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SOME ASPECTS OF AUSTRALITE DISTRIBUTION PATTERN IN WESTERN AUSTRALIA

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ABSTRACT

The original australite distribution pattern was further complicated by the transport, concentration or burial of australites by the action of running water and other natural agents. Aboriginal man was probably responsible for introducing australites into areas from which they had formerly been absent; he also made artifacts on australites, and particularly on the Nullarbor Plain, he might be partly responsible for the generally small size of the specimens found there.

The australite collections constitute an extremely unsatisfactory sample of the Western Australian portion of the strewnfield because of poor documentation and very uneven collecting.

A belt of abundant australite occurrence appears to be present in the Eastern Goldfields. It trends 337° and is convergent northward with the more defined belt of abundant occurrence in eastern South Australia. The reality of the belt and its trend are unproven because of deficiencies in the sample and because of close relationship to the distribution of human activity.

The distribution of australites having mass $\geqslant 20$ g supports the suggestion already seen in the distribution of those of mass >100 g that mass grading could be present in the distribution.

Only 17 australites, or about 0.04% of those examined, were accepted as having been found in the northern half of Western Australia under conditions which might indicate that they were at their sites of fall. Other specimens and reported occurrences were rejected for a variety of reasons. The northern boundary of 'multiple' occurrence (minimum of 10 specimens from any site) is likely to be the original strewnfield boundary, the few widely dispersed northern specimens having been introduced by man.

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INTRODUCTION

Though the most refined developments in chemistry, geochronology and aerodynamics have been applied to the tektite problem, the fundamental questions of tektite genesis, parent material and provenance remain as enigmatic as ever. Additionally, the time (times?) of fall of australites and their unity with east Asian tektites and with 'microtektites' are still in dispute. There might be pointers to the solution of some of these problems in the distribution pattern. Before considering the distribution in Western Australia, it is desirable to review briefly the agencies responsible for the distribution and to examine the quality of the sample represented by the collections.

The abbreviation P.S. is used throughout this paper for Pastoral Station; also H.S., meaning Head Station, the principal homestead and business centre of a pastoral property. Institutions and their collections are referred to thus: BM — British Museum (Natural History), WAM — Western Australian Museum, SAM — South Australian Museum, WASM — W.A. School of Mines.

The Distribution of Australites

It has been very generally conceded that the concentration density of the newly fallen australites varied from one part of the strewnfield to another. This has been recognised by some authors in their use of localized strewnfield names. Superimposed upon the initially irregular distribution have been the effects of agents responsible for removal, concentration, destruction, burial, and sometimes the re-exposure of previously buried australites. Most maps showing sites of find are very inadequate expressions of the distribution because they do not distinguish between the find of a single specimen or of many. Nor is it evident whether blank areas represent absence of australites or lack of collecting; examples of both types of blank area are known.

Rainwash in semi-arid and arid terrain has been especially effective in transporting australites. The most impressive evidence is their concentration into certain lakes of internal drainage in arid regions, the extreme example being the Yindarlgooda-Lapage-Cooragooggine lake complex east of Bulong, from which $>$20 000 australites have been collected. It is generally evident from the environments of these concentrations that the distance of transport of any specimen is unlikely to have exceeded a few kilometres and would average much less. These movements are generally so small relative to the area of the general strewnfield (c.3 x 10^6 km^2 exposed on land, or c.5 x 10^6 km^2 if using the northern boundary as defined by previous authors), that the error involved in accepting the site of find as the site of fall is insignificant on a regional scale.

The recovery of australites from alluvial workings and from the spoil of earth dams sited on rainwash channels and alluvial flats also shows the ability of running water to transport australites and bury them in alluvium. The rarity of australite recoveries from that southern portion of Western Australia having coastal drainage by perennial and semi-permanent streams could be partially accountable to stream processes, but there are other contributory factors arising from circumstances of collection referred to in the next section of this paper. Lake concentrations are often essentially marginal, particularly in the flat outwash fans of streams. Australites also occur in lag gravels formed by solifluction aided by rainwash and as residuals after deflation of inter-dune corridors (Lovering *et al.* 1972).

Aboriginal man had many uses for australites and carried them about (Baker 1957). To some extent these movements within the strewnfield could have been random in distance and direction and for some purposes compensatory, but the aborigine is also one of the agents capable of introducing australites into areas from which they were formerly absent. Prior to white colonisation, he bartered a wide variety of articles along numerous routes within Australia and also to nearby countries (McCarthy 1939). Baker (*op.cit.*) could find no indubitable evidence for the barter of australites but it cannot be dismissed as impossible. Bates (1947, p.124) noted the trade of 'curiously shaped meteorites' over north-south trade routes. Meteorites *sensu stricto* are extremely rare objects and there is no record of the aborigine making use of them, but australites were readily available in the Eucla area of which Mrs Bates wrote and many would qualify as 'curiously shaped'. Australites were certainly carried by the aborigine over long distances as ritual objects. Mr K. Akerman (*pers.comm*) reports seeing such a specimen at Derby in 1973. It had been carried from Hooker Creek, N.T. along portion of a well-known circuitous trade cycle, a distance $>$1100 kilometres.

The aborigine destroyed many larger australites in making artifacts on the Nullarbor Plain where the only other suitable raw material is the siliceous crust developed sporadically over the limestone surface. Around rock holes (natural holes capable of holding water) and around some dongas (shallow sink features sometimes capable of holding water), struck flakes which include australite flakes are often plentiful but australites of usable size are rare or lacking (items 1 - 5, Table 1). Australite flakes constitute 14% of the total number collected at Waddalinya Rockhole (item 5, Table 1) and 7% of the total mass. The sample is an insignificant fraction of the material strewn about the rock hole. Akerman (1975) has reported on 385 australite flakes from a rockhole 15 km N.E. of this site. Localities 4 and 5 were searched because of a growing conviction that australite flakes would be found around almost any source of water on the Nullarbor Plain. The choice of the localities was random to this extent that they were conveniently close to the route taken in connection with an entirely different investigation.

The situation around water sources on the Nullarbor Plain is less marked on the small granite inliers in the western fringe of the Bunda Plateau (item 6, Table 1). Some of the other materials used there can be closely matched with those available in the Precambrian area a few tens of kilometres further west.

The making of artifacts was probably fairly localized to the sources of water as can be seen by the reversed proportions in the material from an area centred 5 km from Billygoat Donga which is the only evident source of water in the vicinity (item 7, Table 1). However, australite distribution over a considerable area was probably affected by the 'import' of australites to the centre of manufacture. The major vehicle tracks on the Nullarbor Plain follow for considerable distances the tracks of an earlier generation which had some dependence on natural water supplies. The nature of the australite sample collected has certainly been affected by the destruction of larger specimens, but collecting by the white man has contributed to the situation now found because — from personal observation on two occasions — he will collect only complete specimens and natural fragments but ignore the flakes unless advised of their scientific interest.

