Mason, B., 1974. Notes on Australian meteorites. *Records of the Australian Museum* 29(5): 169–186, plates 6–7. [15 May 1974].

doi:10.3853/j.0067-1975.29.1974.228

ISSN 0067-1975

Published by the Australian Museum, Sydney

NOTES ON AUSTRALIAN METEORITES

By Brian Mason

Smithsonian Institution, Washington, D.C., U.S.A.

Plates 6 and 7. Figures 1 and 2. Manuscript received 3rd June, 1973.

ABSTRACT

A review of Australian meteorites, eliminating paired falls, gives a total of 184, comprising 67 irons, 9 stony-irons, and 108 stones (6 anchondrites and 102 chondrites); 10 of these were observed falls. Olivine and pyroxene compositions have been determined by microprobe analysis for most of the chondrites, and they have been examined microscopically and classified according to the Van Schmus-Wood classification. Additional data on mineral compositions are given for the enstatite achondrite Mt Egerton and the ureilites North Haig and Dingo Pup Donga; a bulk analysis of a small sample of the eucrite Emmaville has been made. Ringwoodite and majorite are recorded from the Coolamon meteorite, the third occurrence of these meteorite minerals. A list of Australian irons and stony-irons, giving Ni and Ge contents, structural type, and Ge-Ga class has been compiled, and the Ni-Ge data presented in a diagram.

INTRODUCTION

Research on Australian meteorites may perhaps be dated from 1861, the year in which Haidinger published the first account of the Cranbourne irons. At that time two were known, one (the largest of the ten or more now known) weighing 3.5 tons and the other 1.5 tons, both having been found in 1854. The 3.5 ton mass was transported to London and displayed at an exhibition in 1862, being the largest meteorite known at that time, and is now in the British Museum collection. The literature on Cranbourne is very extensive, and has been summarized by Edwards and Baker (1944).

The Barratta meteorite is possibly an even earlier discovery. First described by Liversidge in 1872, it had been obtained by the Government Astronomer, H. C. Russell, when he visited Barratta in April 1871. The actual discovery of the meteorite, according to Russell, was the subject of some disagreement. A stockman said that he saw a brilliant fireball in May, 10 or 12 years earlier (i.e., about 1860), and that the following day some fencers who were camped about four miles northwest of the homestead reported having seen a stone fall near their camp. The stockman went to the place a few days later and saw the meteorite about half-buried in the ground. However, a Mr F. Gwynne, living in the neighbourhood, claimed that he found the meteorite when riding over the plain about the year 1845. In spite of additional inquiries, Russell was unable to resolve the matter. Possibly isotopic analyses could provide an answer, by giving an approximate terrestrial age.

Another early meteorite is the Narraburra iron, found near Temora in 1855, but not reported in the literature till many years later (Russell, 1890). Actually, throughout the nineteenth century meteorites were evidently found but did not come to the attention of the scientific community because of the sparse population and poor communications. A particularly interesting instance is the first fall recorded, the Tenham shower in western Queensland in 1879. This was a spectacular event, seen by the local station owners, and hundreds of stones were collected. However, it was first described by Prior in 1916 under a false locality (Warbreccan), and the details of the fall were assembled and published by Spencer in 1937, almost sixty years after the event.

Several enumerations of Australian meteorites have been published, the first of consequence being that of Cooksey (1897), and these are summarized in Table 1. It is intriguing, as mentioned above, that so few meteorites were recorded by 1897 after over a century of exploration and occupation. The intensive prospecting for gold and other mineral deposits might have been expected to yield some meteorites—however, prospectors probably avoided those areas most favorable to meteorite finds, i.e. the flat sandy regions of the interior plains. Stockmen and ploughmen may have found meteorites, but generally lacked the interest in unusual rocks characteristic of a prospector.

When the totals in Table 1 are plotted, the rate of increase shows a fairly uniform growth for the period 1897–1966, of about 16 new meteorites per decade, save for the 1913–1923 period; the stagnation in that period may be in part due to the disruption caused by World War I. The remarkable increment of 57 new meteorites since 1966 is almost entirely due to discoveries in Western Australia. This can be ascribed partly to the active involvement of the Western Australian Museum and the Kalgoorlie School of Mines in meteorite search and recovery, and partly to the interest of a group of rabbit trappers working on the Nullabor Plain and criss-crossing it on motor cycles. This is documented in the paper of McCall and Cleverly (1970). They list 36 meteorites from the Nullabor Plain, all but 8 found since 1960; of these 24 were found by members of the Carlisle family!

Until the latest count irons formed the most numerous group of Australian meteorites. This is in marked contrast to the world-wide statistics, and to those for other continental areas (except South America), in which stones predominate over irons. The explanation evidently resides in the desirability of meteoritic iron as raw material for plowshares (and swords) for indigenous metal-working peoples in other continents. Iron meteorites were rapidly consumed once a native people had acquired a facility for metal working, a facility not possessed by the Australian aborigine.

Of the Australian meteorites, ten have been observed falls: Tenham (1879), Emmaville (1900), Binda (1912), Narellan (1928), Karoonda (1930), Forest Vale (1942), Woolgorong (1960), Millbillillie (1960), Wiluna (1967), and Murchison (1969). This gives a ratio of falls to finds of 1 : 16, compared to a ratio of 1 : 5 for the U.S. Clearly this is a reflection of the sparse population of Australia compared to the U.S., and its concentration in limited areas close to the southern and eastern seaboards

The geographical distribution of Australian meteorites also presents some intriguing features. Almost half of Australia lies north of the Tropic of Capricorn, yet only about a dozen meteorites have been found in this vast area. True, much of it is essentially uninhabited, and tropical weathering and dense vegetation in the far north is unfavourable to the survival and finding of meteorites. Clearly a reasonably close pattern of settlement, and probably ready access to a museum or geological survey or university is conducive to the recovery of meteorites. Special circumstances, typified by the rabbit trappers on the Nullabor Plain, may be an important factor; yet there have been many areas of active rabbit trapping that have yielded nothing. The Nullabor Plains experience resulted from the fortunate coincidence of interest on the part of the trappers encouraged and developed by personnel at the Kalgoorlie School of Mines. A curious lacuna on the meteorite map of Australia is the state of Queensland—almost a quarter of the area of the continent, but fewer than a dozen meteorites are known from the state, and four of these were found in the extreme south, close to the border with New South Wales.

IRONS AND STONY-IRONS

Nickel contents are available for the metal phase in most Australian irons and stony-irons. Lovering et al. (1957) provided data for 39 of these meteorites, and Wasson, in a series of papers, has presented figures for 46. Many meteorites appear in both lists. Lovering et al. determined nickel by the classical wet-chemical procedure, whereas Wasson has used atomic absorption spectrometry. Comparison of analyses of the same meteorites shows that the results of Lovering et al. are consistently a little higher than those of Wasson. For a few meteorites an independent check is provided by the work of Lewis and Moore (1971); their results are generally very close to those of Lovering et al. on the same meteorite. On this account the nickel percentages given by the latter are preferred in Table 2. The data are plotted on figure 1 to illustrate the grouping by chemical composition.

The following irons and stony-irons have not been analysed: Blue Tier (Om), Castray River (iron), Donnybrook (M), Dorrigo (O), King Solomon (iron), Landor (Of), Lefroy (iron), Mt Dyrring (P), Murchison Downs (Off), and Rawlinna (P). The analysis of Mt Sir Charles (Reed, 1972) is not included in Table 2, because the Ni value (6.8%) is clearly inconsistent with the structure (Of); probably a mislabelled specimen was analysed.

