The Bunjil L6(S4) ordinary chondrite, a new meteorite find from Western Australia

A W R Bevan[1] and B J Griffin[2]

[1] Department of Earth and Planetary Sciences,
Western Australian Museum, Perth, Western Australia 6000
✉ alex.bevan@museum.wa.gov.au
[2] Centre for Electron Microscopy and Microanalysis,
University of Western Australia, Nedlands
Western Australia 6907

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Abstract

A broken, orientated, stony meteorite mass weighing 38.75 kg was found in 1971 at a locality (29° 37' 45"S, 116° 28' 56"E) near Bunjil in the northern wheatbelt of Western Australia. The presence of relict chondrules and the mean compositions of the ferro-magnesian silicates (olivine $Fa_{25.1}$; orthopyroxene $Fs_{21.4}$) show that the meteorite belongs to the L-group of ordinary chondrites. The strongly recrystallized chondritic texture and the presence of large (> 50 μm) crystals of plagioclase feldspar (now partially converted to maskelynite) show that the meteorite belongs to petrologic type 6. Olivine containing abundant planar fractures and displaying incipient mosaicism, together with plagioclase partially altered (< 75%) to isotropic glass with variable compositions, and the presence of shock-veins, indicate that the meteorite has been subjected to shock-loading appropriate to stage 4 (approximately 30 kb shock pressure). Bunjil is very similar to the previously described Latham (L6) ordinary chondrite reportedly found nearby, and the two meteorites may belong to the same fall.

Keywords: meteorite, chondrite, Bunjil, Western Australia

Introduction

Prolonged aridity throughout a large area of Western Australia has provided conditions conducive to the preservation of meteorites. As a result, large numbers continue to be recovered (Bevan 1992; Bevan 1996; Bevan *et al*. 1998). The Bunjil stony meteorite was found in April or May of 1971 and subsequently, the name has been approved by the Nomenclature Committee of the Meteoritical Society (Wlotzka 1995). Following ploughing, a single, broken, flight-orientated mass weighing 38.75 kg was found by Mr Peter Just at a locality 12 km E and slightly N of Bunjil, and about 13.5 km NNE of Latham, Western Australia. The find-site of the meteorite (29° 37' 45" S, 116° 28' 56" E) lies in the Victoria District on Location No. 8898. In 1991, Mr Just deposited the entire mass of the meteorite (now registered WAM 14711) at the Western Australian Museum in Perth.

The roughly conical stone (Fig. 1a,b) measures 37 cm x 25 cm x 23 cm and represents approximately two-thirds of an orientated mass. Deep, fluted regmaglypts occur on the ablated surface of the mass, particularly towards the rear of the stone. The stone is heavily weathered, but retains vestiges of a brown fusion crust. One flat, broken, weathered surface (Fig. 1b) lacks fusion crust and represents a late stage fracture, probably post-atmospheric. At the time of discovery, Mr Just searched the area unsuccessfully for the missing portion of the stone.

Mineralogy, petrology and classification

Bunjil is a chondritic meteorite displaying occasional large chondrules (up to *ca*. 4 mm in diameter) on its crusted and broken surfaces. The meteorite is deeply weathered and the interior is stained brown with terrestrial oxy-hydroxides of iron. Intergranular veins of iron oxides locally pervade the texture of the meteorite. The state of weathering, with moderate oxidation affecting less than 60% of metal and troilite, corresponds to stage W2 of the microscopic weathering scale for the ordinary chondrites as defined by Wlotzka (1993a).

In thin section, Bunjil is thoroughly crystalline, displaying poorly defined relict chondrules set in a coarsely crystalline matrix. Electron microprobe analysis (for operating conditions see Table 1) shows that the meteorite is composed essentially of forsteritic olivine with a mean composition of $Fa_{25.1}$ (n = 10, σ = 0.53), and low-Ca orthopyroxene ($Fs_{21.4}En_{77.0}Wo_{1.6}$, n=7, σ=0.61) (Table 1).