Other raw materials are available on Earaheedy P.S. but 277 (16%) of the 1414 Earaheedy australite specimens in WASM collection are flakes or flaked cores, the majority with well developed patina. A sample received recently from Earaheedy comprises 144 fractured specimens and 31 very small or naturally broken specimens, being the discard from a collection made for sale; the total number in the original collection is unknown. Many flakes in both Earaheedy samples have been confirmed as artifacts; a few very freshly fractured specimens can be dismissed as the result of testing (Baker 1957 p.14).

On the other hand, careful searches around four rock holes within 40 km of Kalgoorlie resulted in no recoveries, though a few artifacts made on australites are known from the district, two of them from the vicinities of the rock holes searched. It was not expected that complete australites or well-formed artifacts would be found because all rock holes in the region were much frequented by the white man during the gold prospecting episode, but it seemed likely that small discard flakes would have been ignored by any except a scientist collector.

Australite flakes are uncommon in the Tillotson collection of >9000 specimens from an area centred upon Kalgoorlie except in samples from parts of the Bulong area and a sample from a granite rock with numerous water holes at McAuliffe Soak on Yerilla P.S. Inclusive also of WASM 11704, material from the Yerilla site comprises 10 complete specimens or weathered natural fragments, only one of which might have been of usable size, and 167 flakes or flaked cores. The lengths of some flakes (to 22 mm) and their curvatures indicate derivation from australites of probable mass >15 grams. An enormous number of chalcedonic and opaline flakes strewn over the granite, grinding stones and a stone arrangement indicate a much used aboriginal site. Mr Tillotson collected 85 australites in a few hours at the lake edge about 3 km distant. It appears that australites were initially so common that they were utilised despite the ready availability of siliceous weathering products over the ultrabasic rocks of nearby hills.

Wangine Soak (90 km N.W. of Kalgoorlie) is a reliable source of water and was an important gathering ground for aborigines until after the arrival of the white man. An australite artifact received from Wangine Soak (WASM 10933) prompted a search of the area. The most obvious signs of aboriginal occupancy are on low sandhills overlooking the soak where deflation has left areas of lag 'gravels' consisting almost entirely of artifacts — flakes and flaked cores of opaline, chalcedonic and cherty materials and grinding stones — mostly broken and consisting of basic igneous rocks which are also foreign to the area. Australites are a minor component of the 'gravels'. From blown out areas totalling about a third of a hectare, five small complete or naturally broken australites and 106 australite flakes or flaked cores were recovered (WASM 11755). As at McAuliffe Soak, australites were used despite an evidently ready availability of suitable alternative materials.

The flaking of australites by aborigines in the Ord region dates from c.18 000 years B.P. (Cleverly and Dortch 1975.) Reference is made by Akerman (1975) and also in the Appendix to this paper to small numbers of flaked australites from many other Western Australian localities, most of which have never been closely searched. The limited available data suggest that outside the Nullarbor Plain where alternative raw materials were available, the destructive usage of australites was more casual except where they were so abundant as to be readily noticed, or conceivably where some custom had developed involving their use. It is emphasised that the majority of localities from which flakes have been recovered have never been closely searched and even if they have been searched, flakes are likely to have been ignored.

At least two of the larger birds of general distribution in Australia are known to use australites as gizzard stones. To judge by the example described by Fenner (1949), the Australian bustard (*Eupodotis australis*) uses stones of mean mass c.2½g and evidently uses australites abundantly (49 taken from a single bird). The emu (*Dromaius novae-hollandiae*) 'uses stones of an inch or so in size' (Baker 1957) i.e. of mass up to c.20g for australites.

It is improbable that transport of australites by man or birds could have affected significantly the distribution pattern in areas of abundance, but it could account for — and at some sites demonstrably does account for — the specimens in areas of rare or diffuse occurrence. Concerning one of the three types of occurrence which he recognises in north-western South Australia, Johnson (1965) states '. . . australites have been found sporadically over the face of the whole region, particularly among the debris of aboriginal campsites, old and new, reflecting the activities of man, and to a lesser extent, of birds using gizzard stones'. It is likely that the destructive usage of australites by aborigines is partly responsible for the small size of specimens collected from the Nullarbor Plain.

REPRESENTATION OF THE AUSTRALITE STREWNFIELD BY COLLECTIONS

Australite distribution pattern is necessarily judged by documented collections.

Eastern Australian collections contain >10 000 australites from Western Australia and the immediately adjoining portion of South Australia. More than 52% of them are attributed to 'Kalgoorlie and district', but this group contains labelled specimens from Hogan's Find (55 km S.E. of Kalgoorlie) and Lake Carey (190 km to N.E.). The private collectors from whom these specimens were obtained were residents of Kalgoorlie; the locality attribution probably has no more meaning than that. A further 39%, principally the W.H.C. Shaw collection (SAM) are from Israelite Bay, points around the Great Australian Bight and northward to the Trans-Australian Railway Line. These are unlocated except that Fenner (1934) quotes Mr Shaw as saying that the majority is from Israelite Bay. Only 8.4% of the specimens in Eastern States collections have the minimal locality information necessary for use in this paper.

Western Australian official collections (including WASM) contain only about 4000 australites but more than 95% of them have sufficient locality information. There are two major private collections. The Tillotson collection of >9000 australites from the Eastern Goldfields is located to within a kilometre or so of various key points, but the even larger C.B.C. Jones family collection has no details beyond the fact that it is almost entirely from Hampton Hill P.S. which has an area of 2430 square kilometres. However, 70% of the Tillotson collection is from the same area and from it a centre of occurrence has been calculated as about 121°57'E., 30°38'S. The bulk of the Hampton Hill component of the Tillotson collection was found within 10 km of that point; the same is probably true for the bulk of the Jones collection.

Inclusive also of some minor official and private collections, c.40 000 Western Australian australites were reviewed. Only 39% have usable locality information; 31% have vague documentation of limited value; the remaining 30% have no value for present purposes.

The collections also have inadequacies resulting from very uneven collecting. Some examples follow.

Fewer than 200 australites represent that part of the State southwest of a line from Geraldton to Esperance (fig. 2), an area of almost 2×10^5 km^2, but nearly 30% of the specimens have mass >50g, i.e. are of unusually large size. In contrast, a much smaller area centred upon Kalgoorlie is known by 100 times as many australites, only 0.03% of which have mass >50 grams. Some of the differences between these samples could be real, but they are attributable in part to the relative ease of detection of australites on the bare ground and dry lake basins in the Eastern Goldfields as contrasted with the difficulties of detection on the cultivated ground or well-vegetated country in the south-west of the State.

An area of c.40 000 km^2 south-west of Coolgardie (fig.2) is represented by only ten specimens, though both from report and brief personal observation, australites are not uncommon in the Bremer Range which is about central to it. There is no permanent habitation in the area.

