Little Minnie Creek, an L4(S2) ordinary chondritic meteorite from Western Australia

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Abstract

The Little Minnie Creek meteorite, weighing 357 g, was found in 1997 at co-ordinates 24° 08' 16.9" S, 115° 52' 17.5" E in the Gascoyne District of Western Australia. Equilibrated ferromagnesian silicates with the compositions olivine ($Fa_{25}Fo_{47}$) and low-Ca orthopyroxene ($Fs_{21.6}En_{77.4}Wo_{1.0}$) show that the meteorite belongs to the L-group of ordinary chondrites. Prominent chondrules, the presence of abundant polysynthetically twinned clinopyroxene, and the wollastonite content of orthopyroxene show that the chondrite is petrologic type 4. Moderate weathering (grade W2) of the meteorite has locally, preferentially attacked troilite over metal and produced a small amount of pentlandite as a secondary weathering product. Preferential attack of troilite may be characteristic of weathering of chondritic meteorites in an arid climate.

Keywords: meteorite, Little Minnie Creek, L4(S2)

Introduction

A small, crusted stony meteorite weighing approximately 357 g was found by one of us (MT) in March 1997 lying on the surface near Little Minnie Creek in the Gascoyne District of Western Australia at co-ordinates 24° 08' 16.9"S, 115° 52' 17.5"E (Fig 1). Subsequently, the name Little Minnie Creek has been approved by the Nomenclature Committee of the Meteoritical Society (Grossman & Zipfel 2001). To confirm that it was a meteorite, the stone was broken in the field into two fragments weighing approximately 305 and 51 g. Beneath a fresh, warty fusion crust, the grey interior is locally stained brown by the rusting of metal particles, and chondrules are clearly visible to the naked eye. On cut surfaces, together with chondrules up to a maximum of 2 mm in diameter, abundant metal particles up to 2 mm across are visible and are evenly distributed throughout the meteorite.

Reconstructed, the meteorite (WAM 15207) is roughly cuboid in shape measuring 7 x 5 x 5 cm (Fig 2). The smaller fragment of the stone was cut, and three polished thin sections prepared for petrographic examination and electron microprobe analysis. Analyses were performed with a Cameca SX50 WDS electron microprobe analyser, at an accelerating potential of 15 kV with an operating current of 30 nA. Standards employed included natural minerals (*e.g.* olivine and pyroxene) as well as glasses and pure metals (Fe, Ni).

Petrology and mineralogy

The Little Minnie Creek meteorite is a chondritic stony meteorite. In thin section, abundant well-defined chondrules ranging from 0.2-0.6 mm across with an average diameter of 0.4 mm are set in a fine-grained matrix. Porphyritic chondrules containing either olivine, or both olivine and pyroxene, and radiating pyroxene chondrules are the most abundant. Chondrule mesostases are devitrified and microcrystalline yielding a composition, under broad beam analysis, close to albitic plagioclase feldspar. Barred olivine chondrules and microporphyritic chondrules are also present in the meteorite. The essential mineralogy of the meteorite is dominated by forsteritic olivine (Fa_{25}) and low-Ca orthopyroxene ($Fs_{21.6}$) although grains of polysynthetically twinned, Ca-poor clinopyroxene also occur both in chondrules and matrix.

Grains of diopside ($Fs_{7.4}En_{46.7}Wo_{45.9}$) together with kamacite, taenite, troilite, chromite, phosphate, and rare grains of native copper enclosed in metal make up the accessory and trace mineralogy of the meteorite. Kamacite typically contains 6 wt % Ni and 0.8 wt % Co, while taenite is strongly zoned with cores of grains ranging from 28.5-35 wt % Ni and less than 0.2 wt % Co. Representative analyses of some of the essential and accessory minerals in the meteorite are given in Table 1 and shown graphically in Fig 3.

Under crossed polars, the ferromagnesian silicates show generally uniform and sharp extinction although some grains of olivine display planar fractures and weakly undulose extinction. Kamacite contains abundant Neumann bands and, under crossed polars, troilite displays deformation bands and localised incipient recrystallisation. Other than in the fusion crust and heat-affected zone below the crust, evidence for shock-melting was not observed throughout the fabric of the meteorite.