Because of geographic propinquity and similarity in composition and structure the following are considered to be paired meteorites:

Barraba and Warialda with Bingera.

Gosnells with Mt Dooling.

Queensland with Gladstone.

Mooranoppin, Mt Stirling, and Quairading with Youndegin.

Loongana Station, Loongana Station West, and Premier Downs with Mundrabilla.

Basedow Range with Henbury.

Hart Range with Boxhole.

In addition, the specimens of Nutwood Downs, reported to have come from a station of that name near Daly Waters in the Northern Territory, are so similar to Henbury that they are considered identical until additional evidence to the contrary is forthcoming. My own inquiries in 1971 to the manager of Nutwood Downs station brought the reply that he knew of no meteorite having been found on the station. Dr J. Wasson (pers. comm.) has analysed specimens of Nutwood Downs, and finds that they are indistinguishable from Henbury in Ni, Ga, Ge, and Ir contents, and notes that they have the same deformed structure.

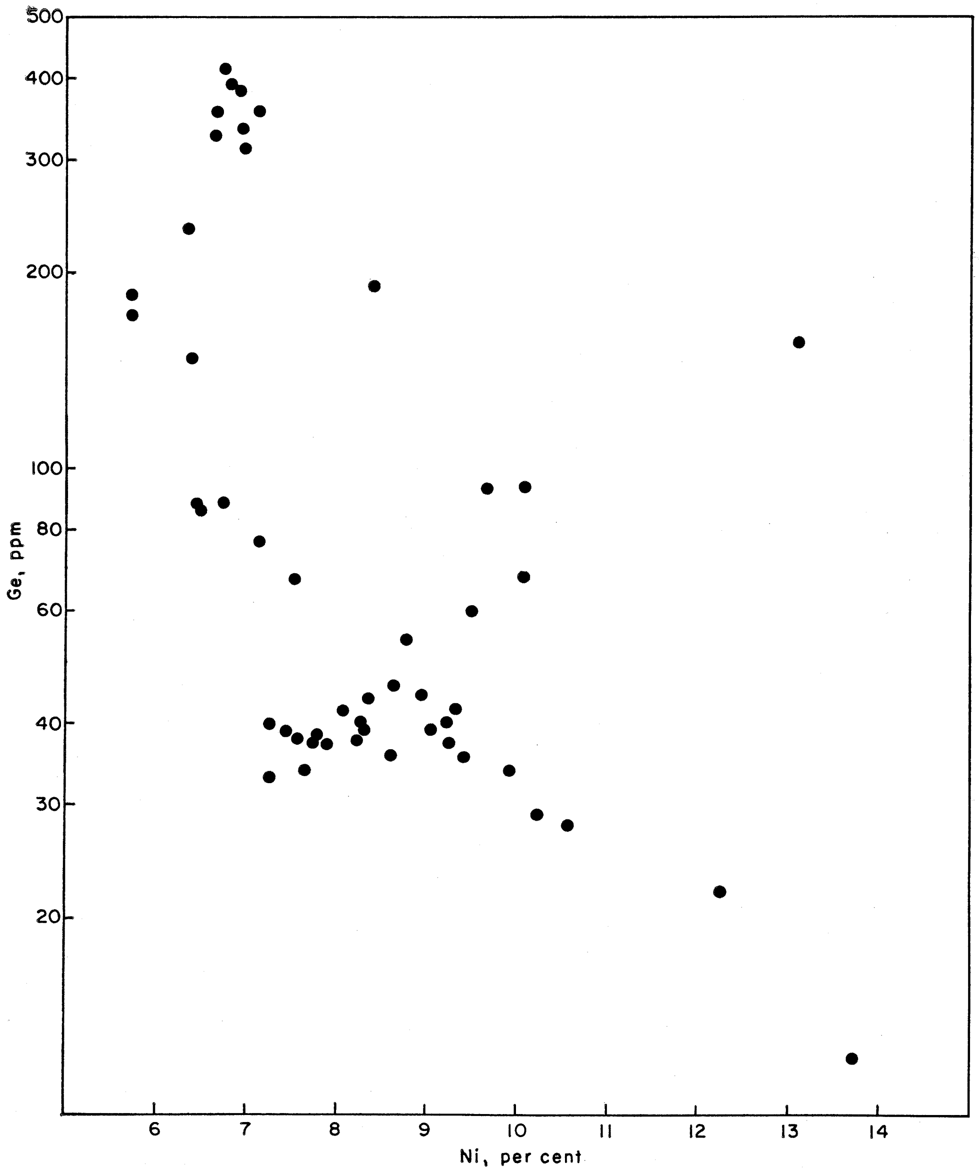


Fig. 1.—Ni (%)—Ge (ppm) plot of Australian iron and stony-iron meteorites, excluding those with less than 10 ppm Ge (Yardea, Moonbi, Boogaldi, Mt Magnet, Warburton Range, Tawallah Valley, Wedderburn)

ACHONDRITES

Relatively few anchrodites have been recorded from Australia. They are: Mt Egerton (enstatite achondrite); Dingo Pup Donga, North Haig (ureilites); Emmaville, Millbillillie (eucrites); and Binda (howardite). The relative paucity of these meteorites can be ascribed to the difficulty of recognition, unless actually seen to fall. They are often rather coarse-grained and friable, and thus tend to break up more readily on weathering than other meteorite types.

Mt Egerton is here considered to be an enstatite achondrite, although it was described by McCall (1965) as a unique type of stony-iron. However, he based his description on about 250 g of fragments from the original find in 1941. The rediscovery of the original site, and the subsequent collection of 19 kg of material by M. K. Quartermaine and A. E. Bain in 1966, and of 8 kg by E. P. Henderson and the writer in 1967, provided the opportunity for a more comprehensive account (Cleverly, 1968). The Mt Egerton meteorite evidently consisted of a poorly coherent aggregate of coarsely crystallized enstatite (crystal fragments up to 7 cm long have been found) with interstitial slugs of nickel-iron, which broke up into innumerable fragments on impact. From bulk density measurements Cleverly estimated the metal content of the meteorite as 21% by weight. This is an exceptionally high metal content for an achondrite, although the Shallowater enstatite achondrite contains about 10% of metal. The similarities in composition, both of metal and silicate, between Mt Egerton and Shallowater strongly favor their being placed together in the same meteorite class.

The only silicate mineral previously recorded from Mt Egerton is enstatite; however, I found a few grains of diopside in some thin sections. Microprobe analyses gave 22.8% CaO in the diopside and 0.4% CaO in the enstatite; if the two minerals crystallized in equilibrium, as the texture suggests, the calcium distribution corresponds to equilibration at about 1000°C, according to the data of Boyd and Schairer (1964).

One of the most remarkable meteorite discoveries of recent years was the finding of two ureilites within a small area on the Nullabor Plain in Western Australia. This almost doubled the total number of ureilites known at that time, from three to five. The two Australian ureilites are North Haig, found by R. F. Kilgallon in 1961, and Dingo Pup Donga, found by A. J. Carlisle in 1965. After their identification as ureilites, it was naturally thought that they might be two pieces of a single fall; however, chemical and mineralogical differences appear to rule out this possibility, and we thus have the statistically improbable occurrence of two meteorites of a rare type falling within 20 miles of each other.