The Nullarbor Plain has yielded thousands of specimens, mostly to private collectors, but because the majority has no locality details, this enormous area is represented by only a few scattered points of occurrence which are quite inadequate to represent the known wide distribution. The Yarri-Yundamindera and the Cosmo Newbery-Warburton Range areas have likewise yielded large numbers of australites, principally to mineral dealers and lapidaries. Most of the specimens seen have either the vaguest and most untrustworthy locality details ('somewhere east of Cosmo Newbery') or none at all, being intermixed with those from other areas on the basis of some superficial characteristic such as size or shape i.e. sale value.

It is evident from the collections that australites are common on Granite Peaks, Carnegie and adjoining pastoral properties but only Earaheedy P.S. is well represented. This is one of several such examples resulting from the interest and energy of one or two persons while large and equally promising areas are almost unknown.

The Tillotson collection, which contains more documented Western Australian australites than all other collections combined, is subject to the severe restraints that it was gathered from places within a day's reach of Kalgoorlie by persons who did not have a 4-wheel drive vehicle available and who have therefore never searched some of the most promising areas.

Private and commercial collectors continually return to areas of known abundant occurrence such as Lake Yindarlgooda and the Menangina-Mt Remarkable area, avoiding those areas of sparse occurrence or unknown potential. Few scientists can afford the time for search except briefly and as a side issue to other field work. The natural differences in distribution density tend to be further emphasized by such collecting.

The collections thus have deficiencies in documentation and severe distributional bias. Only the most cautious and tentative conclusions can therefore be offered in the sections which follow.

I. THE TREND OF AUSTRALITE OCCURRENCES IN THE EASTERN GOLDFIELDS

McColl and Williams (1970) calculated straight regression lines for belts of australite occurrence in southern central Australia. A less defined belt appears to be present in the Eastern Goldfields of Western Australia and its trend has been calculated in a similar manner i.e. weighting the co-ordinates of sites of find of (1 - 10), (>10 - 100), (>100 - 1000) and >1000 australites by 1, 10, 100 and 1000 respectively. The closest significant recoveries outside the belt are from Corrigin (180 km west of the area, >10 specimens) and from Rawlinna (100 km east of the area, >100 specimens, mostly flakes). The resulting line (fig. 1A) has azimuth 337° and is therefore gradually convergent northward with the more eastern and more reliable line of McColl and Williams, which trends 330°.

McColl and Williams had reasons for confidence in the australite deficiency of the areas surrounding the belts of dense occurrence, but no such confidence is possible for the Eastern Goldfields (see comments on areas

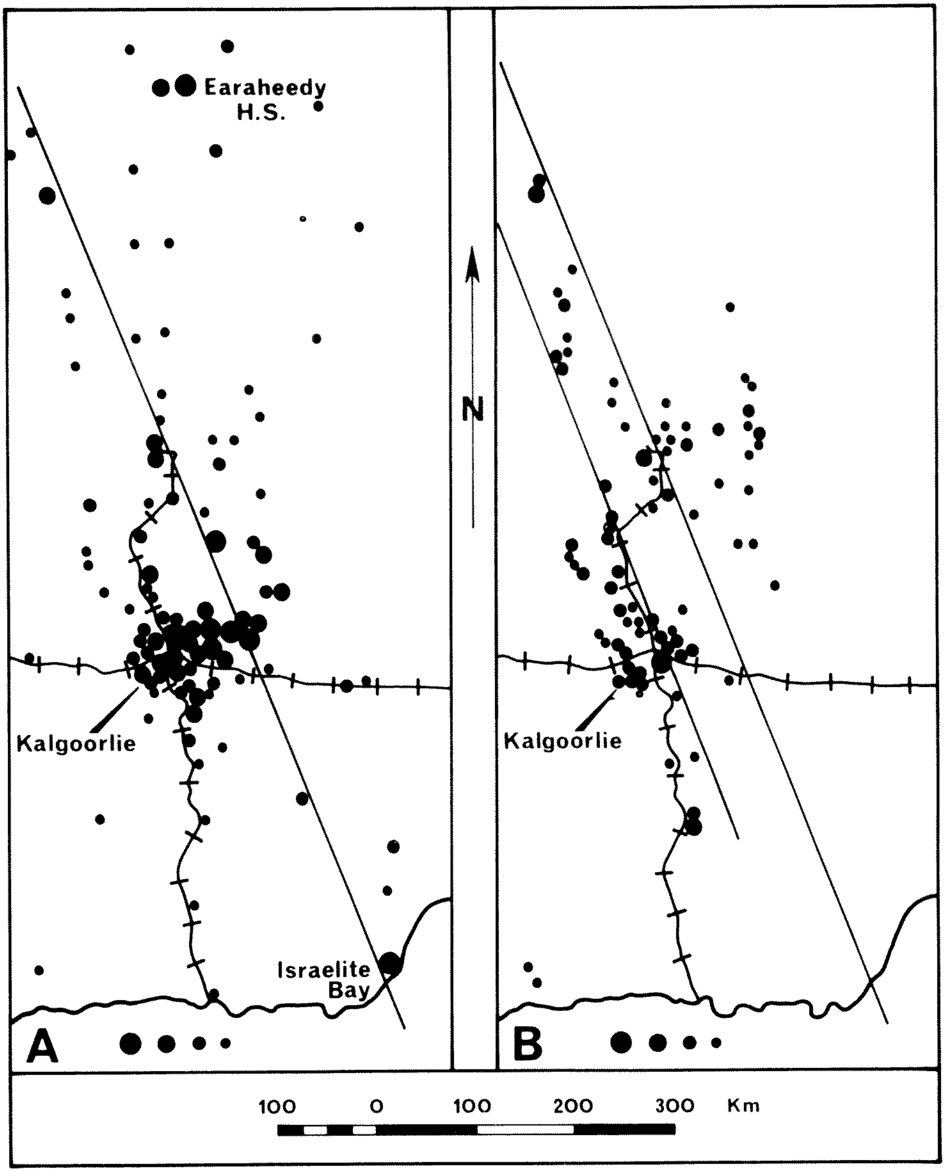

Figure 1A. Portion of southern Western Australia centred upon the Eastern Goldfields showing sites of recovery of australites and first order regression line. The circles, in sequence of decreasing size, represent >1000, >100-1000, >10-100 and 1-10 australites.

Figure 1B. Same area as in A showing centres of gold production and first order regression line on left. The circles in sequence of decreasing size represent total gold production of $>10^7$, $>10^6 - 10^7$, $>10^5 - 10^6$ and $>10^4 - 10^5$ ounces respectively. The line at right is the australite regression line transferred from A.