Abundant, large (> 50 μm) grains of plagioclase feldspar with the general composition of oligoclase occur throughout the matrix. Grains of plagioclase variably show strong undulatory extinction, planar features, and partial isotropism, and are locally converted to maskelynite. Less than 75% of the grains of plagioclase have been transformed to maskelynite. Measured plagioclase compositions in the meteorite are variable within the range $An_{8.5-12.8}$, $Ab_{70.6-85.3}$, $Or_{2.0-16.4}$. Those grains of plagioclase converted to isotropic glass occur mainly in the more severely shocked portions of the meteorite. Accessory minerals recognised in the meteorite include

Table 1

Point analyses (wt %) of typical individual grains of minerals in the Bunjil ordinary chondrite

	olivine	ortho-pyroxene	chromite
SiO_2	37.7	55.1	NA
TiO_2	–	0.14	2.43
Al_2O_3	–	–	6.15
Cr_2O_3	–	0.22	57.6
V_2O_3	NA	NA	0.68
FeO*	22.9	14.3	31.0
MnO	0.35	0.40	–
MgO	38.9	28.9	2.22
CaO	–	0.83	NA
Totals	99.85	99.89	100.08
	$Fa_{25.1}$	$Fs_{21.9}$ $En_{76.5}$ $Wo_{1.6}$	______ 86.3 (Cr+Al)

* total Fe as FeO; – = not detected; NA = not analysed for.

Analytical conditions: JEOL electron microprobe; accelerating potential 20 kV; operating current 20 nA; standards employed, independently analysed minerals and pure metals. (Analyst G. Pooley).

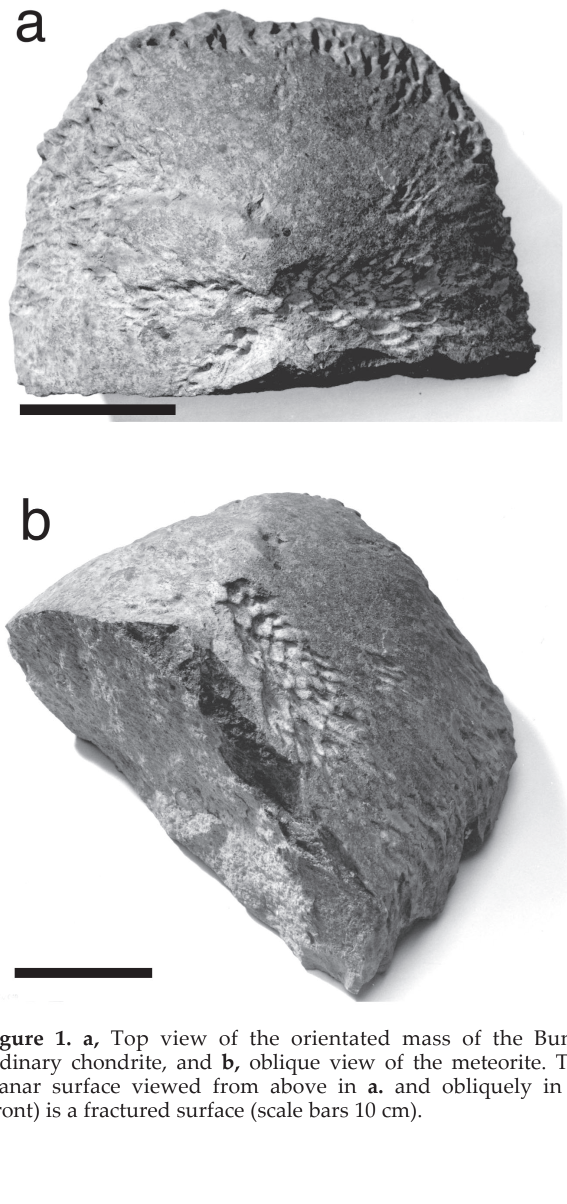

Figure 1. a, Top view of the orientated mass of the Bunjil ordinary chondrite, and **b,** oblique view of the meteorite. The planar surface viewed from above in **a.** and obliquely in **b.** (front) is a fractured surface (scale bars 10 cm).

metallic FeNi (both α-kamacite and γ-taenite), troilite, chromite (see Table 1) and chlorapatite.

Throughout the stone, grains of olivine show abundant planar fractures and incipient mosaicism. Opaque, interconnecting shock veins up to 2 mm wide locally traverse the fabric of the meteorite, and there are also sporadic, apparently isolated, small (< 50 µm) pockets of melted material. Within the shock veins and melt pockets, troilite and metal have been shock-melted and occur as spherical beads and stringers.

