THE WEDDERBURN METEORITE REVISITED

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ABSTRACT: The Wedderburn meteorite from Victoria is a small nickel-rich iron belonging to the rare sLH subgroup of the IAB complex. Donated to the Mines Department in 1950, it came to public attention in 1953 when the initial description was published by Dr Austin Edwards in the *Proceedings of the Royal Society of Victoria*. Since then, pieces of the meteorite have been distributed to major institutions in Europe and North America, where leading researchers have investigated the meteorite's unusual chemistry, mineralogy and microtexture in great detail. The recent approval of a new iron carbide mineral named edscottite, with the formula Fe_5C_2 , in Wedderburn has prompted this review of the meteorite's history, from its discovery to its current classification status.

Keywords: Wedderburn, meteorite, sLH subgroup, iron carbides, edscottite, history

INTRODUCTION

The Wedderburn meteorite is one of 18 recorded meteorites from Victoria (Henry 2003; Birch et al. 2019) and one of five that are broadly categorised as irons (the others are Cranbourne, Lismore, Willow Grove and Ballarat). When it was found is unknown, but it was eventually donated to the Victorian Mines Department in 1950 and brought to the attention of CSIRO mineralogist Dr Austin Edwards. Once his investigation had confirmed it was a meteorite - and a particularly nickel-rich one - Edwards presented his findings to a meeting of the Royal Society of Victoria in October 1951. The publication of his paper in the Proceedings of the Royal Society of Victoria in 1953, followed by further research by John Lovering at the California Institute of Technology (Caltech) and the Australian National University (ANU) in the late 1950s, sparked requests for samples from other meteorite researchers in some of the world's leading institutions. Interest in Wedderburn has continued to the present day, culminating in the characterisation and approval of a new mineral, an iron carbide named edscottite, occurring within it. Triggered by this discovery, this paper examines Wedderburn's history, in particular its distribution, the institutions and researchers involved, and the outcomes of their investigations.

DISCOVERY

As reported by Edwards (1953), the meteorite was discovered by 'Mr C. Bell, of Rushworth, when he was prospecting at a point three miles northeast of Wedderburn'. He was intrigued by its heaviness when he attempted to kick it off the road. In all likelihood, the finder

was Charles Frederick Bell, a well-known local miner and prospector, who spent his entire life from 1889 until 1965 in the Rushworth district. Wedderburn is some 140 km west of Rushworth, so Mr Bell must have prospected over a wide area. Although the description of the find site is not sufficient to establish its location precisely, it is likely to have been on a track through bushland to the north of Glasgow Hill (Figure 1).

It is not known for how long Charles Bell had the meteorite before he took it to the Victorian Mines Department in Melbourne, where it was received on 28 July 1950. On 15 September, the Deputy Director, Dr Alexander Bain, forwarded the specimen to the State Laboratories for analysis. The results, 76.37% Fe and 23.33% Ni, clearly indicated a meteorite, prompting Dr Bain to send the sample to Dr Edwards for detailed investigation. Edwards arranged for a more complete analysis by G.C. Carlos, tested the effects of various reagents on etched polished sections, and identified the main phases present. Once his observations had confirmed the identification, Edwards advised Bain, who sent the sample to the department's geological museum, where it was registered with catalogue number 11893 on 26 September 1951. Two weeks later, Edwards presented his observations in a paper read to the Royal Society of Victoria on 11 October.

Edwards described the meteorite as complete, with well-rounded surfaces and showing a characteristic 'thumb mark' (regmaglypt). Its dimensions were 5 x $3.6 \times 2.6 \text{ cm}$ and it weighed 210 g. After removal of the rusted surface by grinding, the density was measured as 7.94 g/cm^3 , and the overall mass remaining after Edwards' study had been reduced to 159 g (Figure 2).



Figure 1: Locality map for the Wedderburn meteorite find. The red circle is centred on a point roughly 3 miles (5 km) northeast of the town. The pale green shading indicates forest coverage. Grid squares are 1 km on edge.