A - C of fig. 2). The belt of dense occurrence is sub-parallel to the railway system and to the distribution of human population and those are in turn the consequences of the N.N.W. strike of the Precambrian rocks with their contained centres of mineralization. The four centres with the greatest totals of gold production in Western Australia lie within the belt as well as such major base metal discoveries of recent years as Kambalda, Windarra, Agnew and Yeelirrie.

To examine the relationship of australite recoveries to human activity, a regression line was calculated for centres of gold production because the search for and mining of gold have been the major human activities during 75 of the 82 years of white occupation. The co-ordinates of centres with total production ($>10^4$ - 10^5), ($>10^5$ - 10^6), ($>10^6$ - 10^7) and $>10^7$ ounces of gold were weighted by 1, 10, 100 and 1000 respectively. The nearest significant gold recoveries outside the belt under consideration were from Sandstone and Southern Cross (each about 50 km west of the area and belonging to the second of the above four categories; there have been no significant recoveries to the east of the area. The resulting line (fig. 1B) differs $<3^{\circ}$ in azimuth from the australite line but is displaced about 60 km westerly from it. The major australite recoveries of the Earaheedy and Israelite Bay areas (fig. 1A) are unrelated to gold mining activity but their omission affects the trend of the australite line by only two degrees and displaces it c.15 km closer to the gold line.

Because of deficiencies and bias in the australite sample and its relationship to opportunity to collect, the reality of the australite trend is, at best, not proven. At worst, it could be but a large scale example of the same kind of relationship which exists between meteorite sites and rabbit burrows on the Nullarbor Plain. Rabbit trappers, who have found many meteorites, generally travel by vehicle from one group of burrows to another, but they are on foot and see the ground closely in the immediate vicinity of the burrows.

II. MASS GRADING

The australites of mass >100 g known from Western Australia were found within a broad belt extending north-east, the greater number of specimens and the most massive specimens (>200 g) towards the southern end of the belt (Cleverly 1974). A similar but less populous belt extends north-west from western Victoria to the vicinity of Charlotte Waters, and the same features are evident in the distribution. These observations suggest the possibility of mass grading, i.e. a systematic areal variation in the masses of individual specimens related to peculiarities of their distribution in the shower and/or to circumstances of fall.

Collections were searched for well-located Western Australian australites of mass $\geq$ 20.0 grams. The 336 specimens found were listed in sequence of decreasing mass (stated to 0.1g) with geographical co-ordinates (to 0.1^{o}). Three numerically equal categories (nos. 1 - 3) were defined in descending sequence of mass and for each category the mean latitude and longitude were determined i.e. the 'mean sites'. Calculations were also made with the co-ordinates weighted by the masses of the specimens, thereby determining the 'centre of mass' of each category. Similar sets of calculations were made with categories (nos. 4 - 6) containing sub-equal total mass (33,102,201 specimens respectively) and also with categories (nos. 7 - 10) of the type (<320 - 160), --------- (<40 - 20) grams. All calculations yielded points falling very closely along the same line as the particular result illustrated (fig. 2).

The trend of the line is approximately normal to the isohyets of annual rainfall and it might therefore have been influenced by the terrain effect which makes for increasing ease of observation inland. However, the trend is unlikely to be dominated by the terrain effect while attention is limited to the largest and most readily detectable specimens constituting <2% of located specimens available. The terrain effect can account for the large numbers and small average mass of specimens in the eastern collections but it does not explain why those large collections made under ideal observational conditions contain only half as many specimens of mass >50g as the small western collections. As a check, some trial calculations were made with the WAM collection and the E.S. Simpson collection (held at WAM). Though numerically small (c.2000 australites), these collections are remarkable for their wide areal representation. Because they have been acquired from such numerous sources and over a period of more than 70 years, it is possible that they could be a more representative sample of australite distribution than the much larger general sample with its evident bias to certain localities. The resulting mean points were well aligned, somewhat more widely spaced than in fig. 2 and trending 15^{o} more northerly (i.e. roughly parallel to the belt of unusually large australites), but the general style of the result persisted. It is noted that the two belts of large australites radiate from within central Australia and the 'coarse structure distribution pattern' of some major chemical types (Chapman 1971 fig. 2) may also be visualised as sectors of distribution radiating from the same general vicinity e.g. HCu,B type (except a Tasmanian specimen), HCa type, HMg type (except the Wyloo specimen — see Appendix) and normal australite-phillipinite type.

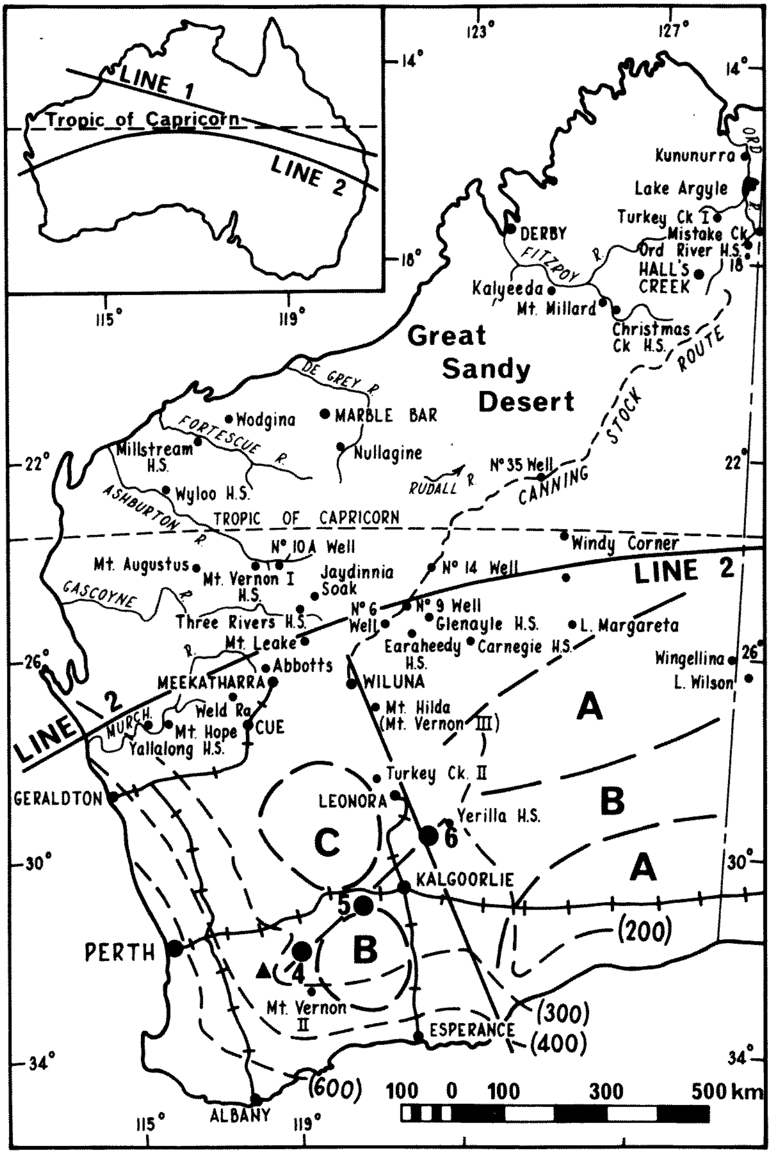

Figure 2. Western Australia. The line trending N.N.W. is the first order regression line for australite recoveries in the Eastern Goldfields. A — indicates areas from which many australites have been recovered, most of which are undocumented. B — uninhabited areas almost unrepresented in collections. C — sparsely inhabited area from which few australites are known. Points 4, 5, 6 are 'centres of mass' for three categories of australites containing sub-equal total mass. The triangle is the site of find of the most massive australite known. Broken lines are smoothed isohyets with annual rainfall in millimetres shown thus: (300).

