percentage occurrence and the numbers of the various australite shape groups represented in the Nirranda Strewnfield, are compared in Table II with those from the Port Campbell and Moonlight Head Strewnfields.

Owing to low numbers in the various shape groups of the Moonlight Head Strewnfield australites, and the fact that less than half the number of shape groups is represented, despite careful searching of the area for more examples, the percentage values for several of the shape groups may be too high. Populations are sufficiently large for statistical significance in all of the Port Campbell and most of the Nirranda Strewnfield australite shape groups.

The percentage distributions of shape groups and fragments among the australite populations of the Charlotte Waters and the Nullarbor Plain Strewnfields respectively have been calculated from the numbers in each shape group and the number of fragments listed by Fenner (1934, 1940) for the Shaw and Kennett collections. The results are compared in Table III with the percentage distributions obtained by combining the total numbers in each shape group and fragment group for the three strewnfields in south-western Victoria. Slight re-arrangements have been made to Fenner's lists for the Shaw and Kennett collections in order to conform with the grouping of forms and fragments from the combined Nirranda–Port Campbell–Moonlight Head Strewnfields.

TABLE II.

Shape Group.	Nirranda Strewnfield.		Port Campbell Strewnfield.		Moonlight Head Strewnfield.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Buttons	32	8·7	215	17·0	6	30·0
Hollow button	1	0·3	..	..	..	..
Lenes	55	15·0	57	3·9	2	10·0
Ovals	37	10·1	100	7·0	3	15·0
Boats	9	2·5	10	2·7	..	..
Canoes	2	0·5	12	0·8	..	..
Dumb-bells	3	0·8	16	1·1	..	..
Teardrops	2	0·5	21	1·5	..	..
Round cores ("bungs") ..	1	1·1	20	1·4	..	..
Elongate cores	10	2·8	12	0·8	1	5·0
Round discs	..	..	11	1·0	..	..
Oval plates	..	..	10	0·7	..	..
Bowls	..	..	9	0·6	..	..
Aberrants	..	..	10	0·7	..	..
Round form fragments* ..	127	34·7	231	16·2	2	10·0
Elongate form fragments ..	19	5·2	111	7·9	2	10·0
Hollow form fragments ..	10	2·8	23	1·6	..	..
Complete flanges (detached)	2	0·5	18	1·2	..	..
Flange fragments ..	11	3·8	313	21·7	1	5·0
Nondescript fragments ..	39	10·7	177	12·2	3	15·0
Totals	366†	100·0	1,115‡	100·0	20	100·0

KEY TO TABLE II.

* The term "round forms" throughout this article refers to australites that are circular in plan aspect (cf. text figure 13 and Plates I and II).

† Four other examples known, but not classified (also 223 examples recently discovered at Stanhope's Bay).

‡ Forty-two other examples known but not classified.

Table III serves to stress certain trends that are common among australites generally. These trends are—(i) the rarity of such forms as the hollow buttons, the canoes, dumb-bells, cores, round discs, oval plates, bowls and aberrants among the complete forms, (ii) the rarity of flanges detached as complete entities (cf. Plate I, figures 4 and 5) from their parent forms, (iii) the preponderance of round forms such as buttons and particularly lenses, over elongated forms (Note: Dunn (1912, p. 3) found that 66 per cent. of the australites from Mt. William in the Grampians, Victoria, were "button-shaped or forms produced from them"), and (iv) significant variations from strewnfield to strewnfield in the percentage populations of some of the various shape groups. Such a variation is most marked amongst the group of lens-shaped australites. Variation in the groups of elongated australites, however, is of no marked significance. The significant variations from locality to locality in the lens

TABLE III.

Shape Group.	Combined South-West Victorian Strewnfields.		Nullarbor Plain Strewnfield.		Charlotte Waters Strewnfield.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Buttons	283	15·5	275	7·0	686	9·6
Hollow button	1	0·01	..	..	..	..
Lenses	111	6·2	1,038	26·6	3,243	45·2
Ovals	140	7·7	168	4·3	740	10·3
Boats	49	2·7	171	4·4	323	4·5
Canoes	14	0·8	81	2·0	10	0·1
Dumb-bells	19	1·0	70	1·8	67	0·9
Teardrops	23	1·3	131	3·4	62	0·8
Round cores (" bungs ") ..	24	1·3	..	..	6	0·08
Elongate cores	23	1·3	..	..	..	..
Round discs	14	0·8	56	1·4	..	..
Oval plates	10	0·5	..	..	10	0·1
Bowls (or " helmets ") ..	9	0·5	..	..	2	0·02
Aberrants	10	0·5	..	..	91	1·3
Round form fragments ..	363	19·8	954	24·3	273	3·8
Elongate form fragments ..	135	7·4	603	15·4	484	6·7
Hollow form fragments ..	33	1·8	28	0·7	11	0·2
Complete flanges (detached)	20	1·1	..	..	..	..
Flange fragments ..	328	17·9	..	..	1	..
Nondescript fragments ..	219	11·9	340	8·7	1,175	16·4
Totals	1,831*	100·0	3,920	100·0	7,184	100·0

* Forty-six other examples known, but not classified, and hence not included in the total (also 223 subsequently discovered at Stanhope's Bay).

group, is largely a reflection of the state of preservation of australites. A greater number of round forms become classified with the lens group, the more the button-shaped australites are eroded and lose all traces of their flanges. Being better preserved, there is thus a greater percentage of buttons than lenses in the combined South-western Victorian Strewnfields (Table III). Being much more abraded, the position is reversed in both the Nullarbor Plain and the Charlotte Waters Strewnfields.

Percentage variations among the groups of fragments of the australites are partly a reflection of variations of the percentage populations of complete forms from which they were derived, but also may be influenced by two other factors, namely (i) as yet incomplete field sampling in some of the strewnfields, and (ii) variations in the processes of erosion from strewnfield to strewnfield. The search for australites in the Nirranda Strewnfield, as in the Port Campbell and Moonlight Head Strewnfields, has been as thorough as possible in the time available. All fragments of all visible sizes and shapes, as well as all complete and nearly complete forms exposed to view were collected, hence the collection is as representative as possible. Herein may lie the explanation of the abundance of flange fragments in the three combined strewnfields in south-western Victoria, compared with their absence from the Nullarbor Plain Strewnfield and the record of one only among 7,184 specimens collected from the Charlotte Waters Strewnfield. Since in each collection there are numerous specimens that must have possessed flanges originally, it is doubtful if all flange fragments in one large strewnfield (Nullarbor Plain), and all but one in another large strewnfield (Charlotte Waters), were destroyed by erosion, while so many (nearly 18 per cent. of the total number of australites found) remained in a third large strewnfield (South-western Victoria). It would be even more doubtful that the flanges were all lost before the australites landed on the surface of the earth, in the strewnfields from which they are not recorded. It is therefore likely that flange fragments have either been overlooked or discarded in collecting from the Nullarbor Plain and Charlotte Waters Strewnfields.

Complete Forms

The lens-shaped group (Plate I, figures 3 and 7) is the most abundantly populated shape group among the Nirranda Strewnfield australites, followed by oval-shaped and button-shaped forms (see Table II). Together, these three shape groups contain 80 per cent. of the complete and nearly complete australites discovered in this strewnfield. Except where much abraded, the various individuals of each shape group reveal similarities to most other properties possessed by australites described from a number of localities in Australia. Variations in weight, size and specific gravity are shown in Table IV and in text figures 2 to 11.

Only three of the button-shaped forms (cf. Plate I, figures 1 and 2) and one oval-shaped form are complete in possessing the entire flange and entire body portion preserved. The entire flange is still attached to the body portions of the button-shaped forms (E766, E818, E1016), but the complete oval-shaped form (reg. no. E836) was found *in situ* as three pieces—complete flange (detached) and two halves of the body portion—which all unite to constitute a complete oval with flange. The pieces were partially, but loosely embedded in soil, with the anterior surface exposed to view.

Several of the button-shaped forms still retain over one-quarter and under two-thirds of the flange still attached to the body portion (cf. Plate I, figure 6), and a number possess attached minute flange remnants (Plate I, figure 8) that serve to indicate the original shape group of the australite. A few forms that might normally have been classified with the lens-shaped group of australites, reveal, on closer inspection with a low power hand lens, vestiges of smooth areas at the edges of the posterior surfaces; these are referred to as "flange bands." The flange bands represent the original surfaces of union between flange and body, and hence round forms possessing them were australite buttons and not lenses. These bands are usually 1 to 2 mm. wide, being a millimetre or so narrower than the average width of the flanges themselves (cf. text figure 6) as measured across their posterior surfaces. Freshly broken away flanges leave an annular band around the equatorial edge of the posterior surface of originally flanged australites. When not excessively bubble-pitted, this band shows a higher vitreous lustre than other parts of the posterior surface. On weathering, however, it becomes dulled and etched, and may in time become almost obliterated and practically indistinguishable as a determinating feature. Under these conditions, the remaining body portion becomes, to all intents and purposes, a member of the lens-shaped group of australites. Where such degrees of wear have been attained, it thus becomes virtually impossible to distinguish lenses derived by loss of material during flight through the atmosphere, from the lenses derived from buttons by loss of all vestiges of flanges due to agents of weathering acting upon them after landing upon the earth's surface.

Many of the Nirranda Strewnfield australites that are grouped as oval-shaped, have outlines in plan aspect that are not far removed from the button- and lens-shaped forms which are circular in plan. Variations of as little as 1 mm. and up to 2 mm. between the two diameters of such forms, seem to be sufficient to warrant their classification with the oval group, especially where the forms are as small as 10 mm. (or less) across, when a difference of 1 mm. between the two diameters constitutes 10 per cent. (sometimes up to 16 per cent.) of the total measurements. In such forms, differences in the two diameters are not due to subsequent erosion, since many of them still retain flange remnants, indicating that the edges of the body portions, across which the measurements were made, have not been differentially worn. Few of the ovals possess well-developed flanges, many show well-marked rims; one example only has a complete flange (E836), and one shows evidence of the rim being extended outwards in the initial stages of flange formation (see Plate IV, figure 24).

Among the more elongated forms of the Nirranda australites, one of the canoe-shaped forms (Plate IV, figures 17-19) is larger than the upper limits (30 mm.) set out by Fenner (1940, p. 313) for this group. The specimen is 31·5 mm. long, and is the largest known canoe-shaped australite so far recorded from the Australian tektite strewnfield.

The teardrop-shaped forms (cf. Plate IV, figure 22) are rather worn, and have lost the greater part of the "tail" portions. The dumb-bell (Plate IV, figure 20), teardrop and boat-shaped (Plate IV, figure 21) groups contain forms that are of medium to small size compared with some examples from other Australian strewnfields.

Cores (Plate III), which constitute some 9 per cent of the Nirranda Strewnfield australites, are in the proportion of 2 elongate cores to 1 round core. Round and elongate cores have been described elsewhere (Baker, 1940*b*, p. 492), and some of the examples from the Nirranda Strewnfield show comparable and characteristic flaked equatorial zones, partly modified by secondary flaking processes resulting from agencies acting upon them while they lay upon the earth's surface. In their initial formation, however, it is believed that these flaked equatorial zones were developed by fusion stripping and perhaps some ablation during atmospheric flight.

Fragments of Various Forms.

Among the groups of the fragments of australites, those from round forms consist of pieces broken from (i) equatorial regions of buttons, and thus show flange remnants or traces of the flange band, sometimes a little of both, (ii) the central core or body portions of buttons and lenses, (iii) posterior surfaces of buttons and lenses, and (iv) anterior surfaces of buttons and lenses.

Elongate-form fracture fragments consist of pieces showing indisputable evidence of derivation from oval-, boat- and dumb-bell-shaped australites. No fragments were found of either teardrop- or canoe-shaped forms. Occasional smaller fragments grouped with the round-form fragments might have come from the body portions of certain elongate forms of larger size, but since there is nothing to indicate this, such fragments are classed with the round-form fragments on the grounds that round forms comprise the greatest populations among australites, and hence should provide greater numbers of fragments on fracturing.

The largest core fragment in the Nirranda collection of australites, is reg. no. E795, which weighs 23·92 grams, and would, on reconstruction, represent a large elongate core measuring 66 x 35 x 19 mm. Such a form would weigh approximately 96 grams, and would thus have been heavier, and larger, than the biggest complete form (reg. no. E922 (Plate III, figure 16) weighing 55 grams) in the collection.

Most of the flange fragments provide evidence of having been originally attached to button-shaped australites. Two are complete or nearly complete flanges (Plate I, figures 4 and 5) detached entire from their parent button-shaped forms; their diameters, &c., are set out in Table IV. Only one flange fragment, constituting one half of the original, provides adequate proof of derivation from an oval-shaped australite. Its dimensions are—25·5 mm. long and 20 mm. across, while its width measured over the posterior surface is 2·5 mm. The detachment of large portions of flanges and of complete flanges from their respective parent forms, is brought about partly by etching, and partly by weakening of the contacts with body portions by various means. The detached flanges become reduced in size by impact with other objects on the ground during surface run-off drainage; at the same time, small fragments are fractured from certain parts of flanged australites, while more firmly attached portions of the flanges remain on the parent form (cf. Plate I, figure 6).

The hollow forms of australites in the Nirranda Strewnfield were all broken on discovery, some to much greater extents than others. Some have been shattered to form large, concavo-convex fragments resembling broken fossilized egg-shells of

Aepyornis. Others are only broken on one surface (Plate II, figure 11), or merely punctured like the example figured in Plate II, figures 9 and 10, but still revealing the original form of the hollow australite. Ten fragments of hollow forms were discovered, and two nearly complete hollow forms. One (Plate II, figures 9 and 10), with a small hole leading inwards from the anterior surface contained abundant fine sand and clay constituents that had filtered into the internal cavity. The cubical contents of the internal bubble contained by this hollow form have been determined as 1·18 cc. by introducing a good wetting fluid (toluene) through the small hole by means of a fine capillary tube, and weighing the australite with and without the fluid, on an air-damped balance. It cannot be decisively determined whether the fracture fragments from the hollow australites were broken by impact on landing, or by subsequent natural effects (or by accident) while resting upon the earth's surface. Judged from the degree of erosion shown by the fragments, breakage evidently occurred a long time ago; the same applies to the more complete hollow button figured on Plate II, figure 11. The almost complete hollow button (Plate II, figures 9 and 10) was apparently punctured by processes involving etching to a great extent, for the reason that the outer end of the opening leading into the internal cavity occurs 2·5 mm. below the external front polar regions of the anterior surface, and is situated at the junction of several radiating grooves (cf. Plate II, figure 9). Two of the hollow form fragments are large enough to furnish the dimensions of the original internal bubbles. One of these was 14·7 mm. across, and the other, 16·6 mm. The cubical contents of these bubbles would have been 1·64 cc. and 1·88 cc. respectively.

The thickness of the bubble walls of the hollow form fragments varies from 0·5 mm. to 7·0 mm. Fragments broken from the equatorial regions (E714), where the anterior surface meets the posterior surface, usually show a marked thickening of the bubble walls in the region where flanges usually form on solid australites. Flanges are usually the exception rather than the rule on hollow australites from other parts of Australia, so that it is of interest to find remnants of well-developed flanges attached to two hollow forms (Plate II, figures 9, 10 and 11) among the Nirranda Strewnfield australites. Fragments from forms belonging to shape groups other than the hollow, button-like examples described, also contain bubbles of more than usual size. These range in size from 4 mm. as in reg. no. E796, and upwards in diameter. One of the hollow form fragments (E830) shows evidence of inward collapse of part of the bubble walls. The collapse occurred in the walls of the internal bubble nearest the anterior surface of the australite, at a time when secondary fusion and ablation had resulted in reduction in thickness of the anterior walls, and so partial collapse of the bubble occurred during atmospheric flight. The plastic glass in the region of collapse became inrolled on to the inner walls of the internal bubble, but solidified before much flowage occurred.

Size, Weight and Specific Gravity of the Members of the Various Shape Groups.

Where sufficiently well-preserved to provide the necessary information, each australite in the collection has been measured to ascertain (i) the depth and diameter of forms that are circular in plan aspect, (ii) the length, width and depth values of elongated forms, and (iii) the width values of flanges, including those still attached to body portions, and detached flange fragments. All the specimens, whether complete, nearly complete or fragmentary, have, after cleaning, been separately weighed in air on an air-damped chemical balance. The specific gravity value of each has been determined in toluene at 20° C., the results listed in Table IV being recalculated values for air-free, distilled water.

The size measurements, the weight values and the specific gravity values are given in Table IV for the different shape groups only. Individual values for the different australites found in the Nirranda Strewnfield have been plotted in the frequency polygons and scatter diagrams shown in text figures 2 to 11.

Size

All values obtained from the measurement of depth, diameter, length and width of the Nirranda Strewnfield australites are recorded to the nearest 0·5 mm. in Table IV. Each depth value represents the maximum thickness measured between the front and back poles of the curved anterior and posterior surfaces respectively (cf. text figure 19). Table IV. reveals that the largest complete forms are in the core group, the smallest in the lens-shaped group.

The relationships betwen the depths and diameters of the round australites (i.e. buttons, lenses and round cores) are indicated in figure 2.

TABLE IV.

Weight, Specific Gravity and Size Values of Nirranda Strewnfield Australites.

Shape Group.	General Classification.	Number Measured.	Range of Weight in Grams.	Average Weight in Grams.	Range of Specific Gravity.	Average Specific Gravity.	Range of Depth in mm.	Average Depth in mm.	Range of Diameter in mm.	Average Diameter in mm.	Range of Length in mm.	Average Length in mm.	Range of Width in mm.	Average Width in mm.	Range of Flange Width in mm.	Average Flange Width in mm.
COMPLETE FORMS																
Buttons	A1	32	1·424–4·390	2·662	2·38–2·45	2·407	6–15	8·5	9–23·5	13	..	..	..	..	2–3	2·5
Hollow Button ..	..	1	..	19·283	..	2·398	..	19·5	..	33	..	..	..	..	..	3
Lenses	A2	55	0·247–3·409	1·395	2·37–2·47	2·409	2–13·5	6·5	7–22·5	12·5	..	..	..	..	..	..
Ovals	A3	37	0·308–4·436	1·344	2·39–2·46	2·413	3–12	6	..	..	7·5–22·5	13	6–21	11	..	2
Boats	A4	9	0·876–3·284	1·742	2·38–2·45	2·399	4·5–7	6	..	..	14–30	18·5	9–12·5	11	..	..
Canoes	A5	2	1·502–3·254	2·378	2·39–2·41	2·397	6·5–8	7	..	..	23–31·5	27	10–13	11·5		..
Dumb-bells ..	A6	3	0·839–1·718	1·223	2·41–2·42	2·415	3–5	4	..	..	21–26·5	24·5	5–8·5	7		..
Teardrops ..	A7	2	1·123–2·013	1·568	2·40–2·43	2·415	1–1·5 (tail) 7–8 (body)	7·5	..	..	17–21	19	3–4 (tail) 10 (body)	3·5 (tail) 10 (body)		..
Cores—round ..	..	4	3·894–10·176	6·736	2·39–2·43	2·406	10–15	13	16–24	20	..	..	..			
Cores—elongate ..	..	10	1·309–55·100	11·157	2·40–2·46	2·419	6–15·5	13	..	..	14–39	22·5	10·5–34	17·5		..
FRAGMENTS																
Fragments of round forms (*a*) .	B1	127	0·274–4·226	1·210	2·36–2·47	2·408	(*e*) 5·5–14	(*e*) 10	(*f*) 13·5–25	(*f*) 18	..				1·5–4	3
Fragments of elongate forms .. .	B2	19	0·977–23·920	3·282	2·39–2·44	2·406	(*c*) 6·5–19	(*c*) 9	..	..	(*h*) 22–60	(*h*) 35	(*d*) 10–35	(*d*) 14		2
Fragments of hollow forms	..	10	0·656–7·792	2·954	2·38–2·41	2·393	..	..	(*g*) 20–30	(*g*) 25·5	..		..			1·5
Detached complete flanges	B1	2	0·538–1·073	0·806	..	2·391	..	..	17–23	20						
Flange fragments .	B1	14	0·130–0·553	0·264	2·38–2·43	2·407	..	..	..		..				2–5	
Nondescript fragments	B3	39	0·090–3·230	0·563	2·38–2·47	2·416										
Total	..	366	0·090–55·100	1·826	2·36–2·47	2·409	2–19		7–30	..	7·5–60		5–35		(*h*) [illegible]	[illegible]

Total Weight 668·396 gms.

(*a*) Pieces from body and pieces of body + flange ; (*b*) 70 specimens ; (*c*) 17 specimens ; (*d*) 16 specimens ; (*e*) 36 specimens ; (*f*) 26 specimens ; (*g*) [illegible] specimens ; (*h*) 7 specimens. higher value obtained by reconstruction.

The distribution (text figure 2) is confined to a relatively narrow zone above the line of unit gradient, showing that diameter is always greater than depth in any given round form. There is revealed a transitional increase in both depth and

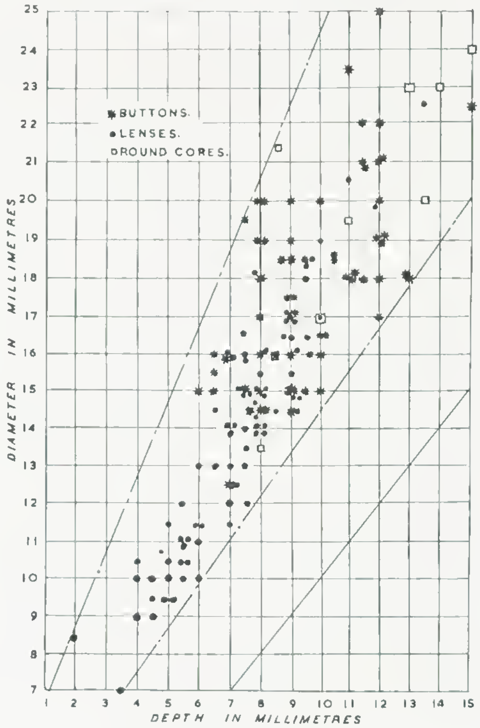

FIGURE 2.

Scatter diagram showing depth–diameter relationships for round forms of the Nirranda Strewnfield australites.

diameter from lenses, through buttons and smaller cores, to the larger cores, with depth increasing as diameter increases. A noteworthy feature of the distribution is that a number of forms with the same diameter have different depth values, and a number with the same depth have different diameter values. This relationship holds for different values of both depth and diameter. There are, for example, 17 buttons and lenses having the same diameter of 15 mm., but depth variability of from 6 to 10 mm., indicating that similar original forms have been ablated to different degrees to produce secondary shapes of the same ultimate diameter and different depths. There are also 24 buttons and lenses with the same depth value of 9 mm., but with diameters varying from 14·5 mm. to 20 mm., thus indicating that original forms of slightly different size have been ablated to different degrees in order to produce secondary shapes of the same ultimate depth. The indications of the production of end members agreeing with one another in certain measurements, from primary forms of originally different size, receive further support from a study of the relationships of the depths and diameters to the radii of curvature of the back and front surfaces respectively (see text figures 23–26).

The frequency polygons for the depth and diameter values of these round forms of australites are shown in text figure 3.

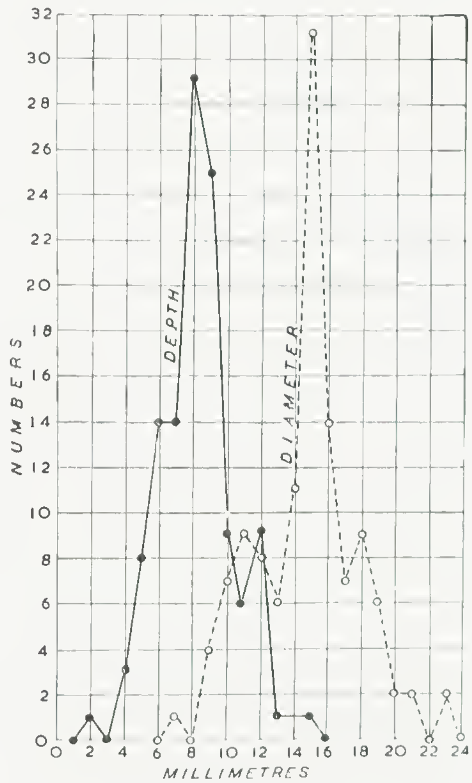

FIGURE 3.

Frequency polygons for depth and diameter values of round forms of the Nirranda Strewnfield australites.

The depth and diameter values (text figure 3) have been plotted to the nearest 1·0 mm. The respective modes, 8 for the depth values, and 15 for the diameter values, bear out the observations that in most of these round forms of australites each diameter value is usually approximately twice the depth value.

Consequently the appearance of these australites in side aspect (or in silhouette) is frequently lenticular (cf. text figure 19). A common size among these button- and lens-shaped australites is that provided by the modes in text figure 3, namely 8 mm. by 15 mm.

The population of complete individuals in each of the remaining six australite shape groups is insufficient for their size relationships to be shown satisfactorily by means of either scatter diagrams or frequency polygons, although the group of the oval-shaped australites yields relatively satisfactory scatter diagrams for length–depth and length–width relationships (see text figures 4 and 5).

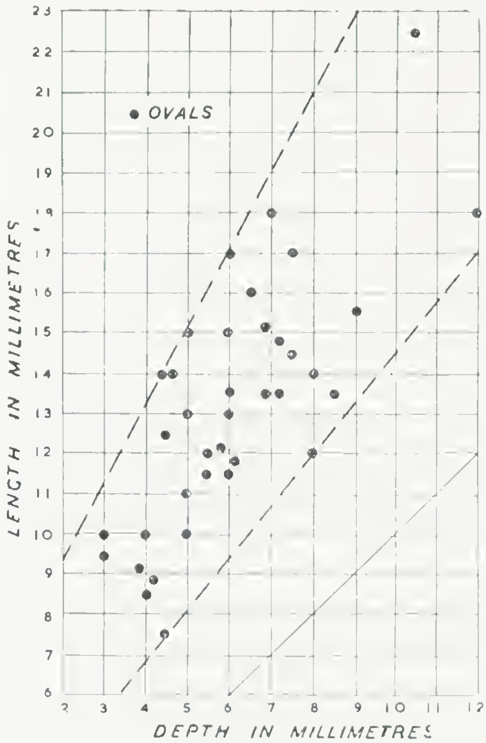

FIGURE 4.

Scatter diagram for length depth relationships of the oval-shaped Nirranda Strewnfield australites.

In text figures 4 and 5, each distribution falls into a narrow zone above the line of unit gradient, and both depth and width increase generally as length increases. A few specimens with the same depth (e.g. 6 mm.) have length variation (from 11·5 mm. to 17 mm.), and a few with the same length (e.g. 11 mm.) vary in depth (from 4·5 mm. to 8 mm.), while comparable trends are also shown for length width relationships, although the variations are not quite as pronounced. Such relationships are somewhat analogous to those already outlined in the groups of button- and lens-shaped australites.

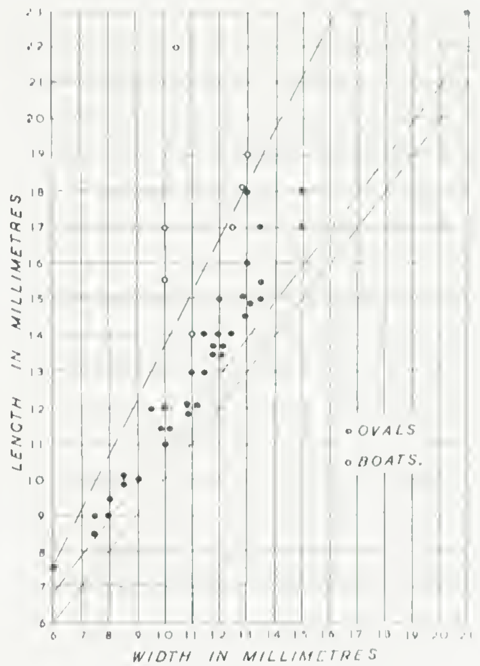

FIGURE 5.

Scatter diagram for length width relationships of the oval-shaped Nirranda Strewnfield australites.

In text figure 5, the relationship between length and width for the small population of boat-shaped australites is such as to reveal a similar increase of width with increased length as in the oval-shaped group, but there is a much wider scatter.

The relationship of widths to numbers of flanges encountered in the strewnfield, is shown in text figure 6. Seventy-two width measurements were made on (i) flanges still attached to both complete and partially fragmented button-shaped australites, (ii) two flanges detached as complete entities from buttons and one from an oval, and (iii) several flange fragments comprising from one sixth to just over one half of the original, mainly from buttons, with one from an oval.

The mode of the frequency polygon (text figure 6) occurs at the 3 mm. width value, and this corresponds with the calculated average value for flange width. The measured range in the width of flanges is 1·5 mm. to 5 mm. (see Table IV), but the range in the frequency polygon (text figure 6) is recorded as 2 to 5 mm., because the measured values have been plotted to the

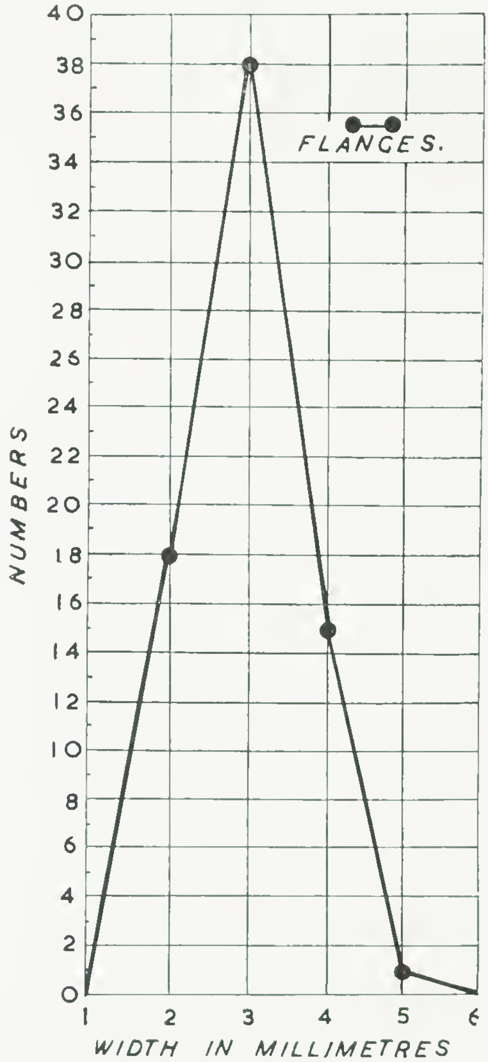

FIGURE 6.