Despite a reasonably fresh appearance, at the microscopic level the meteorite displays extensive weathering (Fig 4). Troilite grains have been partially (5-70% by volume) converted to iron oxide, and where they

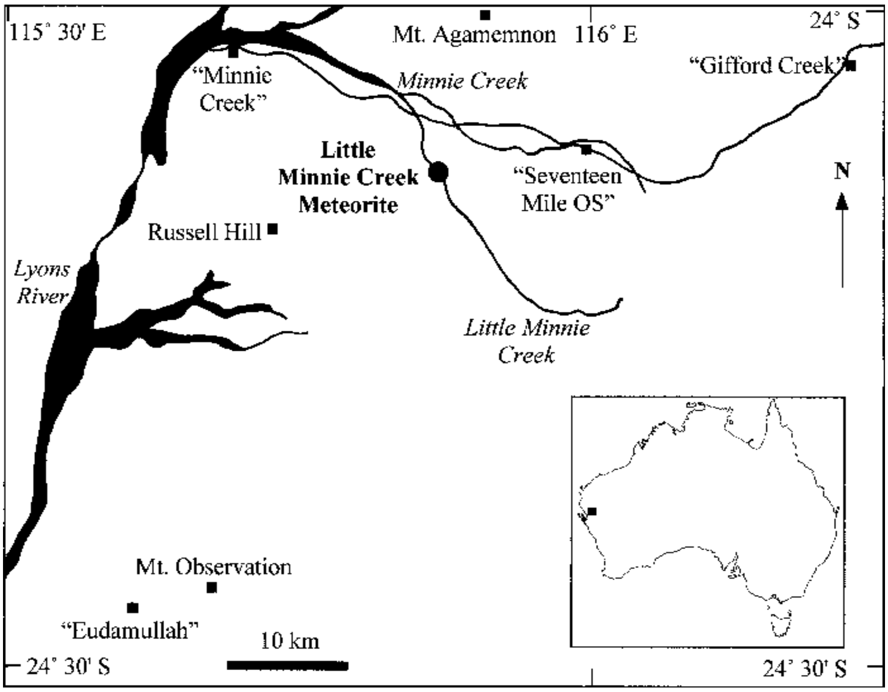

Figure 1. Location map for the find-site of the Little Minnie Creek L4 chondritic meteorite.

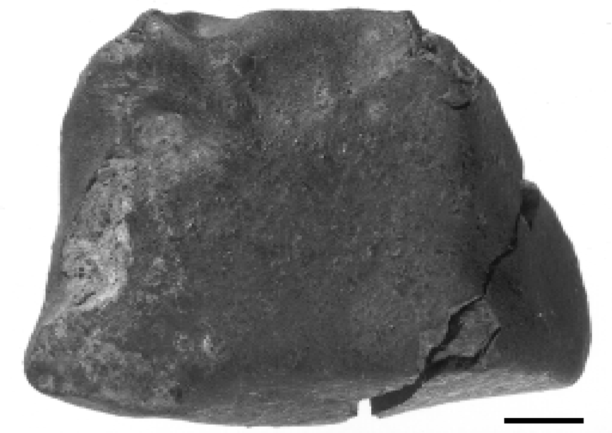

Figure 2. Reconstructed mass of the Little Minnie Creek meteorite (centimetre scale bar)

are in association with weathered metal particles grains show rare, incipient secondary alteration to pentlandite $(FeNi)_9S_8$. In general, metal particles show less (5-30% by volume) alteration to iron oxide than troilite.

Discussion and conclusions

The compositions of the ferromagnesian silicates and the cobalt content of kamacite show that Little Minnie Creek belongs to the L-group of ordinary chondrites. Chromite in the meteorite (Table 1) lies within the range of compositions reported by Bunch *et al.* (1967) for L-group ordinary chondrites. The clarity of chondritic texture of the meteorite, the wollastonite content of the low-Ca orthopyroxene (1 mol %), the abundance of polysynthetically twinned clinopyroxene, and the microcrystalline nature of the chondrule mesostases show that the meteorite belongs to the petrologic type 4 of the Van Schmus & Wood (1967) classification of chondrites.

Table 1.

Representative analyses (wt %) of minerals in the Little Minnie Creek L4 chondrite.

	olivine	orthopyroxene	chromite
SiO_2	38.0	56.1	-
TiO_2	-	-	2.25
Al_2O_3	-	-	6.1
Cr_2O_3	-	-	56.3
V_2O_3	-	-	0.76
FeO*	22.7	13.9	31.5
MnO	0.57	0.55	0.62
MgO	38.5	29.2	2.07
CaO	-	0.52	-
Na_2O	-	-	NA
K_2O	-	-	NA
Totals	99.77	100.27	99.6
moles%	$Fa_{25.3}$ $Fo_{74.7}$	$Fs_{21.6}$ $En_{77.4}$ $Wo_{1.0}$	

*All Fe as FeO; NA = not analysed for; - = not detected.
Analyst P Downes

Minor fracturing associated with weak undulose extinction in silicates, Neumann banding in kamacite, and deformation bands in troilite are all consistent with a history of weak shock-loading. The level of shock alteration is appropriate to S2 according to the shock classification of chondrites given by Stöffler *et al.* (1991) and indicates peak shock pressures of < 10 GPa.