Inset — Australia showing northern limit of 'multiple' occurrence of australites (Line 2) and the strewnfield boundary as usually shown (Line 1).

Only five of the 336 specimens used in the original calculations are from the Nullarbor Plain. The low Nullarbor representation is only partly the result of lack of documentation. Most Nullarbor specimens are small, and to that, aboriginal usage could have been contributory.

The results cannot be regarded as strong evidence for the existence of a graded distribution but they support the impression already evident in the distribution of specimens of mass >100 grams. Extended studies to incorporate eastern Australian specimens are desirable, preferably with the mass range extended down to (say) 10 grams. With the larger and more general sample a more rigorous mathematical treatment should be possible and one which is uncomplicated by the artificiality of a State boundary.

Proven mass grading in a certain direction would not necessarily indicate flight in the direction of increasing mass. Unlike meteorites, the fragmentation of which is an atmospheric event, australites were pre-formed individuals when they encountered the atmosphere. Factors such as temperature-dependent viscosity at the site or origin could have influenced the size range and size distribution within different parts of the shower (Chapman 1971) and hence, ultimately, the distribution upon the earth's surface. Nor is the result necessarily incompatible with the trend deduced in section I of this paper. The result could indicate progressive differences between lines of fall, each of which had N.N.W. trend.

III. THE NORTHERN BOUNDARY OF THE STREWNFIELD IN WESTERN AUSTRALIA

The northern boundary of the australite strewnfield has generally been shown as Line 1 (inset to fig. 2) e.g. by Baker (1957). Line 2 marks the northern limit of multiple occurrence, defined here as sites from which at least 10 specimens have been collected. These are distinguished from occurrences of single, usually isolated specimens which, whether north or south of Line 2, are often suspect as transported specimens. The eastern Australian portion of Line 2 is based upon generally well known and for the most part documented occurrences of the Uralla district, S.W. Queensland (including the strip discovered in recent years from which nearly 1000 specimens have been taken), Mulka, Charlotte Waters, Finke, Henbury (33 specimens in SAM), eight km N. of Alice Springs (24 specimens in Australian Museum), and Mt Davies-Lake Wilson area. In Western Australia, multiple occurrences include Wingellina, L. Margareta (Chapman 1971), a point c.100 km S. of Windy Corner (14 specimens in University of Adelaide collection), Glenayle, Earaheedy and neighbouring pastoral stations, and

Wiluna. The western end of Line 2 is somewhat arbitrarily placed. Isolated specimens from immediately south of the line - no. 9 Well, no. 6 Well, two points in the general vicinity of Mt Leake, Abbotts (G.M.L. White Horse),* 18 km E.S.E. of the same, Weld Ra., Mt Hope, Yallalong P.S. — are not much more plentiful or concentrated than those to the north of it.

The separation of Lines 1 and 2 is so great in Western Australia that the questions arise whether the specimens found north of Line 2 are genuine australites found at the stated localities, and if so, whether they were at their sites of fall. A search of collections and literature disclosed only 17 australites which might have been at their sites of fall in Western Australia north of Line 2. For details of these and other specimens, see Appendix. The total of 17 is generous in that it includes vaguely located specimens from 'east Kimberley' and 'north-west Australia'. It also includes two specimens from Hall's Creek, which is on a recognised native trade cycle, a specimen from Argyle Downs P.S. 'found on a path near a house' (Fenner 1935), concerning which there must be considerable doubt that they were in situ, and a specimen 'found by a native'. Australite flakes and a complete specimen found in cave shelters in the Ord region (Cleverly and Dortch 1975) were clearly not in situ and other specimens were rejected for a variety of reasons. There is no direct evidence that the 17 specimens were found other than has been stated (Table 2) or that they were not in situ.

The 17 australites comprise about 1/2300 of those known from Western Australia but they were dispersed over nearly 49% of the area of the State. The Great Sandy Desert constitutes a major gap in the distribution. No specimens or record could be found to justify the desert occurrences indicated by Fenner (1955 fig. 2). The gap is not necessarily the result of lack of opportunity to collect. Talbot (1910 p.29) specifically sought australites along the Canning Stock Route and there is a later report from Mr R. Verbugt (see no. 35 Well in Appendix).

It is conceivable that australites were transported from the abundant southern sources to the Kimberley region by aborigines, either along the coast or directly across the desert where rock holes and native wells exist (Talbot *op.cit.*). The relationship of the Kimberley sites of find to the valleys of the two major rivers is doubtfully significant because most of the sparse white population is also in those areas i.e. there has been maximum opportunity to collect.

* Gold mining leases of the same name existed also at Laverton, Mt Ida, and Bulong. Abbotts is the locality indicated by Baker (1959 fig. 4), but Bulong, where australites are extremely abundant, is a much more likely locality from which a Kalgoorlie collector (S.F.C. Cook) would have obtained the specimen.

Pearl shell ornaments made on the Kimberley coast were traded all over Western Australia, central and South Australia (McCarthy 1958). Presumably the Kimberley native received something not available locally in exchange for his goods. Australites were one such possibility. Bates (1927 p.124) records that 'pearl shell of the north (was) treasured as magic in the deserts of the south' and almost simultaneously refers to the trade in 'curiously shaped meteorites'. As recently as 1973 a Kimberley pearl shell artifact reached Cundeelee (160 km E. of Kalgoorlie) along native routes; meanwhile, an australite ritual stone had been seen at Derby.

With the exception of four specimens of large size or lacking abrasion, the northern specimens might also have been carried by birds, but there is some slight evidence against transport by either birds or man in the proportions of the shape types of the northern specimens. No particular shape type appears to have been favoured. Round forms predominate and oval forms are common; a boat and a dumbbell represent the less common forms. This is as good a representation of the usual shape proportions as could be expected in a small random sample. On the other hand, the average mass of reasonably complete specimens is 13g, a high figure which may be compared with the average 19g for the very rare, more or less complete specimens recovered over a period of more than 70 years from the Murray-Darling confluence region (Baker 1973), within which they must also be suspected to have been dispersed by Aboriginals.