Frequency polygon for widths of flanges.

nearest 1·0 mm. The widths of the flanges were obtained by measuring across their posterior surfaces, from the outer (i.e. equatorial) edge to the inner edge (or chin- cf. text figure 15).

Weight.

The smallest weight value of a complete form among the Nirranda Strewnfield australites is 0·247 grams, for a small lens (reg. no. E781) measuring 7 mm. in diameter and 3·5 mm. in depth, and having a specific gravity of 2·434. There are 21 fragments with lower weight values than this, the lightest fragment weighing only 0·090 grams.

The largest weight value obtained is 55·100 grams, for a large elongate core (reg. no. E922) measuring 39 mm. long, 34 mm. wide and 28 mm. deep, with a specific gravity of 2·437. This specimen (Plate III, figure 16), from "Errawallun" homestead, one mile south of Nullawarre P.O., was found under a tree in 1910, by Mr. A. Mathieson, Snr., while sheltering from a storm.

The total weights, ranges in weights and average weights for complete australites, and for all specimens including fragments, from the Nirranda Strewnfield, are compared in Table V with those for the Port Campbell and the Moonlight Head Strewnfields.

TABLE V.

Strewnfield.	Number of Specimens Found.	Number of Specimens Weighed.	Total Weight in Grams.	Average Weight in Grams.	Weight Range in in Grams.	Average Weight of Complete Forms in Grams.	Weight Range of Complete Forms in Grams.
Nirranda ..	370	366	668·396	1·826	0·090 to 55·100	2·560 (155 spp.)	0·247 to 55·100
Port Campbell ..	1,487	573	830·322	1·549	0·054 to 56·482	2·734 (212 spp.)	0·065 to 56·482
Moonlight Head ..	20	15	51·052	3·403	0·134 to 25·869	4·912	0·837 to 25·869

Because of low numbers of specimens, weight values for the australites from the Moonlight Head Strewnfield have little statistical significance in comparisons with those of the Nirranda and Port Campbell australites; nevertheless, the numbers listed for the Moonlight Head Strewnfield represent the total population known, and searches in recent years have yielded no more specimens.

Numbers are satisfactory for significance in the Nirranda and Port Campbell Strewnfields, and the fact that the average for all specimens weighed, including both complete specimens and fragments, is lower for Port Campbell than for Nirranda australites, can be explained as a function of the discovery of a greater number of smaller fragments in the Port Campbell Strewnfield, where the average weight of complete forms is a little higher.

The weight distribution of complete forms of australites from the Nirranda Strewnfield is shown in text figure 7.

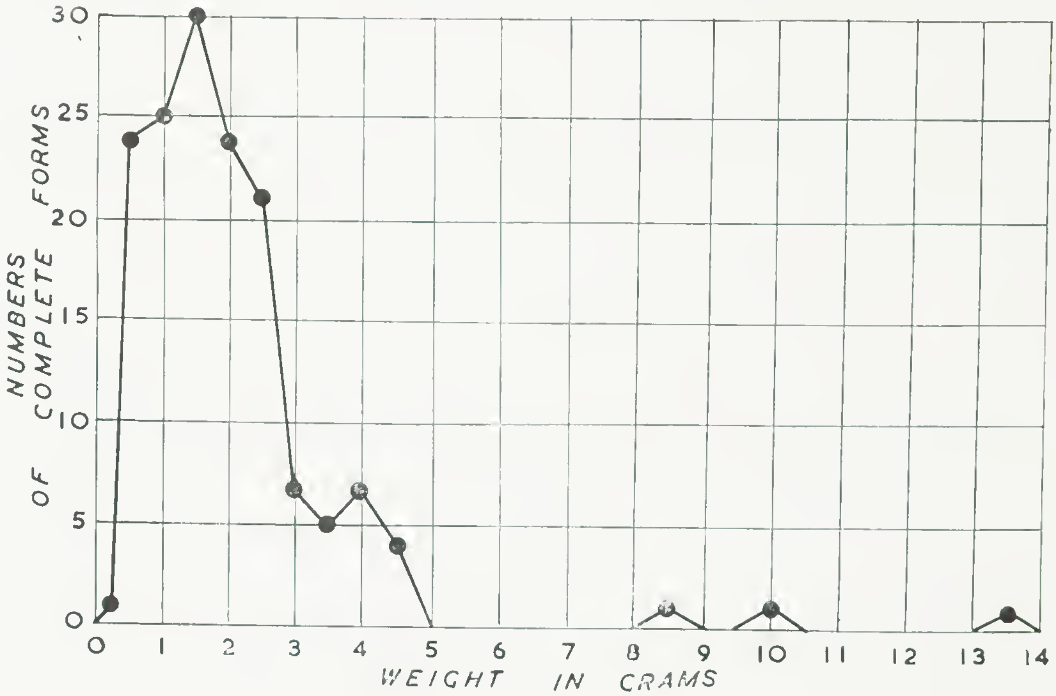

FIGURE 7.

Frequency polygon illustrating numbers of complete australites with similar weight values, Nirranda Strewnfield.

The frequency polygon (text figure 7) reveals that the greatest number (125 or 81 per cent.) of complete and nearly complete australites from the Nirranda Strewnfield occur in the lower weight range, between 0·5 and 2·5 grams, with a prominent mode at 1·5 grams. Three specimens weighing 15·5, 19·5 and 55 grams respectively have been omitted from the frequency polygon for convenience of representation. There is a marked gap in the frequency polygon created by a complete absence of specimens in the 4·5 to 8·5 grams weight range, while there are no complete forms weighing less than 0·25 grams.

The calculated average weight of 2·56 grams (Table V) for the Nirranda Strewnfield australites is strongly influenced by the inclusion of 6 specimens weighing from 8·5 to 55 grams. If these are omitted, the calculated average weight is 1·5 grams, a value which then agrees with the mode of the weight-numbers frequency polygon (text figure 7).

Specific Gravity.

Specific gravity values of the Nirranda Strewnfield australites have been determined to the nearest third decimal place, but they have been plotted in the accompanying frequency polygons to the nearest second decimal place.

The lowest specific gravity value is 2·363 for a core fragment (reg. no. E771) weighing 0·825 grams, and the highest is 2·474 for a lens (reg. no. E1015) measuring 11 mm. in diameter and 5·5 mm. in depth, and weighing 0·772 grams. The calculated average specific gravity value for the 366 specimens is 2·409.

That the specific gravity can vary a little in one and the same australite, is indicated by a specimen of an oval-shaped form (reg. no. E836) that was discovered in three pieces lying in contact, partially embedded in soil. Determinations of specific gravity values for the three pieces separately, and for the three together, are shown with their respective weights thus:

	Weight in Grams.	Specific Gravity.
Whole form	4·436	2·395
Complete flange	0·762	2·410
First half of core	1·886	2·395
Second half of core	1·788	2·394
Two halves of core together	3·674	2·395

Flanges normally have a rather lower specific gravity than body portions of australites (cf. Baker and Forster, 1943, p. 383, and Table 5, p. 384), but this particular oval-shaped form is an exception in having a flange with a significantly greater specific gravity than the body portion. The determination for the complete flange was checked and re-checked, but always with the same result.

In contrast to this specimen, a button fragment (reg. no. E1029) from which the attached flange remnant was broken away, showed the same specific gravity values for flange and for body portion—

	Weight in Grams.	Specific Gravity.
Button fragment with flange attached ..	1·926	2·392
Core portion	1·767	2·392
lange portion	0·159	2·392

The relationships of specific gravity to total numbers of specimens and to the total weights of australite glass having the same specific gravity, are shown in text figure 8.

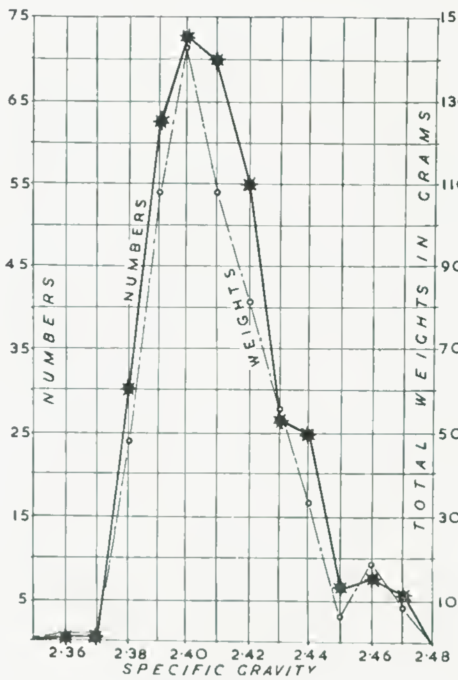

FIGURE 8.

Frequency polygons showing relationships of numbers of specimens and weights of specimens to specific gravity values for Nirranda Strewnfield australites.

The two frequency polygons in text figure 8 show a close parallelism throughout, and a relatively regular increase in numbers of specimens and in weights from the 2·37 specific gravity value to the mode of 2·40, after which there is a steady decline to 2·47, but for a minor peak at 2·46. One specimen weighing 55 grams, with a specific gravity value of 2·44, has been omitted from the total weights–specific gravity frequency polygon; its inclusion would produce a very prominent peak rising to nearly 90 on the 2·44 specific gravity co-ordinate in the weight frequency polygon.

Analysis of the numbers–specific gravity frequency polygon (see text figure 8) by the construction of separate frequency polygons for the different shape groups (see text figures 9 to 11), reveals that it is compounded of populations possessing variously

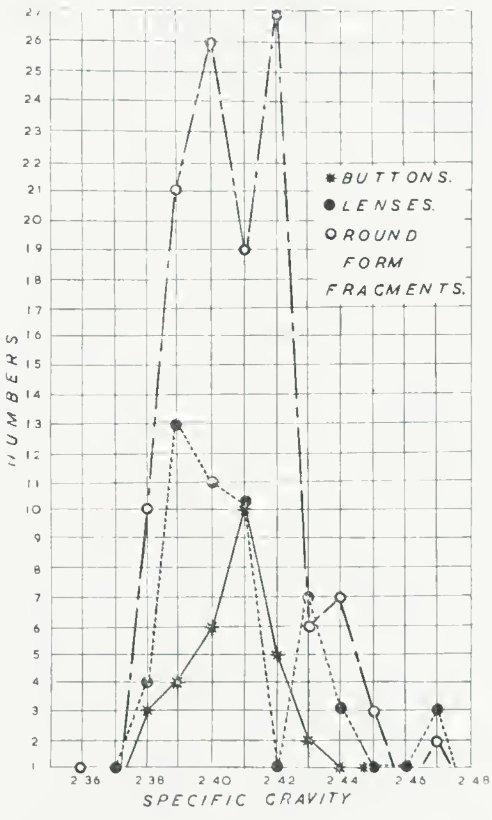

FIGURE 9.

Frequency polygons showing the relationships of numbers to specific gravity values of buttons, lenses and round-form fragments among the Nirranda Strewnfield australites.

situated modes, indicating specific gravity variations from shape group to shape group. In the overall frequency polygon (text figure 8), however, most irregularities, which in themselves are significant, have been smoothed out.

The relationships of numbers of specimens to specific gravities for the round-forms of australites, including round-form fragments, are set out in text figure 9; round cores are not shown because of low numbers (only 4 specimens).

Features of the frequency polygons for the round-forms of australites (text figure 9) are—(i) the more or less regular increase from 2·38 to a mode of 2·41 for button-shaped forms, and a regular decrease thereafter to 2·44, (ii) the existence of two modes (at 2·39 and 2·43) in the frequency polygon for the lens-shaped forms, and a distinct shortage of specimens having a specific gravity of 2·42, (iii) two prominent peaks (at 2·40 and 2·42) in the frequency polygon for round-form fragments, with a marked fall in the 2·41 region and comparatively high numbers of specimens in the 2·39 region; this reflects the original character of the complete forms from which the fragments were developed—some coming from buttons and some from lenses—but there are interesting discrepancies such as (*a*) the occurrence

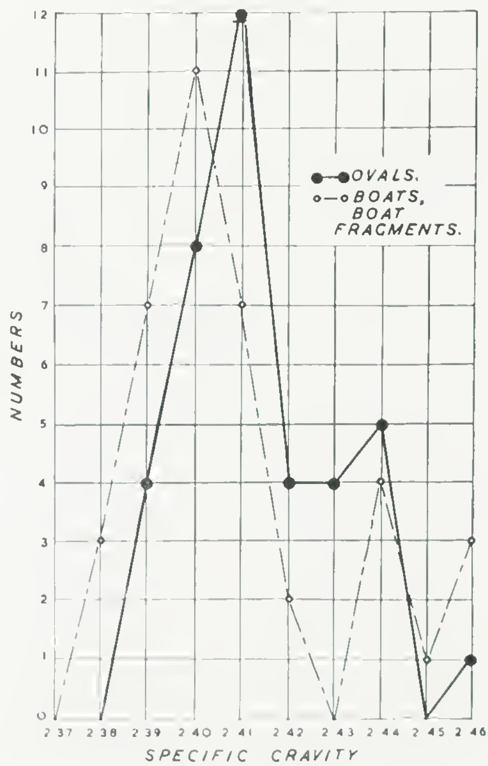

FIGURE 10.

Frequency polygons showing the relationships of numbers of specimens to specific gravity values of oval-shaped forms, and of boat-shaped forms and fragments therefrom, among the Nirranda Strewnfield australites.

of a depression in the round-form fragment polygon on the 2·41 specific gravity value, which is the value of the mode for button-shaped specimens, and (*b*) the occurrence of a peak on the 2·42 specific gravity value, which is a value for which there are relatively low numbers of buttons and even fewer lenses.

Among the elongated forms of australites, the numbers—specific gravity frequency polygons (text figure 10) reveal modes of 2·41 and 2·40 for oval-shaped and boat-shaped australites respectively, the mode for the oval-shaped forms agreeing with that for button-shaped forms. Both of these elongate shape groups show a shortage in numbers of specimens with a specific gravity value of 2·43, and minor peaks at 2·44. The reason for this is obscure, if not a result of sampling.

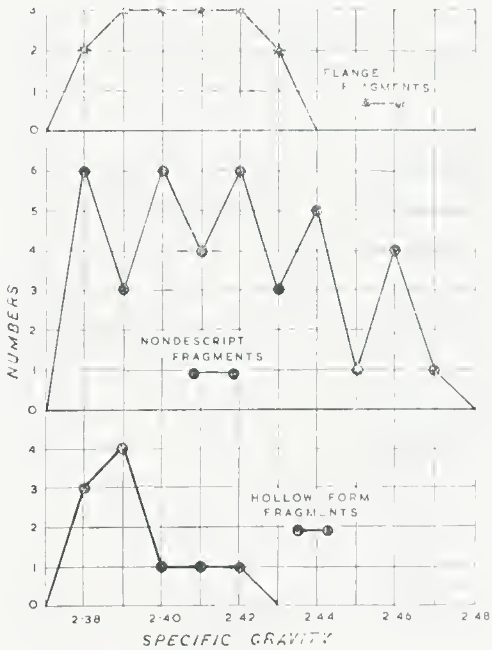

FIGURE 11.

Frequency polygons showing relationships of number of specimens to specific gravity values for flange fragments, nondescript fragments and hollow-form fragments among the Nirranda Strewnfield australites.

Frequency polygons have not been constructed for the groups of elongated australites referred to as dumb-bells, as canoes, and as teardrops, because of low populations of specimens in each of these shape groups. Numbers are a little higher in the group of the fragments which embraces flange fragments, nondescript fragments and hollow-form fragments as distinct groupings from those (round-form and elongate-form fragments) already plotted in text figures 9 and 10. Although they have no especial statistical significance, the numbers—specific gravity relationships of these three separate groups of fragments are shown in individual frequency polygons (text figure 11) for purposes of record.

The absence of a mode in the frequency polygon for flange fragments (text figure 11) is probably due to low numbers, while the serrated character of the frequency polygon for nondescript fragments seems to be partly a result of derivation of these fragments from several of the australite shape groups. Seventy per cent. of the hollow-form fragments occur in the 2·38 to 2·39 specific gravity range, indicating that hollow forms generally have lower specific gravity values than most members of the other australite shape groups. This is not entirely a consequence of their gas content, because the fragments of the hollow forms are themselves relatively free of included gas bubbles.

Compared with similarly constructed frequency polygons for the specific gravity values of 555 Port Campbell australites (see Baker and Forster, 1943, pp. 389-390), and for the weight distribution of complete australites from Port Campbell and other localities (Baker and Forster, 1943, p. 393), the Nirranda Strewnfield australites show similar relationships. For the weights polygon the mode in each occurs at 1·50 grams, and there is a comparable distribution on the left-hand side of each mode, and a comparable distribution on the right-hand side of

TABLE VI.

Strewnfield.	Number of Specimens Found.	Number of Specific Gravity Determinations.	Average Specific Gravity for all Values Determined.	Range of Specific Gravity for all Values Determined.	Average Specific Gravity of Complete Forms.	Range of Specific Gravity of Complete Forms.
Nirranda ..	370	366	2·409	2·363 to 2·474	2·410 (155 spp.)	2·37 to 2·47
Port Campbell	1,487	573	2·397	2·305 to 2·465	2·404 (233 spp.)	2·33 to 2·47
Moonlight Head	20	15	2·411	2·400 to 2·435	2·415 (9 spp.)	2·40 to 2·44

each mode. The frequency polygons for the relationships between specific gravity and total number of specimens for each strewnfield are also generally similar, while there are a few minor variations among the specific gravity polygons for similar shape groups from each strewnfield.

Relationships between the specific gravity values of the Nirranda, Port Campbell and Moonlight Head Strewnfields australites are shown in Table VI.

Fracture and Fragmentation

The glassy nature of australites makes them liable to ready fracture, and 58 per cent. of the Nirranda Strewnfield australites are fracture fragments. The means whereby any particular australite has been fractured is uncertain, but some of the possibilities are (i) fracture by impact on landing, (ii) fracture due to impact by other objects displaced during surface run-off across the exposed areas on which the australites were found, (iii) fracture resulting from diurnal temperature changes, (iv) fracture during usage by aborigines, and (v) fracture or wear in the gizzards of large native birds (emus and bush turkeys).

Unweathered fracture surfaces typically tend to be conchoidal, with a marked ripple fracture on the curved surfaces. Conchoidal fracturing produces curved segments from the equatorial regions of the australites, and these segments sometimes possess still-attached flange remnants, sometimes show a flange band, and sometimes show neither of these features, according to the shape group from which they were derived, or according to the degree of abrasion suffered by an originally flanged fragment.

The result of the fracturing process is to produce various kinds of fragments of different size and shape, both from one and the same, and from different australite shape groups. Most fragments retain sufficient shape and structure to indicate the particular shape group from which they were derived, but a few are classified as nondescript because, although they may retain recognizable remnants of anterior surface, of posterior surface, or of equatorial regions occasionally with flange remnants, they provide no clear indication of original shape. Many nondescript fragments have been derived from the interiors of the body portions of australites, and thus cannot be classified with any particular shape group since internal structures alone do not serve to discriminate one shape group from another.

The type of fracturing occurring in some australites is depicted in text figure 12.

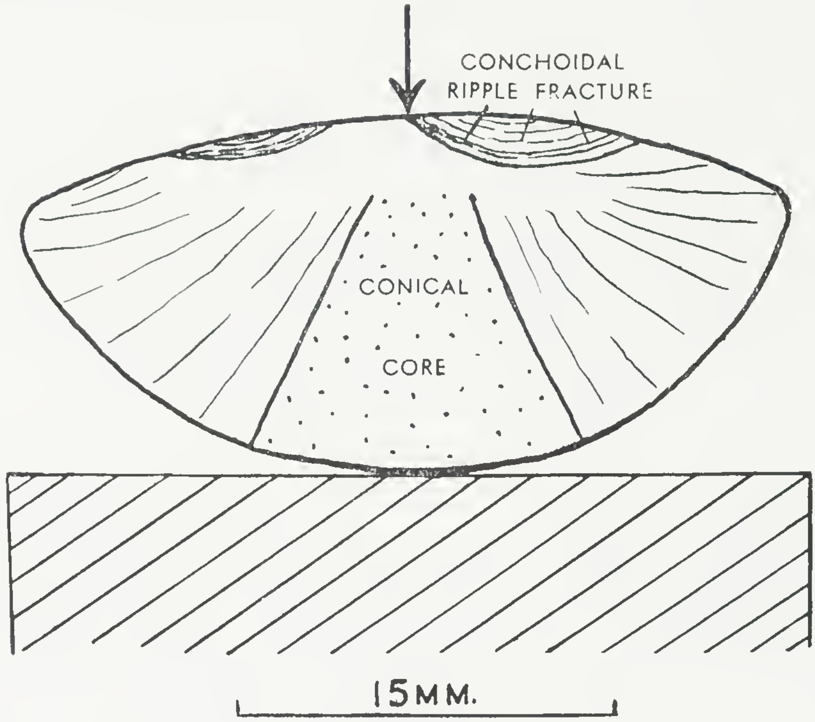

FIGURE 12.

Sketch diagram illustrating the principal types of fracture in australites.

With the posterior surface of the australite in contact with a small steel anvil, repeated light blows in the front polar region of the anterior surface yielded chips showing conchoidal and ripple fracture. With sharper blows, a conical-shaped core was ultimately produced, having a greater proportion of posterior surface than of anterior surface, and thus closely resembling the naturally occurring conical cores (see Plate III, figure 14). This suggests that the glass of the secondarily formed anterior surfaces in australites is rather less mechanically stable than that of posterior surfaces. Moreover, since 87·5 per cent. of specimens were found to have their anterior surfaces upwards, the anterior surfaces are thus more exposed to subaerial weathering agents, once the australites have been uncovered from their soil environment. Anterior surfaces also receive a greater proportion of direct sunlight, and since the coefficient of thermal conductivity of australites is low, between that of Darwin Glass (0·002) and that of artificial glass (0·0005 cals./cm./°C.), rate of heat transference is therefore low, and so the exposed anterior surfaces should be more liable than posterior surfaces to cracking by repeated expansion and contraction.

Several stages in the development of fragmentation products by a process of natural flaking and fracturing have been noted among the Nirranda Strewnfield australites. The onset of fracturing is marked in some specimens by the appearance of fine, hair-like cracks (cf. Plate I., figure 7). These become gradually widened and deepened, partly by etching, and in time deep, more or less parallel-sided grooves result (cf. Plate I, figure 8, and Plate IV, figure 21). The grooves occasionally form a crudely radial pattern on the anterior surface, as shown in Plate II, figure 9. Sometimes they curve around from anterior to posterior surfaces (Plate IV, figure 21) and sometimes they tend to be parallel with the equatorial periphery (see right-hand side of Plate II, figure 10). In course of time, pieces of australites delineated by prominent grooves become fractured from the parent form, largely as a consequence of strains and stresses set up by expansion and contraction caused by diurnal changes of temperature. Since most of the Nirranda Strewnfield australites were located on barren patches, they have been extensively exposed to the full force of the sun's rays during the daytime, and remained unprotected from the lower temperatures prevailing at night-time. Repeated expansion and contraction could therefore well have been responsible for partial fracturing of the australites that possess strongly-marked, relatively deep grooves; such a process seems to have occurred with some australite specimens. The process is further aided by the lodgment of clay and fine sand grains (mainly quartz) in the grooves, accompanied by continued etching. The forces exerted by differential expansion between the material in the grooves and the adjoining australite glass would ultimately lead to fracturing away of any portions outlined by grooves. Similarly, clay and fine sand are sometimes wedged and or cemented into bubble pits.

The importance of the existence of strain lines in australite glass as a factor contributing to their fragmentation, once they became exposed to atmospheric agencies, receives support from Hammond's (1950, p. 272) work on the compressive and tensional strains in non-homogeneous glass. Hammond has shown that even a scratch on the surface of highly strained glass may cause disintegration. The glass of australites is not in a state of high strain, but that the glass is not completely homogeneous and is under some strain is proved by the fact that all forms are completely flow-lined, with certain of the flow-lined areas exhibiting weak birefringence and undulose extinction under the petrological microscope. Opportunities for scratching to initiate fragmentation are plentiful on the wind-swept, rain-washed sandy portions of australite-bearing patches of ground.

The breaking away of flanges, rarely as complete entities (Plate I, figures 4 and 5), more frequently as small pieces, is one of the most common features of australite fragmentation. Fracturing here is largely brought about as a direct result of differential expansion of clay particles and sand grains wedged in the narrow gap separating the equatorial peripheries of the posterior surfaces of australites from the partially overhanging neck surface (cf. text figure 15) of the flanges. The process of flange separation by fracturing is assisted by the fact that the planes of union between the flange and body portions of australites are the least mechanically stable of all australite structures, for here the glass is thin, and often a position where etching processes have been active.

The fracture and fragmentation of hollow forms of australites, and the development of the flaked equatorial zones on the larger cores, have been referred to earlier.

Sculpture Patterns and Etching Effects

The sculpture patterns of the Nirranda Strewnfield australites consist of varying combinations of flow lines, flow ridges, grooves, small bubble pits and larger bubble craters. These features are not as well shown as on the majority of the Port Campbell australites, because of more marked destruction by abrasion. Internal structures, however, show equally as complex flow-line patterns, as can be seen from the photographs of two thin sections of lens-shaped australites (Plate V, figures 26 and 27), and as shown on the walls of deeper grooves that are better protected from abrasion but exposed to etching solutions.

It has not yet been conclusively proved whether the external sculpture of tektites is a primary feature generated prior to and/or during atmospheric flight, or whether it is entirely a secondary feature brought about by natural etching, by soil solutions. As observed on the external surfaces of Australian tektites, it seems that sculpture patterns are manifestations of internal structures, and are at least accentuated by natural etching under certain conditions, practically destroyed by abrasion under other conditions. The appearance of an australite at the time of its discovery thus depends upon whether etching processes or abrasion had been dominant. There is no doubt, however, that the sculpture patterns observed on the external surfaces of australites and fracture fragments of australites depend upon the nature of their flow-lined interiors. This is proved by the following observations—(i) when they are artificially fractured, australites show highly vitreous, relatively smooth, convex and concave surfaces, occasionally with a subsidiary ripple fracture pattern, (ii) naturally fractured surfaces of some antiquity frequently show flow-line patterns and pits, and all have lost their vitreous lustre, (iii) when dull, abraded australites are etched in the laboratory, a sculpture pattern composed of flow lines, pits and shallow grooves is very well brought out, according to the time of immersion and the strength of the etching solution. At the same time, the dulled surface becomes increasingly lustrous, although never as highly vitreous nor as evenly smooth in appearance as freshly fractured surfaces.

Artificial etching tests have yielded some interesting results. An oval-shaped australite (Plate IV, figures 24 and 25) from the Nirranda Strewnfield, had, when first discovered, dulled and smoothly worn external surfaces. It showed occasional ill-defined shallow pits and worn down flow ridges on the anterior surface, and poorly marked bubble pits and flow grooves on the posterior surface. The glass between these sculpture elements showed a very minute pitting as revealed under a x10 hand lens. This specimen was immersed in 4 per cent. hydrofluoric acid at 21·8°C. for 64½ hours, in such a way that all of the anterior surface and half of the posterior surface were immersed. After 64½ hours, the temperature measured 20·5°C., and after washing and drying the specimen, re-weighing revealed a loss in weight of 0·397 grams. If the concentration of the hydrofluoric acid did not vary appreciably during this period, the australite glass dissolved at an approximate rate of 0·006 grams per hour. The non-immersed portions of the specimen remained virtually unaffected, except for slight attack by acid fumes. This portion thus still shows the dull, abraded surface that was evident all over the specimen when it was discovered on the ground. On the immersed portion, however, the former dull character has vanished, and the specimen appears fresh and new (Plate IV, figures 24 and 25). Etching occurred differentially along flow line directions, bringing out the sculpture pattern particularly well. Deeper etching along some flow line directions produced rather deeper flow channels. Closer examination of these channels reveals that some have a vermicular segmented appearance as though composed of strings of small bubble depressions in contact. Other etching effects are the accentuation and deepening of certain bubble pits.

The fact that minor amounts of differential etching occurred in the hydrofluoric acid points to slight variations in composition along flow line directions. Presumably somewhat deeper etching was directed along streaks of australite glass richer in silica, showing that flow-lined australites are not entirely composed of strictly homogeneous glass. In the initial phase of the formation of australite glass there has therefore not been complete and thorough mixing of the original ingredients, suggesting rapid fusion at relatively high temperatures, followed by rapid cooling. In the etch test described above, it has not been possible to detect whether one or the other of the anterior or posterior surfaces respectively became more deeply etched. The eye cannot detect any significantly marked attack of greater degree on one surface more than on the other, even with the aid of a hand lens. It would thus appear that little, if any, chemical variations exist between anterior and posterior surfaces respectively, although there may be physical differences, inasmuch as it is suspected from other evidence (cf. Fenner, 1935, p. 132) that the glass near and at the anterior surface, and the glass of the flange, may be rather less mechanically stable than the glass composing the rest of the australite.

Evidently natural etching only affects those australites that occur in positions favourably situated for attack by weak acidic solutions, enabled to act over a period embracing the last few thousand years of Recent geological time. Such favourable positions require burial in soils or other surficial materials where etching solutions were available. Australite specimens displaying accentuated sculpture patterns on discovery evidently have been recently released from their soil environment, while those with poorly marked sculpture patterns, or none at all, were released long ago, and in the meantime have been exposed to the action of various abrasive agents.