Overall the extent of oxidation of the opaque phases in the meteorite shows that it belongs to weathering group

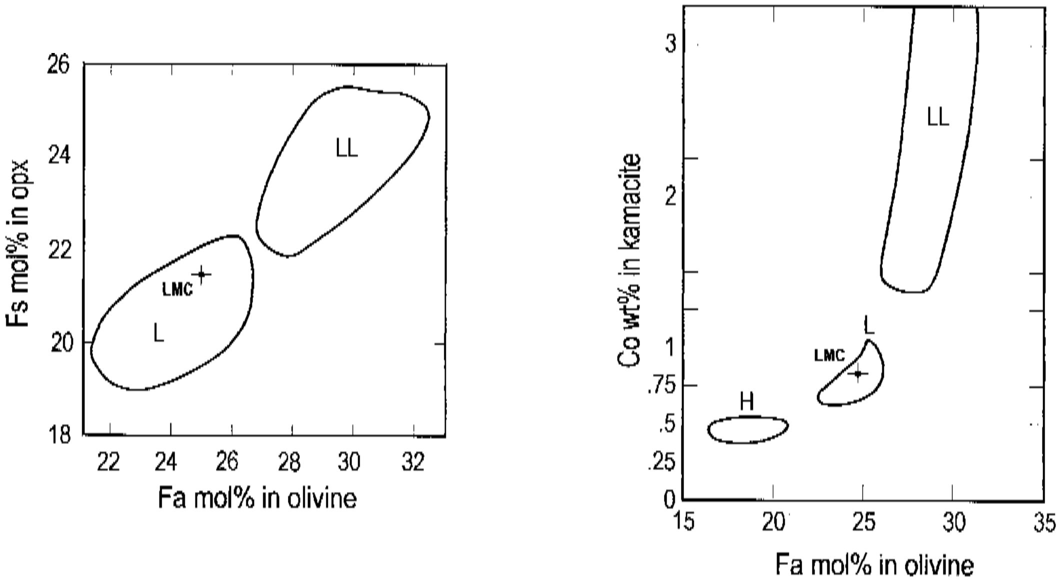

Figure 3. A: Mean compositional fields of olivine (Fa mol%) and low-Ca orthopyroxene (Fs mol%); **B:** Co wt% in kamacite versus olivine composition for the L-, LL- and H-groups of ordinary chondrites (after Ruzicka 1995). Olivine, pyroxene and kamacite compositions of the Little Minnie Creek (LMC) chondrite plot clearly within the L-group field.

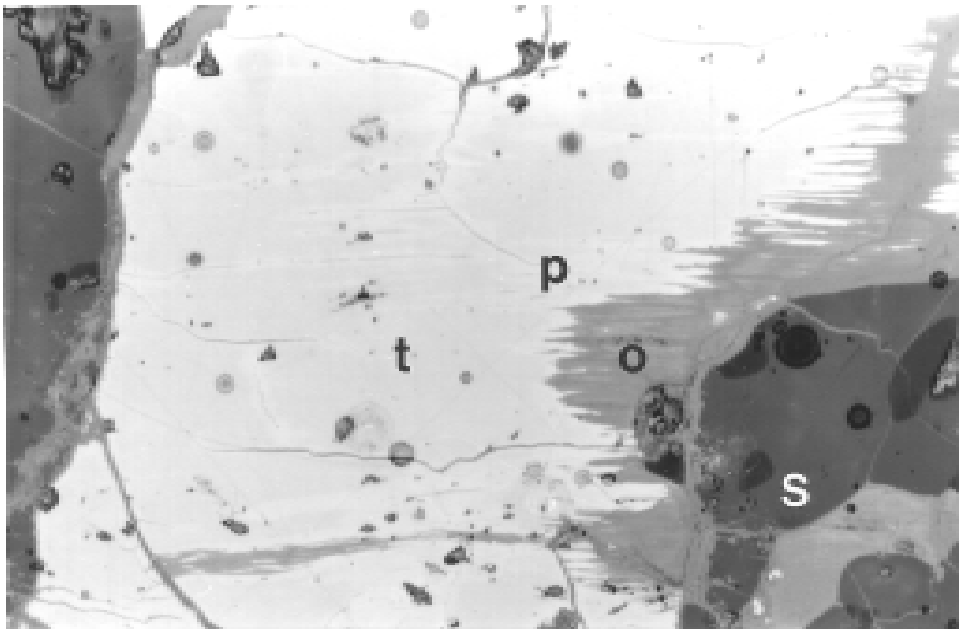

Figure 4. Extensively weathered particle of troilite (t) with dark grey iron oxides (o) surrounded by silicates (s). Weathering of troilite has progressed along (0001) parting planes and there is incipient development of pentlandite (p). Field of view 0.2 mm.