There are important differences between the circumstances in which the northern australite specimens were found and those of the uniquely isolated Martha's Vineyard tektite, concerning which a strictly conservative scientific attitude has always been adopted, though it was found 'just below the point where most tourists view the cliffs' (Kaye *et al.*1961). Searches have been made for further specimens which would demonstrate that Martha's Vineyard is a strewnfield rather than any ready acceptance that the specimen was an import to the area; the nearest recognised strewnfield is in Georgia, distant $>$1700 kilometres. The Martha's Vineyard tektite has been the subject of intensive study. The differences here are that the northern australites were thinly dispersed over an area contiguous with a strewnfield and formerly inhabited by tribes who had developed inter-tribal barter routes which spanned the continent (McCarthy 1939). Moreover, these people used australites in ways ranging from ritual objects and charms to the making of items such as knives, micro-adzes and piercers. Unlike the Martha's Vineyard tektite (if we exclude the tourists), there is therefore a prime suspect for the dispersal of the australites and he had uses for them even in the far north of the State from very early times (Cleverly and Dortch 1975).

This study has considered only the Western Australian material but a perusal of some reported occurrences between Lines 1 and 2 in eastern Australia suggests that there also, a critical review would raise serious doubts that the specimens were genuine and/or in situ. For example, at least two authors have indicated australite occurrence at Bullock's Head, N.T. but the original report (Jensen 1915) is hearsay unsupported by specimens and no confirmation of the occurrence has been forthcoming in the 60 years since the report was made. Specimens from four localities in south eastern Queensland are single specimens or hearsay. West of Blackbutt, 'several were found by a miner, the *one* examined . . .' (Dunstan 1913). Gold miners are notable for itinerancy. Miners from the declining Victorian fields were already widely scattered by 1913 and eventually La Paz (1938) was to note that tektites from the gold fields of Australia were 'exhibited occasionally in placer mining camps in the United States'.

If the occurrence of one australite to an average of >68 000 km^2 requires acceptance of an area as strewnfield, the whole of Western Australia should be included (c.f. O'Keefe 1969 fig. 1), but it is then also accepted that the natural concentration density in the northern half of the State was less than 1/2000 of that in the southern half. Because there is no historical record of the observation of a tektite shower, such a possibility cannot be dismissed.

It is considered more probable that the northern boundary of multiple occurrence was the approximate strewnfield boundary and that the rare northern specimens were introduced, though this contention is not capable of proof. One of the difficulties is that most northern specimens have no documentation except a locality statement which lacks detail and the name of the donor who was not necessarily the finder. An awareness of the problem might have resulted in the recording of significant details of the circumstances of occurrence, associated materials and the reliability of the finder. A further problem is that australite flakes lacking such positive evidence as reworking cannot be attributed with any degree of certainty to the work of man if they have been removed from their context. It is difficult to ignore the probability that all flakes from a site such as McAuliffe Well are the work of man despite the lack of evidence on most individual flakes.

A considerable gap would have existed between the newly-fallen australites and the nearest east Asian tektites in Java. Such a gap need not be critical to the unity of 'australasianites' but it would require explanation. If australasianites indeed originated, as some have supposed, from an impact event in S.E. Asia, conceivably a critical angle of elevation for the ejected material (or alternatively, a critical entry angle from an extra-terrestrial source) could account for the gap as well as for the south easterly gradation from puddle and splash forms through primary shapes of rotation to Javaites with 'proto-australite flanges' (von Koenigswald 1967) and the australites with well-developed features resulting from atmospheric transit.

The suggested northern boundary is regarded as a minimal limit which is to be moved further north and refined in shape as further reliable occurrences become known. The criteria advocated for 'reliable' occurrence are multiple, tangible specimens with flakes constituting a small minority, collected by persons of known integrity from sites which have been searched for signs of aboriginal occupation. It is urged that curators of collections endeavour to obtain maximum information on australites received from any locality north of Line 2.

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REFERENCES

AKERMAN, K. (1975)—The use of australites for the production of implements in the western desert of Western Australia. *University of Queensland Anthropology Museum, Occasional Papers* no.4.

ANON. (1946)—Western Australia, Rep. Dept. Mines for the year 1945.

BATES, DAISY (1947)—*The passing of the aborigines.* 2nd Aust. ed. London, John Murray.

BAKER, G. (1957)—The role of australites in aboriginal customs. *Mem. Nat. Mus. Vict.* **22**: 1-26.

BAKER, G. (1959)—Tektites. *Mem. Nat. Mus. Vict.* **23**: 5-313.

BAKER, G. (1973)—Australites from the Murray-Darling confluence region, Australia. *Mem. Nat. Mus. Vict.* **34**: 199-208.

CHAPMAN, D.R. (1971)—Australasian tektite geographic pattern, crater and ray of origin, and theory of tektite events. *J. Geophys. Res.* **76**: 6309-6338.

CHAPMAN, D.R., LARSON, H.K. & SCHEIBER, L.C. (1969)—Population polygons of specific gravity for various localities in Australasia. *Geochim. Cosmochim. Acta* **28**: 821-839.

CLEVERLY, W.H. (1974)—Australites of mass greater than 100 grams from Western Australia. *J. Roy. Soc. W. Aust.* **57**: 68-80.

CLEVERLY, W.H. & DORTCH, C.E. (1975)—Australites in archaeological sites in the Ord Valley, W.A. *Search* **6**(6): 242-243.

DUNN, E.J. (1912)—Australites. *Geol. Surv. Vict. Bull.* **27**.

DUNN, E.J. (1914)—Further notes on australites. *Geol. Surv. Vict. Records* **3**(3): 322-326.

DUNSTAN, B. (1913)—Queensland Mineral Index and Guide. *Qsld. Geol. Surv. Publ.* no. 241.

FENNER, C. (1934)—Australites, Part I. Classification of the W.H.C. Shaw collection. *Trans. Roy. Soc. S. Aust.* **58**: 62-79.

FENNER, C. (1935)—Australites, Part II. Numbers, forms, distribution and origin. *Trans. Roy. Soc. S. Aust.* **59**: 125-140.

FENNER, C. (1949)—Australites, Part V. Tektites in the South Australian Museum, with some notes on theories of origin. *Trans. Roy. Soc. S. Aust.* **73**: 7-21.

FENNER, C. (1955)—Australites, Part VI. Some notes on unusually large australites. *Trans. Roy. Soc. S. Aust.* **78**: 88-91.

HEY, M.H. (1966)—*Catalogue of Meteorites.* 3rd ed. London, British Museum.

JENSEN, H.I. (1915)—Report on the geology of the country between Pine Creek and Tanami. *In* Anon. *Bull. Northern Territory* no. 14: 1-19.