SAMPLE DISTRIBUTION AND HISTORY OF INVESTIGATION

In November 1951, Edwards sent a 17 g slice of the meteorite to the Australian Museum in Sydney, probably at the request of R. Oliver Chalmers, the curator of the mineral and meteorite collections. The slice was registered as DR 7302 on 6 November 1951 (Ross Pogson, personal communication). At that time, the Australian Museum (AM) was the main repository for Australian meteorites and Chalmers was receiving assistance with curating the

collections from John Lovering, then a student in his early twenties, who had obtained a cadetship with the AM while enrolled at the University of Sydney.

By 1953, Lovering had moved to the Division of Geological Sciences at Caltech to undertake research for his PhD. He commenced a study of the minor elements Ga, Ge, Co, Cr and Cu in meteorites, including 88 irons and nine stony-irons (Lovering et al. 1957). Wedderburn was among the Australian meteorites he analysed, most



Figure 2: The Wedderburn meteorite: (a) Current surface after partial removal of oxidised crust; (b) Cut surface; the heavily striated surface is uppermost; later portions have been cut from both ends. Dimensions are approximately 35 x 24 mm. Photos by Rodney Start (Museums Victoria). MV E12197.

of which were sourced from the Australian Museum's collection, courtesy of Oliver Chalmers. Whether Lovering received the museum's complete 17 g sample or an offcut is not recorded, but the Australian Museum's specimen has been listed as 'missing' for some time (Ross Pogson, personal communication).

By 1957, Lovering had been appointed a Research Fellow in the Department of Geophysics at ANU. While there, he undertook thermomagnetic analyses of two nickel-rich ataxites from Australia — Tawallah Valley and Wedderburn — in order to estimate temperature gradients and ablation rates (Lovering et al. 1960). The AM was acknowledged as the source of the samples of both meteorites. It is possible that Lovering used the same sample for both the minor element analysis at Caltech and the ablation measurements at ANU. There is currently no entry for Wedderburn in the ANU's meteorite collection register (Yuri Amelin, personal communication), so it appears that the material investigated by Lovering has been lost.

In July 1965, John L. Knight, then Assistant Director of the Geological Survey of Victoria (GSV), provided a 4.65 g sample of Wedderburn to John Wasson at the Institute of Geophysics and Planetary Physics in the University of California Los Angeles (UCLA). Wasson and his team had been analysing and classifying every iron meteorite they could track in museum collections, and Wedderburn was on their want list. Their sample was designated IN0040, part of which was used for destructive radiochemical neutron activation analysis (Wasson & Schaudy 1971). Another section, designated TK 143, was prepared from the remainder.

Vagn Buchwald, from the Department of Metallurgy in the Technical University in Lyngby, Denmark, borrowed a UCLA specimen from John Wasson for a few days in early June 1969. He described it as 'a thin slice 16 x 15 x 1 mm mounted in bakelite, polished and etched' (personal communication to Ed Scott). These dimensions suggest it weighed about 2 g, and was therefore part of IN0040. Buchwald used the section to compile the detailed description of Wedderburn's mineralogy and texture for the entry in his *Handbook of Iron Meteorites* (Buchwald 1975).

Around the same time as he supplied the sample to UCLA, John Knight received a request for a sample of Wedderburn from the Max Planck Institute for Chemistry (MPI) in Mainz, Germany. The request may have come from Dr Friedrich Begemann, who in 1961 had approached the National Museum of Victoria for samples of the Cranbourne iron meteorite. Wedderburn was among 36 iron meteorite samples analysed at MPI by mass spectrometry for the noble gas isotopes ³He, ⁴He, ³⁸Ar and ²¹Ne, produced

by cosmic ray exposure (Schultz & Hintenberger 1967). These data were used by Voshage (1967) to estimate a cosmic ray exposure age. The amounts used in these analyses were not supplied in the papers, but when first recorded in the MPI catalogue in 1984, the sample had a mass of 9.5 g and had been given the inventory number MPI 623/1; currently it has a mass of 8.3 g (Jutta Zipfel, personal communication). This specimen is now in the Senckenberg Museum in Frankfurt following the transfer of the MPI meteorite collections to the museum in 2005 on a permanent loan basis.

The difference between the original and current mass of the MPI sample is due to a 1.2 g piece having been provided to Bruce Fegley at Washington University in 1995. It was intended for a study of the kinetics of metal–gas reactions that produced troilite and magnetite, using iron meteorites. Canyon Diablo and Gibeon were used, but the research did not extend to the rarer types before it was closed. The Wedderburn piece has been retained in the department (Bruce Fegley, personal communication).