B, or weathering category W2 of Wlotzka (1993). Metal is usually more susceptible to terrestrial oxidation than troilite, with kamacite typically weathering faster than taenite (Ikeda & Kojima 1991). Localised, preferential weathering of troilite over metal has previously been noted by Ruzicka (1995) in an L6 chondrite (Nullarbor 018) that was found on the Nullarbor Plain. Ruzicka (1995) suggests that this may be the result of weathering in an arid climate, although the critical conditions are poorly understood. In the Nullarbor example, Ruzicka (1995) found that S had been preferentially leached from the meteorite. Oxidation and hydration reactions for troilite generally produce S-bearing weathering products that are relatively soluble in water, whereas Fe-bearing weathering products such as hematite are relatively insoluble, thus providing an explanation for why S is selectively leached under such conditions (Ruzicka 1995). Evidently, in Little Minnie Creek more than one weathering reaction involving sulphide has taken place. Nickel liberated from oxidising Fe-Ni metal locally reacted with troilite to cause incipient alteration to secondary pentlandite.

Ruzicka (1995) suggested two thermodynamically favourable reactions for troilite alteration, although he did not consider the involvement of oxidation products (NiO) from decomposing metal. Essentially, troilite is converted to hematite in the presence of water and oxygen with sulphur flushed from the system in aqueous solution. With the additional presence of carbonate (as in the case of the Nullarbor), a similar reaction occurs but with the evolution of gaseous CO_2 and both sulphur and calcium removed in solution. Ruzicka (1995) notes that mineral precipitates from such solutions include both anhydrite and gypsum.

The Little Minnie Creek meteorite was found sitting on a thin (< 30 cm) veneer of red soil over subcropping fresh granite. The site lies within 100 m of a river marked by a sheet wash of quartz / iron scree subject to periodic inundation. In the vicinity, calcrete has developed on the edge of small drainages leading into the river, but was mostly absent at the find-site. Because it was derived from the granite, the soil is not particularly iron- or manganese-rich but instead is strongly potassic. This environment is in stark contrast to the Nullarbor and its calcareous clay soil, yet a similar pattern of weathering has developed in the opaque minerals in the meteorite to that seen in some Nullarbor chondrites. The climatic conditions of generally high ambient temperatures, prolonged aridity with occasional inundation, may be more important controls on troilite versus metal weathering than the substrate on which the meteorite is lying.

When Fe-Ni metal and troilite react, pentlandite is formed. In this reaction, during the decomposition of troilite and metal to iron oxides in the presence of water and oxygen, Ni is released from metal to react with residual troilite to form a small amount of pentlandite with the excess sulphur flushed from the system in aqueous solution.

Bland *et al.* (1998, 2000) have considered the weathering rates of ordinary chondrites from several desert areas of the world, including the Nullarbor of Australia. Typically, pristine L-group ordinary chondrites contain around 8% metal and 6% troilite by weight. In meteorites that have suffered prolonged weathering the ferric iron alteration products include magnetite, maghemite, ferrihydrite, lepidocrocite, goethite and principally, akaganéite (Bland *et al.* 1998; Buchwald & Clarke 1989). From a study of terrestrially age dated ordinary chondritic meteorites, Bland *et al.* (2000) have shown that initial weathering of chondritic meteorites (< 1 ka after fall) appears to be rapid before oxidation is retarded and weathering abates. Arrested weathering rates appear to be related to a reduction in the porosity of the meteorite caused by mobilised corrosion products filling the available pore space and so preventing the subsequent percolation of fluids. Bland *et al.* (2000) suggest that the environment during the initial post fall period generally controls the extent of weathering. Once the porosity is reduced and the weathering rate arrested, even a moderately weathered meteorite may avoid significant alteration during subsequent humid periods. The extent of weathering in Little Minnie Creek, with the presence of abundant oxyhydroxides of iron, suggests that it is not a recent fall and may have a significant terrestrial age.

Other ordinary chondrites found in the vicinity of Little Minnie Creek include several stones of Dalgety Downs (25° 20' S, 116° 11' E), another L4 chondrite (Grady 2000). However, Dalgety Downs is more deeply weathered than Little Minnie Creek and shows a higher level of shock alteration (S4) indicating that they are distinct falls.

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