Bubble Pits.

Etching experiments with australite glass, using 4 per cent. hydrofluoric acid, have shown that the smaller pits can be initiated and accentuated on the worn external surfaces of australites. They develop above tubes of glass of slightly more acidic composition, such tubes of glass being evident in thin sections of australites by virtue of slight differences in refractive index values, compared to neighbouring parts of australite glass. The etch pits so produced tend to resemble some of the smaller depressions that have become regarded as the impressions left by the escape of very small gas bubbles on the primary surfaces of australites, and which are now preserved on posterior surfaces only, provided those surfaces have not been unduly weathered.

The larger circular to oval-shaped depressions on posterior surfaces of the body portions of australites (cf. Plate I, figures 2 and 6, Plate III, figure 12) are accepted herein as representing positions of gas bubble escape, and from a study of their radii and arcs of curvature (see later) the posterior surfaces are considered to be remnant portions of the original primary forms of australites. The presence of bubble pits on the original surfaces of these primary forms would point to high temperatures of formation, and possibly some boiling at the surface.

Bubble pits are seldom encountered upon the posterior surfaces of flanges, but minute etch pits are present (Plate I, figure 2). Bubble pits are also infrequent features of anterior surfaces generally, so that they are thus relatively uncommon upon all of the structures of australites that have had a secondary origin. The bubble pits that do appear occasionally on anterior surfaces could well represent internal bubbles (sometimes seen in thin sections) that have become exposed at the surface on the particular levels to which a process of sheet fusion and ablation had progressed (cf. Baker, 1944, Plate I, figure 4). This suggestion receives support from the observation that some such bubble pits reveal evidence of inward collapse against pressure. They sometimes show inrolling of the upper edges of the collapsed bubble pit walls, under the influence of the secondary phase of melting of thin surface films and other processes responsible for the formation of anterior surfaces. More open pits in this category sometimes show a small pyramid of glass at the bottom of the collapsed bubble pit.

Flow Ridges.

Flow ridges (Plate I, figures 1 and 8, Plate IV, figure 19) are characteristic of the anterior surfaces (i.e. front or forwardly directed during flight) of australites. In fact they are invariably confined to the anterior surfaces of the body portions and the flange portions, where flanges are still present. Their distribution is remarkably regular over the major portion of the anterior surface of any particular australite, but their shape and distribution vary a little in the different australite shape groups where flow ridges are developed, variation being according to the particular forms upon which they have been generated. The spacing apart of the flow ridges varies from 2 to 4 mm., but the distance from crest to crest across the intervening shallow troughs is more usually approximately 3 mm.

The smaller forms of lens-shaped australites (Plate I, figure 3) seldom have flow ridges preserved, larger forms such as "bungs" and large cores (Plate III) evidently did not develop flow ridges. It is therefore only on forms of intermediate size that flow ridges are to be observed—forms such as the buttons, the larger of the lenses, the ovals, and some of the boats, canoes, teardrops and dumb-bells. This indicates that there is an optimum size requisite for flow ridge development. Forms without flow ridges in the shape groups where flow ridges are a characteristic feature of anterior surfaces have had them obliterated by weathering upon the earth's surface.

Among the Nirranda Strewnfield australites are 100 complete or nearly complete forms (i.e. 37 per cent. of the total number discovered) that reveal the flow ridges in a sufficiently preserved state for their character to be determined. Several fragments from this strewnfield show parts of flow ridges on their broken anterior surfaces, but there is never enough preserved to decide whether the complete flow ridges were originally concentric or spiral in arrangement.

Concentric (Plate I, figure 8) and spirally arranged flow ridges are present on the Nirranda Strewnfield australites in the proportions shown in Table VII. Some of the spiral flow ridges are arranged in a clockwise fashion, others are counter-clockwise (Plate I, figure 1).

In comparison with the percentage shown in Table VII, Fenner (1934, p. 74) found that of 75 buttons selected at random from the Shaw Collection, 42 (i.e. 56 per cent.) had concentric flow ridges, while 18 (24 per cent.) were anticlockwise spiral, and 15 (20 per cent.) were clockwise spiral.

In addition to the main types listed in Table VII, an unusual and rare variety of flow ridge is crudely radially arranged on a large fragment from a hollow form (E830).

TABLE VII.

Flow Ridge Arrangement.	Per cent.
Concentric	46
Anti-clockwise spiral	27
Clockwise spiral	27
Double spiral	1 specimen

Normally the spiral flow ridges commence near the front poles of the anterior surfaces, and continue more or less uninterruptedly until they merge into the equatorial periphery of the specimens (text figures 13B and 13C). Generally there is thus one continuous ridge on each of the australites having spiral flow ridges. One specimen (E887) among the Nirranda Strewnfield australites, however, is unusual in possessing two open spiral ridges (text figure 13D) arranged in a manner simulating the two arms of certain spiral nebulae.

The number of concentric flow ridges on australites is a little variable. Some of the very small lenses are fundamentally too small to show flow ridges, slightly larger specimens may have one concentric flow ridge only. Larger lenses and most button-shaped australites, also several oval-shaped forms of comparable size, generally have two or three, sometimes four, concentric flow ridges. Occasionally the outermost flow ridge coincides with the rim of forms that do not possess flanges. In the larger of the flanged button- and oval-shaped australites, the existence of a greater number of flow ridges than usual is indicated by the complex merging and interlacing of several ridges in the equatorial regions, principally on and near the anterior surfaces of the attached flanges, where complicated wavy flow-ridge patterns have been generated. Sectional aspects of such specimens (cf. Plate VI, figure 28) reveal the presence of five or six, sometimes seven, flow ridges for the form as a whole. Spiral flow ridges do not show such marked crenulation on reaching the equatorial peripheries.

A few (6 per cent.) of the button-, lens- and oval-shaped australites are similarly finely pitted on both the anterior and the posterior surfaces. They show no flow ridges characteristic of anterior surfaces, and none of the bubble pits that typify posterior surfaces, hence, unless a flange, flange remnants or flange band are present, it becomes impossible to detect which is the posterior and which the anterior surface. In view of the fact that the pitting is of a very fine character, and very unlike that of normally bubble-pitted surfaces, it seems that such "two-surface pitting" arises as an effect of rather extensive weathering and etching, rather than being the result of the action of agencies operating during the phase of atmospheric flight.

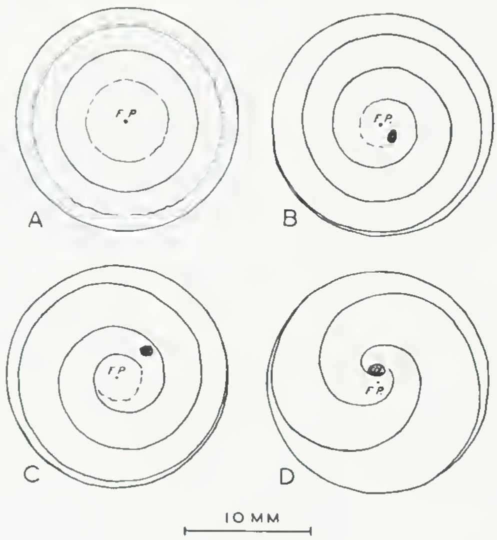

FIGURE 13.

Diagrammatic representation of flow ridges on the anterior surfaces of australites that are circular in plan aspect.

A — concentric flow ridges; B — spiral clockwise flow ridge; C — spiral anti-clockwise flow ridge; D — double spiral flow ridges.

(F.P. indicates the front polar regions of each anterior surface. The small dark, oval-shaped areas in figures B, C and D represent etch pits.)

In text figure 13A, the flow ridge nearest the front pole of the australite is sometimes sharply marked, but often ill-defined due to subsequent erosion. The outermost flow ridge depicted is shown as being somewhat "crinkled" to indicate the onset of the development of a wavy character brought about by several flow ridges running into one another near the equatorial periphery. The intermediate flow ridge shown in figure 13A is most frequently the best defined, largely because of less abrasion in its vicinity.

Regarded from the front polar regions, outwards towards the equatorial limits of these flow-ridged australites, the spiral flow ridges can be pictured as descending helical spirals, the apex of which is at the front pole, the spiral broadening out towards the equatorial edge of the specimens, and the respective heights of such spirals being equivalent to the distance between the front pole and the radical line* of each australite possessing flow ridges of this nature. Heights of spiral flow ridges are thus equivalent to the lengths OM shown in text figure 19.

Few, if any, of the spiral flow ridges commence as sharply marked ridges right at the front pole position of each australite possessing a spiral flow ridge (cf. Plate I, figure 1). They are often initiated from one side or the other, rarely from both sides, of an elongated etch pit situated within the front polar region (cf. text figures 13B and 13D). The development of the spiral character of flow ridges on these forms can be partly accredited to the presence and position of such pits, for they evidently affect the smooth and regular flow wave motions generated in thin films of plastic australite glass moving away under frontal pressure from front polar to equatorial regions, at any particular stage of a process involving sheet fusion of australite glass. It is difficult to assess exactly what effects variations in boundary layer flow of the air in contact with the fast-moving australites may have had upon such surface features as the flow ridges. No doubt they were partly responsible for their development, and it seems probable that the character and changing nature of front surfaces, which alter as the arc of curvature of the forward surface varies with degree of ablation, would have marked effects upon variation in boundary layer flow, and this would be reflected in the position and migration of flow ridges. Boundary layer flow associated with drag effects operating upon the front surfaces of australites during supersonic flight, was evidently such that taken in conjunction with the development of etch pits in front polar regions, flow ridges with a spiral arrangement could be generated without necessarily assigning their origin to a process of rotation. There certainly seems to be no need to call upon rotation of australites during atmospheric flight to explain the more commonly developed concentric flow ridges, for

* The radical line is the line joining points of intersection of the two curved surfaces (constituting the posterior and anterior surfaces in australites (cf. text figures 19 and 20), and is thus a measure of the diameter of the forms, provided each circle passes through the front and back poles respectively.

they would be formed as relatively regular features during a state of maintained steady flight. Possibly some wobbling developed in forms containing spiral flow ridges; this could come about by certain buffeting effects created by turbulence in the air stream separating from the equatorial regions of such australites.

The pits that occur in the front polar regions of some flow-ridged australites (cf. text figure 13) are not necessarily all normal bubble pits. They could well be etch pits produced during atmospheric flight by the removal of slightly less stable centres of glass. Bubble pits like those on the posterior surfaces of australites are normally rare features of anterior surfaces, and where encountered, are most likely internal bubbles exposed at a particular level reached at certain stages of ablation. Forms with concentric flow ridges seldom show pits of any nature in front polar regions, although some show shallow grooves resulting from etching (possibly while on the earth's surface). Some forms with spiral flow ridges reveal no etch pits, but such may have been present in the immediately preceding stage of ablation, when the spiral ridges could have been initiated. The fact that etch pits can be readily generated and accentuated by artificial means, such as treatment in 4 per cent. hydrofluoric acid, suggests the likelihood that during ablation, certain levels are reached in the glass of the anterior surfaces of australites, where the slight inhomogeneities of certain parts lend themselves to more ready removal, forming pits. Once developed, these pits could then be partly responsible for the control of spiral flow ridge development. Under such a set of circumstances, there is reason to suppose that at various stages of anterior surface ablation, one and the same australite could have concentric flow ridges at an early stage, clockwise or anti-clockwise spiral flow ridges at a subsequent stage, and even revert again to concentric flow ridges at a still later stage. As found, the several types of flow ridges noted on anterior surfaces appear to represent the end stages of arrested flow wave phenomena, developed just prior to final consolidation of the last films of secondarily re-melted australite glass produced and forced from front polar to equatorial regions, over the surface of relatively un-heated, underlying glass. The sub-surface flow-line pattern, however, is such as to indicate that glass has been stripped from flow-trough regions more than from flow-ridge regions, in the final stages of the development of anterior surface sculpture.

The foregoing remarks apply essentially to the development of flow ridges on the anterior surfaces of australites that are circular in plan and of a suitable size and shape for their formation. The fact that the larger round forms of australites, namely the group of the round cores, do not show flow ridges, indicates that there must be an optimum, ablation-reduced size of the primary forms, at which flow ridges can be formed. This state is attained evidently after at least one half to two thirds of the glass of the primary form has been removed by ablation.

Forms of australites in other shape groups also show flow ridges, and again they are developed on examples that are smaller than the correspondingly shaped, non-flow-ridged core (and "bung") forms. Boats and canoes (Plate IV, figure 19) mainly show a tendency for the formation of concentric flow ridges, with a certain amount of flow-ridge-linkage in places, due to interference where crowding occurs near the equatorial edges of the forms.

Complete dumb-bells and teardrops among the Nirranda Strewnfield australites show no flow ridges, partly because of their small size, and partly because of destruction of such features by abrasion of somewhat larger forms. One dumb-bell fragment, representing one half of the original form, shows one concentric flow ridge constricting towards the waist region.

A study of the flow ridge variation on the anterior surfaces of certain dumb-bell-shaped australites from other south-western Victorian localities, provides substantial support for the validity of the postulate that anterior surfaces of australites as found, are secondary in development, and resulted from a process of frontal melting and ablation during a non-rotational phase of flight through the earth's atmosphere. Text figure 14 illustrates this point.

Flow ridges on the specimen from Mt. William (text figure 14, no. 1B) occur in two series that are each concentric in sense, being centred about each front pole and following the general outline of each bulbous portion of the dumb-bell-shaped form. The flow ridges become wrinkled and irregular due to mutual interference near the outer periphery of the australite. Text figure 14, no. 2B shows the type of ridges developed on dumb-bell-shaped forms that have been considerably ablated, and instead of the anterior surface being bi-polar as in text figure 14, no. 1B, the anterior portions of the bulbous ends have been removed by ablation, and the anterior surface of the form as a whole has become mono-polar, with the single front pole now situated centrally. The flow ridges are arranged in a generally concentric manner about the front pole, but show marked angularity near the outer periphery. The sketches 1A and 2A of text figure 14 depict the side aspects of these two forms, and reveal the relationship between the disposition of the flow ridges and the nature of curvature of respective anterior surfaces.

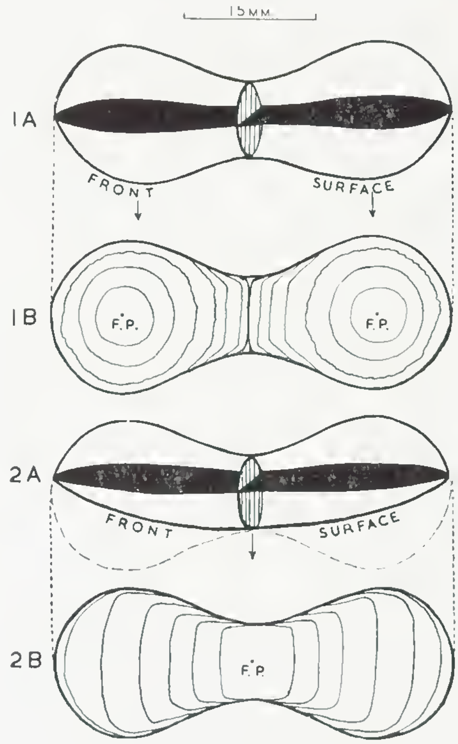

FIGURE 14.

Diagrammatic representation of flow ridges on the anterior surfaces of dumb-bell-shaped australites.

(Flanges have been omitted from the sketches).

1A—Three-dimensional side aspect of dumb-bell from Mt. William, Grampians, Victoria.

1B—Generalized plan aspect of the front surface of the form sketched in figure 1A. Based on figures 1 and 1B, Plate 5 of Dunn (1912).

2A—Three-dimensional side aspect of modified dumb-bell from Port Campbell, Victoria.

2B—Generalized plan aspect of the front surface of the form sketched in figure 2A, and based on a number of additional specimens.

The abbreviation F.P. indicates the position of the front polar regions in these australites. Arrows indicate direction of propagation through the earth's atmosphere.

Flow ridges are intimately connected with flange-building processes in australites, and added to the nature of the flow ridges, the fact that these dumb-bell-shaped forms (text figure 14) possess remnants of flanges that in each are more or less the same width in waist regions as around bulbous portions, strongly suggests the possibility that rotation was not only unnecessary, but most probably unlikely, during the phase of formation of these flow ridges and flanges.

The flow ridge patterns illustrated in text figure 14 are idealized diagrammatically; many forms of the dumb-bell-shaped australites occur in which the flow ridges are rather more irregular than illustrated, due to interference with one another, or at times, possibly due to slight inhomogeneities in the glass. Moreover, there is evidence among other examples, from the Port Campbell Strewnfield, for example, that there are several modifications of the type depicted in text figure 14, no. 2B. One such modification is that the flow ridges trend in parallel fashion away from the front polar region of one only of the original bulbous ends (cf. text figure 14, no. 1B), extending from this position transversely across the waist region and across the other bulbous portion. In such a form, the second bulbous portion is somewhat smaller and has a flatter arc of curvature for its anterior surface, thus indicating that rather greater amounts of fusion and ablation occurred in its front polar region, and that it reached a stage of relative stability before the first bulbous end. Continued frontal fusion in the polar regions of this larger bulbous end, then yielded melted glass that flowed more readily from its pole, in one direction along the length of the form and thus across the second bulbous portion, and in the diametrically opposed direction to the peripheral regions of the form.

Consideration of the side aspects of the two forms illustrated in text figure (nos. 1A and 2A), leads to the assumption that it is possible for two teardrop-shaped forms of australites to result from continued ablation in the waist regions of one dumb-bell-shaped australite. Hence all teardrop-shaped forms are not necessarily products of constriction and separation in regions of dumb-bells during rotation, as advocated by Fenner (1934, figure 2, p. 65). The evidence provided by some of the smaller teardrop-shaped australites could well be interpreted in terms of the effects of surface fusion and ablation of thin melted films on cold glassy bodies during the non-rotational end (i.e.

atmospheric) phase of the earthward flight of solid dumb-bell-shaped australites. Larger teardrops, however, provide evidence of probably having entered the earth's atmosphere as already well-developed teardrop-shaped bodies of glass, produced as such from dumb-bells during the phase of development of the primary forms as rotating, completely molten glassy bodies in an extra-terrestrial environment.

The relationship between the arrangement of flow ridges and the trends of flow lines on the anterior surfaces of the flow-ridged australites, is of considerable significance to any postulate seeking a solution as to whether or not australites rotated through the earth's atmosphere during the period when their secondarily developed anterior surfaces were under production. At the outset, this relationship is regarded herein in its simplest form, so that any minor irregularities and complexities due to interference of flow line trends, such as slight inhomogeneities in the glass itself, or the encountering of small internal bubbles at various levels of the ablation process, have been purposely overlooked in making generalizations concerning the relationships between flow ridges and flow lines on anterior surfaces. It can be observed on the anterior surfaces of many australites (e.g. E755, E760, E836, E837, E926, E971, E1025, E1040), that such fine flow lines as are present, cut right across the flow ridges without any displacement in trend, no matter whether the flow ridges are concentric or spiral. These fine flow lines mainly arise in the front polar regions of anterior surfaces, and tend to radiate out towards the equatorial edge of each form. The flow lines are thus at right angles to the flow ridges on the curved anterior surfaces; they are never parallel with them, nor do they anywhere appear obliquely tangential to the flow ridges. If rotation had occurred during the period of formation of the flow ridges, then the flow lines, more particularly than the flow ridges, would be expected to show spiral trends. None of the flow line patterns on anterior surfaces show any tendency whatsoever to be spiral in arrangement. This fact provides an additional pointer to the probability that australites did not of necessity rotate throughout the whole period of their transit through the earth's atmosphere. The formation of flow ridges and associated radial flow line trends, and the intimate connection between flow ridges and flange-building processes, thus seem to be manifestations of the nature of the movement of thin films of secondarily melted glass under the influence of frontal pressure and drag, acting on the outwardly curved forward surfaces of non-rotating bodies of australite glass.

Flow Lines.

The flow-line directions of australite glass are made evident on the surfaces of different forms by the presence of fine, narrow, thread-like streaks and channels, in most parts accentuated by natural etching. Flow-line patterns also become well-marked on naturally etched fracture fragments of australites. In thin sections of australites, the flow lines are pronounced under certain conditions of lighting, as long, slender streaks of glass which have slightly different refractive index values to neighbouring glass, and in parts show strain polarization.

The patterns formed by the flow lines are variable and remarkably complex within the body portions of australites (Plate V, figures 26 and 27). Within the flanges, they are usually arranged in spiral fashion (see Baker, 1944, Plates I to III), and often show puckered complications in the chin regions due to the jamming and contortion of warmer glass moving in against cooler glass (cf. Baker, 1944, Plate II, figures 2, 3, 5, 6 and 7). Some of these flow-line patterns in flanges are quite clearly defined on several naturally etched flange fragments from the Nirranda Strewnfield.

On the external surfaces of non-fractured australites, flow-line directions trend radially outwards from the front pole on anterior surfaces. They are concentric on the posterior surfaces of flanges (cf. text figure 15), and also on the neck surfaces of flanges, where they represent the outcrops of the internal spiral and puckered flow lines. Flow lines are not characteristic features of the posterior surfaces of body portions, unless abrasion, followed by prolonged natural etching, has removed the outer primary surface and thus exposed lower layers of the interior. Flow-line patterns generated in this way usually reveal the complexity of the internal flow-line structures. A few of the Nirranda Strewnfield australites (e.g. reg. no. E1022), like certain australites from other strewnfields, possess occasional smoother, non-pitted, circular to ovate swirls that reveal irregular spiral flow-lining (Plate III, figure 15). These swirls are surrounded by the characteristically bubble-pitted regions of posterior surfaces. They are evidently areas of the primary surface that escaped boiling or gas accumulation, and probably represent rather more viscous portions of molten glass that became swirled about in a quite local vortex motion.

The internal flow-line pattern of an australite button is shown diagrammatically in text figure 15, in order to bring out the relationship of the complexities of the interior compared with the more simplified patterns on the outside surface. Portion of the posterior and neck surfaces of the flange have been included to show these relationships for the flange in particular. The terms " chin," " neck " and " seat " employed in text figure 15, have been described elsewhere (Baker, 1944, p. 8).

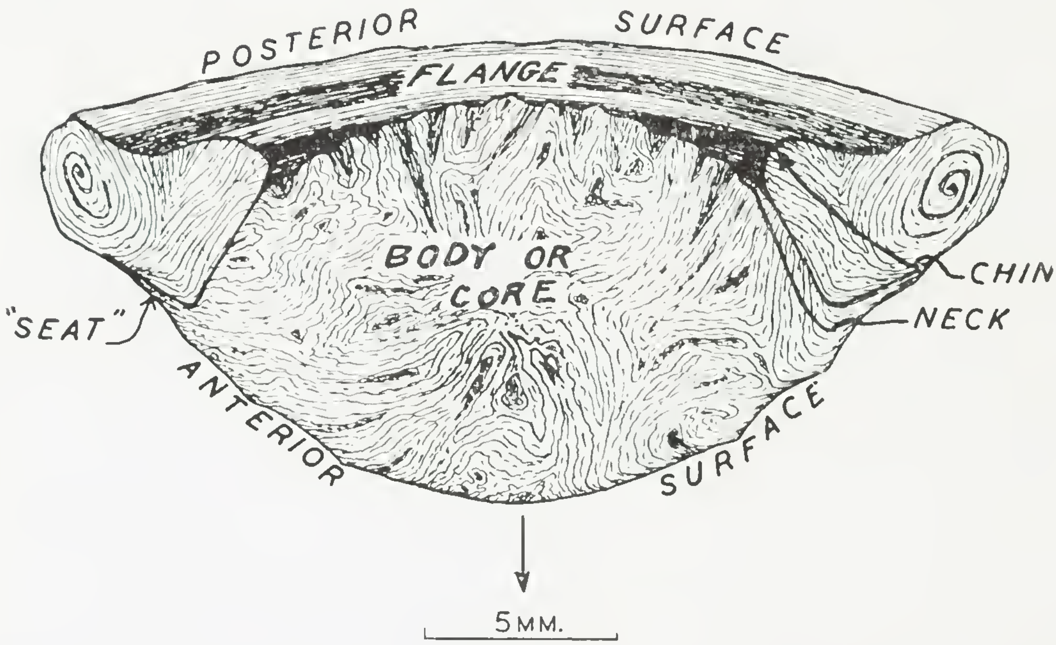

FIGURE 15.

Diagrammatic representation of a vertical section taken between the polar plane and the equatorial region of a flanged australite button. Arrow indicates direction of propagation through the earth's atmosphere.

The complex character of the primary internal flow structures is indicated in the body or core portion in text figure 15, and shown in greater detail in Plate VI, figure 28. There is a tendency on the posterior portion of the body for flow lines to indicate streaming towards the bases of bubble pits, whereas the complex internal flow-line pattern is frequently cut off abruptly by the secondarily developed flow lines and flow troughs of the anterior surface portions. The outermost thin film of australite glass on the anterior surface, shows a trend of secondary flow lines away from the front polar regions towards equatorial regions where the flange is built up; this trend of flow lines is best observed in the partially ablated " seat " regions.

A most characteristic and significant feature of the internal flow lines of the flange is the generally coiled or spiral pattern. The outcrops of these flow lines on the posterior and neck surfaces of the flange, generally provide concentric flow-line patterns, irrespective of shape group, so that these external flow lines are parallel to the outer (and inner) edges of flanges, which themselves are parallel to the outline of the form to which they are attached in any particular shape group.

The plane spiral character of the internal flow lines of any one flange is maintained all round the flange—no matter in which position a vertical radial section is made through a flange, this spiral character remains evident, with only minor variations from place to place in one and the same flange. This fact, added to the concentric nature of these flow lines on the external surfaces of the flange, indicates that the flange structures have been formed by the streaming in and over of glass secondarily melted from the front pole (i.e. from the region of the arrow in text figure 15), and forced under pressure towards equatorial regions.

Boundary layer flow in the medium (earth's atmosphere) through which the australites had a supersonic trajectory, is considered to have been partly responsible for the structures of anterior surfaces of body and flange. Where the boundary layers separated from contact with the object, at the outermost edge of the flange, turbulence was created (cf. Plate VI, figure 28), with the development of eddy currents in the low pressure region immediately behind the flange. These eddy currents are regarded as being responsible for shaping the cooling flange glass into the form we know it, and they probably account for the generally smooth nature and often slightly concave character of the posterior surfaces of flanges. Here again, it seems unnecessary to invoke rapid spinning about a vertical axis, to account for the development of these particular secondary features of australites. In fact, it is more than likely that the spirally coiled annular band of glass constituting a flange would not reveal the structures present if rotation had occurred throughout flange-building. Moreover, during rotation, liquid glass should largely have been thrown off by centrifugal forces, and thus be unavailable for extensive flange formation.

Internal flow lines constitute the major internal structures of australites (cf. Plate V, figures 26 and 27). Associated with them are less common features such as small internal bubbles, larger internal bubbles (Plate II, figure 11) and rare, minute lechatelierite particles. Where drawn-out, the lechatelierite particles contribute to the flow streaks in australite glass, and where exceedingly drawn-out, small bubbles do likewise, while the larger internal bubbles cut directly across the internal flow structures (cf. Baker, 1944, Plate I, figure 12). These features have been dealt with in some detail elsewhere (cf. Barnes, 1940, Baker, 1944), and studies of similar features in the Nirranda Strewnfield australites bear out the conclusions drawn from these earlier studies.

Grooves.

The grooves on the surfaces of australites have been referred to earlier, in connexion with the control they exert in the process of fragmentation of australites. The origin of these grooves on tektites generally has been the subject for much debate, and the deeper grooves and channels have been variously referred to in tektite literature as "bubble grooves", "bubble tracks", "saw-marks", "saw-cuts", "knife-marks", "cannelures", "canals", "flow-grooves", "gouttières", "gutters", "furrows", "open channels", and "crevasses."

The evidence for the origin of these grooves in the Nirranda Strewnfield australites points to development by natural etching along flow-line directions (i.e. mostly along lines of strain). Shallow channels are at first developed, and with progressive etching, aided by diurnal temperature changes and the effects of differential expansion and contraction of foreign materials that become lodged in these channels, occasionally resulting in the spalling away of narrow slivers of australite glass from the walls, the grooves thus become widened and deepened. These grooves are thus fundamentally "flow-grooves," inasmuch as flow-line directions in the australite glass control the positions of their initiation. Along the flow-line directions the australite glass is more siliceous, as evidenced from optical characteristics, and hence it is more readily dissolved out by the etching solutions in soils. Occasionally, the flow-line directions are marked by associated strings of small bubbles; these would provide sites for the lodgment of small quantities of etching solutions, and the resulting grooves have a segmented appearance. A few grooves seem to have been single bubbles, now drawn-out into very long slender shapes; such types are more typical of the " tails " of teardrop-shaped australites.

Not all the grooves on the surfaces of australites follow flow-line directions. Some represent the positions of original fine fracture lines that cut right across flow-line directions, and have evidently been deepened and widened by etching; flow-line patterns continue on either side of such grooves, with no apparent displacement. The bottoms of most grooves are generally smooth and rounded downwards, so that in cross-sectional aspect, they are deeply U-shaped. Some of the grooves on the Nirranda Strewnfield australites, however, tend to be more or less flat at the bottom, and in rare examples they tend to be convex upwards (e.g. in reg. no. E1052).

Some of the grooves pass inwards from the exterior of certain specimens for as much as 1·5 cms., and as deeply as 0·5 mm. from the surface. Sometimes they extend superficially from the equatorial edge to the front polar regions of anterior surfaces (Plate II, figure 9), in radial fashion, and thus parallel the general directions of the radial flow lines. The fine sand and clay constituents that invariably become wedged into the grooves are sometimes loose and incoherent, but in some grooves (and occasionally in some bubble pits on posterior surfaces, and in the gap betwen flange and body of flanged forms) these constituents have become firmly cemented in place and compacted by siliceous and iron hydroxide cementing materials. The fine sand and clay constituents match those of the soils in which the australites were embedded, and so are terrestrial products in no way connected with the origin of australite glass.