In 1971, Knight received yet another request, this time from Stuart Agrell in the Department of Mineralogy and Petrology at Cambridge University. Agrell was widely respected for his early meteorite research, which had led to his involvement as a principal lunar sample investigator in the Apollo program in the 1960s. By the time Knight sent the Wedderburn sample to Cambridge in May 1971, Agrell had returned to his meteorite research. He was also supervising Edward Scott, who was researching carbides in iron meteorites for his PhD degree (Scott 1972). Scott discovered that Wedderburn contained a new iron carbide, which he termed 'W-carbide', with the formula Fe25C (Scott & Agrell 1971). While it was known synthetically, nearly 50 years would elapse before this phase was fully characterised and named as the new species, edscottite (Fe_5C_2) , by Ma and Rubin (2019). Knight had requested that the 'polished section' he supplied be returned to the GSV. However, the section remained in the department's meteorite collection before being assigned a Sedgwick museum number (1991.203) in 1991 (Dan Pemberton, personal communication). After the author's recent approach to the museum, the sample has been returned to Museums Victoria, in acknowledgement of the original loan. It is a slice with a mass of 10.95 g and dimensions 3.5 x 2.5 x 0.2 cm, representing a full cross-section of the meteorite (Figure 3). These length and width measurements indicate that the meteorite had initially been cut in half perpendicular to its longest dimension in order to supply slices. The dimensions also suggest that Edwards had ground away an outer rind about 0.5 mm thick in order to remove the oxide coating.



Figure 3: Polished slice loaned by the Victorian Geological Survey to Cambridge University in 1971 and returned to Museums Victoria in November 2019. MV E19492.

From 1987, the Museum of Victoria became custodian of the surviving main mass of the Wedderburn meteorite following the transfer of the historic collections of the Mines Department and GSV. By then, following the distribution of pieces to researchers, the meteorite had been reduced to just 76 g along with 6 g of filings, presumably those remaining from the surface ground off by Edwards. The new registration number E12197 was assigned to both the main piece and the filings. There were no polished sections with the sample and those prepared by Edwards have not been found.

In 1996, Neena Bashir and co-workers at Caltech and Lawrence Livermore Laboratory undertook ion microprobe and electron microprobe measurements for C, Ni, Co, Cu and P in three iron meteorites, including Wedderburn. Zoning profiles in taenite (γ -alloy) close to the interface with kamacite (α -alloy) allowed modelling of cooling histories at low temperatures (Bashir et al. 1996). John Wasson at UCLA had provided the samples, including Wedderburn, which was a 10 x 9 mm piece cut from IN0040 in 1977 and designated TK 143, the same sample used by Ma and Rubin (2019) to characterise the new mineral edscottite. TK 143 was returned to the meteorite collection of the Department of Earth, Planetary and Space Sciences, UCLA, in August 2019, and is now the holotype for edscottite.

After being informed in December 2000 that the Australian Museum's specimen could no longer be found, John Wasson contacted Dermot Henry, then Collection Manager at Museum Victoria, seeking another sample of Wedderburn for duplicate instrumental neutron activation analysis (INAA). A slice 2–3 mm thick, weighing about 2.05 g, was removed from the remaining portion of the meteorite (E12197) and sent to UCLA in February 2001, where it was registered with number 1756. Data for 12 elements were obtained from replicate INA analyses of 150 iron meteorites, providing the basis for a new classification scheme based mainly on nickel and gold contents (Wasson & Kallemeyn 2002).

In January 2012, Ed Scott, at the University of Hawaii's Institute of Geophysics and Planetology, approached the author, then Senior Curator at Museum Victoria, with a request to borrow a polished section of Wedderburn for transmission electron microscope studies of carbides. As no polished sections existed in Museum Victoria's collections, it was suggested that he approach John Wasson at UCLA to use the sample registered as 1756. This suggestion was duly taken up, but whether this sample played any role in characterising edscottite is not known.