North Haig and Dingo Pup Donga were described by McCall and Cleverly (1968), with chemical analyses by E. Jarosewich and W. R. O'Beirne. The analyses showed appreciable amounts of carbon (4.10% in North Haig and 3.10% in Dingo Pup Donga), and Vdovykin (1970) has established that some of this carbon is present as diamond, as in the other ureilites; he also identified lonsdaleite, the wurtzite structure polymorph of carbon, in North Haig. He divided the ureilites into two types, the Novo-Urei and Goalpara types, on the basis of the olivine structure, coarse-grained in Novo-Urei and fine-grained in Goalpara, and classes Dingo Pup Donga with Novo-Urei and North Haig with Goalpara.

Other features also serve to distinguish these two ureilites. The pyroxene content is notably lower in North Haig than in Dingo Pup Donga. Jarosewich (pers. comm.) found 34.1% acid-insoluble in Dingo Pup Donga and 18.9% in North Haig, and these figures are essentially a measure of the pyroxene content of the meteorite, since the other minerals except carbon are acid-soluble, and the carbon was largely removed by ignition before weighing. Calculations of normative pyroxene from the published analyses give 37.6% in Dingo Pup Donga and 22.7% in North Haig. These figures are consistent with the acid-insoluble figures, and with estimates from the examination of thin sections. Optically, the pyroxenes in the two meteorites are distinctly different; in Dingo Pup Donga the pyroxene shows coarse polysynthetic twinning (which caused it to be originally misidentified as calcic plagioclase), whereas in North Haig most of the pyroxene is untwinned.

Although the chemical analyses of the two meteorites are rather similar, the chemical compositions of the olivine and pyroxene, determined by microprobe analysis, are distinctive.

	Olivine		Pyroxene					
	Range	Mean	Range			Mean		
	Fa	Fa	Wo	Fs	En	Wo	Fs	En
1.	14.0–14.9	14.6	4.1–4.5	14.0–14.9	80.8–81.8	4.3	14.6	81.1
2.	7.8–24.5	14.9	0.4–7.1	0.6–15.1	79.8–99.0	4.0	9.0	87.0

Thus the compositions of these minerals are very uniform from grain to grain in Dingo Pup Donga, in contrast to a wide variation in North Haig. This is further evidence for the belief that these meteorites represent two distinct falls.

A brief discussion on the relationship of the ureilites to other classes of meteorites may perhaps be included here. The ureilites are usually included as a class of the calcium-poor achondrites, since they are stony meteorites which lack chondrules, and the calcium content is low, generally less than 1%. However, they are unique among all stony meteorites in containing diamond. Among the calcium-poor achondrites, the only one resembling them in chemical and mineralogical composition is the unique meteorite Chassigny; however, the structure of Chassigny is quite distinctive (it resembles a terrestrial dunite), and the olivine and pyroxene are much more iron-rich. Some researchers have argued for a close relationship between the ureilites and the carbonaceous chondrites, and indeed Vdovykin (1967) and Mueller (1968) have concluded that ureilites formed from carbonaceous chondrites through the collision of asteroids. While this conclusion provides a satisfactory explanation for the formation of diamonds, it demands a remarkable degree of fractionation of the major elements which seems unlikely to be produced by impact alone. For example, the Mg/Si ratio (weight) averages 1.15 for the ureilites, 0.93 for the carbonaceous chondrites (Type I), and relative to the carbonaceous chondrites the ureilites are notably depleted in Al, Na, Ni and S. Sulphur, being readily volatilized, might be lost in an impact process, but it is difficult to explain the selective loss of Al, Na, and Ni, and the fractionation of the lithophile elements magnesium and silicon.

The calcium-rich achondrites from Australia comprise Millbillillie, Binda, and Emmaville. Millbillillie was evidently an observed fall in 1960, although no material was collected until 1970; it is being described by Dr R. A. Binns. Binda was found on June 5, 1912, following a bright fireball on the night of May 25. Anderson and Mingaye (1913), who described the meteorite, commented "It is not absolutely certain that the stone found is actually that seen in flight on 25th May, but circumstantial evidence is strongly in favour of this being the case". Actually, the freshness of the stone leaves no doubt in my mind that Binda should be classed as an observed fall. Binda is a typical howardite, and the analysis by Mingaye is in excellent agreement with the observed mineralogy. However, his figure for K_2O (0.13%) is probably too high, since recent analyses of howardites and eucrites consistently show very low potassium contents, of the order of 300 ppm. Duke and Silver (1967) give a modal analysis of Binda—75% hypersthene (average Fs_{32}), 25% plagioclase (average An_{90}), <1% accessories (chromite, ilmenite, troilite, nickel-iron), no olivine or free silica. The trace amount of nickel-iron is kamacite with an unusually high Co content; Lovering (1964) gives probe analyses showing Ni = 0.44 — 2.10%, Co = 1.38 — 2.22%. My own examination of this meteorite agrees with that of Duke and Silver except that I found a few grains of tridymite (n = 1.474) in a light ($D < 2.5$) fraction. The meteorite has a cataclastic, brecciated structure, with pyroxene clasts up to 3 mm in greatest dimension, and plagioclase clasts up to 1 mm; the plagioclase clasts show deformed twin lanellae. Pyroxene is mostly hypersthene, often showing thin exsolution lamellae of augite; a few grains of pigeonite were seen. Some or all of the hypersthene could be inverted pigeonite. Microprobe analyses of the pyroxene gave compositions ranging from Fs_{33} to Fs_{36}, with a mean of Fs_{35}, slightly higher than found by Duke and Silver.

Emmaville is a small (99 g) undescribed stone. It fell in 1900 and was recorded by Anderson (1913) in the Australian Museum collection. I saw it there in 1963 and recognized it as probably a eucrite from its characteristic black glossy fusion crust. Petrographic examination of a small fragment confirmed this diagnosis. It is a granular aggregate of calcic plagioclase and pyroxene (mostly pigeonite); it is unusually fine-grained for a eucrite, the maximum grainsize being about 0.1 mm. A notable feature is the presence of veinlets of brown glass, up to 0.2 mm wide, giving the section a brecciated appearance. At my request, Dr A. L. Graham took a 1.5 mg sample, fused it with lithium borate flux, and made a microprobe analysis of the bead produced; his results are: SiO_2 52.6, TiO_2 0.66, Al_2O_3 12.2, Cr_2O_3 0.36, FeO 18.5, CaO 10.2, MgO 6.12, Na_2O 0.51, K_2O 0.03, sum 101.2. The analysis is very similar to that of the Haraiya eucrite (Allen and Mason, 1973), except that the SiO_2 figure is about 4% higher; in view of the small amount of sample and the technique used, an error of this extent in the SiO_2 value is understandable.

CHONDRITES

As mentioned in the introduction, the number of Australian chondrites has greatly increased in recent years, largely because of greater interest by museums in meteorites, and by the activities of rabbit trappers on the Nullabor Plain. Thanks to the cooperation of the local curators, I have received samples of most of those meteorites for examination. As standard procedure, I have obtained polished thin sections of these samples, studied them petrographically, and analysed the olivine and pyroxene with the microprobe. The results are presented in Table 3.