OPTICAL PROPERTIES

Complete or nearly complete australites, and the larger of the fragments are pitch-black in colour, but thin fragments are translucent and brownish-green in colour when held up to a light.

The glass comprising the Nirranda Strewnfield australites, is pale yellowish-green in colour as observed in thin sections. It is practically isotropic under crossed nicols of the petrological microscope, except for minor streaks along some flow-line directions. These streaks exhibit very limited and weak birefringence, and the fact that extinction is seen in places to be distinctly undulose, more particularly with the aid of a sensitive tint plate, indicates a certain amount of strain in parts of the glass.

No crystallites or allied bodies have been observed in thin sections under the petrological microscope, and no opaque minerals are revealed in polished surfaces examined under the reflection microscope. Apart from internal flow lines with slightly variable refractive index values compared to the rest of the glass (Plate V, figures 26 and 27), the only other features of thin sections of the glass are rare, minute gas bubbles and even more rare partially drawn-out lechatelierite particles. Only two of the Nirranda Strewnfield australites, however, were sliced for the preparation of thin sections, but these reveal little difference to some three dozen thin sections of Port Campbell Strewnfield australites, as far as colour, internal flow lines, lack of inclusions apart from lechatelierite particles, general isotropism and the presence of a few small gas bubbles are concerned.

Refractive index measurements of the glass of three Nirranda Strewnfield australites used for chemical analysis show a range from 1·511 to 1·513, compared to a range of 1·513 to 1·515 for those of three chemically analysed Port Campbell Strewnfield australites. Inasmuch as these three Nirranda examples have slightly lower refractive index values, it is to be expected from Spencer's (1939, p. 425) observations that as SiO_2 increases in natural glasses, specific gravity and refractive index decrease, then they should be a little more acidic than the Port Campbell examples. Table VIII shows these relationships between SiO_2, specific gravity and refractive index for australite glass from the two strewnfields, with SiO_2—specific gravity relationships for an analysed specimen from Peterborough added for comparison.

The Nirranda examples are more acidic than those selected for analysis from Port Campbell, and the trend noted by Spencer (1939) for other natural glasses is again evident from Table VIII, for the specific gravity and refractive index values are lower for a greater SiO_2 content. Although its refractive index value is unknown, a similar trend is indicated by the specific gravity—SiO_2 relationships for the Peterborough example, where the specific gravity is even lower for a still higher SiO_2 content. In the field, the most acidic australite from these three localities, occurred in an intermediate position. Peterborough being approximately midway between the sites of greatest australite concentration in the Nirranda and Port Campbell Strewnfields respectively. These examples therefore

TABLE VIII.

	Nirranda Strewnfield.	Peterborough.	Port Campbell Strewnfield.
SiO_2 content	75·90	79·51	71·62
Specific gravity in the powdered form (at 18° C.)	2·398	2·370	2·427
Refractive Index	1·511 to 1·513	*	1·513 to 1·515

* No material available for determination, and refractive index value not given in the literature (Summers, 1913).

do not show the trend of provincial distribution of australites that is evident across the Australian continent (Summers, 1909, p. 437, Baker and Forster, 1943, p. 394). However, this is not very significant in itself, when it is remembered that the three examples illustrated above are from a relatively small area only 25 miles long. Such an area constitutes but a very small portion of the vast Australian Strewnfield, where generalizations concerning provincial distribution according to chemical composition, refer to a length of some 2,000 miles across the continent, and an area of approximately 2,000,000 square miles.

CHEMICAL COMPOSITION

Approximately 5 grams of australite glass from the Stanhope's Bay locality in the Nirranda Strewnfield were chosen to include the flange portion and body portion of button-shaped australites. With this end in view, seven fragments were selected—three button core fragments, two flange fragments, one fragment representing half a button core without flange, and one button fragment with flange remnants attached. These represent registered nos. E740, E742, E765, E769, E822, E824 and E832 in the National Museum Collection, Melbourne. All the material was used in chemical analysis and refractive index determinations. The specimens were carefully freed of all extraneous foreign material prior to crushing for analysis.

For comparison, similarly selected material from the Loch Ard Gorge area, south-east of Port Campbell township, was treated in like manner. The chemical analyses were carried out by Mr. G. C. Carlos. The results are set out in Table IX, together with an earlier analysis of an australite (shape not stated) from Curdie's Inlet, Peterborough.

TABLE IX.

—	1.	2.	3.
SiO_2	75·90	71·62	79·51
Al_2O_3	10·83	13·68	10·56
Fe_2O_3	1·48	0·85	0·60
FeO	4·07	4·90	3·11
MgO	1·42	2·15	1·35
CaO	2·94	3·24	1·48
Na_2O	0·92	0·98	0·91
K_2O	1·69	1·90	1·25
H_2O (+)	0·11	0·10	0·19
H_2O (−)	Nil	Nil	Nil
TiO_2	0·60	0·53	0·63
MnO	0·06	0·05	0·06
Li_2O	..	..	sl. tr.
P_2O_5	Nil	Nil	Nil
CO_2	Nil	Nil	Nil
SO_2	Nil	Nil	Nil
Cl_2	Nil	Nil	Nil
NiO	..	..	Nil
BaO	..	..	Nil
CoO	..	..	Nil
Total	100·02	100·00	99·65
Sp. Gr. powder	2·398	2·427	2·370
R.I.	1·511 to 1·513	1·513 to 1·515	..

1. Australite glass from north-east corner of Stanhope's Bay, 15 miles south-east of Warrnambool, South-western Victoria. (Anal. G. C. Carlos.)

2. Australite glass from Loch Ard Gorge district, 4½ miles south-east of Port Campbell, South-western Victoria. (Anal. G. C. Carlos.)

3. Australite glass from Curdie's Inlet, Peterborough, South-western Victoria. (Anal. G. A. Ampt, see Summers, 1913, p. 190.)

Principal variation in the australite glass analysed from the above three localities (see Table IX) in South-western Victoria, is in the silica content, that for the Nirranda Strewnfield australite glass (i.e. Stanhope's Bay analysis) being intermediate in amount to those for the Port Campbell and Peterborough examples. Total iron is a little variable, likewise the state of oxidation of the iron. Lime, magnesia, alumina and the alkalies, show little variation from example to example, while the oxides of the minor elements are equally low in the three analyses.

CURVATURE AND RELATIONSHIPS OF ANTERIOR AND POSTERIOR SURFACES

Australites have a symmetry un-matched among the various components of the several tektite strewnfields of the world, and so far little has been done to determine the nature and relationships of the curvature of their two distinct surfaces—posterior (rear) and anterior (forward) surfaces—separated from each other by flanges in certain forms (e.g. buttons, some ovals, &c.), rims in some forms (e.g. lenses) and flaked equatorial zones (Plate III, figures 13 and 16) in other forms (e.g. cores). An elementary approach is made herein to the study of the geometry of australites, in order to illustrate variability in the curvatures of the two different surfaces and to indicate their probable relationships to the primary forms from which the shapes of australites were derived.

The Nirranda Strewnfield provides a satisfactory number of australites, in a fair state of preservation, for the determination of the radii of curvature and the nature of the arcs of curvature of posterior and anterior surfaces of various forms in the different shape groups.

The results obtained from radius of curvature determinations for these two surfaces have been compared (i) one against the other (text figure 18), (ii) for the different shape groups (see Table X), and also (iii) for their relationships to diameter and depth (text figures 23 to 26 and Table XI) mainly for the round forms of australites.

Method of Obtaining Arcs and Radii of Curvature.

The method of obtaining the arcs and radii of curvature of both posterior and anterior surfaces of sufficiently well-preserved australites involved the use of silhouette tracings of the various forms. This method was found to be quicker and more suitable than using a spherometer, because of the slight natural irregularities due to bubble pits, &c. on most of the curved posterior surfaces of australites, and to flow ridges on most curved anterior surfaces.

Each australite was mounted with plasticene on a glass slip in the manner illustrated by text figure 16.

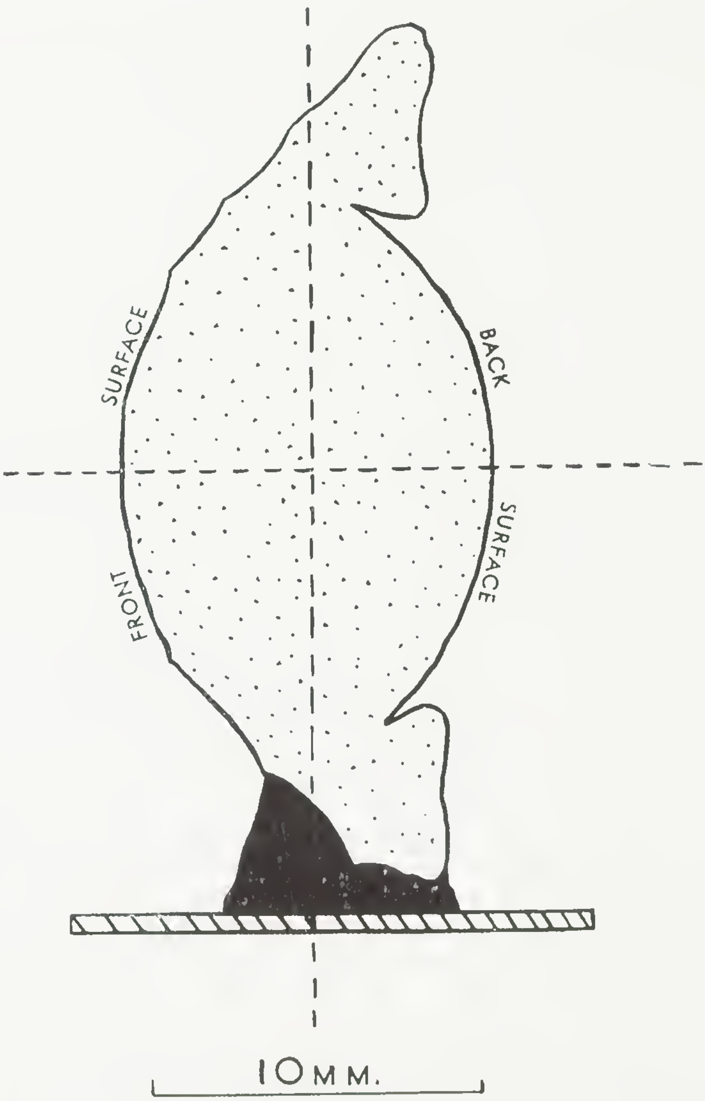

FIGURE 16.

Sketch of button-shaped australite mounted in position for deriving curvature of anterior and posterior surfaces.

Each australite was adjusted in the beam of light from a projector so that the plane containing its diameter was, as near as could be arranged by eye, parallel with the direction of the beam. Each specimen was placed in turn at the focal point of the projector lenses, and the image thrown on to a mirror set at 45°, and thence down on to the working bench. After tracing the silhouette in a convenient size (x3·75), and smoothing out minor irregularities caused by the presence of bubble pits and flow ridges, each australite was rotated to the 45° and 90° positions, when it was found, for buttons, lenses and round cores, that the silhouettes in these positions matched almost exactly the original tracing. This indicates the maintenance of a similar degree of curvature over any one particular surface, and shows that both the posterior and the anterior surfaces each form portions of different hemispherical surfaces.

For elongate australites such as ovals, boats, and canoes, two different silhouette tracings (cf. text figure 20) were obtained for two positions at right angles, corresponding to the major and minor diameters of the forms. One tracing therefore corresponds to the outline of a section taken in a plane at right angles to the major diameter and containing the minor diameter and the depth, and the other corresponds to the outline of a section taken in a plane at right angles to the minor diameter and containing the major diameter and the depth. The major diameter is hereafter referred to as the length, and the minor diameter as the width of the elongated australites.

For the dumb-bell and teardrop-shaped australites, only the silhouette outlines of end-on aspects were traced, i.e. corresponding to the outline of a section taken in a plane at right angles to the length and containing the maximum width and maximum depth of the bulbous portions of these forms.

For each arc of curvature obtained in this way for both the anterior and posterior surfaces of 215 australites from the Nirranda Strewnfield, three chords were constructed, bisected, and normals drawn through the mid-points. Most of these provided three point intersections, some showed a small triangle of error. With the intersections as foci, constructed circles were superposed upon each arc of curvature obtained from the silhouettes, and in most there was perfect concordance, in a few, minor departures occurred towards the edges—i.e. in the equatorial regions where the anterior surfaces of some flanges on flanged forms, were slightly flattened over a minor portion of the arc of curvature.

The arcs of curvature of the two surfaces of almost all of these australites, are themselves minor arcs of curvature, seldom being more than 30 per cent. of complete circles in round forms, 45 per cent. in end-on aspects of ovals, boats, canoes, dumb-bells and teardrops, and only 25 per cent. and less in side aspects of the elongate australites such as boats and canoes. The possibility therefore exists that some of the arcs of curvature among round forms of australites could correspond to certain parts of the arcs of curvature of ellipses rather than of circles (cf. text figure 21); in other words, some forms, especially the elongate forms, have evidently been derived from spheroids of revolution (text figures 31 and 32), and not all from spheres (text figure 30).

From the nature of the arcs of curvature for australites most likely to have been derived originally from spheres, it is evident that any vertical section cutting through the anterior surface, through the posterior surface and through the

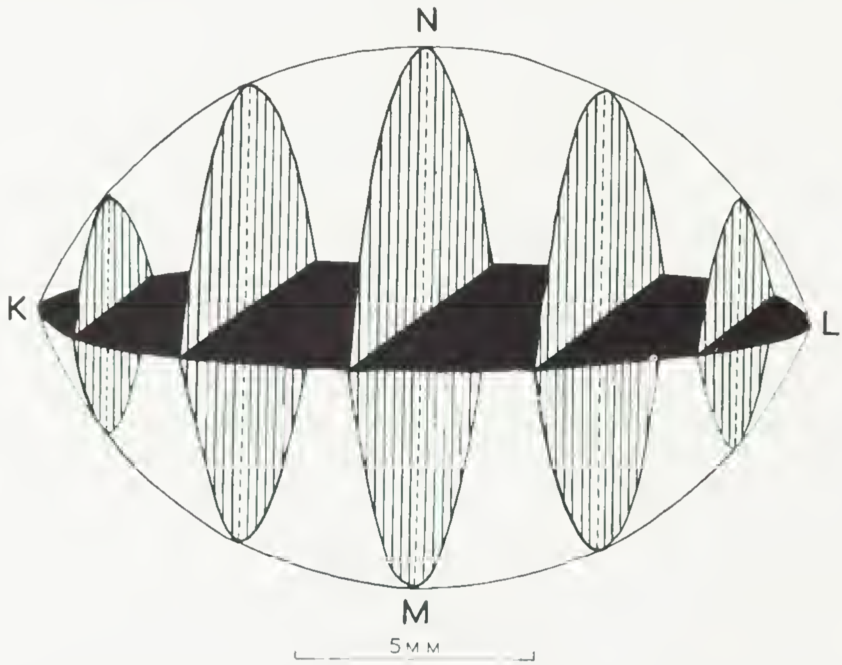

FIGURE 17.

Sketch illustrating nature of planes in a round-form of australite, where the anterior and posterior surfaces form the minor arcs of two intersecting coaxal circles.

equatorial regions of these round forms (i.e. forms that are circular in plan aspect), will show the curvatures of the anterior and posterior surfaces as the minor arcs of two intersecting, virtually coaxal circles (see text figure 17).

Only radial sections passing through the front pole (M in text figure 17) and back pole (N in text figure 17), will provide a true measure of the maximum depth and diameter values (i.e. NM and KL respectively in text figure 17). The plane KNLM in text figure 17 is one such radial section; the plane containing NM is another. All vertical sections parallel to the plane containing NM will have a generally similar shape, but will be of smaller size, and hence will not give true measures of the depth and diameter values. The horizontal plane containing the radical line KL (plane shown as solid black in text figure 17) is of circular outline, similarly all other parallel (but smaller) planes above and below this plane. The arc of curvature KNL never does, and KML seldom does, reach a stage in australites where they represent sections through the entire arc of curvature of a hemisphere. Only in rare examples of complete buttons do the anterior surfaces approach a hemisphere in size, and only in the very rare round hollow forms (cf. text figure 33B) do posterior and anterior surfaces each approach hemispherical dimensions.

Radii of Curvature Values.

The ranges of the measured values of the radii of curvature of anterior and posterior surfaces for the different shape groups among the Nirranda Strewnfield australites, are shown in Table X. The two different radii of curvature are connoted by the symbols R_F and R_B respectively. R_F represents the radius of curvature of the secondarily developed front (anterior) surface, while R_B represents the radius of curvature of the back (posterior) surface which is regarded herein as a remnant of the original primary surface.

In Table X, the values for R_F and R_B are given to the nearest 0·1 mm., and have been derived by dividing the values obtained on measurement of the enlarged silhouette diagrams by the reduction factor 3·75. The infinity sign in Table X refers to forms that possess almost flat surfaces in certain aspects, and there are only a few such forms. The T.S. heading to some columns in Table X refers to values determined from silhouettes obtained normal to the length and parallel to the depth and width measurements of elongate forms, while L.S. refers to those determined parallel to the length and depth and normal to width measurements of elongate forms. Where the ranges in R_F and R_B are set out in the L.S. columns in Table X, the numbers of measurements possible were limited by employing fragments that gave satisfactory measurements for the T.S. values only, hence (*a*) refers to L.S. measurements obtainable

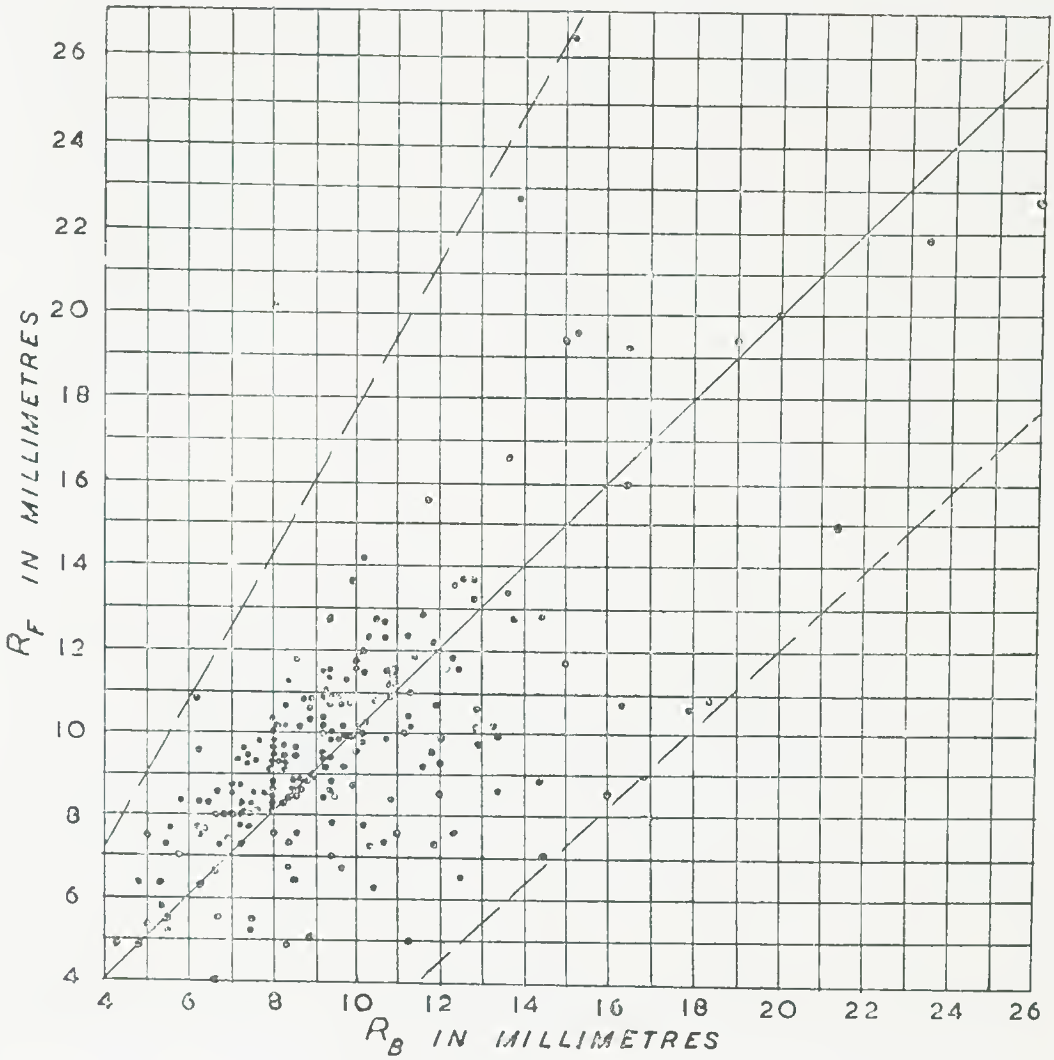

FIGURE 18.

Scatter diagram showing radius of curvature values for anterior and posterior surfaces of Nirranda Strewnfield australites.

from seven specimens only, (*b*) to four specimens, (*c*) to two specimens, (*d*) to three specimens, (*e*) to ten specimens, (*f*) to fourteen specimens, (*g*) to two specimens, and (*h*) to one specimen only.

TABLE X.

Showing percentage relationships and ranges of $R_F > R_B$: of $R_F = R_B$, and of $R_F < R_B$ for each shape group.

Group.	Total Number	$R_F > R_B$ (to 0·1 mm.).						$R_F = R_B$ (to 0·1 mm.).						$R_F < R_B$ (to 0·1 mm.).					
		No.	%	T.S.		L.S.		No.	%	T.S.		L.S.		No.	%	T.S.		L.S.	
				R_F Range.	R_B Range.	R_F Range.	R_B Range.			R_F Range.	R_B Range.	R_F Range.	R_B Range.			R_F Range.	R_B Range.	R_F Range.	R_B Range.
Buttons	38	24	63	8·5 to 12·9	7·0 to 11·7	..	..	3	8	10·2 to 13·5	10·2 to 13·5	..	..	11	29	8·3 to 16·0	9·9 to 17·9	..	..
Lenses (+ fragments) ..	81	49	61	7·0 to 14·1	5·8 to 13·6	..	..	9	11	8·4 to 12·0	8·4 to 12·0	..	..	23	28	4·0 to 11·8	6·7 to 19·2	..	..
Ovals (+ fragments) ..	41	21	51	5·3 to 12·8	5·0 to 10·6	8·8(a) to 14·8	7·3(a) 14·4	4	10	6·4 to 9·2	6·4 to 9·2	10·1(c) to 13·9	10·1(c) to 13·9	16	40	5·0 to 11·0	6·7 to 80·8	7·5(e) to 13·0	8·5(e) to ∞
Boats (+ fragments) ..	22	18	82	6·4 to 12·9	4·8 to 10·7	15·7(b) to 41·6	11·7(b) to 20·5	1	4	9·3	9·3	∞(d)	∞(d)	3	14	7·5 to 7·8	8·0 to 9·3	10·4(f) to 18·0	13·8(f) to 37·6
Canoes	2	..	..	..	..	..	..	2	100	4·8 to 7·2	4·8 to 7·2	..	..	..	..	..	..	13·7(a) to 18·6	42·7 (a) to ∞
Dumb-bells (+ fragments)	4	3	75	4·8 to 7·7	4·3 to 5·6	..	..	1	25	5·5	5·5	..	..	..	..	..	..	..	..
Teardrops	2	1	50	5·8	5·4	..	..	..	..	..	..	..	..	1	50	5·1	5·5	..	..
Cores (+ fragments) ..	20	3	15	19·4 to 26·4	15·2 to 19·0	..	..	2	10	20·0 to 30·1	20·1 to 30·1	..	..	15	75	6·1 to 22·7	9·4 to 26·1	25·6(h)	31·5 (h)
Hollow Forms	5	5	100	12·8 to 22·8	9·3 to 16·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Totals ..	215	124	58	4·8 to 26·4	4·3 to 19·0	8·8 to 41·6	7·3 to 20·5	22	10	4·8 to 30·1	4·8 to 30·1	10·1 to ∞	10·1 to ∞	69	32	4·0 to 22·7	5·5 to 80·8	7·5 to 18·6	8·5 to ∞

In each group, the greatest percentage of forms have R_F greater than R_B. Forms with R_F and R_B the same in value, are in the minority, those with R_F less than R_B are intermediary in number. This relationship is further brought out in the scatter diagram shown in text figure 18, where the R_F and R_B values for individual australites have been plotted to the nearest 0·25 mm.

A few higher values for R_F and R_B lie outside the scatter diagram shown in text figure 18. These are values for forms with (i) $R_F = 30$ mm and $R_B = 30$ mm., (ii) $R_F = 25 \cdot 5$ mm. and $R_B = 31 \cdot 5$ mm., (iii) $R_B = 81$ mm., and (iv) one or two forms having almost flat primary surfaces, so that R_B values are infinite and may thus be regarded as parts of the arc of curvature of spheres having infinite radius, whose centres are at infinity on the axes, or else parts of flattened spheroids of revolution.

Except in the flat-topped forms, the values for R_F and R_B do not vary widely from shape group to shape group. End-on aspects of dumb-bells and teardrops naturally provide the lowest radii of curvature values, while the greatest values are found in the largest of the cores and the larger of the hollow forms. Intermediary values as for buttons, lenses and ovals show no particularly significant variations. The small variations that do exist are functions of the sizes of the primary forms from which these secondary shapes were derived, as far as the R_B values are concerned, and the degree of ablation suffered, as far as the R_F values are concerned.

The fact that sometimes the R_F value of any particular australite is greater than its R_B value simply reflects the flatter arc of curvature of the anterior surface, and the development of a flatter arc of curvature for anterior surfaces is only to be expected with ablation of the original hemispherical front surfaces of the majority of the forms.

Effects of R_F—R_B Variations.

The effect of having (i) R_F less than R_B, (ii) R_F equal to R_B, and (iii) R_F greater than R_B is illustrated diagrammatically in text figure 19.

In text figure 19, diagrams A, B and C are typical of the cross sectional aspects of australites that are circular in plan, the sections being taken through the back (N) and front (M) poles of the objects. NM represents the depth of each form, KL the diameter, and O the point of intersection of NM and KL. KNL is the arc of curvature of the back surface and KML that of the front surface in each diagram.

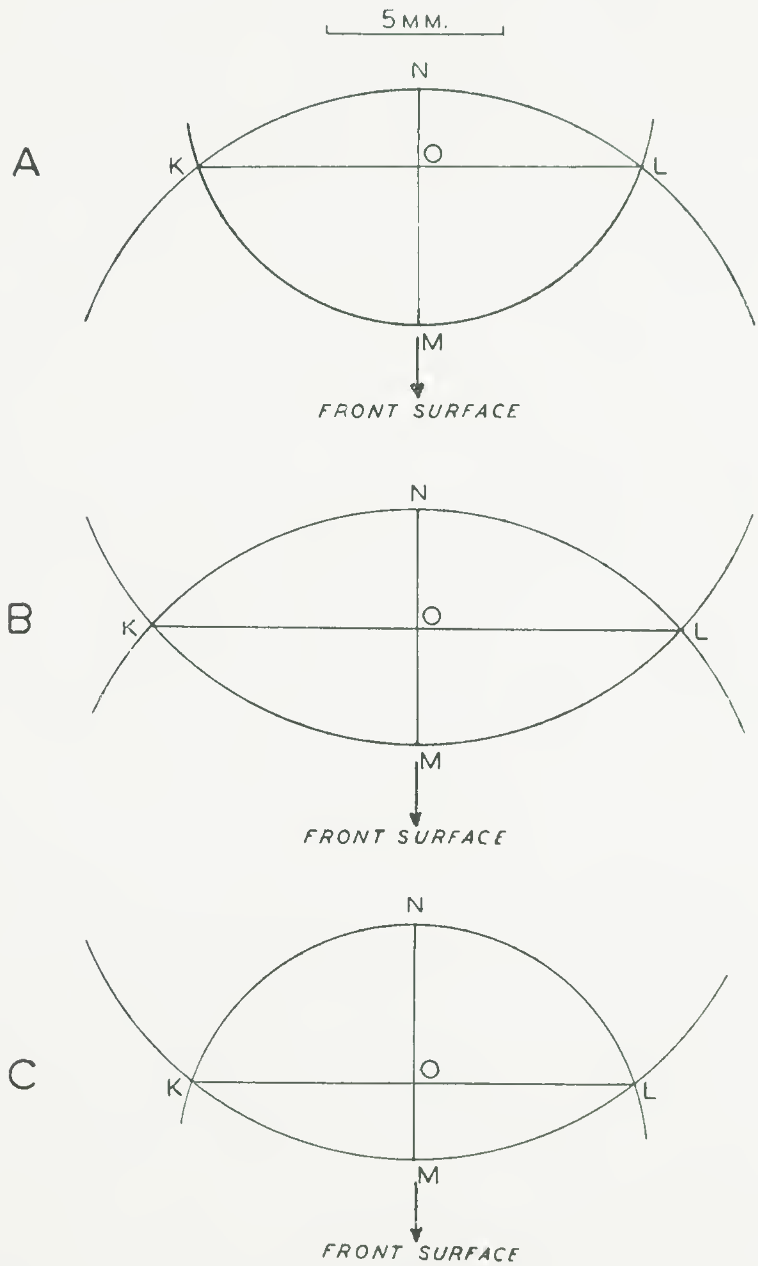

FIGURE 19.

Sections through australites showing in outline the relationships of varying curvature of posterior and anterior surfaces.

Depending upon the depths of the australites and the points of intersection of the two varying arcs of curvature for posterior and anterior surfaces respectively, the radical line (the line joining the points of intersection of the two coaxal circles of which the two arcs of curvature are part) will be nearer to or further from the front poles of australites, as indicated in text figure 19.

When R_F is greater than R_B, the sectional aspect is that of diagram C (text figure 19), where the front surface is somewhat flatter, O is nearer to the front pole (M), and less ablation has occurred than in either of the examples represented by diagrams A and B (text figure 19). In this example (diagram C, text figure 19) and in the one represented by diagram A (text figure 19), the horizontal plane containing KL is no longer a plane of symmetry, but NM is.