Figure 4: Reflected light image of a polished section of Wedderburn showing an elongated grain of nickelphosphide mantled by kamacite in a matrix of taenite with kamacite spindles. Platy grains of edscottite can be seen cutting across the kamacite envelope (see red arrowed grain in upper part of envelope). Image is 1.2 mm wide; courtesy of Ed Scott.

DESCRIPTIONS OF THE MICROTEXTURE

The microtexture of Wedderburn has been examined by many of the researchers named above, but the descriptions published by Edwards (1953) and Buchwald (1975) are the most detailed. Edwards noted the matrix is an extremely fine-grained intergrowth of a-iron bodies (kamacite, or 'low-nickel iron') enclosed in y-iron, which generates an incipient Widmannstätten pattern seen after light etching. Buchwald described the plessite matrix as having a bainitic to martensitic texture, and with profuse kamacite 'spindles' of variable size up to about 100 µm long, parallel to the Widmannstätten structure. Both authors observed numerous irregular bodies of iron-nickel phosphide (referred to in meteoritical terminology as 'schreibersite') dispersed through the matrix; Edwards gave their dimensions as being up to 0.1 x 0.1 mm, compared to Buchwald's figures of 400 x 50 µm. The phosphide grains are commonly rimmed by a-iron envelopes up to 0.05 mm thick (Figure 4). Troilite grains with a granular to polycrystalline texture are associated with the phosphide. Edwards noted minute areas of 'carbonaceous matter' that he tentatively identified as cliftonite, but Buchwald expressed doubt as to its occurrence. A more puzzling observation made by Edwards was of two small areas that he identified and illustrated as gold (Edwards 1953, his fig. 4). As an experienced ore mineragrapher, he had considerable expertise in recognising gold in polished sections, so it is difficult to fault his identification. Nevertheless, Buchwald cast doubt on it, and no researcher subsequently has noted its presence.

Edwards described a marginal phase 2–3 mm thick consisting entirely of γ -iron that resisted etching. He attributed this feature to rapid chilling, whereas Buchwald noted this marginal α_2 zone, which he estimated was 4–7 mm wide, had been heat-affected due to frictional heating during passage of the meteorite through the atmosphere (see Lovering et al. 1957). Both researchers observed that near-surface corrosion (differential rusting) has affected the kamacite envelopes and spindles in the matrix.

Scott and Agrell (1971) described 'W-carbide', Fe_{2.5}C, as plates a few microns thick enclosed in kamacite. Now renamed edscottite, Ma and Rubin (2019) described it as subhedral, elongated platy single crystals up to 4 μ m thick and 18 μ m across in the kamacite rims around grains of nickelphosphide (the nickel-dominant analogue of schreibersite in mineralogical terminology) (Figure 5).



Figure 5: High-resolution back-scattered-electron image showing edscottite plates enclosed within kamacite (low-Ni iron) around nickelphosphide. Image courtesy of Chi Ma.

RESULTS

Bulk chemistry

Several methods have been used historically for the bulk analysis of Wedderburn. That carried out by G.C. Carlos in CSIRO's Mineragraphic Section (Edwards 1953) probably used mainly wet chemical methods. This analysis showed that Wedderburn contained 23.95% nickel, making it the most nickel-rich meteorite then known from Australia. The analysis also showed that 0.5% cobalt, 0.78% phosphorus and small amounts of sulphur and carbon were present. Buchwald (1975) suggested that the phosphorus determination was probably unreliably high. The spectrographic analysis undertaken by Lovering et al. (1957) gave 22.2 % nickel and 0.63 % cobalt, as well as 580 ppm copper, 1.8 ppm gallium and less than 1 ppm germanium and chromium. Wasson and Schaudy (1971) used atomic absorption analysis to determine a nickel content of 22.36% and INAA to determine gallium, germanium and iridium concentrations of 1.51, 1.47 and 0.052 ppm respectively. New INAA data were obtained for these four elements, as well as for Cr, Co, As, Sb, W, Re, Ir, Pt and Au by Wasson and Kallemeyn (2002).

For the present study, fragments from the filings in MV sample E12197 were mounted and polished for analysis by electron microprobe. The fragments show considerable distortion of the metal phases, consistent with the effects of grinding, while the phosphide grains are shattered (Figure 6). There is little evidence for an oxide crust of any thickness. These observations, along with the analyses yielding a near-identical composition for the 'matrix' taenite as in previous studies (see Table 1), confirm that the filings are from the Wedderburn meteorite.