In Table 3 the co-ordinates are, as far as possible, the actual recovery site; however, in some instances the available information is insufficient for precise location. The class has been determined from the olivine composition. The type (Van Schmus and Wood, 1967) has been established by microscopic examination of thin sections, independently by a research assistant and myself; complete agreement was found in about 90% of the meteorites, and for the remainder the difference was not more than one unit; disagreement with previous investigators is recorded in specific notes. The Fa and Fs figures for olivine and pyroxene are given to one decimal place; however, variations within the meteorite, and experimental uncertainty, render the decimal figure of doubtful utility.

The Fa and Fs data are plotted on figure 2, which illustrates the marked compositional break between H and L groups, and the minor break between L and LL groups. The points for most of the chondrites cluster closely along the line joining the extreme compositions (for Cocklebiddy and Lake Labyrinth). The meteorites that fall markedly off this line are the Type 3 or unequilibrated chondrites. Their composition points all fall well below the line, that is, the average pyroxene composition is considerably lower in Fs content than that in equilibrated chondrites of equivalent composition. The pyroxene in these unequilibrated chondrites is exclusively clinobronzite or clinohypersthene, whereas in the equilibrated chondrites it is mainly orthopyroxene. In addition to the difference in iron content, the clinobronzite and clinohypersthene differ from the corresponding orthopyroxene in having a lower calcium content; probe analyses show an average of 0.4 mole per

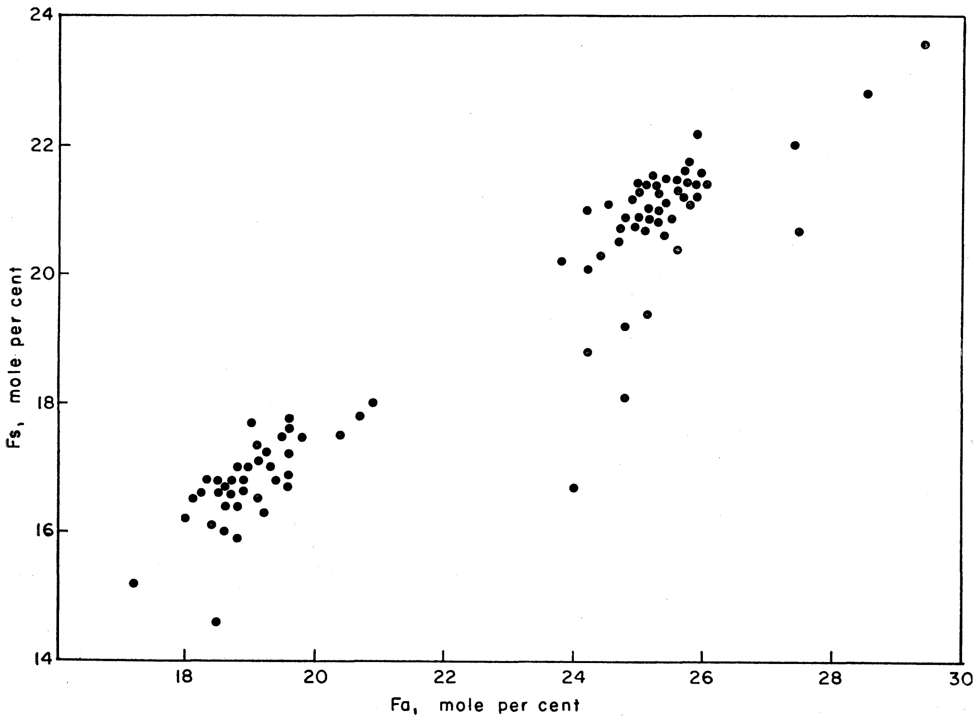


Fig. 2.—Mean values of olivine (Fa) and pyroxene (Fs) composition in Australian chondrites

cent $CaSiO_3$ in the clinobronzite and clinohypersthene, compared to an average of 1.4 mole per cent $CaSiO_3$ in orthopyroxene in the equilibrated chondrites. If equilibrated chondrites have been derived from unequilibrated chondrites by thermal metamorphism, as has been proposed, extensive diffusion of calcium into the pyroxene must have occurred; the most probable source of this calcium would be the interstitial glass characteristic of the unequilibrated chondrites.

There are probably a sufficient number of Australian chondrites in the H and L groups to provide a statistically valid comparison with worldwide occurrences of these meteorites. Such a comparison is provided in Table 4, in which the numbers of these meteorites in Table 3 are compared with the numbers given by Van Schmus and Wood (1967). The agreement between the two sets of numbers is interesting in confirming the validity of the statistical distribution, and supports the utility of the Van Schmus-Wood classification, in spite of the somewhat arbitrary and subjective criteria for distinguishing between adjacent types.

Some notes on individual chondrites follow.

Barratta: This meteorite was classified L4 by Van Schmus and Wood (1967). However, sections I have examined show transparent pink glass in many chondrules, and the pyroxene is entirely polysynthetically twinned clinobronzite and clinohypersthene of highly variable composition (Fs_{14}—Fs_{22}, mean Fs_{17}); these properties are characteristic of Type 3 chondrites.

Bond Springs: The description (Baker and Edwards, 1941) mentions that plagioclase was observed in a thin section, suggesting that this is a Type 6 chondrite.

Carraweena: Two other meteorites from this area, Accalana and Monte Colina, are petrologically identical with Carraweena. Since they belong to the relatively rare L3 Type, it is reasonable to conclude that they are all pieces of the same fall. Heymann (1965), from the similarity in rare gas contents, deduced that Accalana and Carraweena are parts of the same meteorite.

Cartoonkana: This meteorite and Yandama are indistinguishable petrologically, and come from the same area in northwestern New South Wales, close to the South Australian border. There are thus reasonable grounds for considering them as pieces of a single meteorite. However, they belong to the common L6 Type, so the evidence is not as conclusive as for the Carraweena group.

Cockburn: This meteorite was described by Johnson and McColl (1967) on a 10-gram specimen found by Mr Johnson. Four small pieces, totalling some 200 grams, were found by repeated collecting. In July 1973 I visited the area and found two additional specimens, one of 2207 grams and one of 53 grams. Cockburn is an L6 chondrite, with a recrystallized texture and small areas of clear plagioclase grains.

Coolamon: This meteorite contains ringwoodite, a spinel of olivine composition, the third record of this mineral (the previous records are from the Australian chondrites Tenham and Coorara). As in the prior occurrences, the ringwoodite occurs as small (up to 0.1 mm) purple grains in a veinlet traversing the meteorite (plate 6). The material of the veinlet is colorless and isotropic, and is probably majorite, the garnet analogue of pyroxene. Microprobe analyses, using the corresponding minerals in the Coorara meteorite as standards, show that the Coolamon ringwoodite and the vein matrix are essentially identical in composition to the Coorara ringwoodite and majorite. A shock origin is probable for the ringwoodite and majorite, since the meteorite as a whole shows signs of severe shock, specifically the conversion of the plagioclase to maskelynite.

59682-B

Coorara: McCall and Cleverly (1970) classify it as an L5 chondrite, but thin sections show a recrystallized texture and areas of clear feldspar (transformed to maskelynite), features characteristic of Type 6 chondrites.

Doolgunna: The description (Macleod, 1968) mentions the presence of small clear plagioclase grains, indicating that it is probably a Type 6 chondrite.