With R_B greater in value than R_F (text figure 19, diagram A), the arc of curvature of the rear surface is the flatter, O is nearer the back pole (N), and considerable ablation has occurred on a primary sphere that originally had a somewhat greater diameter than is represented in diagram C (text figure 19). In these and practically all other round forms of australites there has been maintenance of symmetrically curved surfaces throughout the processes of ablation producing the secondary shapes. Various stages occur between those represented by examples depicted in diagrams A and C (text figure 19); the example illustrated in diagram B represents the average relationship. The series indicates that at the outset the trend in primary spheres, on ablation, is for the radius of curvature of the front surface to increase, and hence for this surface to become flatter in its arc of curvature compared to that of the unaltering back surface. This condition holds until the average relationship (diagram B, text figure 19) is reached, but thereafter, as R_F decreases with respect to R_B, the arc of curvature of the front surface sometimes, but not always, becomes steeper compared with that of the back surface, evidently because of greater ablation in equatorial than in front polar regions, at the smaller sizes.

The cross sectional aspects of such types of australites are equivalent to the silhouettes utilized in determining the radii of curvature and, in them, the outlines represent the shapes produced by two intersecting circles. The line joining the points of intersection, i.e. the radical line, is a common chord to both circles and represents the diameter of australites. In the majority of examples it has been found by construction that the line joining the centres of the two intersecting circles is perpendicular to the radical axis, hence the two centres are collinear and the circles are thus coaxal circles. It also follows that this perpendicular line where it intersects the front and rear poles of each australite provides a measure of the true depth of the form. Such relationships indicate that most australites maintained a relatively stable position throughout the period of transit through the earth's atmosphere. In very few examples the two intersecting circles are not quite coaxal, and forms represented by this relationship evidently may have contracted a slight wobble from buffeting effects during rapid forward propagation.

The depth values (NM) of these australites vary according to (*a*) the values for R_F and R_B in each particular form, and (*b*) the proximity of the centres of the intersecting circles to O in text figure 19. This, again, is ultimately a function of the degree of ablation to which any particular original sphere of australite glass was subjected.

When R_F and R_B are equal, the two arcs of curvature are the same and O is equidistant from the back and front poles (see diagram B, text figure 19). The outline of the form in sectional aspect is then that of a biconvex lens having one plane (horizontal plane) of symmetry along KL, and radial symmetry through NM for the round (in plan aspect) forms of australites.

When two (or more) comparable forms have the same R_B and the same diameter they most often have different depth values. Hence their R_F values differ, and the arc of curvature of one front surface is either flatter or steeper than in the other form (or forms), indicating variations in degree of ablation of two originally similar primary spheres of australite glass.

Conversely, when two (or more) forms have the same R_F values and the same diameter, but different R_B and depth values, the arc of curvature of one back surface is flatter than that of the other, indicating two originally dissimilar sizes of australite glass spheres. In order to produce similar arcs of curvature of the two front surfaces from two original spheres of different diameter, one sphere must have been subjected to greater degrees of ablation than the other, and this can have come about as a consequence of slight differences in the time of transit through the earth's atmosphere, arising from different angles of traverse, so that one, in effect, travelled through a greater thickness of atmosphere than the other.

Fenner's (1934, p. 66) statement that no two australites are alike in the Shaw Collection is also applicable to most known Victorian australites. There are in the Nirranda Strewnfield australite collection, however, three lens-shaped forms (reg. nos. E865, E866 and E867) that are almost identical in surface features, they have the same depth and diameter values, the RF and RB values are approximately equal with a maximum variation from lens to lens of only 0·5 mm. Differences of weight are up to only 0·3 grams, and in specific gravity of up to 0·05. Although therefore not identical in every respect, these three lenses are generally very much alike in practically all of their characteristics. The conclusion to be drawn from these observations is that several similar size spheres of australite glass were formed primarily, irrespective of slight variations in specific gravity, and were subjected to similar amounts of ablation during their supersonic flight through the earth's atmosphere, producing similar secondary shapes with similar arcs of curvature of their forwardly-directed surfaces.

Oval-shaped australites have a longer and a shorter diameter (Plate IV, figure 23), with one of these diameters a few millimetres longer or shorter than the other. In two positions at right angles there are thus two different arcs of curvature for each of the posterior and anterior surfaces, and there are two radical lines of different length, as indicated in text figure 20.

K′L′ is the radical line (representing the diameter) across the shorter axis of the oval-shaped form sketched in text figure 20, and KL the radical line representing the longer diameter for the position at right angles. The radius of curvature of the front surface is greater for the longer than for the shorter diameter, hence its arc of curvature is somewhat flatter. The same applies to the back surface. Two pairs of coaxal circles result, with the members of separate pairs in contact at the front and rear poles respectively, and intersecting each other at K and L for the long diameter, and at K′ and L′ for the shorter diameter. The sketch in text figure 20 is of a form where RF and RB are of much the same value. There are other examples where RF is greater or less than RB but, in them, the general relationships of the curvatures of the two surfaces in the two positions at right angles are as depicted in text figure 20.

From such relationships as these it is deduced that oval-shaped australites were derived from spheroids of revolution rather than from spheres, despite the fact that each arc of curvature accords with the arcs of curvature of constructed circles. The reason for this accordance is again to be ascribed to the fact that the curved surfaces of these australites correspond with only minor arcs of such circles, just as do certain portions of the arcs of curvature of spheroids.

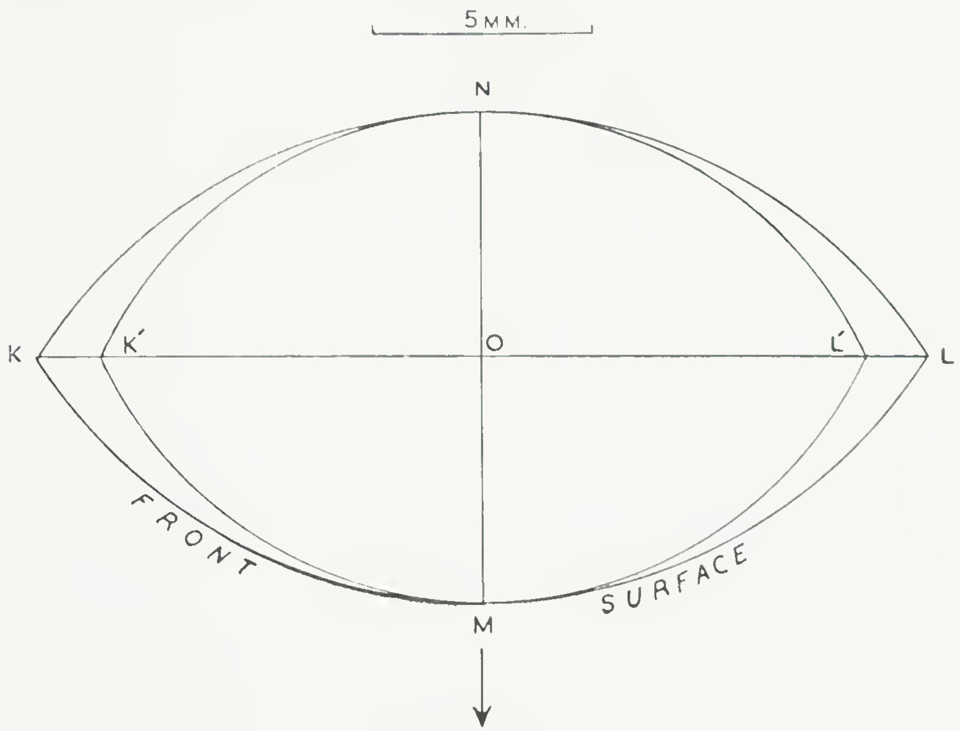

FIGURE 20.

Diagrammatical representation of two sections in right-angle positions through an oval-shaped australite, showing variations in arcs of curvature, meeting at N and M respectively for a constant depth, and different lengths of the radical lines KL and K′L′.

Much the same relationships exist for boat- and canoe-shaped australites as for oval-shaped forms, except that differences in length between KL and K′L′ (see text figure 20) are considerably increased, hence there are greater differences in the radii of curvature for each diameter of the front and back surfaces respectively, so that much flatter curvatures result along the direction of the longer diameter. It is thus even more likely that boats and canoes were derived from spheroids of revolution rather than from spheres, such spheroids being originally more elongated along one axis than were the primary spheroids from which oval-shaped australites were derived. Some of the possible cross sectional aspects of these elongated specimens of australites are shown in a cross section through a spheroid of revolution in text figure 21.

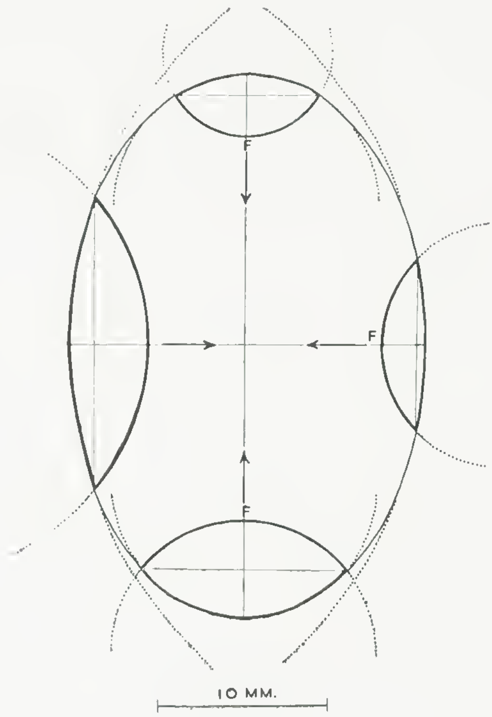

FIGURE 21.

Cross sections of elongate australites depicted as being derived from four positions of a spheroid of revolution.

For convenience in text figure 21, four possible cross sections are shown in the cross section through one spheroid of revolution. F indicates the forward surface for each form developed after ablation of the spheroid. Slightly varying cross sections would result for the end products by commencing with a spheroid of revolution of different length—breadth relationships to those shown in text figure 21. Considered as a prolate spheroid traversing the earth's atmosphere at supersonic speeds, and with its longer axis parallel with the direction of propagation, the top and bottom cross sectional aspects of the final shapes produced (text figure 21) could well be those of some lens- and button-shaped australites, as well as of oval-shaped forms having minor differences between the longer and shorter diameters, because the arcs of curvature in these positions conform also to the arcs of curvature of small spheres (indicated by the broken lines of part circles at the top and bottom of text figure 21), as well as to the arcs of curvature around the top and bottom poles of the spheroid of revolution.

Considered as an oblate spheroid, the two sections depicted on the left- and right-hand sides of the sketch (text figure 21) conform to the longitudinal sections through boat- and canoe-shaped australites, i.e. forms which usually have a much flatter curvature of the posterior than of the anterior surface, and which are longer than broad. Here again, the arc of curvature of the posterior surface for each example can conform to part, although a very minor part, of the arc of curvature of a constructed circle (indicated by the broken lines of part circles on the left- and right hand sides of text figure 21) with a greatly increased radius compared with that constructed around the front and back poles of the spheroid itself.

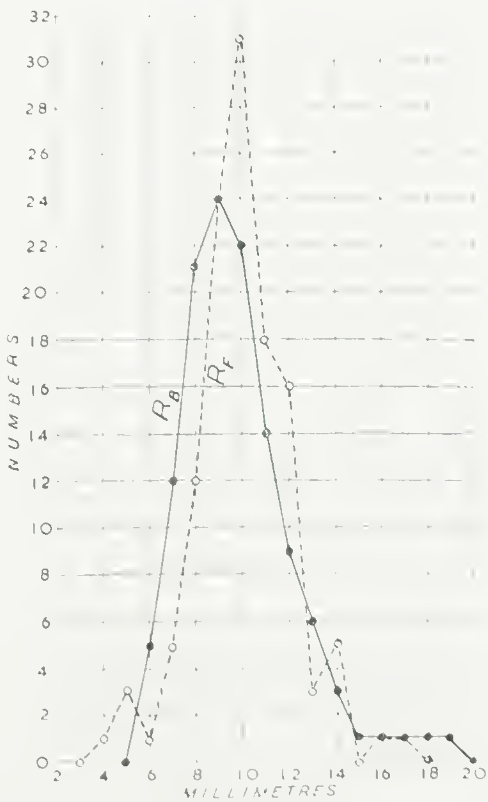

FIGURE 22.

Frequency polygons for RF and RB of the Nirranda Strewnfield australites.

The relationships between numbers measured and the values resulting from measurements of RF and RB in button- and lens-shaped australites from the Nirranda Strewnfield are shown in text figure 22.

The frequency polygons shown in text figure 22 verify the observation that RF is generally greater than RB among the Nirranda Strewnfield australites, the mode for RF occurring on the 10 mm. co-ordinate, while that for RB lies on the 9 mm. co-ordinate. It also transpires that these modal values tally with a relatively common combination among button- and lens-shaped australites, i.e. many forms have RF values of 10 mm., and RB values of 9 mm.

Relationships of RF and RB to Depth and Diameter Values.

The scatter diagrams shown in text figures 23 to 26 indicate distribution relationships as between (i) RF and diameter, (ii) RF and depth, (iii) RB and diameter, and (iv) RB and depth. They also provide a record of these values for each individual australite collected from the Nirranda Strewnfield for which such measurements could be obtained.

Text figure 23 shows that most of the Nirranda Strewnfield australites possess diameter values that are a little greater in amount than the RF values. The same applies for RB–diameter relationships shown in text figure 25. The position is reversed for RF–depth (text figure 24) and RB–depth (text figure 26) relationships, where a greater number of forms have both the RF and the RB values greater in amount than the depth values, although there is a somewhat larger number of individuals with depth values greater than RF and RB values than there are with RF and RB values greater than diameter values. Moreover, there are rather more individuals with depth values greater than RB values than there are with depth values greater than RF values. These relationships are expressed on a percentage basis in Table XI.

Relationships of the Intercepts Made by the Radical Line Upon the Depth Line of the Nirranda Strewnfield Australites.

The intercepts of the radical line upon the depth line of the Nirranda Strewnfield australites are indicated diagrammatically in text figures 19 and 20, where the length cut off between the front pole and the point of intersection of the radical

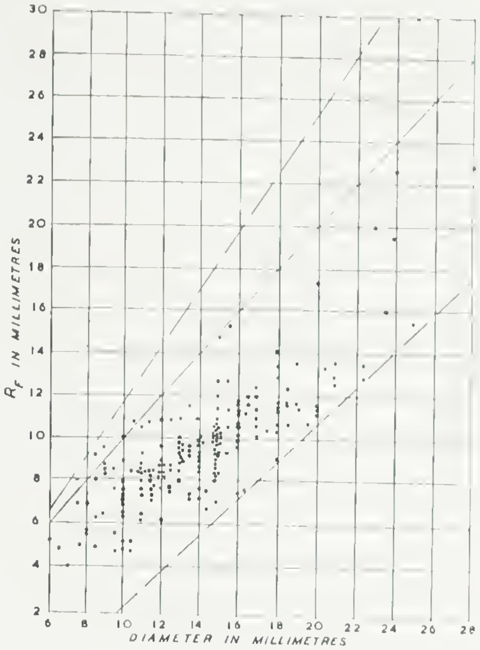

FIGURE 23.

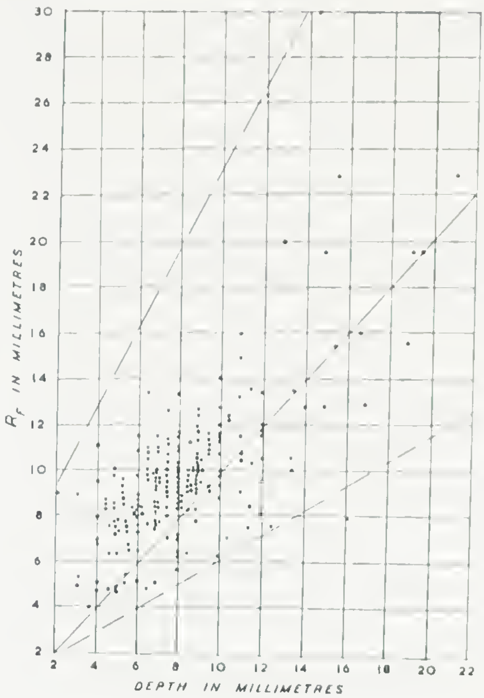

FIGURE 24.

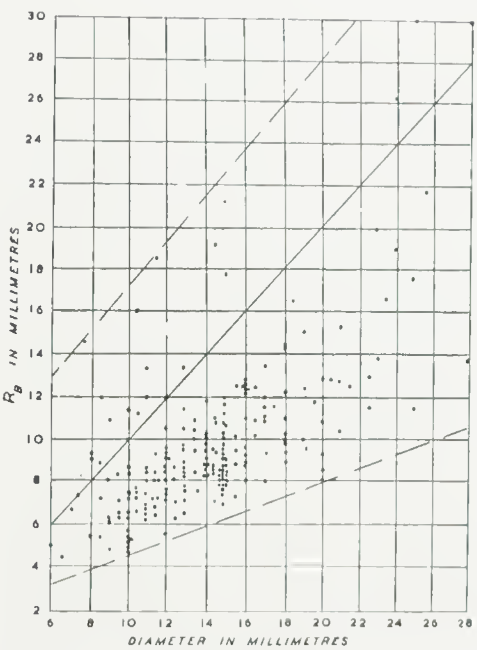

FIGURE 25.

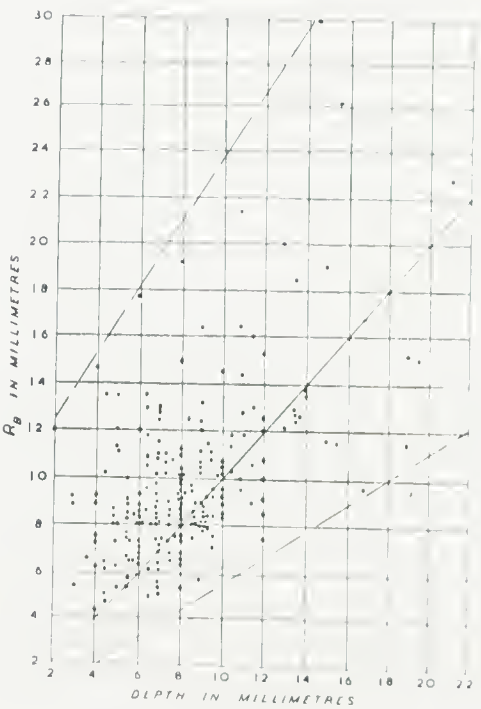

FIGURE 26.

Scatter diagrams showing relationships of radius of curvature of anterior (R_F) and posterior (R_B) surfaces to diameters and depths of australites from the Nirranda Strewnfield.

line with the depth line is represented by the length OM, and that for the back pole by ON. OM and ON values therefore represent the distances of the front and rear poles respectively from the centre of the radical line for each of the australites from which the relevant information could be obtained.

The relationships of the measured values for OM and ON are presented in text figure 27, where the values have been plotted to the nearest 0·25 mm.

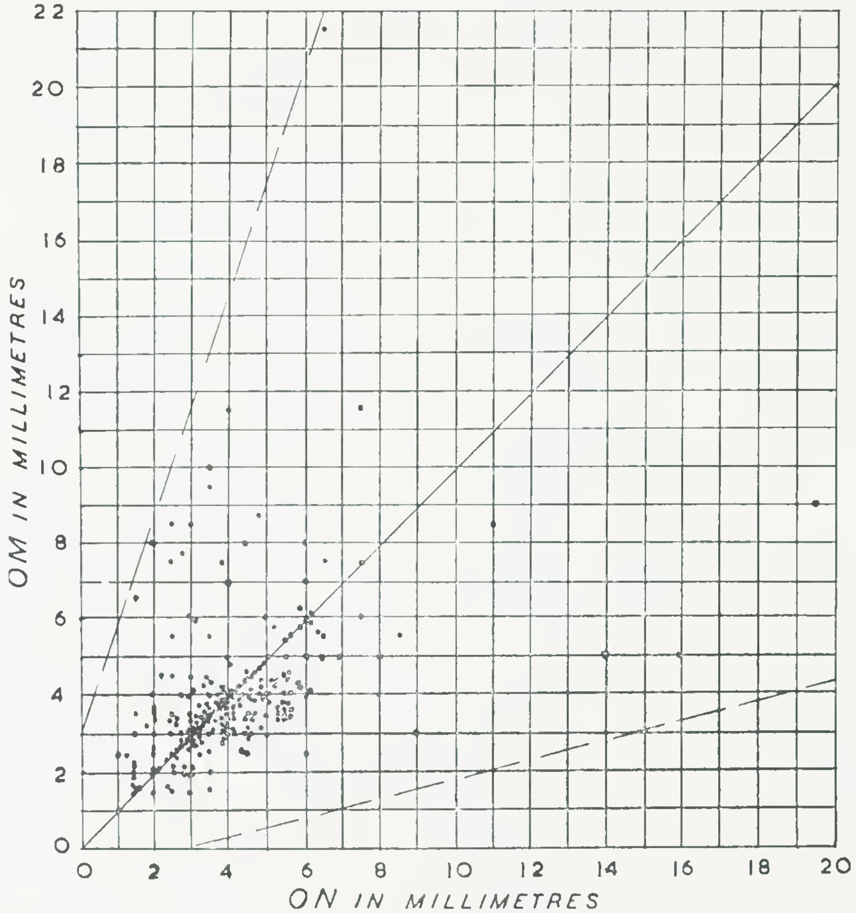

FIGURE 27.

Scatter diagram showing OM ON relationships for Nirranda Strewnfield australites.

A large number of the values are clustered along the lower limits of the unit gradient line, indicating that in many of the australites the front and back poles are more or less equidistant from the radical line and, in many, these values are low and show differences of little more than 1 mm. A small number of forms possess ON values that are greater than OM values, and vice versa, in terms of the scatter diagram (text figure 27). In them, therefore, a few of the australites have a greater bulk of glass on the back polar side of the radical line, and a few have the greater bulk on the front polar side. This state of affairs in no way upset the stable position of flight of australites through the earth's atmosphere. The greater number of forms, in which OM and ON are equal or almost so, possess similar amounts of glass on either side of the radical line. This is only a generalization, however, as can be gathered from inspection of Table XI, where the percentage calculations are based on values taken to the nearest 0·1 mm.

The relationships of OM and ON throughout are fundamentally controlled by the radius of curvature of the front surface compared with that of the back surface. In addition, since the arcs of curvature of these two surfaces represent minor arcs of coaxal circles, they are also controlled by the positions of intersection of the two surfaces in the equatorial regions of the australites; in other words, the distance apart of the centres of the coaxal circles.

Extreme examples where OM : ON :: 3 : 1, and where ON : OM :: 3 : 1 are very rare. Since the intercepts OM and ON are intimately related to the radii of curvature R_F and R_B, the ratios of OM to ON and of R_B to R_F have been calculated and are plotted side by side in the frequency polygons represented in text figure 28.

The inset diagram in text figure 28 provides a key to the measured values from which the ratios have been determined. The ratios have been plotted from calculations based on determinations taken to the nearest 0·25 mm., and both the frequency polygons reveal prominent modes at unit ratio. In the calculation of the ratios OM : ON, OM was retained at unity throughout. The greatest numbers (85 per cent.) with ratios of OM and ON approximating unity, contain most of the button- and lens-shaped forms that are more or less regularly lenticular in side aspect, and which thus have the radical line spaced approximately equidistant from the front and back poles respectively. To the left of the mode of the left-hand frequency polygon in text figure 28 occurs the group of the cores, wherein OM is mainly greater than ON. To the right of this same mode occurs a lesser number of button-, lens- and oval-shaped forms where OM is mainly less than ON, and such forms have slightly flatter posterior than anterior surfaces.

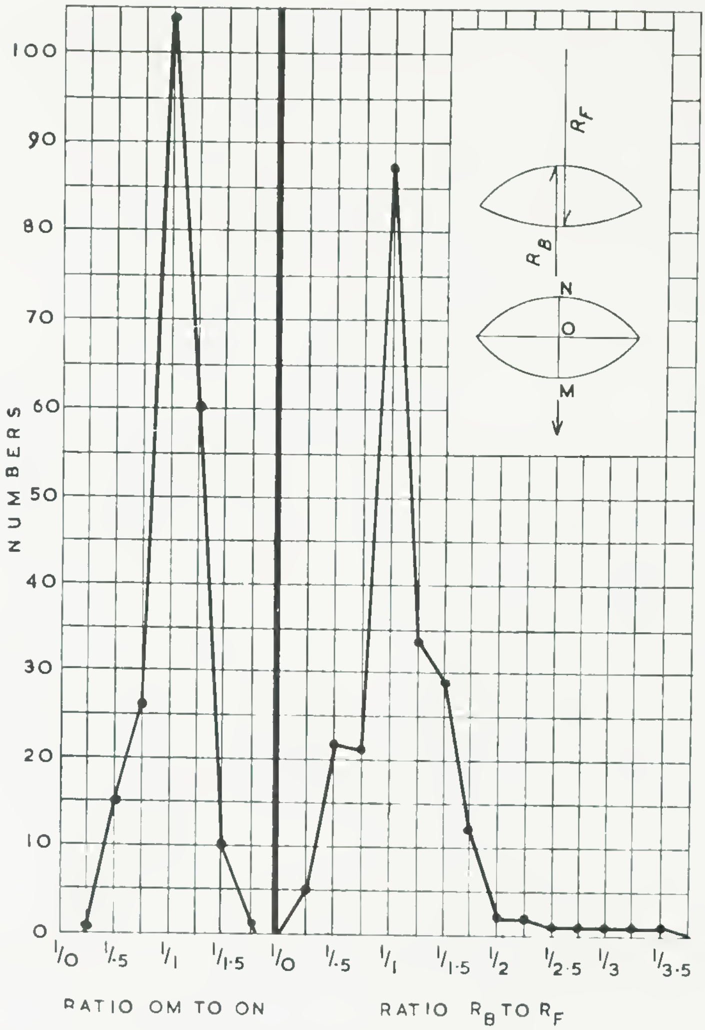

FIGURE 28.

Frequency polygons showing distribution of ratios of OM to ON, and of RB to RF for Nirranda Strewnfield australites.

In the frequency polygon showing the relationships of numbers to the RB : RF ratio (right-hand diagram in text figure 28), a range in ratios of 1/0·25 to 1/3·5 is shown. RB has been retained at unity. The greater number of examples occur on and within the immediate region of the 1·0/1·0 ratio,

TABLE XI.

Factors Compared.	Relationship of Factors.	Percentage.
R_F—R_B	$R_F > R_B$	60·0
	$R_F = R_B$	8·5
	$R_F < R_B$	31·5
Di—De	Di > De	100·0
	Di = De	0
	Di < De	0
R_F—Di	$R_F >$ Di	2·5
	$R_F =$ Di	2·5
	$R_F <$ Di	95·0
R_B—Di	$R_B >$ Di	9·5
	$R_B =$ Di	1·5
	$R_B <$ Di	89·0
R_F—De	$R_F >$ De	80·0
	$R_F =$ De	5·0
	$R_F <$ De	15·0
R_B—De	$R_B >$ De	66·5
	$R_B =$ De	5·0
	$R_B <$ De	28·5
OM—ON	OM > ON	25·0
	OM = ON	28·0
	OM < ON	47·0
R_F—OM	$R_F >$ OM	97·7
	$R_F =$ OM	0·9
	$R_F <$ OM	1·4
R_F—ON	$R_F >$ ON	100·0
	$R_F =$ ON	0
	$R_F <$ ON	0
R_B—OM	$R_B >$ OM	100·0
	$R_B =$ OM	0
	$R_B <$ OM	0
R_B—ON	$R_B >$ ON	98·1
	$R_B =$ ON	0
	$R_B <$ ON	1·9

indicating equal or approximately equal Rf and Rb values. To the right of the mode are examples with flatter arcs of curvature of the anterior surfaces, since Rf is greater than Rb. The reverse applies for examples to the left of the mode.

The several related factors (*a*) radius of curvature of anterior surfaces (Rf), (*b*) radius of curvature of posterior surfaces (Rb), (*c*) diameter (Di), (*d*) depth (De), and (*e*) the intercepts OM and ON, as determined from the measurement of just over 200 Nirranda Strewnfield australites, have been placed on a percentage basis, given in summarized form in Table XI.

From Table XI it is seen that values for Rf and Rb are mainly less than values for diameters, but greater than values for depths among the secondary shapes that constitute the australite population of the Nirranda Strewnfield, while diameters are all greater than depths. The radius of curvature of anterior surface (Rf) is greater than that of posterior surface (Rb) in almost two-thirds of the specimens.

The percentage of australites in which the members of any given pairs from among the factors Rf, Rb, Di and De are equal to one another is low throughout, being least (0 per cent.) in diameter depth relationships and greatest (8·5 per cent.) in Rf–Rb relationships.

The lengths of the intercepts OM and ON, which represent distances from the centres of radical lines to the front (M) and back (N) poles of the australites, show from Table XI, that, in approximately one-quarter of the specimens, lengths (OM) are greater than lengths (ON). In approximately one-quarter of the specimens these two distances are equal in value, and in approximately one-half, the distances from centres to front poles are less than the distances (ON) to back poles.

Being intercepts on the depth line (cf. text figures 19 and 20), the lengths OM and ON must always be less than De, and consequently always less than Di, since Di is always greater than De. Rf is universally greater than ON and Rb greater than OM, but Rb is not always greater than ON, and Rf is not always greater than OM. There are, for example, 1·9 per cent. of the Nirranda Strewnfield australites with Rb values less than ON values, and such examples are typically the hollow forms of australites. There are also 0·9 per cent. of specimens with Rf equal to OM, and 1·4 per cent. with Rf less than OM, and these specimens are all the larger core types of australites.