Figure 6: Back-scattered-electron image of a fragment filed from the outer surface of the Wedderburn meteorite by Edwards in 1951. Note distortion in the kamacite bands (mid-grey) and the fracturing of the phosphide grain near the right-hand edge. The fragment is 0.15 mm long. Photo by Graham Hutchinson.

Noble gas isotopes

Measurements of ³He, ⁴He, ³⁸Ar, ³⁶Ar and ²¹Ne contents in Wedderburn gave 92, 316, 5.6, 3.66 and 1.30 x 10⁻⁸ cm³ STP/g, respectively, where STP is standard temperature and pressure (25°C and 1 atm) (Schultz & Hintenberger 1967; Schultz & Kruse 1989). These results were used to calculate an indicator of relative irradiation hardness caused by exposure to cosmic rays. A cosmic ray exposure age of between 100 and 200 million years was estimated for Wedderburn by Voshage (1967).

Mineral analyses

The only published electron microprobe data for the main phases in Wedderburn are from Ma and Rubin (2019). Ed Scott provided the author with some previously unpublished analyses from his 1972 PhD dissertation. For kamacite, the same formula Fe_{0.93}Ni_{0.06}Co_{0.01} is derived from both sets of analyses. For taenite, Ma and Rubin's data yielded a formula of Fe_{0.67}Ni_{0.32}Co_{0.01}, compared to Scott's data (22.7% Ni and 0.64% Co) giving Fe_{0.78}Ni_{0.22}Co_{0.01}. The latter is very similar to the bulk composition (see above) and to the average composition (Fe_{0.77}Ni_{0.22}Co_{0.01}) of the fine-grained matrix of the meteorite determined by Ma and Rubin. For the phosphide, Ma and Rubin derived a formula of (Ni1.63Fe1.37Co0.01)P0.99, thereby classifying it as nickelphosphide (Ni,Fe)₃P, rather than schreibersite, as used by Edwards (1953) and Buchwald (1975), who did not have the benefit of microprobe data. The zonation profiles determined by Bashir et al. (1996) show the taenite is much richer in Ni (up to 40%) towards contacts with kamacite. Co contents in taenite zone downwards from 0.6 % to 0.3 %, Cu zones upwards from about 0.05 % to 0.2 %, while P remains relatively uniform between 0.01 and 0.02 %. Carbon abundances range between 0.05 and 0.15 wt % in taenite (y-iron) and are below detection limit in kamacite. For edscottite, Ma and Rubin (2019) determined an empirical formula of $(Fe_{4.73}Ni_{0.23}Co_{0.04})C_{2.00}$ and for coexisting cohenite (Fe_{2.82}Ni_{0.13}Co_{0.03})C_{1.03}.

Ablation and cooling rates

The surfaces of recently fallen iron meteorites always show thermal effects resulting from frictional heating during passage through the atmosphere. These changes in the microstructure are typically recognisable in the outer few millimetres. For older meteorite finds, these heataltered zones are frequently missing due to weathering of the outermost parts. Wedderburn has such a thermal alteration rim, in this case up to 7 mm thick, as observed by Buchwald (1975) but slightly thinner as noted by Edwards. The thermomagnetic analysis of this alteration zone in Wedderburn (and Tawallah Valley) by Lovering et al. (1960) yielded temperature estimates ranging from about 650°C at the inner boundary to about 1480°C at the surface undergoing melting. Assuming an ablation rate of 0.18 cm/sec and atmospheric passage time of 3.3 seconds, these authors calculated Wedderburn had lost about 60% of its pre-atmospheric mass. This meant that the original mass was about 500 g.

Cooling rates for several iron meteorites in the same group as Wedderburn were estimated to be between 2 and 5°C per million years (Goldstein & Short 1967; Wasson & Schaudy 1971). Goldstein et al. (2013) included the Tazewell iron, from the same classification group as Wedderburn (see below), in measurements of cooling rates based on sizes of taenite bands in matrix cloudy zones. Based on thermodynamic modelling of the Fe– Ni–C system, Bashir et al. (1996) estimated that the C concentration in taenite at its interface with kamacite indicated the equilibration temperature, i.e. the temperature below which diffusion of C through the two alloys ceased, was c. 400°C for Wedderburn.