Elsinora: A thin section made from a specimen in the Smithsonian Institution collection (USNM #1460, obtained by exchange from the Australian Museum in 1949), shows a very large (5 mm diameter) barred olivine chondrule (plate 7), completely enclosed within the normal-textured chondrite (maximum chondrule diameter approximately 1 mm). Petrographic and probe analyses of the main mass of the chondrite show that it is an equilibrated chondrite with the classification H5. Probe analyses of the large included chondrule show that it is highly unequilibrated; olivine compositions range from Fa_6 to Fa_{19}, with a mean of Fa_{12}. The chondrule appears to consist entirely of olivine, except for the fine-grained interstitial material, which is devitrified to a microcrystalline aggregate, probably pyroxene and plagioclase.

The presence of an unequilibrated chondrule within an equilibrated chondrite raises an intriguing problem of genesis. Van Schmus and Wood (1967), when they established the classification of chondrites by petrographic type, stated "We do believe, however, that the Type 4 chondrites were derived from Type 3 chondrites, and that Types 5 and 6 represent higher degrees of metamorphism". This position has been supported by other investigators, and additional evidence for it adduced by Dodd (1969). However, the presence of a chondrule with highly variable olivine composition within a chondrite with olivine of essentially constant composition is inconsistent with the metamorphism hypothesis. How did the large chondrule avoid equilibration when the main mass of the chondrite was undergoing metamorphism? It does not appear to have been incorporated within the meteorite at a later time, since the specimen in which it occurs shows no sign of brecciation.

In a general paper on olivine composition in chondrites (Mason, 1963), I stated that the Nardoo #1 meteorite was identical with Elsinora. They both come from the same general area northwest of Wanaaring, show a similar degree of weathering, and are of the same type (H5). However, this is the commonest type of H group meteorite, and I now believe they are probably different meteorites and should not be paired.

Hammond Downs: This meteorite was obtained in 1964 as one of a collection of stones from the Tenham fall. However, recent examination has shown that it is a distinct meteorite (Mason, 1973).

Karoonda: The original report states that 42 kg of this meteorite were recovered. However the latest catalogue of the South Australian Museum records only 6.4 kg in that institution, and the British Museum catalogue records less than 2 kg in other institutions. Since this is a unique meteorite with an unusual mineralogy, it is important that all available material be recorded.

During examination of a thin section, a relatively large (0.5 mm diameter) monosomatic olivine chondrule enclosing grains (0.05 mm in maximum dimension) of green isotropic mineral was seen. Probe analyses showed that the green mineral is pleonaste spinel (52 mole per cent $FeAl_2O_4$, 48 mole per cent $MgAl_2O_4$); the olivine composition is Fa_{33}, which is the average for the meteorite as a whole.

Kulnine: While on superficial examination this appears to be a typical L6 chondrite, probe analyses revealed that the orthopyroxene has an unusual composition, being considerably higher in calcium than other chondritic orthopyroxenes. In terms of mole per cent $CaSiO_3$, Kulnine orthopyroxene has a mean content of 3.2%, compared to the usual mean of 1.4%. The texture of the meteorite is also rather unusual; only the vaguest outlines of chondrules can be detected in thin sections, the texture being one of large (up to 1 mm) orthopyroxene crystals in a groundmass of finely granular olivine. The high Wo content of the orthopyroxene suggests a temperature of crystallization higher than for most chondrites. Similar high-calcium orthopyroxene has been recorded from the Shaw chondrite (Fredriksson and Mason, 1967), who postulated as unusually high temperature of crystallization, around 1100°C, for this meteorite.

Laundry East: McCall and Cleverly (1970) classified this meteorite as an H4 chondrite. However, it contains transparent pink glass in some chondrules, and the pyroxene shows the variable composition (Fs_{13}—Fs_{21}) characteristic of Type 3 chondrites.

Laundry West: McCall and Cleverly (1970) classified this meteorite as an L5 chondrite. However, condrules are sharply bounded and well-defined, many of them contain turbid partly devitrified glass, and the pyroxene is mostly clinobronzite and clinohypersthene, characteristics indicating classification as a Type 4 chondrite.

Mellenbye: This meteorite and Yalgoo come from the same general region, but the exact place of find for either of them is unknown. I received small fragments of each from the Western Australian Museum, and established that both were LL-group chondrites; olivine composition (by X-ray diffraction) is Fa_{27}. Insufficient material remained for thin sections. In view of their unusual composition (only four other LL-group chondrites are known from Australia) and their geographic propinquity, I believe they are probably different pieces of a single meteorite.

North East Reid: McCall and Cleverly (1970) classified this meteorite as an H4 chondrite. However, in a thin section I have examined chondrule boundaries are diffuse and ill-defined, and no polysynthetically twinned clinopyroxene was seen. On this account a classification as H5 is preferred.

Willaroy: This chondrite was recently found in western New South Wales and is being described by R. O. Chalmers and myself.

Wiluna: This chondrite was classified as a Type 4 by McCall and Jeffrey (1970). However, the advanced degree of integration of chondrules with matrix, the dominance of bronzite over clinobronzite, and the presence of plagioclase all support a classification as Type 5.

ACKNOWLEDGMENTS

I would like to express my appreciation to my companions on extensive field trips investigating Australian meteorites, Dr E. P. Henderson, of the Smithsonian Institution, and Mr R. O. Chalmers, of the Australian Museum. I am indebted to the curators of meteorite collections in the Australian Museum, the National Museum of Victoria, the South Australian Museum, the Kalgoorlie School of Mines, and the Western Australian Museum for research material. Miss Camille Calabro assisted me in the petrographic and microprobe analyses. Field work was supported by grants from the National Geographic Society and the Smithsonian Research Foundation. Additional information and critical reviews of the manuscript have been provided by Mr R. O. Chalmers and Dr S. J. B. Reed.

REFERENCES

Allen, R. O. & Mason, B., 1973. Minor and trace elements in some meteoritic minerals *Geochim. cosmochim. Acta* 37, pp.

Anderson, C., 1913. A catalogue and bibliography of Australian meteorites. *Rec. Aust. Mus.* 10: 53–76.

Anderson, C. A. & Mingaye, J. C. H., 1913. Description and analysis of the Binda meteorite. *Rec. Aust. Mus.* 10: 49–52.

Baker, G. & Edwards, A. B., 1941. The Bond Springs stony meteorite. *Mem. natn. Mus. Vict.* 12: 49–58.

Boyd, F. R. & Schairer, J. F., 1964. The system $MgSiO_3$—$CaMgSi_2O_6$. *J. Petrology* 5: 275–309.

Cleverly, W. H., 1968. Further recoveries of two impact-fragmented Western Australian meteorites, Haig and Mount Egerton. *J. Proc. R. Soc. West Aust.* 51: 76–88.

Cleverly, W. H. & Thomas, R. P., 1969. The Yarri octahedrite iron meteorite. *J. Proc. R. Soc. West Aust.* 52: 89–94.

Cooksey, T., 1897. The Nocoleche meteorite with catalogue and bibliography of Australian meteorites. *Rec. Aust. Mus.* 3: 51–62.

Dodd, R. T., 1969. Metamorphism of the ordinary chondrites: a review. *Geochim. cosmochim. Acta* 33: 161–203.

De Laeter, J. R., McCall, G. J. H. & Reed, S. J. B., 1973. The Redfields Meteorite—a unique iron from Western Australia. *Mineralog. Mag.* 39: 30–35.

Duke, M. B. & Silver, L. T., 1967. Petrology of eucrites, howardites and mesosiderites. *Geochim. cosmochim. Acta* 31: 1637–1665.