Origin of the Shapes of Australites

The known shapes of australites are secondary shapes that can be traced to a few typical primary forms such as spheres and the forms of revolution consisting of prolate spheroids, oblate spheroids, apioids and dumb-bells as illustrated in text figure 29.

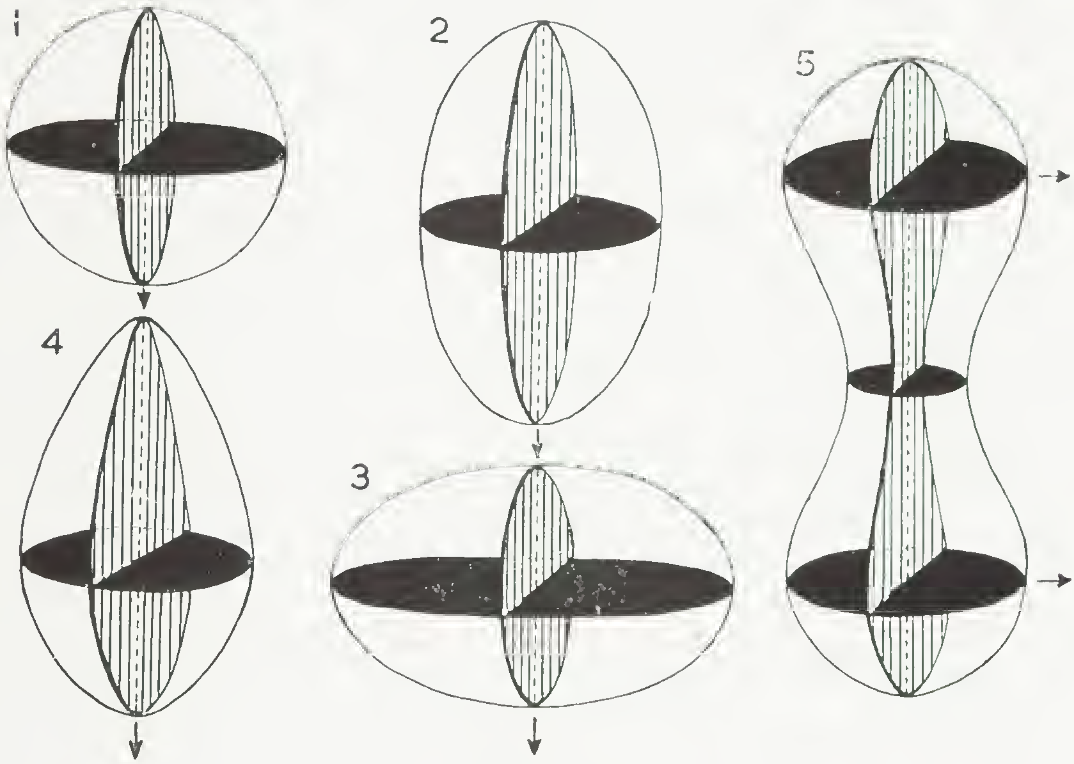

FIGURE 29.

Three dimensional sketch diagrams illustrating the sphere and the characteristic figures of revolution that constituted the primary forms from which were produced the majority of the secondary shapes possessed by australites. 1 = sphere, 2 = prolate spheroid, 3 = oblate spheroid, 4 = apioid, and 5 = dumb-bell.

In text figure 29, the arrows indicate the direction of subsequent propagation through the earth's atmosphere, and are placed at the front poles of each form. There is no evidence that forms of revolution such as the annular torus and the paraboloid were developed as primary forms of australites. The sphere is possible only when there is no rotation (cf. Kerr Grant, 1909, p. 447), the prolate spheroid is stable only at high speeds of rotation, while the oblate spheroid is stable only at low speeds of rotation. The prolate and oblate spheroids depicted in text figure 29 are biaxial ellipsoids in the sense that they have a longer or shorter vertical axis and equal lateral axes. Triaxial ellipsoids, with the lateral axes unequal, were evidently the primary forms from which the oval-shaped secondary forms of australites were developed. They would have to be produced by a uni-directional equatorial flattening of original prolate and oblate biaxial ellipsoids, possibly near the end stages of cooling of the original rotating spheroids. Some, perhaps all, of the boat-shaped secondary shapes of australites were possibly generated from primary triaxial ellipsoids that were rather more flattened than the parent forms from which the oval-shaped secondary forms were produced.

Approximate ranges in the original sizes of the primary forms, as deduced from australites figured in tektite literature and or examined by the writer, are set out in Table XII.

TABLE XII.

Primary Forms.	Size Range in Millimetres.
Spheres	10 to 55
Prolate spheroids	10 x 20 to 40 x 100
Oblate spheroids	10 x 20 to 40 x 100
Apioids	10 x 35 to 35 x 50
Dumb-bells	9 x 20 to 40 x 100

Among the spheres, the rare hollow examples sometimes range in size up to 60 or 65 mm. across. Among the prolate and oblate spheroids, some forms are more equal in their axial values, so that instead of being originally 10 x 20 mm. in size, some of the primary ellipsoids were more like 13 x 17 mm. in size. Other prolate and oblate spheroids were rather more massive than this, in having dimensions such as 40 x 100 mm., but some were more slender and measured in the vicinity of 10 x 50 mm. There were various gradations in the size and shape of the spheroids between the probable extremes listed above.

In the past, it has been considered (Fenner, 1934, p. 65) that the elongate forms of australites were derived from round forms by rotation in the earth's atmosphere, and that certain specimens, such as the canoe-shaped forms, were somewhat puzzling as far as their origin is concerned. Their origin becomes more readily pictured if the primary forms are regarded as spheres and as forms of revolution developed in an extra-terrestrial environment, and if the secondary forms represented by all examples of all secondary shapes that are possessed by australites are regarded as the end results of processes of ablation affecting the primary shapes of virtually cold bodies (except for a transient, thin, partially fused front skin) travelling through the earth's atmosphere without a spinning trajectory, but at ultra-supersonic speeds.

As found upon the earth's surface, the known secondary shapes of australites are essentially modified versions of the few accepted primary forms such as spheres and primary forms of revolution. It is most likely that these forms were generated in an extra-terrestrial rather than a terrestrial environment, some instantaneously as spheres which rapidly cooled as such, others as rotating masses of molten glass that rapidly cooled to form spheroids, apioids and dumb-bells. Such bodies were evidently cold on first entering the earth's atmosphere, and the question of the origin of the secondary shapes that are possessed by australites, developed as an outcome of frontal softening in thin films followed by ablation, hinges on three possibilities, namely (i) whether they rotated through the earth's atmosphere for the whole of their earthward journey, (ii) whether some forms were spinning on first entry into the atmosphere and ceased to spin thereafter, or (iii) whether they maintained a relatively stable position of non-rotatory flight throughout the entire phase of transit through the earth's atmosphere, with only slight wobbling developed in some specimens.

Since spheres are only possible when no rotation occurs, it is not likely that they started to spin on entering the earth's atmosphere. If still spinning on entry into the atmosphere, the primary forms of revolution soon ceased to do so. Much of the evidence provided by the secondary shapes and secondary structures of australites is interpreted herein as going a long way towards indicating non-rotation while being propagated at high speeds over a short period of time through the earth's atmosphere.

Allowing for tertiary modifications brought about by ordinary processes of erosion, the secondary shapes of australites as found upon the surface of the earth, are thought to be of a kind that can be formed from glassy bodies of pre-determined shape, travelling at ultra-supersonic velocities through a not very highly resisting medium—the earth's atmosphere—without rotating, but subject to pressure and frictional heating, surface sheet melting in thin films, fusion stripping and ablation of their forward surfaces under the influence of the effects of aerodynamical flow.

The nature of the secondary structures such as flow ridges, and the flow lines that occur with them in typical associations indicating non-rotational flight, has already been described (see text figures 13 and 14), likewise the fact that flange building can be accounted for without invoking rotation through the atmosphere. There now remains to be considered the secondary shapes themselves in relation to their primary forms, and these are dealt with in descriptions of text figures 30 to 34.

First it should be noted that the axes of the secondary shapes that constitute australites, are not always axes of symmetry like the axes of rotational symmetry possessed by the primary forms from which they were produced. Developed as secondary shapes from spheres, the buttons and lenses have equal lateral axes and always a shorter vertical axis. The vertical axis is virtually an axis of rotational symmetry, but the lateral axes are not always axes of twofold symmetry, only being so when the forms are regularly biconvex with bilateral symmetry. Oval-shaped australites have unequal lateral axes and a shorter vertical axis. Boat-shaped forms have a somewhat longer and a shorter lateral axis, and a short vertical axis that is sometimes equal to, more often less than, the shorter lateral axis. In these elongated australites, the vertical axis is no longer an axis of rotational symmetry, but is twofold.

Dumb-bell-shaped australites have one longer and one shorter lateral axis, and a short vertical axis equal to or less than the shorter lateral axis (i.e. omitting the waist region from consideration here). Among the teardrop-shaped australites, it is evident that some traversed the atmosphere in much the same way as aerial bombs, with their longer axis parallel to the direction of propagation (cf. Baker, 1946, Plate X), hence such examples have more or less equal lateral axes (considered as passing through the swollen portions of their apioid shape), and a longer vertical axis. Some teardrops, however, provide evidence of having travelled through the atmosphere in a position that might appear at first to be somewhat unstable—with the longest axis horizontal (cf. text figure 34c, and cf. Baker, 1946, Plate IX, figures 9 and 10). The nature of the anterior surface and of the flaked equatorial zone in such forms, point to this position of flight as being a stable position, otherwise these secondary features would not have been developed in the positions that they occupy. Hence such forms are comparable with (half) dumb-bells in having a longer lateral axis, a shorter lateral axis, and a vertical axis that is shorter than the short lateral axis.

The many button- and lens-shaped australites represented among the Nirranda Strewnfield collection evidently had their origin in the ablation of primary spheres (or spheroids with nearly equal axes), as indicated in text figure 30.

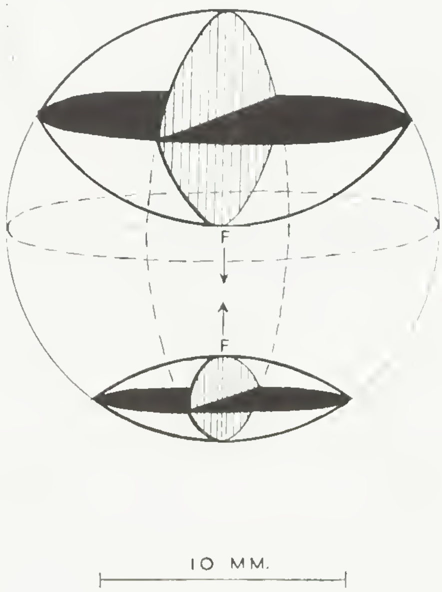

FIGURE 30.

Diagram illustrating suggested origin of button- and lens-shaped australites from a primary sphere. (Flanges possessed by button-shaped forms have been omitted).

Two secondary forms are depicted in a sketch of one sphere in text figure 30, for convenience of representation. F indicates the forwardly directed surface of each secondary form, and the arrows represent the direction of propagation through the earth's atmosphere. These arrows will naturally be directed in the same sense in actual fact. The possibility is not overlooked that similar button- and lens-shaped secondary forms could result from the ablation of a prolate spheroid of a type indicated in text figure 31, in much the same way as from the ablation of a sphere (text figure 30). Rather more australite glass has to be ablated from the primary prolate spheroid.

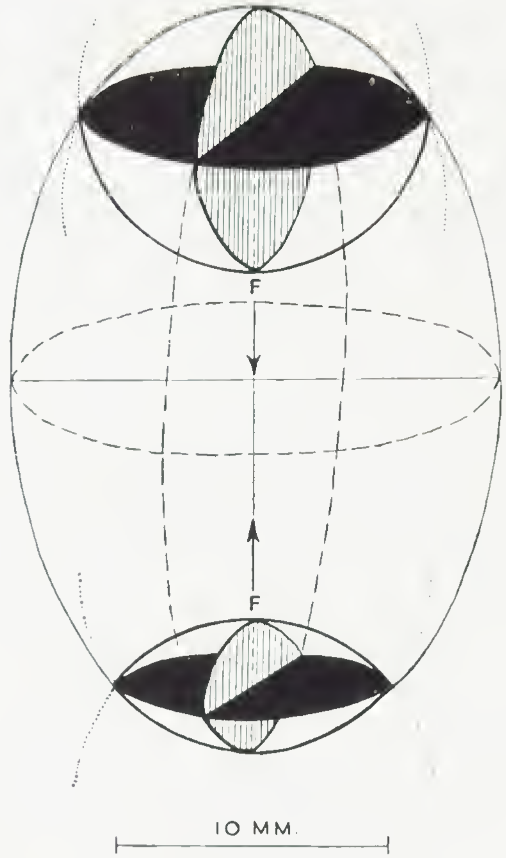

FIGURE 31.

Diagram showing secondary forms resulting from the ablation of a prolate spheroid of australite glass.

The arcs of curvature of the back (i.e. primary) surfaces of the secondary shapes of some australites conform to the arcs of constructed circles, just as do the arcs of curvature of the polar regions of certain prolate spheroids. Different arcs of curvature of the back surfaces of button- and lens-shaped australites and possibly also some oval-shaped specimens developed in this way, would arise from differently shaped (i.e. broader or narrower) prolate spheroids.

Many of the oval-shaped australites having (i) the two different radii of curvature for each of the two curved surfaces, and hence (ii) two different arcs of curvature in two positions at right angles for each of the two surfaces, and (iii) major and minor diameters with no very marked difference in length between them, such as depicted in sectional aspect in text figure 20, probably arose from the ablation of forms of revolution less elongated than the spheroid shown in text figure 31, and yet not as spherical as the primary form shown in text figure 30. They would thus be secondary shapes intermediary between those of the button and lens groups and those of the boat and canoe groups, and had their origin in primary forms of revolution initially intermediate in shape between the primary forms of these groups.

Other oval-shaped australites, in which the two diameters are more significantly different in length, probably arose from oblate spheroids approaching the character of the example shown in text figure 32. Boat- and canoe-shaped australites certainly seem to have been derived from oblate spheroids (text figure 32).

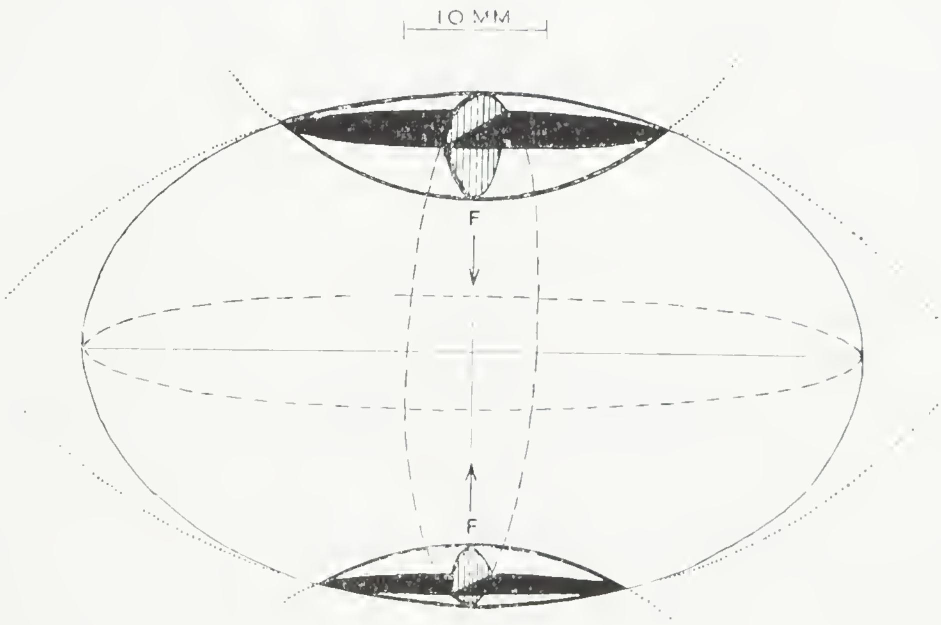

FIGURE 32.

Diagram showing elongated secondary forms such as boat- and canoe-shaped australites, developed by the ablation of an oblate spheroid of australite glass.

The australite "cores" (cf. Baker, 1940b, p. 492) or "bungs" (cf. Fenner, 1938, pp. 200, 204), are much larger than the cores (body portions) derived by the loss of flanges and peripheral regions from smaller australite forms such as buttons, lenses and ovals. These large cores have round (in plan aspect), oval, boat and dumb-bell shapes and often, though not invariably, possess characteristic flaked equatorial zones but never flanges. They evidently represent the earliest arrested stages of larger primary forms that have been the least modified by processes of fusion stripping and ablation (cf. text figure 35).

Round cores of this nature were derived from original spheres in the manner indicated by text figure 33.

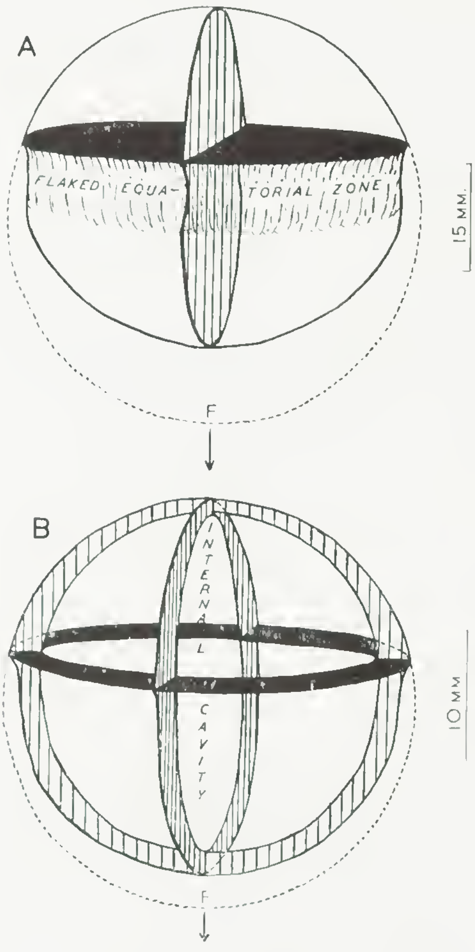

FIGURE 33.

A—round core with flaked equatorial zone, developed by fusion stripping and ablation of an original sphere (dotted line).

B—hollow form derived from original hollow sphere (dotted line represents continuation of original outer walls).

F—indicates original positions of front poles of primary spheres, and arrows indicate direction of propagation through the earth's atmosphere).

Some hollow forms of australites have the same external shape as some of the large round cores (cf. text figure 33), and have thus been subjected to similar processes of fusion stripping and ablation. Indeed, some even show similar flaked equatorial zones.

Preservation of certain hollow forms as complete entities throughout the operative phases of fusion stripping and ablation, demands the original development of a primary hollow sphere with an eccentrically disposed internal bubble, so that the walls at one pole were thicker than the walls at the opposite pole. A hollow form with an eccentrically placed bubble would be expected to travel on its line of flight with the thickest wall forward, so that the anterior surface had thicker walls than the posterior surface (cf. text figure 33B). All hollow australites, of which there are comparatively few known, provide evidence which indicates that this expected position was actually a stable position of forward propagation. Some hollow forms subjected to excessive ablation compared to the thickness of their forwardly directed walls, have collapsed inwards during flight, as evidenced by the presence of inrolled edges in certain hollow-form fragments from the Nirranda and Port Campbell Strewnfields. These inrolled edges show evidence of secondary flow of glass over the collapsed edges and inwards towards the inner walls of the original internal cavity, and the fragments on which they occur are fragments broken from the polar regions of anterior surfaces.

In text figure 33B, which is based on a sliced hollow australite from Hamilton, Victoria, figured by Dunn (1912, figure 2A, Plate 7), the thickness of the walls at the front pole was originally 10 mm., but is now 3.5 mm. on account of reduction by ablation. At the anterior pole, the glass walls were four times as thick as the walls (2·5 mm.) at the back pole. Up to approximately 8 mm. thickness of glass has thus been removed by processes of ablation from front polar regions.

A hollow australite from Horsham, Victoria, figured by Walcott (1898, Plate III, figures 1 and 1A) had an original thickness of 12·5 mm. for the walls at the front pole, while the thickness at the back pole is 2·5 mm., so that the forwardly directed walls of this australite glass bubble were originally five times as thick as the rear walls, and the internal cavity was eccentric with respect to the original walls of the primary hollow sphere.

Hollow forms with even more eccentrically disposed internal cavities, which have very much thicker anterior walls, can withstand fusion stripping and ablation to the same degree to which certain solid forms have been subjected, and yet need not collapse, by virtue of the fact that the internal cavity is situated well back towards the posterior surface. Of such a nature is an example (reg. no. E1052) from the Nirranda Strewnfield, where ablation has been operative to such an extent that a flange has been developed on a form (Plate II, figures 9 and 10) with a relatively large internal cavity. Although this form is practically complete, possessing only a small hole 1 mm. across leading to the internal cavity, it has been possible to form an estimate of the dimension of the internal bubble along the polar axis by inserting a needle through the aperture and across the internal cavity. The following dimensions were obtained:—

(1) Distance from front pole to bottom of aperture 2 mm.

(2) Distance from front pole to back wall of internal cavity .. .. .. 16 mm.

(3) Distance from front pole to back pole .. 19 mm.

By substracting measurement (1) from measurement (2), the depth of the internal cavity is arrived at as 14 mm. Measurement (1) provides the thickness of the walls at the front pole, while the difference between measurement (3) and measurement (2) shows that the thickness of the walls of the internal cavity at the posterior surface is only 3 mm. The cavity is thus eccentrically placed with respect to the positions of the front and back poles, a condition that was even more pronounced before ablation of the front polar regions. Radiographs of this form reveal the following dimensions of the internal cavity:—front polar aspect: 12 x 13 mm., two side aspects at right angles: 14 x 13 and 14 x 12 mm. respectively. The internal cavity thus has slight polar elongation.

The large elongate cores of boat-, dumb-bell and teardrop-shaped australites are indicated in text figure 34, where the primary forms from which they were derived are shown as broken lines. End-on aspects of these forms generally resemble the shape of the round core depicted in text figure 33A.

Some larger cores have flatter posterior surfaces than indicated in text figure 34, and were evidently derived from primary forms having flatter arcs of curvature along their sides, thus approaching cigar-shaped ellipsoids—they did not traverse the atmosphere end-on, however, except in rare examples of the apioids that now have aerial bomb-like shapes.

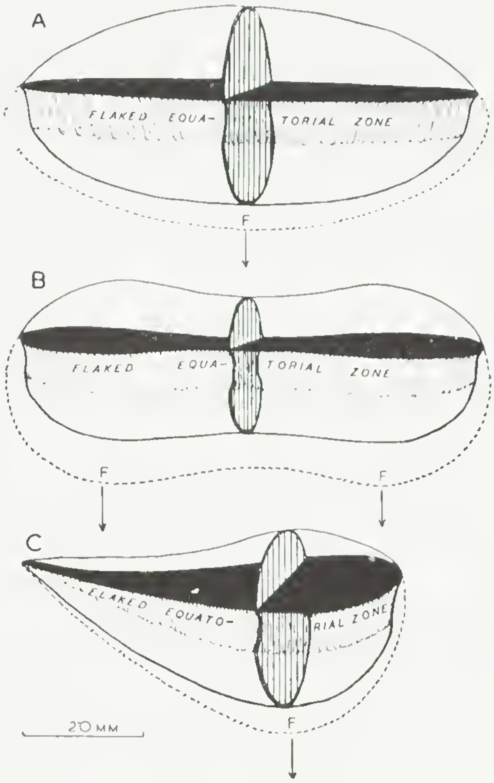

FIGURE 34.

A—elongate core (boat-shaped).

B—elongate core (dumb-bell-shaped).

C—elongate core (teardrop-shaped).

The material between the dotted lines and the anterior surfaces in each sketch, has been removed by ablation.

F—indicates position of front poles.

The elongate core shown in text figure 34A was derived, by ablation, from an oblate spheroid of revolution. For allied examples, the length of the original spheroid compared to its breadth, increases from short ovals through longer ovals to the more elongated boat-shaped cores. The flaked equatorial zone of such examples is a common feature, but one or two specimens are known in which flaked equatorial zones have not been developed. In them, the anterior is demarked sharply from the posterior surface by a well-developed rim (but never a flange in australites of the size under consideration). This suggests the possibility of limited ablation having occurred, without accompanying fusion stripping of equatorial regions.

The dumb-bell-shaped cores (text figure 34B) were developed by the frontal ablation of originally rather larger dumb-bell forms of revolution in which the bulbous ends initially had a constant thickness in any one given plane (cf. figure 29, No. 5), and in which the constriction in the waist regions was much less pronounced than in the smaller dumb-bells on which flanges became subsequently developed. Flaked equatorial zones are again characteristic features of most of these dumb-bell-shaped cores. No dumb-bells have yet been observed that would point to any of these forms having travelled through the atmosphere with their long axis parallel with the direction of propagation.

The larger teardrop-shaped cores have a flaked equatorial zone developed in such a way as to indicate that the stable position during flight was like that depicted in text figure 34C. Ablation occurred most dominantly at the front pole of the bulbous portion of the original apioid, and ultimately produced the teardrop-shaped core. A further stage in the melting and flowage of glass from the front polar regions than that shown in text figure 34C, is sometimes one in which secondarily fused glass has become carried around the bulbous end on to the equatorial edge of the posterior surface (cf. Baker, 1946, Plate IX, figures 9A and 9B). In still later stages, more evident with the smaller teardrop-shaped australites, the size of the teardrop has been much reduced by the processes of ablation, and the stage of flange-building has been reached. Here again, it does not seem likely that the teardrop-shaped forms were rotating at any of these stages when secondary features were being produced during atmospheric flight.

The progressive developmental stages in the formation of such secondary shapes as the various round forms of australites from primary spheres of natural glass of presumably extra-terrestrial origin, are indicated in text figure 35.

The posterior surface, shown uppermost in each of the sketches A to H in text figure 35, is regarded throughout as a residual portion of each primary sphere. The anterior surfaces are secondarily developed surfaces arising from the fusion stripping and ablation of the forwardly directed hemispherical half of the primary form. It is considered that the same general principles apply to the other shape groups, as outlined here for the group of australites that are circular in plan aspect.

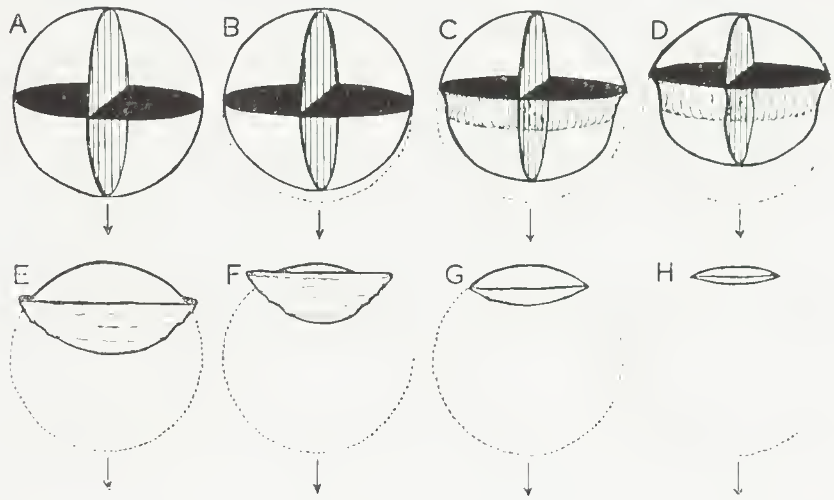

FIGURE 35.

Progressive stages in the development of round forms of australites from primary spheres of australite glass.

A to D—round cores. E to F—buttons. G to H—lenses.

In text figure 35, the spheres from which the cores (or " bungs ") were developed, are frequently twice as large as those from which the button- and lens-shaped australites were produced. The original spheres for the buttons and lenses depicted in text figure 35 had much about the same size range among themselves.

Diagram A (text figure 35) shows a primary sphere, and diagram B depicts initial ablation in its front polar regions. With more ablation and some fusion stripping, a round core of the type shown in text figure 35c is produced, and, at this stage, approximately 10 per cent. to 15 per cent. of the original sphere has been removed. Continued loss of glass melted from the front surface leads to reduction in the size of the core and increase in the radius of curvature of the anterior surface, as indicated by text figure 35d. This process continues with complete loss of the melted glass which becomes whipped away and in part volatilized and dispersed in the wake of the speeding australite body.

Commencing with somewhat smaller spheres of australite glass entering the earth's atmosphere in an originally similar cold condition, ablation and fusion stripping occur soon after frontal melting has been initiated. This may continue until approximately one half or more of the primary glass sphere has been removed, the condition then being reached at which the remaining solid glass has passed into the requisite size and shape for the onset of flange-building and the development of the flow ridges on anterior surfaces.

The position of separation of the boundary layer flow in the medium (earth's atmosphere) through which each australite body with its modified shape was moving, constantly changed as the arc of curvature of the forwardly directed surface became flatter in character, and as the rim of the form migrated along the front hemisphere backwards from the front polar regions, and beyond the original position of the equator of the primary form. At this stage, the separation of the boundary layer flow from the equatorial edge of these small secondary shapes travelling at ultra-supersonic speeds evidently generates turbulence which becomes responsible for forcing some of the melted australite glass around on to the edge of the posterior surface. As this process is maintained for a while, more glass is piled up in the position indicated, thus leading to the construction of a substantial flange all around the equatorial edge of the object; at the same time there is a marked development of flow ridges on the anterior surface, as in text figure 35F. A somewhat later phase of the process is one in which flange-building glass has been accumulated rearwards to such an extent that the posterior surface of the secondary shape can no longer be seen when the flanged australite is viewed in side aspect, and the majority of flanged australites, as found on the earth's surface, are either of this nature or else reveal a small portion of the posterior surface protruding a short way above the edge of the flange.