CLASSIFICATION

Edwards (1953) recognised that Wedderburn's incipient Widmanstätten structure and high Ni content represented an anomalous combination and used the term 'eotaxite' to describe it. Lovering et al. (1957) were the first to fit Wedderburn into a group based on compositional data. They found iron meteorites could be divided into four relatively distinct groups based on germanium and gallium contents. Wedderburn belonged to the group of 15 meteorites, designated as Group 4, which had the lowest contents of both elements, namely 1-3 ppm Ga and ≤ 1 ppm Ge. In a series of papers, Wasson and coauthors subdivided the four groups defined by Lovering et al. (1957) into nine, based on improved chemical data for over 450 iron meteorites. Two new groups, designated IIIC and IIID, were established by Wasson and Schaudy (1971), based on relative concentrations of Ni, Ge, Ga and Ir. Wedderburn was one of five meteorites in group IIID, characterised by high Ni contents (16.6–22.6%), Ga and Ge contents between 1.4 and 5.2 ppm, and low Ir contents (0.02–0.07 ppm). Of the five, Wedderburn had the lowest Ge and Ga contents (see Table 1).

Since these classification systems were implemented, there have been further modifications made by Wasson and others, which need not be discussed here (see Wasson & Kallemeyn (2002) for an historical summary, including references). The two groups IIIC and IIID distinguished by Wasson and Schaudy (1971) were subsequently combined as IIICD. New, high quality data (Choi et al. 1995) could not detect any distinct gap between IAB and IIICD groups on Ga–Ni, Ge–Ni and Ir–Ni diagrams, and these authors recommended that they be treated as a single group (IAB-IIICD), otherwise known as the IAB complex.

This classification system was revised again by Wasson and Kallemeyn (2002), who used diagrams of gold versus other elements (Ni, Co, As, Ga, Ge, W, Cu and Sb) to distinguish six compositional sets. This method produced trends that were better defined than those arising from the Ni-versus-element plots (see Figure 7). The most populated compositional set includes about 70 meteorites and was named the IAB main group. The remaining five sets were designated as subgroups, and named based on their relative Au (H=high, L=low) and Ni contents (H=high, M=medium, L=low). This approach enabled the former IIICD group to be unpicked into IIIC and IIID, renamed sLM and sLH, respectively. Application of this notation would mean that Wedderburn is now classified as belonging to subgroup sLH in the IAB complex. However, meteorite classification is in a continual state of flux, illustrated by the subdivision of irons into 13 groups by Weisberg et al. (2006), under which scheme Wedderburn would remain in the IIID group.

COMPARISON WITH OTHER METEORITES

Edwards (1953) contrasted the incipient Widmannstätten texture in Wedderburn with the finer-grained texture

Reference	Ni	Co	Cu	Ga	Ge	Cr	As	Sb	W	Re	Ir	Pt	Au
Edwards (1953)	23.95	0.50											
Lovering et al. (1957)	22.2	0.63	580	1.8	<1	<1							
Wasson & Schaudy (1971)	22.36			1.51	1.47						0.052		
Wasson & Kallemeyn (2002)	23.4	0.61	529	1.45	1.47	10	32.7	1.19	<0		0.058	2.4	1.997
This study	22.37	0.60											

Table 1: Summary of bulk chemical data for the Wedderburn meteorite (values in ppm except for Ni and Co in %).

of another Australian iron, Tawallah Valley (Hodge-Smith & Edwards 1941), which has 18 % (Ni + Co). He attributed this difference to the presence of phosphorus in Wedderburn stimulating the transformation of γ -iron to kamacite, despite its higher Ni content. However, as pointed out by Buchwald (1975), Edwards failed to notice abundant phosphide grains, among other features, in Tawallah Valley, which is now classified as one of 16 meteorites in the IVB group.