Edwards, A. B., 1960. The Lismore meteoritic iron. *Proc. R. Soc. Vict.* 72: 93–94.

Edwards, A. B. & Baker, G., 1944. The Cranbourne meteorites. *Mem. natn Mus. Vict.* 14: 23–35.

Fredriksson, K. & Mason, B., 1967. The Shaw meteorite. *Geochim. cosmochim. Acta* 31: 1705–1710.

Hey, M. H., 1966. Catalogue of meteorites with special reference to those represented in the collection of the British Museum (Natural History). British Museum, London (third edition).

Heymann, D., 1965. Rare gas evidence for two paired meteorite falls. *Geochim. cosmochim. Acta* 29: 1203–1208.

Hodge-Smith, T., 1939. Australian meteorites. *Mem. Aust. Mus.* 7: 1–84.

Houston, B. R., 1971. Two meteorites from northwest Queensland. *Qd Govt Min. J.* 72: 482–486.

Johnson, J. E. & McColl, D. H., 1967. An aerolite from Cockburn, South Australia. *Trans. R. Soc. S. Aust.* 91: 37–39.

Lewis, C. F. & Moore, C. B., 1971. Chemical analyses of thirty-eight iron meteorites. *Meteoritics* 6: 195–205.

Lovering, J. F., 1964. Electron microprobe analysis of the metallic phase in basic achondrites. *Nature* 203: 70.

Lovering, J. F., Nichiporuk, W., Chodos, A. & Brown, H., 1957. The distribution of gallium, germanium, cobalt, chromium, and copper in iron and stony-iron meteorites in relation to nickel content and structure. *Geochim. cosmochim. Acta* 11: 263–278.

MacLeod, W. N., 1968. A meteorite fragment from Doolgunna station, Meekatharra district, Western Australia. *Ann. Rep. geol. Surv. West. Aust.* 1967: 68–69.

Madigan, C. T., 1939. The Huckitta meteorite, Central Australia. *Mineralog. Mag.* 25: 353–371.

Mason, B., 1963. Olivine composition in chondrites. *Geochim. cosmochim. Acta* 27: 1011–1023.

Mason, B., 1973. Hammond Downs, a new chondrite from the Tenham area, Queensland, Australia. *Meteoritics* 8: 1–7.

McCall, G. J. H., 1965. A meteorite of unique type from Western Australia: the Mount Egerton stony-iron. *Mineralog. Mag.* 35: 241–249.

McCall, G. J. H., 1968. The Avoca meteorite. *Mineralog. Mag.* 36: 859–861.

McCall, G. J. H. & Cleverly, W. H., 1968. New stony meteorite finds including two ureilites from the Nullabor Plain, Western Australia. *Mineralog. Mag.* 36: 691–716.

McCall, G. J. H. & Cleverly, W. H., 1970. A review of meteorite finds on the Nullabor Plain, Western Australia, including a description of thirteen new finds of stony meteorites. *J. Proc. R. Soc. West. Aust.* 53: 69–80.

McCall, G. J. H. & Jeffrey, P. M., 1970. The Wiluna meteorite fall, Western Australia—2 September 1967. *Mineralog. Mag.* 37: 880–887.

Mingaye, J. C. H., 1916. Notes on the Molong meteorite. *Rec. geol. Surv. N.S.W.* 9: 161–165.

Mueller, G., 1968. Genetical interrelations between ureilites and carbonaceous chondrites; in Millman, P. M. (Ed), Meteorite Research, 505–517. Reidel Publishing Co., Dordrecht, Holland.

Prior, G. T., 1923. Catalogue of meteorites with special reference to those represented in the collection of the British Museum (Natural History). British Museum, London.

Prior, G. T. & Hey, M. H., 1953. Catalogue of meteorites with special reference to those represented in the collection of the British Museum (Natural History). British Museum, London (second edition).

Reed, S. J. B., 1972. Determination of Ni, Ga, and Ge in iron meteorites by X-ray fluorescence analysis. *Meteoritics* 7: 257–262.

Russell, H. C., 1890. Description of Narraburra meteor. *J. Proc. R. Soc. N.S.W.* 24: 81–82.

Simpson, E. S. & Murray, D. G., 1932. A new siderolite from Bencubbin, Western Australia. *Mineralog. Mag.* 23: 33–37.

Van Schmus, W. R. & Wood, J. A., 1967. A chemical-petrologic classification for the chondritic meteorites. *Geochim. cosmochim. Acta* 31: 747–766.

Vdovykin, G. P., 1967. Uglerodistoye veshchestvo meteoritov (carbonaceous matter in meteorites). Nauka Press, Moscow; English translation available as NASA Technical Translation F-582, Washington, 1970.

Vdovykin, G. P., 1970: Ureilites. *Space Sci. Rev.* 10: 483–510.

Wasson, J. T., 1970. The chemical classification of iron meteorites IV. Irons with Ge concentrations greater than 190 ppm and other meteorites associated with Group I. *Icarus* 12: 407–423.

Table 1. Australian meteorites in collections, 1897–1973

References	Irons	Stony-Irons	Stones	Total
Cooksey, 1897	15	..	4	19
Anderson, 1913	29	4	13	46
Prior, 1923	29	4	15	48
Hodge-Smith, 1939	45	8	24	77
Prior-Hey, 1953	52	8	35	95
Hey, 1966	61	8	57	126
This paper	67	9	108	184

Table 2. Australian irons and stony-irons and their structural type and Ge-Ga classification

Meteorite	Ni%	Ge, ppm	Structural Type	Ge-Ga Class	References
Alikatnima	13.0	<3	D	Anom	3
Answer	12.5		D		5
Arltunga	10.08	68	D	Anom	1
Avoca	8.65	46	Om	III A	11
Balfour Downs	8.39	194	Og	I	4
Ballinoo	10.06	94.4	Off	II C	1, 4
Bencubbin	6.20		Anom		2
Bendock	9.20	40	P		1
Bingera	5.71	185	H	II A	1, 4
Boogaldi	8.99	0.132	Of	IV A	1, 4
Boxhole	7.72	37.2	Om	III A	1, 4
Coolac	6.95	335	Og	I	1
Corowa	13.13	159	D	Anom	4
Cowell	8.2	38	Om	III A	3
Cowra	13.72	12.3	Opl	Anom	1, 4
Cranbourne	7.12	358	Og	I	1, 4
Dalgaranga	8.79	54.6	M		4
Delegate	9.34	41.7	Om	III B—Anom	1, 4
Duketon	7.52	38.1	Om	III A	4
Gladstone	6.74	418	Ogg	I	1, 4
Glenormiston	7.12	76.8	Anom	Anom	1, 4
Gundaring	8.32	43.9	Og	III A	1, 4
Haig	7.24	32.8	Om	III A	4
Henbury	7.66	33.7	Om	III A	1, 4
Huckitta	8.98		P		12
Kumerina	9.69	93.4	Of	II C	4
Kyancutta	8.28	39.5	Om	III A	1, 4
Lismore	7.79		Om		9
Milly Milly	7.45	38.6	Om	III A	4
Molong	8.61		P		10
Moonbi	7.99	0.826	Om	III F	1, 4
Moorumbunna	8.98	44	Om	III AB	4
Morden	6.6	329	H	I	3
Mt Dooling	6.41	234	Ogg	I—Anom	1, 4
Mt Edith	9.40	35.7	Om	III B	1, 4
Mt Magnet	14.72	5.26	Opl	Anom	1, 4
Mt Padbury	7.18		M		6
Mundrabilla	7.78		Om		8