Only a narrow contact exists between the flange and the posterior surface of the secondary shape, and much of the flange glass overhangs parts of the edge of the posterior surface without making direct contact (cf. text figure 15). Ultimate loss of some flanges by the combined effects of later stages of ablation, a little fusion stripping and possibly fragmentation during flight, operating more particularly in the "seat" regions (cf. text figure 15), yields the non-flanged lens form depicted in text figure 35G, with its lesser number of flow ridges. Further ablation then reduces this form to the smaller type of lens shown in text figure 35H, or, if conditions are suitable, a small flanged button may be developed. Such small flanged buttons have been found, but it is uncertain whether they were developed in the manner suggested, or whether some of them were derived from originally much smaller primary spheres which were subjected to comparable processes of ablation.

As an example of the amount of australite glass lost by ablation at the stages indicated by text figures 35E and 35F, the weight of the original sphere of glass from which a flanged button was derived has been calculated as 11 grams, from the specific gravity value of the specimen and the radius of curvature of its posterior surface (i.e. a value that provides the radius of the primary sphere). The separate weights of the flange and of the body portion of this australite are known, so that the amount of glass lost can be determined, thus:

	Per cent	Weight in grams.
Original sphere	100	11·0
Body portion of australite	33·4	3·674
Flange	6·9	0.762
Amount lost	59·7	6·564

It is thus seen that over half of the original glass sphere has been ablated away and nearly 7 per cent. moved around to the rear surface to form a flange. In the same way, it can be calculated that something over 80 per cent. of an original glass sphere was ablated before the residual end product such as a lens of average size was developed.

The causes leading to the generation of flanges on australites have already been discussed as an outcome of the study of the internal flow line patterns of australites generally (under the section dealing with Flow Lines). A few relevant facts remain to be added, from the aspect of the situations of the flanges relative to the primary forms from which australites were developed, and relative to the secondary end products which australite shapes represent.

It is obvious that, because of its steep forward curvature, and its exposure to the greatest amounts of frontal pressure generated during high speed flight, the forwardly facing hemispherical half of a sphere of australite glass (cf. text figure 35A), can provide no stable position for accumulation of fused glass forced away from the front polar regions. The earliest fused glass would be rapidly whipped away under the influence of drag effects, and, as the process of fusion stripping and ablation progressed, there occurred gradual reduction of the front surface. The radius of curvature of the front surface increased, so that its arc of curvature became flatter (cf. text figures 35B, 35C and 35D). The front pole of the original sphere migrated rearwards to within or beyond the region of its original centre before flange-building could commence, for by then, the rim, developed as a secondary feature delimiting the newly formed anterior surface from the remnant portions of the primary rear surface, had passed beyond the former equator of the original sphere. A situation has therefore been produced which is suited to flange-building, for now the equatorial edge of the posterior surface has less steeply sloping backward curvature, so that a more stable position is available for the accumulation of such melted glass as reached and remained in the equatorial regions. Here, under the influence of eddy currents and possibly some friction created by the separating boundary layer flow (cf. text figure 36), the secondarily fused, migrated glass began to cool and be moulded into shape. Rapidly following, newly introduced and still warm glass frequently became jammed against the cooler glass already present in the flange regions, causing considerable contortion in some of the flow line patterns of some flanges (cf. complex puckering shown in Plate II, Baker, 1944).

It is not yet fully understood why the flange glass in its final form consolidated in a position partially overhanging the equatorial edge regions of the body portion in flanged australites. Possibly, a buffer of reflected air from the cold posterior surface in these regions, was responsible, associated with the viscous state of the glass itself. Evidently the viscous state of the glass was an important factor, for a contrast is provided by rare specimens of australites in which ostensible flange glass was rather less viscous, and instead of building up into a flange structure, it has spread out on to the posterior surface for some distance from the equatorial periphery (in the manner indicated by figures 9A and 9B of Plate IX, Baker, 1946).

The posterior surfaces of flanges were located in low pressure regions during the phase of high speed earthward flight of australites, and these surfaces are characteristically smooth and often slightly concave. On the other hand, anterior surfaces of australites were located in high pressure regions, and their equatorial edges where flanges were built up were positions of greatest frictional drag; hence the anterior surfaces of the flanges, which are convex generally, reveal complexly wrinkled flow ridges. It is in the " seat " regions of flanges (cf. text figure 15) and from thence to their equatorial edges, that loss of glass is most noticeable as a result of the final phases of the processes producing the end products now representing the secondary shapes of australites. It can be observed from thin sections, that in the anterior surface regions of the flange extending from the " seat " to the equatorial edge, flow lines in the glass of the flow ridges are parallel with flow lines in the immediately underlying glass, whereas the outlines of the intervening flow troughs cut right across secondarily developed, flangeward-trending flow lines (cf. Baker, 1944, Plate III, figure 1), thus indicating removal of thin films of glass from the flow trough regions to rather greater extents than from the flow ridges, during these end stages.

Small bowl-shaped and the disc- and oval-plate-shaped forms of australites, which have not yet been located in the Nirranda Strewnfield, have been discussed elsewhere (Dunn, 1916, p. 223; Baker, 1940*a*, p. 312), but the manner of their origin has not yet been satisfactorily explained in its entirety. These are essentially thin forms of australites, averaging 1 mm. to 1.5 mm., seldom 2 mm. in thickness, and their thickness is out of all proportion to their diameter, the diameters of most forms being 10, sometimes 20 times as great as their thickness. Such forms could possibly be the end products of very small buttons, lenses and ovals that had become so thin by ablation that they were completely softened under the influence of frictional heat, and flattened by frontal pressure to form disc- and oval-plate-shaped australites (cf. Baker, 1946, Plate VI, figures 1 and 2), or even turned backwards where sufficiently unstable, to form bowl-shaped (or " helmet-shaped ") australites (cf. Baker, 1946, Plate VI, figures 3A and 3B). In the writer's opinion, there are no features of these small, thin australites that would indicate the operation of rotational processes during their formation as secondary shapes, even though they seem to have become softened throughout during these end phases of flight, after which they cooled prior to landing upon the earth's surface, at much reduced speeds.

The origin of the shapes of several of the relatively rare aberrant forms of australites that have come under the notice of the writer (cf. Baker, 1946, Plate VII, figures 6A and 6B, Plate VIII, figures 7A and 7B, and Plate XI), can generally be satisfactorily explained by initial reference to modified primary forms of revolution, some of which may have been accidentally deformed during pre-atmospheric flight and consequently did not behave like the more regularly shaped forms during the phase of atmospheric flight. The aberrant forms of australites are usually of such a type that the idea of rotational motions while passing through the earth's atmosphere seems scarcely tenable.

Viewed on the above basis of the theory of fusion stripping and ablation during high speed flight for the origin of their secondary shapes, certain deductions are herein made concerning the specific gravity values of australites. These deductions seem to give credence to the postulates set out in the foregoing pages. The fact that in any particular australite strewnfield, the smallest australites often have specific gravity values the same as those of the medium-sized and even the largest australites known, and that both lower and higher specific gravity values occur among all sizes, would suggest that complete fluidity of each australite was not attained during atmospheric flight. Had this occurred, it would be expected that more volatile constituents would escape—more being lost from the ultimately smaller, than from the finally larger australites. Since, under such conditions, heavier constituents would be the more volatile, lighter constituents should thus concentrate in the smaller forms, which would then have the lesser specific gravity values (cf. fusion experiments, Baker and Forster, 1943, p. 398). Since this is not shown by the thousands of specific gravity values determined for australites (Baker and Forster, 1943, p. 403), it is concluded that variations in specific gravity among australite specimens of different size, in each separate shape group found from different or the same localities, are essentially a function of their primary phase of formation. During atmospheric flight, progressive fusion and removal of microscopically thin films of melted australite glass from the forward surfaces would not give rise to any really significant specific gravity variation as between the primary form and the ultimate secondary form derived therefrom. It could, however, account for the fact that flanges generally, though not always, have lower specific gravity values than body portions of such of the australites as formed flanges during flight. The flange glass, during secondary melting and migration, possibly lost some of the heavier, more volatile constituents, thus resulting in a slightly more silica-rich residuum with slightly lower specific gravity values.

Effects of Aerodynamical Flow-Phenomena during Ultra-supersonic Flight.

There is every reason to believe that australites are extra-terrestrial objects which entered the earth's atmosphere at cosmical velocities similar to those possessed by iron and stony meteorites. On first reaching the atmosphere, they were evidently cold, non-rotating bodies of glass with complex internal flow-line structures generated in their birthplace. Their speed of traverse through the earth's atmosphere no doubt became progressively lessened as they passed through the increasingly denser lower atmospheric layers nearer to the earth's surface, as a consequence of increased frictional resistance, so that they lost their high cosmical speeds, and fell to earth at speeds controlled by the earth's gravitational forces. The nature of the airflow must have changed considerably and continuously as their speed decreased. No parts of the australites are considered to have been fluid on landing upon the earth's surface.

During transit through the atmosphere at very high speeds, certain aerodynamical factors must have operated in such a way as to produce the known secondary shapes and secondary structures of australites from a small variety of primary forms (cf. Baker, 1944, pp. 18-19).

The rate of fall to earth, at a distance of say 60 to 70 miles above the earth's surface, would be some 6 miles per second if falling due to gravity alone, while the maximum velocity, if at all comparable with that of iron and stony meteorites, would be in the region of 20 to 40, or even 50 miles per second according to various estimates. The time taken to travel through the earth's atmosphere would thus be very short, a matter of a few seconds to a few minutes at most, according to the angle of entry. At such speeds, the velocity of approach of australites to the earth's surface is ultra-supersonic, with a Mach number* somewhere in the region of 27 at the minimum speed of 6 miles per second, some 60 to 70 miles above the earth's surface, and of 192 to possibly 248 as a probable maximum Mach number at the same height. Since, however, the Mach numbers would not be comparable units at these heights as at sea level, because of differences in temperature, pressure and density of the atmosphere at the different levels, they would not be nearly as high as given above, since Mach numbers

* The Mach number (M) is the ratio of the speed of supersonic flow to the speed of sound, so that if M = 1.0, the speed of supersonic flow equals the speed of sound, which is 760 m.p.h. at the standard sea level temperature of 15°C. (cf. Black, 1953, p. 252).

decrease in value with increase in height above the earth's surface. Nevertheless, they would still be relatively high and no doubt much greater than those so far attained with guided missiles that have reached supersonic speeds. The guided missiles, which reach heights of up to 250 miles above the earth's surface, and travel at some 2,000 miles per hour, have a Mach number of 2.6, and they travel upwards from denser to less dense layers of the atmosphere. Australites, on the other hand, travel downwards from less dense to denser layers, penetrating all layers of the atmosphere from the most tenuous to the most dense, at speeds which are decreased by frictional resistance of the atmosphere, but which at times are in the vicinity of something between 21,600 and 144,000 to 180,000 miles per hour. Their Mach numbers must therefore be high, even after allowing for decrease in speed with nearer approach to the earth's surface, and also allowing for the fact that Mach numbers fall in value at the greater heights.

Travelling earthwards at ultra-supersonic speeds, the temperature of thin films of the forwardly directed surfaces of spheres, spheroids, apioids and dumb-bells of australite glass, was considerably raised (to at least the softening temperature of tektite glass), by virtue of the development of shock waves ahead of each form (see text figure 36 for a primary sphere of australite glass), for where the air is brought to rest in shock waves, compression is so great as to produce much increased temperatures.

At supersonic speeds, certain important factors come into operation, chief among which are those connected with the aerodynamics of high-speed flow, the behaviour of the air being a function of the relative motion between the atmosphere, which for these purposes can be regarded as virtually at rest, and the australites, which it is presumed must have travelled at very high velocities. To begin with, during supersonic flight, a permanent type of disturbance would be set up in the air piled up ahead of any particular primary form of australite travelling at such speeds, thus creating the important shock waves. Shock waves are regarded as sheets where there exists an abrupt discontinuity of velocity of flow (cf. Durand, 1935), and they are narrow zones of intense compression. The air that flows over the surface of any australite travelling at ultra-supersonic speed, can do so only after it has penetrated the narrow arcuate region of compression known as the frontal shock wave. The frontal shock wave (see text figure 36) travels a short distance in front of the australite, in the same direction at similar speed. Its shape would be broadly hemispherical, with a radius of curvature a little greater, but otherwise generally conforming with the arc of curvature of the forwardly directed hemispherical surface of the primary australite form, such as the one depicted in text figure 36.

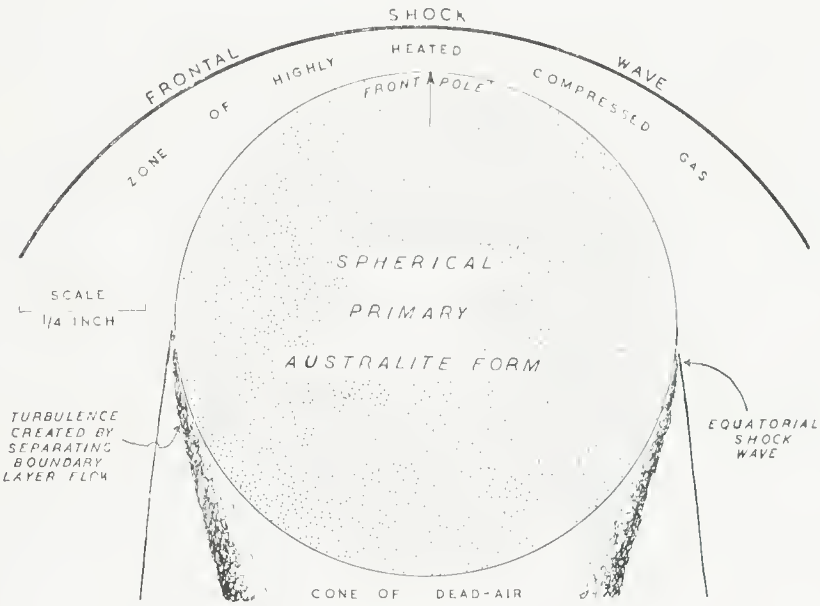

FIGURE 36.

Diagrammatic sectional representation of the probable form and nature of shock waves and turbulent zones created by a non-rotating primary sphere of australite glass travelling earthwards through the atmosphere at ultra-supersonic velocity. (Based on a reproduction by Black, 1953, p. 254).

Along the sides of the primary form, subsidiary shock waves would develop in positions lying obliquely to the direction of propagation, and in them, compression, although high, would probably not be as intense as in the frontal shock wave. For general purposes of illustration, the primary forms of australites are regarded as being initially relatively smooth (cf. text figure 36), and varying in size from 10 to 55 mm. in diameter for spheres, and from 9 x 20 mm. to 40 x 100 mm. for elongated forms. The subsidiary shock waves generated by such forms, are pictured as equatorial shock waves, produced as narrow zones of high compression that lie very obliquely backwards and most likely somewhat detached from the equatorial regions of the sphere (cf. text figure 36) as a result of thickening in the boundary layer of air induced by the objects having such high Mach numbers. The original surfaces of the primary forms of the australites, however, were no doubt somewhat bubble-pitted, hence the subsidiary shock-wave phenomena would probably be much more complex than indicated in text figure 36.

Behind the fast-moving australite sphere, turbulence is created where the main flow becomes separated in the equatorial regions, by the action of reverse and secondary reverse laminar flow producing vorticity in the relatively thin boundary layers of the atmosphere in contact with the surface of the sphere. It is within the thin boundary layers that all frictional effects arise between the anterior surface of the australite and the fluid medium (the earth's atmosphere) through which it has its trajectory. Thus there would arise stresses in the gaseous medium along the anterior surface of the australite producing skin friction as a tangential component, and stresses in the positions where turbulent flow was generated in equatorial regions producing form drag (Whitlock, 1943, Chapter V). Inside the turbulent wake region, immediately behind the posterior surface, there would most likely exist a cone of virtually dead-air, as indicated in text figures 36 and 37. Its existence enables the posterior surface to be maintained at temperatures well below the fusion temperature of australite glass.

The frontal shock wave constitutes a narrow zone of immense pressure, while behind it, a slightly broader zone extends from the back of the shock wave to the front surface of the primary sphere of australite glass. Although the velocity of the air is decreased in this zone, high pressures, and hence high temperatures persist. A state of steady flow of a permanent type producing shock waves can only be developed when the motion of an object travelling at supersonic or ultra-supersonic speeds, is confined to one direction (cf. Durand, 1935). Therefore it is deduced that there was no major change in the direction of forward propagation of any of the australites that have been recently studied, and there was evidently no rotatory motion.

During the maintenance of shock waves, all the mechanical energy generated at supersonic speed, would be converted into heat, due to the viscosity and conductivity of the air in the zone behind the frontal shock wave. Hence, as long as supersonic speed prevails, a cap of highly heated compressed air travels ahead of the australite, as diagrammatically illustrated in text figure 37.

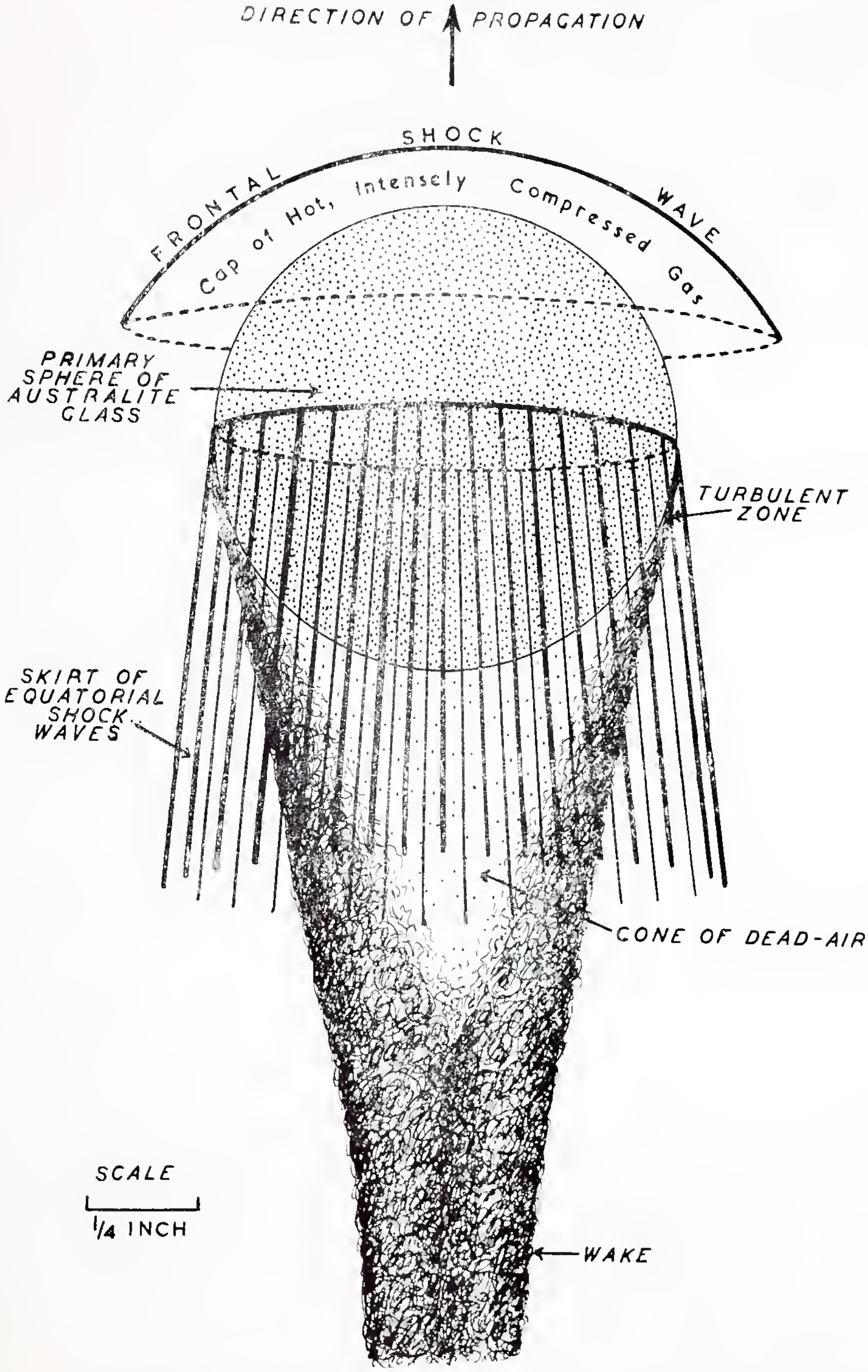

FIGURE 37.

Diagrammatical three dimensional concept of the aerodynamical phenomena of high-speed flow past a primary sphere of australite glass travelling at ultra-supersonic speed.

Under such conditions, during the early stages of development that were eventually to lead to the formation of secondary shapes of australites, this cap of highly compressed air supplied the temperature rise necessary to the softening of thin films of australite glass in the front polar region, where pressures would be greatest. It caused particles of the glass to volatilize, thus initiating the process of ablation that hereafter becomes an important factor in shaping the anterior surface. The cap of compressed air also protected the anterior surface from loss of heat during the very short period of time available for secondary shape development. As a consequence of this process, a proportion of the primary australite forms, most probably the smaller ones, was undoubtedly lost by complete volatilization. Many others, however, survived the effects of the aerodynamical flow phenomena that prevailed throughout the period of maintenance of ultra-supersonic and supersonic speeds, but during their operation, these primary forms became considerably reduced in size and altered in shape, on the forward surface. The separation of the main flow stream from the equatorial regions of the larger primary forms, is regarded as being responsible for the process of fusion stripping that gave rise, on the larger of the forms, to flaked equatorial zones such as are depicted in text figures 33 and 34. In this region occurs the transition zone where laminar flow in the thin boundary layer ends, and turbulence supervenes. The turbulence thus emerges from the thin boundary layer, and being packed with vortices would generate much more intensive form drag.

The final, or near-final, conditions prior to the landing of a button-shaped australite on the earth's surface, are pictured in sectional aspect in Plate VI, figure 28, and in this connexion, reference should be made to Plate I., figure 1, in order to obtain some conception of the character of the frontal aspect of the anterior surface of a button-shaped australite at the end stages of development. At this stage (cf. Plate VI, figure 28), the frontal shock wave is still maintained, although its shape has changed, because the arc of curvature of the anterior surface of the australite has become flatter as a consequence of considerable frontal ablation, hence increasing the angle of the shock waves to the airstream. This change can be judged by comparing Plate VI, figure 28, with text figure 36, where the end stage shown in Plate VI has been derived from a sphere originally the same size as that depicted in text figure 36.

It is known that frontal shock waves lie at various angles to the airstream in supersonic flow (cf. Black, 1953), and with objects travelling at supersonic speeds, these angles are controlled essentially by the shape of the forwardly directed surface. Since the front surfaces of all the primary and the majority (i.e. flattened forms excepted) of the secondary shapes of australites are never perpendicular to the airstream during their journey through the earth's atmosphere, frontal shock waves would never be generated normal to their path. In other words, during the important formative stages of secondary shape development, the frontal shock waves would always be of the oblique type where pressures, which depend upon deflection, are seldom more than 50 per cent. of the pressures generated when perpendicular shock waves are formed ahead of a perpendicular reflecting surface. Inasmuch as the arc of curvature of the front surface of the secondary shape (cf. Plate VI, figure 28) is flatter than that of the primary australite form (cf. text figure 36), however, the shock wave ahead of the secondary form must be less oblique than that ahead of the primary form, and consequently pressures somewhat greater, and hence drag is more pronounced along the anterior surface. The shape in cross section of the ultimate secondary anterior surface of the australite, is thus not vastly different from that of the isoclinic wings of certain transonic aircraft, as far as the backswept character is concerned. The australite, however, does not have the pointed nose, but this lack would be offset by the greater speeds at which australites travelled.

A few of the smaller australites have been flattened, evidently in the end phases of atmospheric flight, when they had been ablated to very thin forms such as the disc- and oval-plate-shaped examples. If produced at supersonic speeds, then pressures on the front surfaces of such thin forms must have been at a maximum, for their frontal shock waves would have been virtually perpendicular. This may explain why they are flattened and why some of them were even bent backwards into bowl-shaped forms.

In australites with forwardly curved front surfaces, i.e. all other forms, the arc of curvature of the frontal shock wave not only varies with the changing curvature of the ablating anterior surface, but changes also occur in the subsidiary shock waves. Thus the marked skirt of equatorial shock waves of the primary australite sphere (text figure 37) becomes replaced, near the end stages of flight, by a number of flow ridge shock waves, which arise locally around the front surface of the secondary form (Plate VI, figure 28) at positions where the flow ridges slightly project above the general curvature of the anterior surface. These projections, which are situated some distance away from the front polar regions of the secondary shape, and occur at progressively decreasing intervals towards the equatorial edge, are positions where local accelerated flow arises. Five such projections and their attendant shock waves are illustrated in Plate VI, figure 28 in sectional aspect. Behind each flowridge shock wave, would occur expansion cones of cross section resembling the fan-like expansion regions illustrated by Black (1953, p. 254). Such expansion cones would arise in the flow trough regions, where local scouring-out of glass occurred during these final stages of secondary shape development. The material removed below the level of flow ridges that occur on either side of such flow troughs, is of relatively minor amount, at the most being 0·25 mm. thick from flow troughs nearest the front poles, and 0·40 mm. from flow troughs at the equatorial edge of the secondary shape. Such material was no doubt largely removed as a result of drag in two dimensional boundary layer flow of air in contact with the front surface, for such laminar flow would become an increasingly important factor in the lower, denser layers of the atmosphere, where the secondary shape of the australite received its final sculpturing.

Now Dodwell (see Fenner, 1938, p. 207) has calaculated from Opik's mechanics of meteor phenomena, that friction in the earth's atmosphere would yield a thickness of only 0·001 cms. of liquid film on a medium size australite of 10 mm. radius, and that the temperature difference would be enormous between the surface and the bottom of the film. Moreover, the rate of heat transfer through australite glass is so low that the internal and rear regions must remain relatively cold, this being aided in rear surface regions by the existence of the cone of dead-air. Hence the amount of australite glass in the fused state at any particular instant, must of necessity be small, and it is thus considered to be out of the question that the australite could become completely molten throughout during the atmospheric phase of flight, and yet remain as an entity in itself.

An important result of pressure on the frontal area of an australite moving at ultra-supersonic or even at ordinary supersonic speeds, is the production of drag. This evidently becomes manifest in the thin laminae of contact air during boundary layer flow, where frictional effects are predominant. It is therefore to be expected that the thin liquid film of australite glass produced at any given time during high-speed flight, would be forced away from the place where developed, very shortly after its formation, almost instantaneously in fact, thus exposing a new under-surface of the glass to the heating process and so the process proceeded continuously while supersonic speeds were maintained. Particles of liquid glass removed from the frontal area of the australite, where pressures are greatest, would become rapidly volatilized in the highly heated, highly compressed cap of gas lying behind the frontal shock wave, and either swept away into the wake of the speeding australite, or else dissipated obliquely sideways in the region of the lateral flowridge shock waves. As this process continued, the front pole of the original primary sphere receded, the arc of curvature of the front surface became flatter, and the edge of the secondary form constantly moved back and beyond the equatorial zone of the primary sphere. When such a stage was reached, the primary sphere had been reduced to an optimum size and shape where conditions were suitable for the construction of a flange structure, attended by marked flow ridge development and the generation of other subsidiary shock waves. It can be assessed from comparison of the primary sphere indicated in sectional aspect in text figure 36, with the ultimate secondary form indicated by a section through its front and back poles in Plate VI, figure 28, that approximately 60 per cent. to 65 per cent. of the primary sphere has been lost by ablation in attaining the final secondary shape. Not all of the secondarily fused australite glass was lost by ablation and fusion stripping, for some became pushed back to build up the flange, as seen in section in Plate VI, figure 28. During flange growth, turbulence in equatorial regions played an important part in shaping the posterior surface of the flange. Eddy currents operated from the equatorial edge of the flange inwards, at a time in the phases of development when the fusion stripping process that had operated to produce flaked equatorial zones on larger forms (cf. text figures 33 and 34) was no longer a major factor with which to be reckoned on these reduced, originally smaller forms. Near the final stages of secondary shape formation, of which the thin section shown in Plate VI, figure 28 reveals the structure of the end product, the velocity of the australite had considerably lessened, hence pressure and temperature had decreased, and the final act of the now less potent aerodynamical forces, seems to have been a minor amount of scouring in flow trough regions and in the equatorial regions of the anterior surfaces of the flanges, for the australite had by now entered the lower and denser layers of the earth's atmosphere where drag effects were pronounced. The buffeting effects that normally arise from drag and from shock wave formation, were evidently negligible during the formational stages of secondary shapes possessed by australites.

It is considered that the operation of the aerodynamical flow-phenomena, and their effects as outlined above, would be similar for other primary shapes of australites as for the primary sphere utilized in these conjectures. Minor variations may have occurred, although they are not evident from the study of the ultimate secondary shapes produced from different primary forms.

It has already been indicated that the arcs of curvature of shock waves ahead of one and the same australite, would vary and change according to the change in curvature of the anterior surface with ablation. Arcs of curvature of shock waves would also vary from form to form according to the radius of curvature of different primary forms. Moreover, in the smaller number of australites that have the final arc of curvature of the anterior surface steeper than that of the posterior surface, the shape of the frontal shock waves started off steeply curved and hemispherical, then became rather flatter, only to ultimately approach the more steeply curved hemispherical shape again, so that pressure must have oscillated considerably with the varying angle of the deflecting anterior surface to the airstream, being greatest in the intermediate stage, least in the initial and ultimate stages.

In oval-, boat-, canoe-, and teardrop-shaped secondary forms of australites, the frontal shock wave pattern as viewed normal to the polar axes of these forms, would generally parallel the outline of the forwardly directed surfaces, in a similar manner to that depicted (cf. text figure 37) for primary spheres and that for secondary forms (buttons) derived therefrom (cf. Plate VI, figure 28). In dumb-bell-shaped examples, however, it seems likely that two shock wave fronts may have been produced, one ahead of each forwardly directed bulbous portion (cf. text figure 14), so that complexities might be expected in the waist regions ahead of which shock wave interference is surmized.