The compositions of the ferro-magnesian silicates in the Bunjil meteorite show that it belongs to the L-group of ordinary chondrites. The crystalline nature of the stone, and the presence of abundant large crystals (50 µm) of plagioclase feldspar (now partially converted to isotropic glass), indicate that the meteorite is petrologic type 6 of the Van Schmus & Wood (1967) classification. The wollastonite content of the low-Ca orthopyroxene (1.6 mol%) is also consistent with petrologic type 6 (Scott *et al.* 1986).

Chromite in Bunjil is slightly higher in Cr_2O_3, Al_2O_3 and MgO, and slightly lower in FeO than the average for equilibrated L-group chondrites (Table 1). However, chromite lies within the range of compositions measured for L5-6 ordinary chondrites by Bunch *et al.* (1967) and Wlotzka (2005).

The overall level of shock-metamorphism exhibited by the stone is appropriate to stage 4 (S4) of the shock classification of the ordinary chondrites proposed by Stöffler *et al.* (1991). The variability of the plagioclase compositions is consistent with plagioclase described from other shocked ordinary chondrites of stages 4–5, and may have resulted from the mobilisation of Na during shock-loading (Rubin 1992).

Discussion and conclusions

Bunjil is an L6 ordinary chondrite that has suffered post-recrystallization shock-loading appropriate to shock pressures in the range 30–35 GPa according to the classification of Stöffler *et al.* (1991). However, more recently, Schmitt (2000) has calibrated experimentally the pressures required to induce similar shock features in an ordinary chondrite (Kernouvé H6). The shock recovery experiments (Schmitt 2000) indicate that these shock effects may be produced at shock pressures < 30 Gpa at a low initial temperature (293 K), and at < 25 Gpa at a high initial temperature (920 K). In the equilibrated L-group ordinary chondrites, shock stages of S3 and above are commonly observed. Many of these severely shocked meteorites display extensive blackened veins containing melted material. However, Stöffler *et al.* (1991) advised against the use of shock veins as the primary indicators of shock levels, since they are not representative of the overall equilibrium shock pressure experienced by the meteorite. The general condition of the olivine and plagioclase grains in such shocked meteorites is a much better indicator of equilibrium shock pressures (Stöffler *et al.* 1991). More recently, van der Bogert *et al.* (2003) have shown experimentally that severe shock deformation is not always required for the formation of melt veins and darkening in chondrites. Instead, high strain rates and frictional melting are particularly