Table 2. Australian irons and stony-irons and their structural type and Ge-Ga classification—*continued*

Meteorite	Ni%	Ge, ppm	Structural Type	Ge-Ga Class	References
Mungindi	12.27	22.1	Of	III C	1, 4
Mirnpeowie	6.47	85.4	Anom	Anom	1, 4
Narraburra	10.22	28.7	Om	III B	1, 4
Nocoleche	6.42	148	Anom	Anom	1, 4
Nuleri	7.32		Om		7
Pinnaroo	9.50	60	M		1
Redfields	6.65	93	Anom	Anom	8
Rhine Villa	8.63	36.3	Og	III E	4
Roebourne	8.40	42.4	Om	III A	1, 4
Roper River	9.91	33.9	Om	III B	1, 4
Tawallah Valley..	18.21	0.068	D	IV B	1, 4
Temora	6.66	355	Ogg	I	1
Thunda	8.27	38.9	Om	III A	1, 4
Tieraco Creek	10.55	28.0	Om	III B	1, 4
Warburton Range	17.80	0.064	D	IV B	4
Wedderburn	22.2	1.43	D	IV	1, 4
Weekero	7.51	67.0	Anom	Anom	4
Wolf Creek	9.22	37.3	Om	III B	4
Wonyulgunna	9.05	39.6	Om	III B	1
Yardea	7.7	8	Om	Anom	3
Yarri	7.77	38.5	Om	III A	4
Yarroweyah	5.70	171	H	II A	1, 4
Yenberrie	6.97	312	Og	I	1, 4
Youanmi	7.85	37.7	Om	III A	4
Youndegin	6.92	383	Og	I	1, 4

References to Table 2:

1. Lovering et al. (1957). 2. Simpson and Murray (1932). 3. Reed (1972). 4. Wasson (1970) and pers. comm. 5. Houston (1971). 6. Jarosewich (pers. comm.). 7. Cleverly and Thomas (1969). 8. de Laeter et al. (1973). 9. Edwards (1960). 10. Mingaye (1916). 11. McCall (1968). 12. Madigan (1939).

Table 3. Geographical coordinates, classification, and compositions of coexisting olivine and pyroxene in Australian chondrites

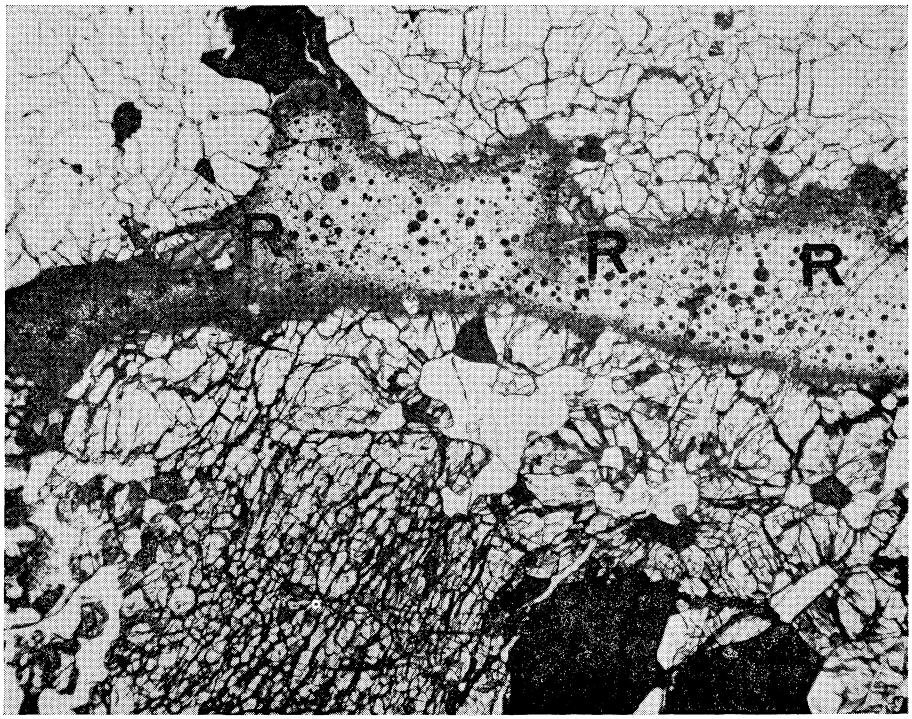
Name	Coordinates		Class and Type	Fa	Fs
Artracoona	29° 04′	139° 55′	L6	25.6	20.4
Baandee	32° 37′	118° 02′	H		
Barratta	35° 18′	144° 34′	L3	24.0	16.7
Billygoat Donga	30° 08′	126° 22′	L6	25.1	21.4
Bond Springs	23° 33′	133° 54′	H		
Burnabbie	32° 03′	126° 10′	H5	18.5	16.6
Burrika	31° 58′	125° 50′	L6	25.0	21.3
Cadell	34° 04′	139° 45′	L6	25.5	20.9
Cardanumbi	32° 10′	125° 38′	L5	25.7	21.5
Caroline	37° 59′	140° 59′	H5	20.9	18.0
Carraweena	29° 14′	139° 56′	L3	24.8	18.1
Cartoonkana	29° 45′	141° 02′	L6	25.7	21.6
Cockarrow Creek	26° 40′	120° 10′	L6	25.4	21.5
Cockburn	32° 08′	141° 02′	L6	25.1	21.4
Cocklebiddy	31° 56′	126° 13′	H5	17.2	15.2
Cocunda	32° 49′	134° 48′	L6	25.8	21.1
Coolamon	34° 49′	147° 08′	L6	25.9	21.4
Coomandook	35° 29′	139° 50′	H6	18.8	17.0
Coonana	29° 51′	140° 43′	H4	19.2	16.3
Coorara	30° 27′	126° 06′	L6	25.9	22.2
Credo	30° 22′	120° 44′	L6	24.9	21.2
Crocker Well	32° 01′	139° 47′			
Dalgety Downs	25° 20′	116° 11′	L5	25.2	21.4
Dimboola	36° 30′	142° 02′	H5	19.4	16.8
Doolgunna	25° 56′	119° 18′	L		
Edjudina	29° 35′	122° 11′	H4	18.7	16.6
Eli Elwah	34° 30′	144° 43′	L6	25.3	21.0
Ellerslie	28° 54′	145° 53′	L5	25.2	20.9
Elsinora	29° 27′	143° 36′	H5	19.8	17.5
Fenbark	30° 26′	121° 15′	H5	19.6	16.7
Forest Vale	33° 21′	146° 51′	H4	18.6	16.0
Forrest	30° 49′	128° 13′	H5	19.6	17.6
Forrest Lakes	29° 25′	129° 30′	LL5	27.5	20.7
Frenchman Bay	30° 36′	115° 10′	H3	18.5	14.6
Gilgoin	30° 23′	147° 12′	H5	18.0	16.2
Gunnadorah	31° 00′	125° 56′	H5	19.1	16.5
Hamilton	28° 29′	148° 15′	L6	25.3	20.8
Hammond Downs	25° 28′	142° 48′	H4	18.8	16.4
Hermitage Plains	31° 44′	146° 30′	L6	25.6	21.3
Jeedamya	29° 35′	121° 10′	H6		
Kaldoonera Hill	32° 37′	134° 51′	H6	18.7	16.8
Kappakoola	33° 15′	135° 32′	H6	19.6	17.2
Karoonda	35° 06′	139° 56′	C4	32.5	
Kielpa	33° 36′	136° 06′	H5	18.9	17.0
Kingoonya	30° 57′	135° 24′	L4	23.8	20.2
Kittakittaooloo	28° 02′	138° 08′	H4	18.9	16.8
Koraleigh	35° 06′	143° 24′	L6	26.0	21.4
Kulnine	34° 09′	141° 47′	L6	25.4	20.6
Kybunga	33° 54′	138° 29′	L5	25.0	21.4
Lake Bonney	37° 45′	140° 18′	L6	24.5	21.1
Lake Brown	31° 00′	118° 30′	L6	25.0	20.9
Lake Grace	33° 04′	118° 13′	L6	25.9	21.2
Lake Labyrinth	30° 33′	134° 45′	LL6	29.4	23.6
Laundry East	31° 31′	127° 08′	H3	18.5	16.8
Laundry Rockhole	31° 32′	127° 01′	H5	20.4	17.5
Laundry West	31° 28′	126° 56′	L4	24.2	18.8
Mellenbye	28° 51′	116° 17′	LL	27	