An important question to be considered in treating of the origin of the secondary shapes as developed during ultra-supersonic flight, concerns the likely temperature values generated in the cap of highly compressed gas ahead of an australite travelling earthwards at high speeds. If australites travelled at 21,600 miles per hour as a probable minimum value, or as much as 180,000 miles per hour as a calculated maximum value, at heights of some 60 to 70 miles above the earth's surface, temperatures should be enormous in the highly compressed cap of gas. On the basis that guided missiles released at the earth's surface, travelling at 3,220 kilometres per hour (i.e. = 2,000 m.p.h.) develop a temperature rise of 1°C. for every 100 Km. hr., their increased temperature (approximately 300°C.) would be small compared to that computed for australites (2,200°C. to 18,000°C.) by extrapolation. However, temperature values derived in this way, by extrapolation, may have little validity, for the reasons that (*a*) the known temperature rise indicated above may not be maintained, (*b*) australites are not passing through the denser portions of the atmosphere in the earlier stages of atmospheric flight, but in the final stages, and (*c*) at the critical stages of secondary shape formation, speeds may be lower than at a height of 60 to 70 miles above the earth's surface, because of increased drag effects. Hence temperature values in the highly compressed cap of gas could be considerably less than the upper limits given above, but are not likely to be below the lower limits. The temperature necessary to cause solid australite glass to pass into the liquid state, has been determined as 1,324°C. by Grant (1909, p. 447). Therefore the molten film of glass measuring 0.001 cms. produced on the anterior surface of an australite during supersonic flight, must be at least 1,324°C., but since the temperature of melting increases with pressure, the effect of intense compression generated by the formation of frontal shock waves would be to considerably raise the temperature of fusion at ultra-supersonic speeds, so that temperatures at the anterior surface may well have been in the region of 2,000°C. or more. To volatilize this glass during the operation of the ablation process at front surfaces, however, considerably higher temperatures are necessary, so that temperatures equal to the temperature of volatilization of the silicate glass forming australites, must have been attained in the cap of hot, compressed gas behind the frontal shock wave. Because of the opportunity available for reaction between particles of volatilized australite glass and oxygen in this region, certain chemical effects would come into play. Most of the available oxygen would evidently be consumed during volatilization, so it is not to be expected that outer oxidized films of glass would be extensively or continuously produced on the front surface of the australite itself. Such oxidized films are never found on the outer surfaces of australites on discovery, although they can be produced by heat treatment under certain conditions in the laboratory. Thus, a flange fragment and a body fragment from different australites in the Port Campbell Strewnfield, also a small button-shaped form with flange remnants (reg. no. E845) from the Nirranda Strewnfield, all developed reddish-brown skins after heating them to 1,200°C. for two hours under atmospheric pressures in an oxidizing atmosphere, in an electrically heated tube furnace. The oxidized film of glass so produced, was exceedingly thin, measuring under 1 micron, and microscopic examination revealed that no particular strain phenomena had become evident in the glass immediately below the film. At this temperature, softening of the glass had just become initiated in one place, indicated by sticking at a point of contact between the australite glass and the containing silica boat. The reddish-brown, thin oxidized film had a marked satin-like lustre, and its colour is due to the complete conversion of ferrous to ferric iron in the outer skin of australite glass.

If any such oxidized films tended to develop on the highly heated front surfaces of australites during ultra-supersonic flight downwards through the earth's atmosphere, they were evidently rapidly removed by the effects of drag in the laminar boundary layer flow along the anterior surface. Now since the flange glass of australites represents material moved from front polar regions to equatorial regions, at certain phases of development of the secondary shapes of australites, then flanges are the places to seek evidence for the possibility of front film oxidation having occurred. Thin sections of some three dozen flanged australites, reveal that the flange glass in the majority is always the same colour as the body glass, and moreover, in the body glass itself, there is no colour difference between posterior surface regions, anterior surface regions or central regions. In two examples of flanges, however, (cf. Baker, 1944, p. 12 and Plate II, figures 1 and 9) a limited amount of banding of deep brownish colour is present. Dunn (1912, p. 6) also noted occasional colour differences in the flanges of australite sections he described. These bands can only indicate that some oxidation of the front film had occurred, and that only in a few examples was this oxidized glass incorporated with the non-oxidized glass which forms the bulk of the flanges.

Since it appears logical to assume that australites travelled through the earth's atmosphere at greater than ordinary supersonic velocities, all the processes outlined above in forming secondary from primary shapes, must have occurred in a very short period of time. Thus, if their fall was vertical through the atmosphere, the primary forms of australites suffered frontal melting, fusion stripping and ablation, and flange-building processes, and were developed into the secondary shapes as we find them upon the earth's surface, all in a matter of 10 to 15 seconds, if travelling at the upper speed limits of 40 to 50 miles per second, or a matter of 1½ minutes at the most at the lower speeds of 6 miles per second, (not allowing for the slowing down effects of transit from more tenuous upper atmosphere to more dense lower atmospheric layers). If their path of fall was oblique, the time taken would be approximately up to three times as long, according to the angle of entry into the atmosphere. During their high speed flight, high compression in the air ahead of australites produced high temperatures which operated for a very short period of time, and so opportunities were rather limited for oxidation to occur in thin films of fused glass, hence only meagre evidence exists to indicate that a small measure of oxidation did arise in these thin films.

CONCLUSIONS

The evidence revealed by a detailed study of the Nirranda Strewnfield australites, together with the accumulated results of observations carried out on approximately 2,000 australites from the south-western Victorian region, indicates that australites need not have rotated during their short periods of rapid translation through the earth's atmosphere.

Apart from the spheres, which are essentially non-rotational bodies, the other primary forms from which some secondary shapes of australites arose were certainly produced by rotation, since the evidence indicates initial generation of typical forms of revolution from rotating molten bodies of glass. The birthplace of the primary forms was undoubtedly extra-terrestrial.

On entering the earth's atmosphere, and at that stage possessing the low temperature equivalent to that of outer space, the onset of conflict of the primary glass bodies with the earth's atmosphere, through which they travelled the greater portion at ultra-supersonic speeds, generated pressure and frictional heat in the front regions of each object. This was insufficient to produce complete melting throughout, but was adequate to result in sheet fusion and thus progressive frontal melting of thin films of glass. If any of these glassy bodies entered the earth's atmosphere initially rotating, which is very doubtful, then they evidently lost their spinning motion very quickly, and continued along their line of flight at ultra-supersonic speeds, until slowed down near the earth's surface, by which time some had become completely evaporated, and the remainder became very much modified in shape. Glass melted from their anterior surfaces was thus not whirled away by rotational forces, but was forced back under pressure and the influence of frictional drag from the front polar regions towards the equatorial regions of each non-rotating body.

Much glass was completely lost in this way from the greater number of the separate primary bodies, assisted by the agencies of rapid fusion stripping and ablation, until the shapes of australites, as they are now known, were developed.

The final secondary shapes of australites show several marked stages in the progressive operation of these processes. Larger forms show flaked equatorial zones, but no flanges and no flow ridges. Medium sized forms have developed flanges at certain specific sizes and shapes, and with them, concentric, anticlockwise spiral or clockwise spiral flow ridges on anterior surfaces only. Smaller forms mostly lost their flange, largely during flight, but some as a consequence of subsequent sub-aerial erosion.

Microscopic complete forms of australites have never been found, although searched for among the materials upon which australites of macroscopic size have been discovered. It is not likely that microscopic australites will ever be discovered, because complete dissipation by ablation seems to have occurred, both of all the glass melted from front surfaces during the generation of the secondary shapes (allowing for that retained in equatorial regions as flanges), while all forms below a specifically limited lower size value have also been completely ablated. It is to be expected that after any particular primary form had been ablated down beyond a certain minimum size, it completely evaporated, for the reason that ablation depends essentially upon the size of the surface, and that with diminishing volume, the relative size of the surface increases. In a similar, but not quite identical way, raindrops that reach the earth, have a certain minimum size. The smallest known complete australite is one from Port Campbell, Victoria (see Baker, 1946, Plate VI, figure 1), which weighs 0.065 grams and measures 9 x 6 x 1 mm. It is doubtful if complete australites less than 0.05 grams in weight are ever likely to be found.

The majority of known australites have been further modified by erosion while they lay upon the earth's surface, some to greater degrees than others, and many have been fractured by various causes. Some specimens have been so much more affected by erosion than others, that sometimes they scarcely appear at first to belong to the australite fraternity. These later modifications to the secondary shapes of australites must always be carefully considered, particularly where the smaller cores (body portions) are concerned, before a final decision can be made regarding their original primary form and their subsequent secondary shapes.

As found upon the surface of the earth, australites have evidently passed through the following principal stages:—

(A) Initiation, some as spheres, some as primary forms of revolution, in an extra-terrestrial environment.

(B) Secondary modification of the primary forms by virtue of their short periods of flight at ultra-supersonic velocities through the earth's atmospheric envelope.

(C) Tertiary modification of the secondary shapes by the relatively prolonged action of terrestrial agencies after landing upon the earth.

As extra-terrestrial bodies that have passed through the whole thickness of the earth's atmosphere, the symmetrical Australian tektites must have experienced velocity reductions of a very marked degree, in a sequence from initially ultra-supersonic, through supersonic and transonic, to ultimately subsonic, in a very short period of time, before coming to rest upon the surface of the earth. Their secondary shapes were impressed upon them in the early to intermediate stages, at speeds greater than transonic speeds.

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DESCRIPTION OF PLATES

Plate I.—(x3).

Figure 1—Anterior surface of complete button-shaped australite (E1016)* showing counter-clockwise flow ridge and tendency to radial arrangement of flow lines outwards from the front pole. Coll. E. D. Gill.

* Numbers so given are registered numbers in the Rock Collection of the National Museum of Victoria.

Figure 2—Posterior surface of complete button-shaped australite (E1016) showing bubble-pitted surface of core and finely etched surface of flange.

Figure 3—Posterior surface of flat, lens-shaped australite (E736), the second smallest complete form in the Nirranda Strewnfield australite collection. Coll. G. Baker.

Figure 4—Posterior surface of naturally detached, almost complete flange (E835) from a button-shaped australite. Coll. G. Baker.

Figure 5—Posterior surface of a smaller, naturally detached complete flange (E962) from a button-shaped australite. Coll. G. Baker.

Figure 6—Posterior surface of incomplete button-shaped australite (E928) that has lost approximately one third of the flange. Coll. M. K. Baker.

Figure 7—Posterior surface of lens-shaped australite (E876) showing narrow superficial groove extending from equatorial to polar regions. Coll. A. E. Gill.

Figure 8—Anterior surface of incomplete button-shaped australite (E847) with flange remnants and concentric flow ridges, and showing deep groove extending approximately three parts across the form. Coll. E. D. Gill.

Plate II.—(x3).

Figure 9—Anterior surface of hollow button-shaped australite (E1052) showing crudely radial arrangement of deep grooves. A hole at the front pole where several of the grooves unite, leads to an internal cavity. Note concentric flow ridge. Coll. R. T. M. Pescott.

Figure 10—Posterior surface of hollow button-shaped australite (E1052) showing two remnants of flange and bubble-pitted, irregularly flow-lined surface of core.

Figure 11—Broken posterior surface of hollow button-shaped australite (E816) indicating size of internal cavity and showing small remnants of a narrow flange. Breakage was natural, by impact or by weathering. Coll. G. Baker.

Plate III.—(x3).

Figure 12—Posterior surface of oval-shaped australite core (E961) showing bubble pits. Coll. G. Baker.

Figure 13—Side aspect of oval-shaped australite core (E961) showing flaked equatorial zone between posterior surface (uppermost) and anterior surface (lowermost).

Figure 14—Side aspect of conical core (E1109) showing strongly flaked equatorial zone. (This form is round in plan aspect). Coll. E. D. Gill.

Figure 15—Posterior surface of australite core (E860) showing bubble crater situated in smoother flow-lined swirl having crudely counter-clockwise spiral flow lines, and surrounded by finely bubble-pitted glass. Coll. A. M. Gill.

Figure 16—Side aspect of oval-shaped australite core (E922) showing well-developed flaked equatorial zone with small grooves and pits. Pres. Mrs. A. Mathieson, Snr.

Plate IV.—(x3).

Figure 17—Posterior surface of canoe-shaped australite (E809) showing bubble pits. Drawn-out bubble pits and flow lines occur at the narrowed ends. Coll. M. K. Baker.

Figure 18—Side aspect of canoe-shaped australite (E809) showing recurved ends.

Figure 19—Anterior surface of canoe-shaped australite (E809) showing smoother surface and concentric flow ridges.

Figure 20—Posterior surface of dumb-bell-shaped australite (E761) showing small bubble pits and fine flow lines parallel with long axis of slender form. Coll. A. E. Gill.

Figure 21—Oblique view of one side of posterior surface of boat-shaped australite (E785) showing deep grooves (" saw-cuts "). The grooves continue around the anterior surface to the opposite edge of the posterior surface. Coll. A. E. Gill.

Figure 22—Posterior surface of teardrop-shaped australite (E744) showing minute pits and flow lines. The flow lines at the bulbous end (bottom of photograph) are counter-clockwise spiral, and extend along the length of the form to the narrow, flange-like end (top of photograph). Coll. A. E. Gill

Figure 23—Posterior surface of oval-shaped australite (E759) showing bubble pits and flow pattern. Coll. A. E. Gill.

Figure 24—Side aspect of artificially etched oval-shaped australite (E710) showing flow lines and vitreous lustre where etched, and dull portion in polar regions of posterior surface (top of photograph) where non-etched. Note partially developed flange. Coll. E. D. Gill.

Figure 25—Anterior surface of artificially etched oval-shaped australite (E710) showing vitreous lustre and minutely etch-pitted pattern.

Plate V.—(x7).

Figure 26—Thin section of lens-shaped australite (E749) showing internal flow-line pattern. Coll. A. E. Gill. (Section taken through front and back poles; posterior surface uppermost.)

Figure 27—Thin section of lens-shaped australite (E932) taken at right angles to that shown in figure 26, showing internal flow-line pattern. Coll. M. K. Baker. (Section taken through equatorial plane.)

(These two thin sections are radial and equatorial sections respectively, of two lens-shaped australites of the same specific gravity and similar depth.) (Note swirls and complex " fold-like " flow pattern.)

Plate VI.—(x5).

Figure 28—Thin slice of button-shaped australite with flange, from Port Campbell, Victoria, showing relationship of front (anterior) surface to surmized aerodynamical flow phenomena created during ultra-supersonic flight, and relationship of back (posterior) surface to turbulence phenomena.

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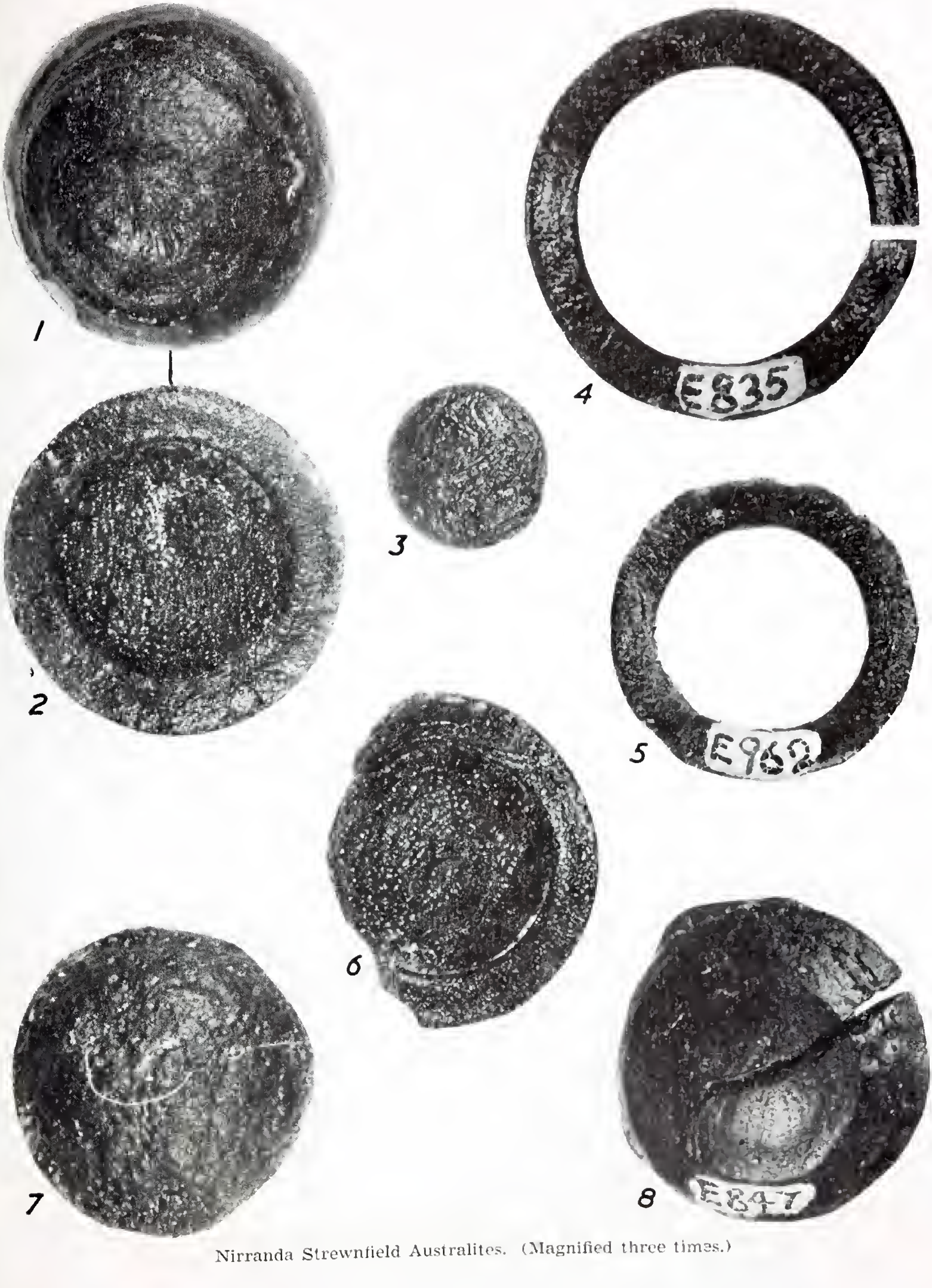
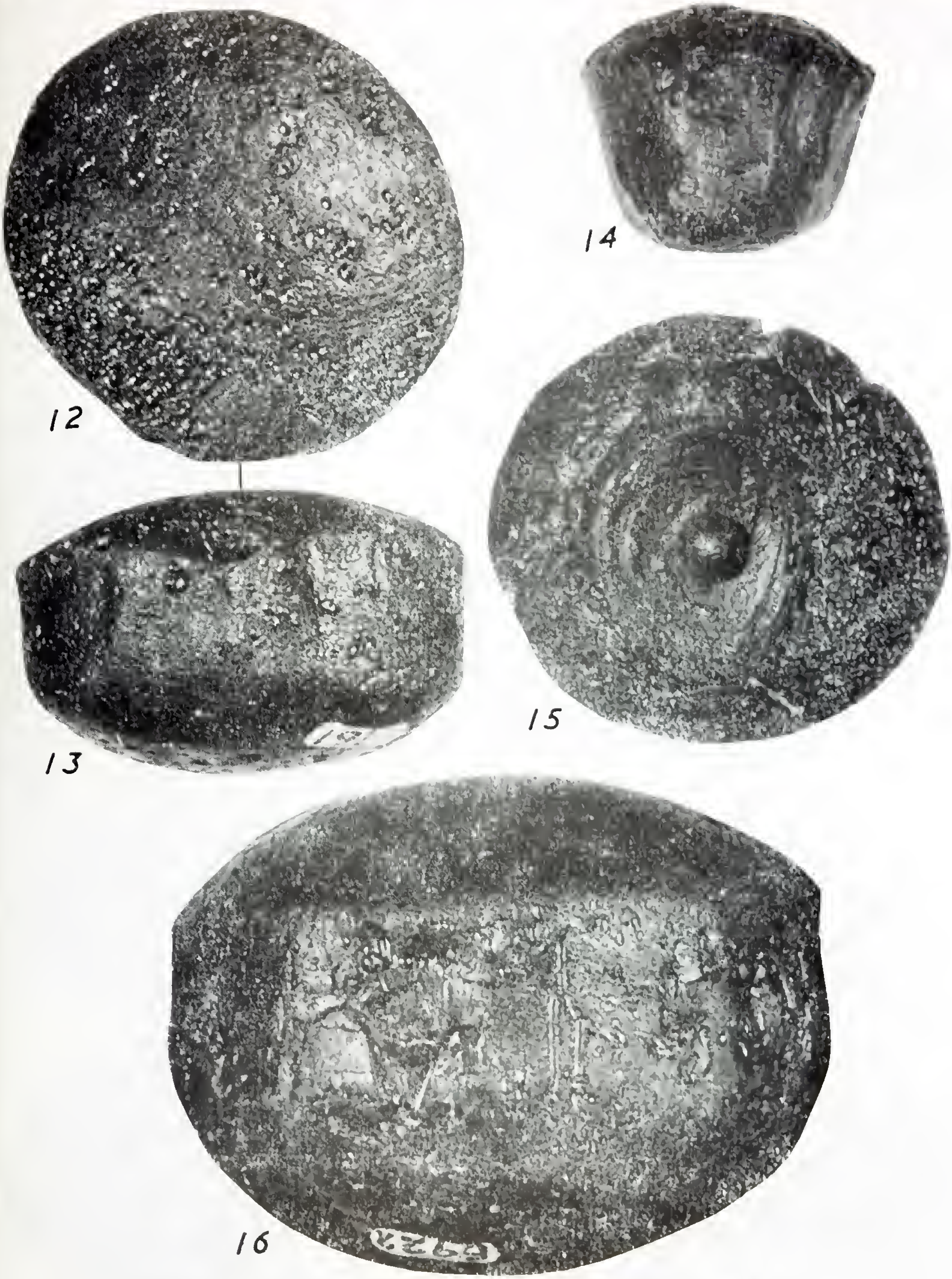


Nirranda Strewnfield Australites. (Magnified three times.)

Nirranda Strewnfield Australites. (Magnified three times.)



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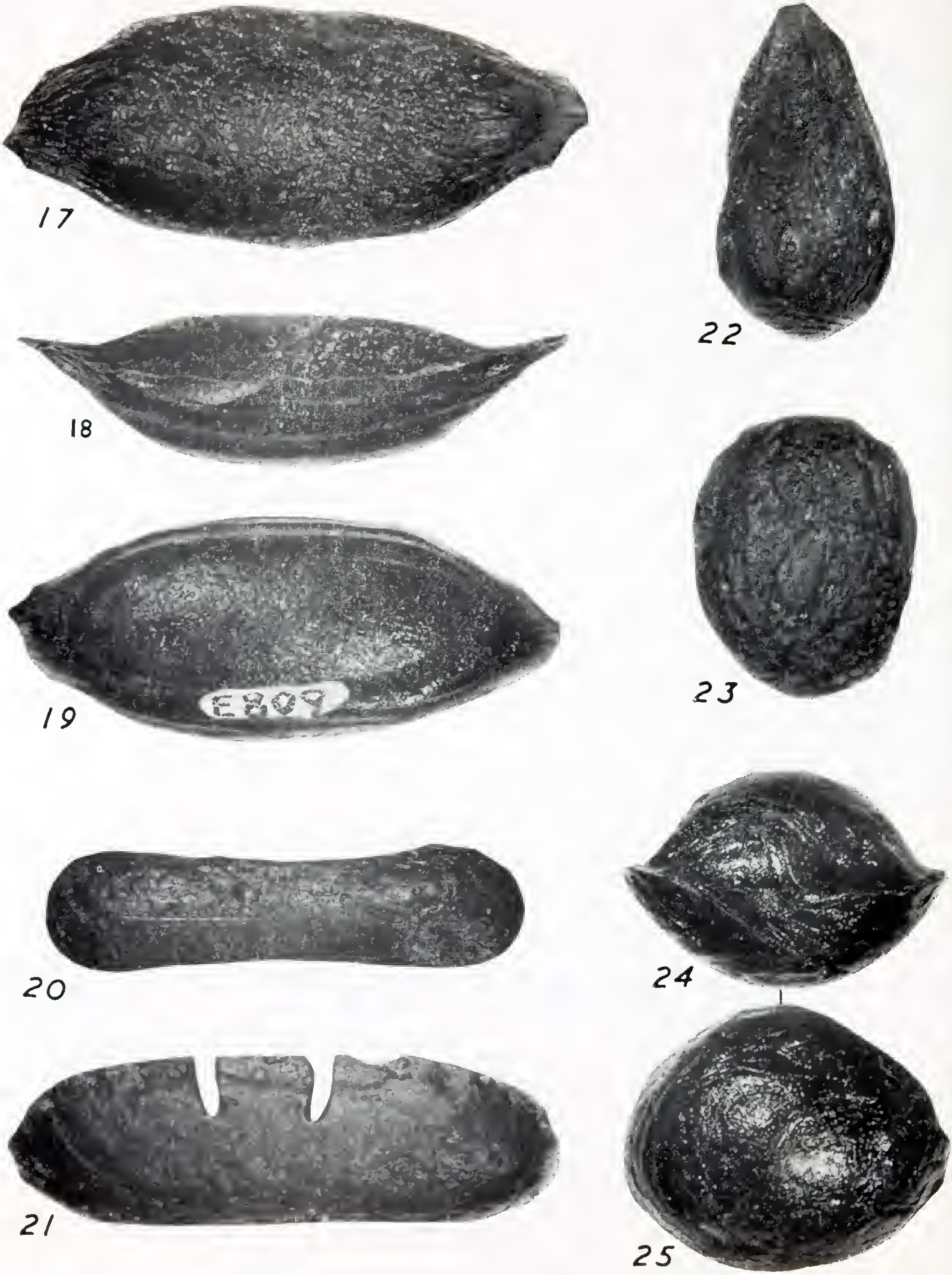
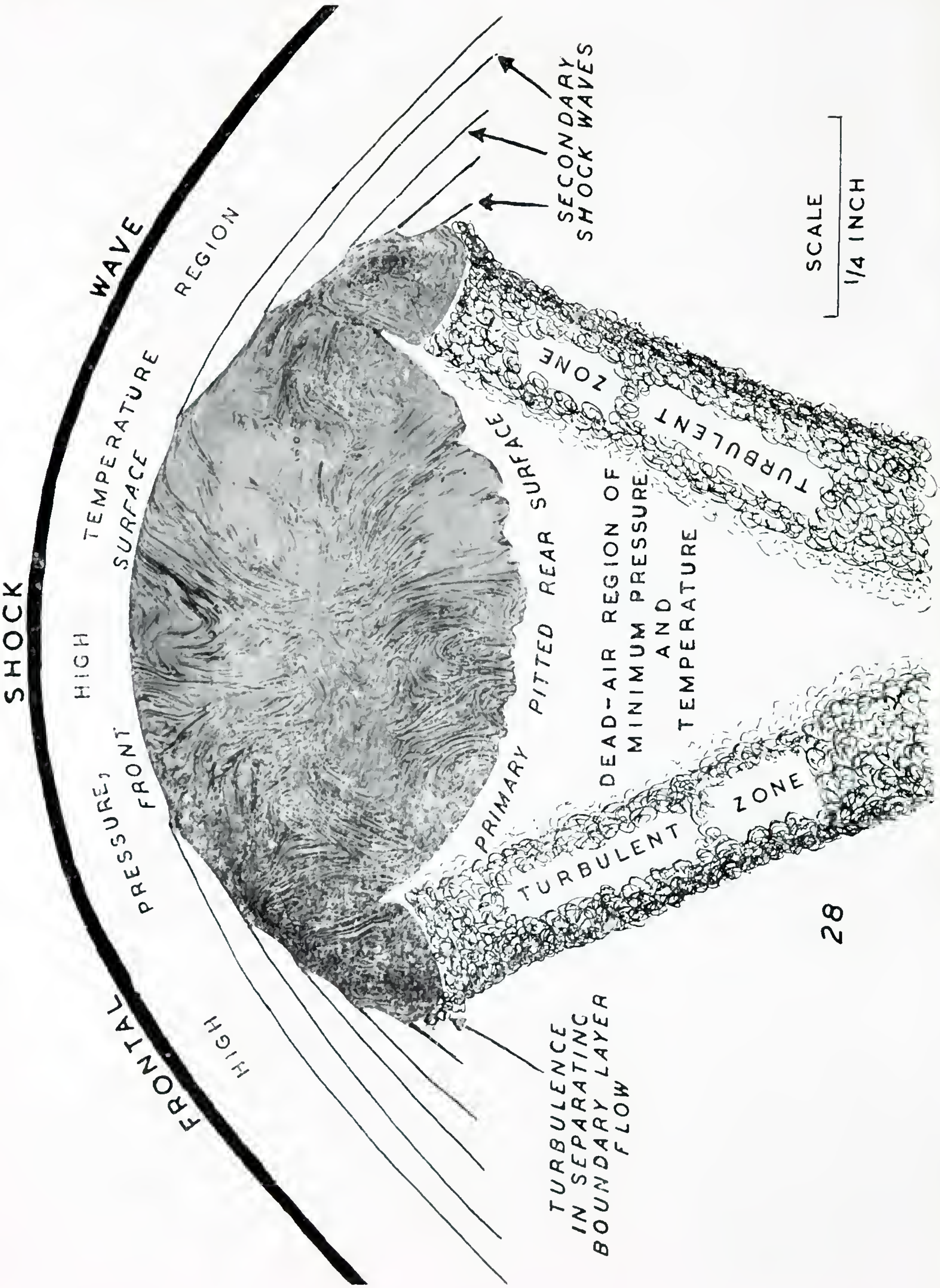


Nirranda Strewnfield Australites. (Magnified three times.)

26

27

Flow Structures in slices of Nirranda Strewnfield Australites. (Magnified seven times.)



Supersonic Flow Phenomena in Relation to Australite.