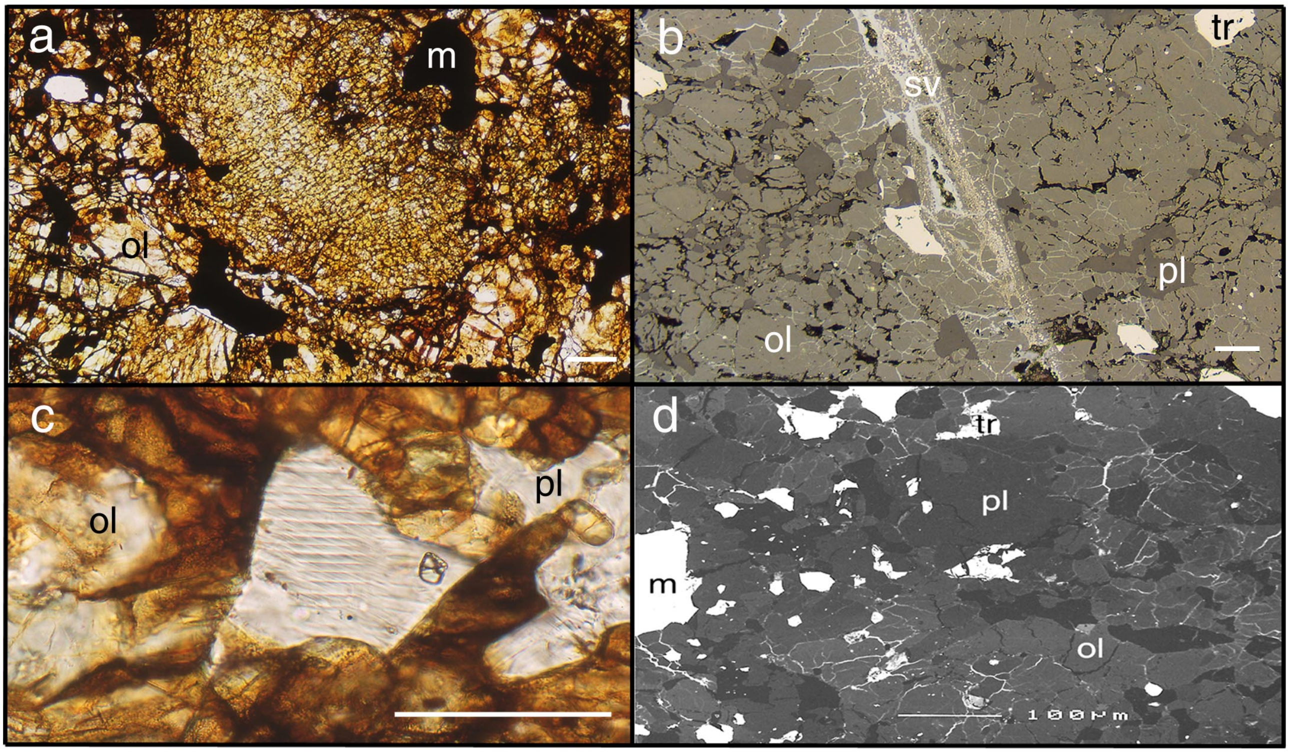

Figure 2. Photomicrographs of the Bunjil L6 ordinary chondrite in **a.** plane-polarised light (PPL) showing strongly recrystallised chondritic texture with olivine (ol). Dark patches are metal (m) and other opaques. (scale 100 µm) **b.** reflected light showing a large shock vein (sv) containing melt droplets of metal and troilite (tr) (scale 25 µm). **c.** A grain of plagioclase feldspar (centre, PPL) showing planar features as the result of shock metamorphism (scale 50 µm). **d.** Back-scattered electron image showing plagioclase (pl), olivine (ol), troilite (tr), and FeNi metal (m) (scale 100 µm).

important for the formation of veins at low shock pressures. Moreover, Rubin (2002) has suggested that the presence of "shock" veins in some apparently unshocked ordinary chondrites indicates that they suffered prolonged post-shock thermal annealing that effectively repaired the shock damage in their minerals.

In Bunjil, the pervasive, shock-damaged condition of the meteorite's constituent silicate minerals (planar fractures, planar features, incipient mosaicism, and maskelynite) do not indicate any significant post-shock annealing of the silicates. In Bunjil, then, the black veins are very likely to have been formed by shock-related frictional melting.

The planar, fractured surface on the Bunjil stone suggests that the original mass broke late in flight, or perhaps on impact. Another chondritic meteorite, Latham, found in 1977 in the same general area as the Bunjil stone is also an L6(S4) chondrite (Bevan 1992; Wlotzka 1993b) and may be a fragment of the missing portion of the Bunjil stone.

Little is known of the recovery of the Latham ordinary chondrite. A fragment of unknown weight was reportedly found in the general vicinity of Latham (29° 45' S, 116° 26' E), although the exact locality is unknown. The main fragment of the Latham meteorite remains in the possession of the finder and is unavailable for further study. However, a chip weighing 1.1 grams (registered WAM 13456), and a thin section are in the collection of the Western Australian Museum. Latham contains olivine ($Fa_{24.3}$) (incorrectly reported in Wlotzka [1993b] as $Fa_{4.3}$) and low-Ca orthopyroxene ($Fs_{20.4}$) with ranges of compositions that overlap with those measured for these minerals in Bunjil. The Latham chondrite is also moderately to strongly shocked containing some maskelynite. A microscopic comparison between Bunjil and Latham (this work) shows that they are petrologically similar, and appear to belong to the same stage (S4) of shock alteration of the Stöffler *et al.* (1991) classification. There is a possibility that Latham and Bunjil are from the same fall and, pending further studies (terrestrial age and noble gases), the meteorites should be paired.

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