Buchwald considered that Wedderburn's structure and composition are intermediate between Föllinge (Jämtland, Sweden) and Freda (North Dakota, USA). Föllinge contains continuous but very narrow kamacite lamellae, whereas the high nickel contents in Freda and Wedderburn inhibited the early growth of kamacite, so it occurs mainly as pointed spindles. Wasson and Schaudy (1971) added Tazewell (Tennessee, USA), Dayton (Ohio, USA) and Lewis Cliff (Antarctica) to the subgroup they classified as IAB-sLH, and another four irons have since been included, making a total of ten in the subgroup. Like others in the subgroup, Wedderburn is considered to be a Ni-rich iron meteorite that cooled slowly from melts produced by impact events either on one asteroid, or on several asteroids that were similar in composition (Wasson & Kallemeyn 2002).

Ma and Rubin (2019) compared the carbide mineralogy of Wedderburn, Freda and San Cristobal, noting that Freda and San Cristobal contain haxonite $(Fe,Ni)_{23}C_6$, and cohenite $(Fe,Ni,Co)_3C$, whereas Wedderburn contains edscottite and minor cohenite. The smaller grain size shown by edscottite may reflect carbide growth in Wedderburn at lower temperatures than in Freda and San Cristobal. A combination of high nickel and high phosphorus contents in Wedderburn may also influence the carbide mineralogy, through the lowering of the solvus temperature for C saturation in the Ni–Fe system, and the relative abundance of phosphides around which kamacite and carbides nucleate (Ma & Rubin 2019).

CONCLUSIONS

For a lemon-sized lump of iron, discovered by serendipity some 70 years ago in the forest of central Victoria, the Wedderburn meteorite has had a remarkable history of investigation (as John Wasson has commented, it's been quite an odyssey). It can now be said to be unique, as it is the only iron meteorite known, so far, to contain the iron carbide Fe_5C_2 . As has been suggested by Ma and Rubin (2019), it is possible that edscottite is among the suite of carbides stable under the conditions within the Earth's core. Wedderburn also has distinctive chemical features that place it close to, or at the end of trends for minor element contents within the rare subgroup sLH of the IAB complex.

As this investigation has shown, approximately 44 g of Wedderburn have been distributed to (and between) institutions for research purposes since the initial study by Edwards (see Table 2). This amount was taken from the



Figure 7: Compositional plots for Ni v Au and Ir v Au (based on data provided by John Wasson). Note that Wedderburn is classified within the sLH subgroup of the IAB complex and is distinguished by the bright pink symbol.

Mass	Institution	Date	Reg. No.	Remarks
17 g	Australian Museum	Nov. 1951	DR 7302	Sample used by Lovering et al. (1953, 1957) None retained by Australian Museum
4.7 g	UCLA	1965	IN0040	Sample divided. One used for NAA; another (TK 143) used for edscottite description
9.5 g	MPI	c. 1965	MPI 623/1	Noble gas determinations 1.2 g sample sent to Washington University in 1995.
11 g	Cambridge University	1971	1991.203	Carbide studies (Scott 1972). Sample transferred to Sedgewick Museum.
76 g	Museums Victoria	1987	E 12197	Main mass transferred from GSV
2 g	UCLA	2001	1756	INAA (Wasson & Kallemeyn 2002)

Table 2: Summary of distribution of Wedderburn meteorite.

159 g left after he had completed his description. Taking into account the 74 g mass remaining in the Museums Victoria collection, there are about 41 g unaccounted for. It is possible that much of this could have been lost during the removal of the various slices provided to researchers. Fortunately, the high nickel content appears to have mitigated any deterioration in storage, thereby minimising the prospect of further long-term loss of material and the need for special conservation techniques.

The find site for Wedderburn appears to be close to or partly within a Crown Land reserve that has been popular with gold prospectors, armed with metal detectors, for about 40 years. While no estimation of the meteorite's terrestrial age by ¹⁴C dating has been attempted, its discovery on a track through forested country suggests it is an historical fall, within the span of time represented by European settlement in central Victoria. While Edwards described a rust coating that he removed by grinding, surviving fragments suggest this was little more than a patina, implying that the meteorite had not been on the surface for long. This raises the intriguing possibility that there are more pieces of Wedderburn still out there waiting to be found. Perhaps some have already been cast aside by fossickers more intent on finding lumps of gold than lumps of iron.

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Conflict of interest

The refereeing process for this paper was handled by Associate Editor Fons VandenBerg.