JOHNSON, J.E. (1965)—Geological factors in tektite distribution, northwestern South Australia. *Geol. Surv. S. Aust. Quart. Geol. Notes* no. 14: 5-6.

LA PAZ, L. (1938)—The great circle distribution of the tektites. *Popular Astronomy* **46**: 224-230.

LIEBERMAN, K.W. (1966)—The determination of bromine in terrestrial and extra-terrestrial materials by neutron activation analysis. *Univ. Kentucky Tech. Rep.* ORO - 2670 - 13.

LOVERING, J.F., MASON, B., WILLIAMS, G.E. & McCOLL, D.H. (1972)—Stratigraphic evidence for the terrestrial age of australites. *J. Geol. Soc. Aust.* **18**(4): 409-418.

McCARTHY, F.D. (1939)—'Trade' in aboriginal Australia and 'trade' relationships with Torres Strait, New Guinea and Malaya. *Oceania* **9**: 405-438, **10**: 1-104, 171-195.

McCARTHY, F.D. (1958)—'Material culture' in the entry 'Aborigines'. *Australian Encyclopaedia* 1: 3-99. Sydney, Grolier Society of Australia Ltd.

McCOLL, D.H. & WILLIAMS, G.E. (1970)—Australite distribution pattern in southern central Australia. *Nature* **226**: 154-155.

O'KEEFE, J.A. (1969)—The microtektite data: implications for the hypothesis of the lunar origin of tektites. *J. Geophys. Res.* **74**: 6795-6804.

TALBOT, H.W.B. (1910)—Geological observations in the country between Wiluna, Hall's Creek and Tanami. *Geol. Surv. West. Aust. Bull.* 39.

THORP, C.G. (1914)—A contribution to the study of australites. *J. Nat. Hist. Sci. Soc. West. Aust.* **5**: 20-43.

VON KOENIGSWALD, G.H.R. (1963)—Tektite Studies VI. Rims, flow ridges and flanges in Javanese tektites. *Proc. K. Ned. Akad. Wetensch. Amsterdam.* (B)**66**(4): 198-205.

Table 1. Australites found near sources of water on and marginal to the Nullarbor Plain

Item	Locality	Number of australite specimens		Most massive specimen of preceding column and its largest dimension	Registered number of specimens
		recently fractured	not recently fractured		
1.	Rock hole c.86 km N of Loongana	34	3	1.9 g 16 mm	WASM 9492
2.	Laundry R.H., 43 km N of Madura Pass	15	1	1.4 g 15 mm	WASM 9493, 10272, 10312
3.	26-mile R.H., c.33 km NNW of Nurina	24	4	0.7 g 15 mm	WASM 11643
4.	Rock holes 3 km SW of Ryan's Well (25 km W of Rawlinna)	20	Nil	- -	WASM 11646(b)
5.	Waddalinya R.H., 14 km SW of Rawlinna	109	2	3.2 g 23 mm	WASM 11647(b)
6.	Ray's Rock, 123°34′E., 33°05′S.	9	3	0.7 g 13 mm	WASM 11668
7.	Area centred 5 km N of Billygoat Donga	18	85	22.9 g 34 mm	WASM 10273, 10872, 11028

Table 2. Physical details of tektites found in northern Western Australia.

Collection and Registered number	Site of find	Shape type	Mass g	Dimensions mm	S.G.	Notes
Not known	Argyle Downs P.S.	'Flat oval without flange'	-	-	-	Reported by Fenner (1935)
W.A. Museum B2150	Gundarim Hill rock shelter	Broad oval	6.222	28.6 x 21.3 x 9.1	2.448	Cleverly and Dortch (1975)
W.A. Museum B888	Monsmont rock shelter	Flake (artifact)	0.750	16.4 x 9.9 x 4.3	2.476	Cleverly and Dortch (1975)
W.A. Museum B938	Monsmont rock shelter	Flake (artifact)	0.390	16.0 x 13.8 x 2.3	2.46	Cleverly and Dortch (1975)
W.A. Museum B250	Miriwun rock shelter	Curving fragment (artifact)	0.050	11.2 x 2.6 x 2.0	2.43	Cleverly and Dortch (1975)
W.A. Museum B249	Miriwun rock shelter	Flake (artifact)	0.328	11.6 x 9.9 x 3.7	2.40	Cleverly and Dortch (1975)
W.A. Museum B2079	Miriwun rock shelter	Flake (artifact)	0.318	15.1 x 8.4 x 2.9	2.43	Cleverly and Dortch (1975)
W.A. Govt. Chem. Labs. 3278	Ord River P.S.	Round core, conical as result spallation losses	2.750	(17.6 - 16.9) x 9.0	2.30	Low S.G. accountable to bubble cavity beneath posterior surface
Priv. coll. P.J.W. Nevill	Vicinity Mistake Ck. P.S.	Discoidal	3.389	c.20 x 9.7	2.389	(?) Phillipinite. See additional notes
Aust. Museum 4737	Hall's Creek	Narrow oval	4.727	c.26.9 x 14.5 x 11.4	2.381	Incomplete (cut). Length taken from cast
Aust. Museum 4737	Hall's Creek	Narrow oval	3.397	c.25.4 x 12.8 x 9.5	2.436	As above
Aust. Museum 4736	East Kimberley	Round core	2.951	c.17.8 diam. x 10.9	2.435	As above. Diameter taken from cast
E.S. Simpson coll. 13	Christmas Creek	About ¾ of artificially broken round core	19.801	32.3 x 23.5 x 22.3	2.428	Form and deeply etched grooves resemble those of some phillipinites
E.S. Simpson coll. 85	Mt Millard	Round core	40.08	(38.2 - 37.0) x 21.5	2.47	
E.S. Simpson coll. 14	Kalyeeda	Dumbbell	36.65	67.2 x 21.9 x 17.8	2.456	See additional notes
E.S. Simpson coll. 15	Wodgina	Spalled fragment of small core	2.039	11.9 x 9.5 x 10.2	2.438	
Aust. Museum 8152	North-west Australia	Round core	13.131	(27.2 - 25.5) x 15.7	2.441	
E.S. Simpson coll. 16	Rudall River	Broad oval core	4.392	18.5 x 15.5 x 13.5	2.457	
W.A. Museum 12161	Millstream P.S.	Round core	11.225	23.9 x 22.2 x 18.0	2.420	
Brit. Mus. (N.H.) 1925, 1079	Wyloo P.S.	-	11	-	-	Not examined. See additional notes
E.S. Simpson coll. 21	Mt Vernon P.S. (Mt Vernon I).	Round core	5.086	(19.5 - 17.4) x 12.9	2.453	5 km N of No. 10A Well on Peak Hill to Nullagine Stock Route
WA. Museum 12755	Mt Augustus P.S.	Boat core with remnants of stress shell	4.285	30.7 x 13.6 x 8.8	2.502	'Indicator' of 'trilobite' type
E.S. Simpson coll. 18	Jaydinnia Soak	Round core	15.884	(29.0 x 28.2) x 14.7	2.432	
E.S. Simpson coll. 17	Three Rivers P.S.	Round core	29.275	(34.5 - 32.4) x 21.5	2.452	

APPENDIX

Tektites from Western Australia north of Line 2 (inset to fig. 2)

Physical details of tektites from northern Western Australia are shown in Table 2 and localities are indicated on fig. 2. Supplementary notes, if required, are given below together with notes on unacceptable specimens and reported occurrences which are unsupported by specimens. Multiple usage of two locality names is indicated by I, II, III.