Table 3. Geographical coordinates, classification, and compositions of coexisting olivine and pyroxene in Australian chondrites—*continued*

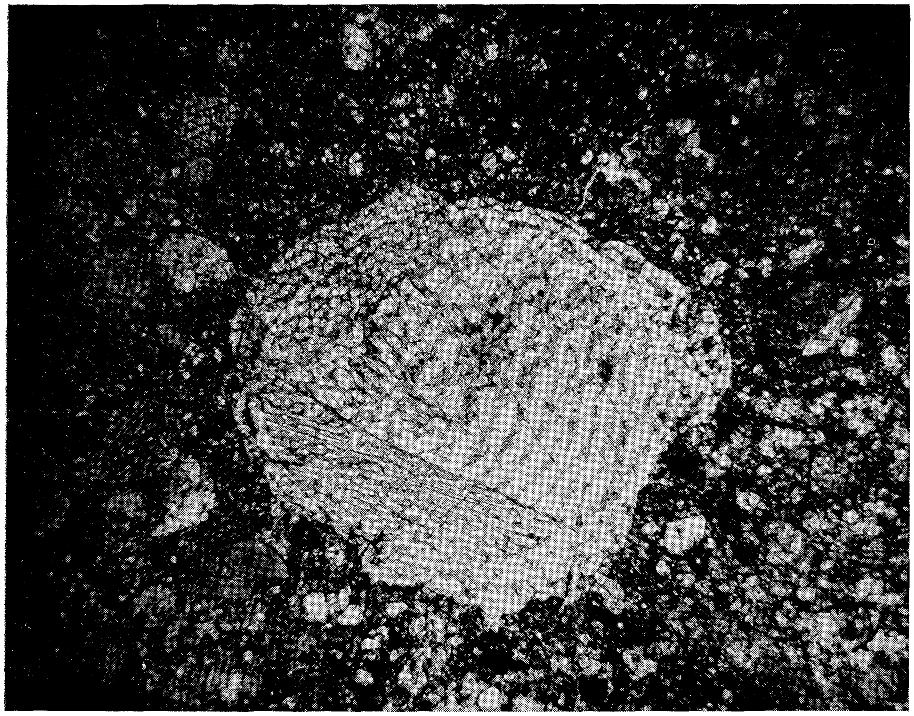
Name	Coordinates		Class and Type	Fa	Fs
Moorleah	40° 59′	145° 36′	L6	24.4	20.3
Mossgiel	33° 19′	144° 47′	L4	24.2	20.1
Motpena	31° 06′	138° 16′	L6	25.8	21.7
Mt Browne	29° 48′	141° 42′	H6	18.1	16.5
Mulga (north)	30° 11′	126° 22′	H6	19.3	17.0
Mulga (south)	30° 12′	126° 22′	H4	18.4	16.1
Mulga (west)	30° 11′	126° 22′	C4		
Murchison	36° 40′	145° 14′	C2		
Nallah	31° 58′	126° 15′	H	18	
Nardoo #1	29° 32′	143° 59′	H5	18.8	15.9
Nardoo #2	29° 30′	144° 04′	L6	25.0	20.9
Narellan	34° 03′	150° 41′	L6	25.3	21.4
Naretha	31° 00′	124° 50′	L4	24.8	19.2
Nora Creina	37° 19′	139° 51′	L4	25.1	19.4
North East Reid	30° 09′	128° 43′	H5	18.6	16.6
North Forrest	30° 30′	128° 06′	H4	19.1	17.1
North Reid	30° 08′	128° 38′	LL5	27.4	22.0
North West Forrest	30° 36′	127° 49′	E6		0.3
Oak	31° 35′	127° 42′	L5	25.7	21.2
Pannikin	32° 02′	126° 11′	L6	24	
Pevensey	34° 45′	144° 40′	LL5	28.5	22.8
Rawlinna	30° 22′	126° 05′	H5	19.4	16.8
Reid	30° 11′	128° 41′	H	18.4	16.9
River	30° 22′	126° 01′	L5	24.7	20.9
Rowena	29° 48′	148° 38′	H6	19.5	17.6
Silverton	31° 53′	141° 12′	L6	25.4	21.0
Sleeper Camp	30° 15′	126° 20′	L6	24.7	20.6
Tenham	25° 38′	142° 50′	L6	25.1	20.8
Ularring	29° 58′	120° 36′	L6	25.6	21.5
Vincent	35° 01′	139° 56′	L5	24.2	21.0
Webb	31° 45′	127° 47′	L6	25.3	21.4
West Forrest	30° 40′	127° 50′	H5	18.7	16.7
West Reid	30° 11′	128° 40′	H6	19.6	17.7
Wilbia	26° 27′	131° 00′	H5	19.0	17.7
Wildara	28° 14′	120° 51′	H5	20.7	17.9
Willaroy	30° 06′	143° 12′	H3	14.6	14.5
Wiluna	26° 36′	120° 20′	H5	19.2	17.2
Wingellina	26° 04′	128° 57′	H4	18.2	16.6
Witchellina	30° 00′	138° 00′	H4	19.1	17.3
Woolgorong	27° 45′	115° 50′	L6	25.2	21.0
Wynella	28° 57′	148° 08′	H4	18.7	16.4
Yalgoo	28° 23′	116° 43′	LL	27	
Yandama	29° 45′	141° 02′	L6	25.0	20.9
Yayjinna	32° 02′	126° 10′	L6	26.0	21.6
Yilmia	31° 12′	121° 32′	E6		

Table 4. Numbers and percentages of Australian chondrites in H and L groups and types, compared with the worldwide data on Van Schmus and Wood (1967)

	Australian		Worldwide	
	Number	Per cent	Number	Per cent
H3	3	3	7	2
H4	10	12	35	9
H5	19	22	74	19
H6	8	9	44	12
L3	2	2	9	2
L4	5	6	18	5
L5	7	8	43	11
L6	32	38	152	40
Total	86	100	382	100



Veinlet (maximum width 0.2 mm) of majorite, with grains of ringwoodite (R), in the Coolamon meteorite. [Photo: Smithsonian Institution].



Large (5 mm diameter) unequilibrated olivine chondrule in the Elsinora meteorite. [Photo: Smithsonian Institution]