Turkey Creek I (unacceptable). Thorp (1914) first listed this locality and indicated it on the accompanying map (Pl. XVII). Though the name was not used officially for a second creek (II) in the Mt Clifford area until 1936, this usage was already known to Mr L. Glauert of the WAM (Fenner 1935) and could have been established when Thorp was writing because Mt Clifford had been an active mining centre since 1900; australites are abundant in the nearby Leonora area. A third usage on Mt Vernon P.S. (I) is — at least officially — much more recent. Fenner (*op. cit*) stated that the specimen was in the WAM collection but no such specimen is registered. Nor is it listed by Hey (1966) in the BM collection which received Thorp's private collection from his estate (J. Hall *pers. comm.*). Dunn (1912; 1914) did not list the locality though "Mr Thorp, of Derby" was a contributor to the additional localities in the second publication. Only a few months later in Perth Thorp (1914) gave the address in which Turkey Creek was first mentioned. It therefore appears likely that the report arose from Thorp's west Kimberley experience and it would be wrong to dismiss it as a southern locality. It was in Derby that Mr K. Akerman (*pers. comm.*) saw an australite ritual stone in 1973, and Turkey Creek I is within easy reach of the trade cycle which he describes.

Mistake Creek P.S. (unacceptable). The locality is stated as "Duncan Highway, about 100 miles south of Kununurra" and hence in the vicinity of Mistake Creek H.S. The surface of the specimen is coarsely scoriaceous and the general appearance is similar to the "spongy" type of phillipinite (Type II of Chapman *et al.* 1964 fig. 11). The bubble cavities are closely crowded, sometimes interconnected by circular "windows", but evidently confined to the outer part of the specimen because an artificial fracture surface across the thickness reveals only rare, small (to 0.4 mm) cavities. Thin edges of the liquid — immersed specimen show abundant, small, usually ovoid inclusions which are isotropic and of lower refractive index than the enclosing glass. The inclusions are evidently lechatelierite which is common in tektites, but the specimen is morphologically quite unlike australites.

Kalyeeda P.S. "Found by a native near Kallaida" (now Kalyeeda) is taken to mean that H.W.B. Talbot acquired the specimen from an aborigine and accepted the locality statement which he made. Though the specimen has areas of close and deep pitting (c.f. Baker 1959 Pl. V A), the form is that of a typical australite. Specimens with similar pitting are rare in Western Australia except in the Corrigin-Yealering district (10 specimens distributed in three collections).

Fitzroy Valley (unacceptable). An undescribed specimen additional to those of Christmas Creek, Mt Millard and Kalyeeda reported by Fenner (1935) cannot be traced.

Nullagine (unacceptable). WAM 12358 is catalogued with anomalous locality "Nullagine near Cue". The towns are 680 km apart and on opposed sides of Line 2. The donor could not be contacted.

Wyloo P.S. Hey (1966) records a BM specimen (1925, 1079) from Peake (*sic*) P.S., Ashburton River. It was formerly in the collection of C.G. Thorp who obtained it from M. McGrath. Records of the Lands and Surveys Department show the McGrath family as the original holders of Peak P.S., now part of Wyloo P.S. The mis-spelling of the name suggested a confusion with Peake P.S., South Australia, a known source of australites to which Thorp (1914) had once referred. Because of the traceable history, attribution to the Western Australian station now appears genuine, though this does not mean that it was necessarily at its site of fall.

Mt Vernon P.S. (Mt Vernon I). A specimen from no. 10A Well on Mt Vernon P.S. has been accepted but two further specimens, one of which gave anomalous chemical results (Lieberman 1966), are believed to have been incorrectly attributed to this area. The two specimens (SAM T 515) were from the collection of S.F.C. Cook, who made his collection during a period of active gold mining and prospecting. Excluding the two Mt Vernon specimens and about 50 from the Nullarbor Plain or outside the State, 100% of the remaining 4700 specimens in the collection are from gold mining centres. There is another Mt Vernon (II) in an area where australites are known but that also has no gold mining associations. A third Mt Vernon (III) was the site of Corboys (gold find) and was so named by Mr Corboy. The name later adopted officially is Mt Hilda. This last, in an area of known australite occurrence, was most active as a gold mining centre 1925-31 when Cook was collecting and is therefore the most likely source of the specimens. The chemical anomaly was resolved without recourse to locality considerations. Present occupants of Mt Vernon P.S. state that occasional australites seen in the possession of aborigines are imports from the Wiluna area.

No. 14 Well, Canning Stock Route (unacceptable). Australites were reported by Talbot (1910) in the area of good pasture about this well. It is an isolated area completely surrounded by sand dune country. Talbot was an acute observer and a contributor of australites to the Simpson collection. The veracity of his report is not doubted but there is doubt that the australites were in situ. Talbot's map shows a native well and rock holes in the general vicinity. The area was thus known to and hunted over by the aborigine in good seasons and there were abundant australite supplies less than 100 km to the south. No specimens could be located in collections. It needs to be verified that australites other than flakes and the occasional specimen found about rock holes occur naturally at no. 14 Well.

The fragments of an australite (W.A. Govt. Chem. Labs. coll. 305) from "200 miles N.E. of Wiluna" (Anon. 1946 p.136) are not from no. 14 Well as would be inferred if the distance is scaled direct. They were found "out from no. 9 Well" (The Weld Spring), the finder having evidently stated the distance by the only trafficable but circuitous access road via Earaheedy P.S. and Glen Ayle P.S.

No. 35 Well, Canning Stock Route (unacceptable). Mr R. Verbugt, who collected australites from c.100 km S. of Windy Corner — the most northerly acceptable multiple occurrence in W.A. — also reported verbally to D.H. McColl that australites occur much further north at 125°13′E., 22°15′S., i.e. in the general vicinity of no. 35 Well on the Canning Stock Route. No specimens were lodged in collections. There are three native wells and several rock holes along the stock route in the general area. The site is marginal to an extensive area which is free of dunes or has few dunes compared with the surrounding desert. The environment of the site and the circumstances of the report closely parallel those of no. 14 Well. Tangible, un-flaked specimens are considered pre-requisite to acceptance as a site of natural occurrence.