

Collaborative scientific drilling at Hickman Crater

by

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Hickman Crater lies in the Hamersley Range, about 36 km north-northwest of Newman, on a contact between early Paleoproterozoic Woongarra Rhyolite and overlying Boolgeeda Iron Formation. It has a partially eroded circular rim about 260 m in diameter that rises up to 30 m above a flat circular floor (Fig. 1). The crater was first noticed on Google Earth imagery by Geological Survey of Western Australia (GSWA) geologist Arthur Hickman in 2007. Following preliminary ground observations consistent with an impact origin, the site was named Hickman Crater by Andrew Glikson (Australian National University) in recognition of Hickman's initial discovery, and his achievements in the geological investigation of

the Pilbara Craton over a period of 35 years (Glikson et al., 2008). Despite morphological and structural features typical of simple (i.e. bowl-shaped and lacking central uplift) impact craters, and the presence of surrounding breccia interpreted as impact ejecta, the early studies did not find unequivocal evidence of an impact origin — such as physical or geochemical traces of the projectile or conclusive shock metamorphism (Glikson et al., 2008). This is not surprising because in small simple craters the critical evidence commonly lies within the shattered crater basement and overlying lens of impact breccia (French, 1998; French and Koeberl, 2010). Both are subsequently buried by crater-filling sediments, so that



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Figure 1. Diamond drill rig on the central crater floor viewed from the south rim of Hickman Crater

drilling is often the only way to recover samples. For example, after a century of debate the impact origin of the approximately one km-diameter Tswaing Crater (Pretoria Saltpan) in South Africa was only confirmed after drilling to provide petrographic and geochemical samples of the impact breccia and basement (Reimold et al., 1992). In the case of Hickman Crater, a pre-existing creek broke through the northern crater rim at some time after the crater's formation, thereby accelerating the crater-filling process. Preliminary age estimates range from a few tens of thousands up to 100 000 years (Glikson et al., 2008), thus recovery of unoxidized meteoritic material at surface is unlikely.

Drilling

In late 2012 Hickman Crater was diamond cored from surface in a collaborative project between Atlas Iron Ltd, which holds an exploration licence over the area, and GSWA (Fig. 1). The vertical hole was sited in the centre of the flat crater floor and reached a total depth of 64.7 m. The unconsolidated sediments and breccia, and intensely fractured basement presented challenging drilling conditions, but slow drilling and short core runs using triple-tube methods and large diameter core achieved good recovery for most of the hole. The only comparable drilling of a small suspected impact crater in Australia is that of the roughly 1.2 km-diameter Darwin Crater in Tasmania, which was drilled in 1975 and 1983, but this failed to conclusively demonstrate an impact origin (Howard and Haines, 2007). From a comparison with the new Hickman Crater core the deepest Darwin Crater core may have stopped in a post-impact mass-wasting boulder deposit above potentially impact-diagnostic lithologies.

Core stratigraphy

The Hickman Crater drillhole intersected the full sequence of units expected for a simple impact crater (Figs 2, 3). The succession from surface to 48.4 m consists of red-brown clay, sand and gravel, representing crater-fill sediment, interspersed with large boulders of rhyolite and banded iron-formation (BIF) near the base. Apart from the gravel interbeds, the sediment is clay-dominated in

the lower part of the crater-fill succession (from 48.4 m to about 30 m), but comprises fine clayey sand above about 30 m. This change coincides with a significant increase in the magnetic susceptibility of the sediment above 30 m (Fig. 3) and likely marks the transition from an isolated (perhaps ephemeral) crater lake, to a stream-fed lake after stream breakthrough of the northwest crater rim. The higher magnetic susceptibility likely represents the introduction of stream sediment carrying soil-derived maghemite. The magnetic susceptibility of this upper succession is comparable to modern red soils around the crater and on the crater floor, each of which gives much higher susceptibility values than outcropping rhyolite or BIF. Large boulders of rhyolite and BIF near the base of the lower interval probably tumbled down to the topographically lowest centre of the crater from the initially very steep and unstable rim early in the crater's history.

The interval from 48.4 to 55.1 m consists of very poorly sorted angular fragments of altered rhyolite and minor BIF interspersed with small fragments of highly vesicular and commonly clast-rich glassy melt rock typical of a type of proximal impact breccia termed suevite. The remainder of the hole from 55.1 to 64.7 m intersected strongly fractured and altered Woongarra Rhyolite, interpreted as in situ crater basement. The alteration of the rhyolite in the basement and impact breccia, compared to the relatively fresh rhyolite in some unfractured boulders above the impact breccia, is attributed to the weathering action of groundwater penetrating fractures and breccia porosity.

Geochemistry, petrography and discussion

Samples from the core and surface materials are currently being analysed by GSWA and the Western Australian Museum. Fresh, clast-free glass fragments have been hand-picked from the breccia and submitted for $^{40}\text{Ar}/^{39}\text{Ar}$ dating at the John De Laeter Centre for Isotope Research.

Geochemical analysis of six samples spaced through the melt-bearing breccia show a pronounced enrichment in Ni, Co, Au and platinum group elements (PGE) compared with samples of rhyolite and BIF from the

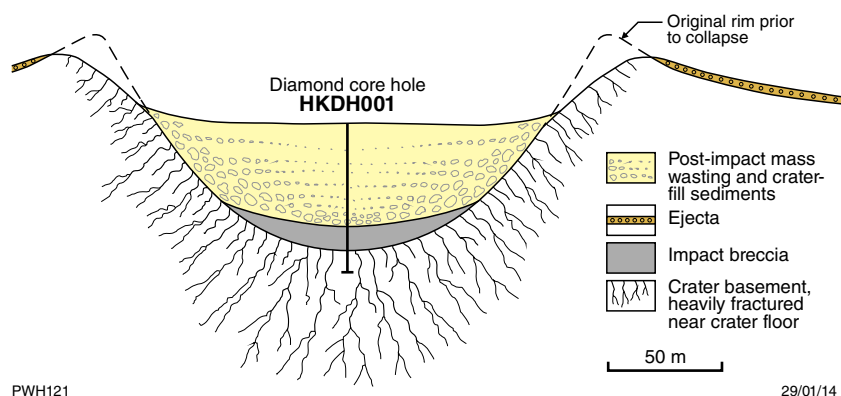


Figure 2. Interpreted cross section through Hickman Crater and the drillhole (no vertical exaggeration)

HKDH001 Hickman Crater summary log

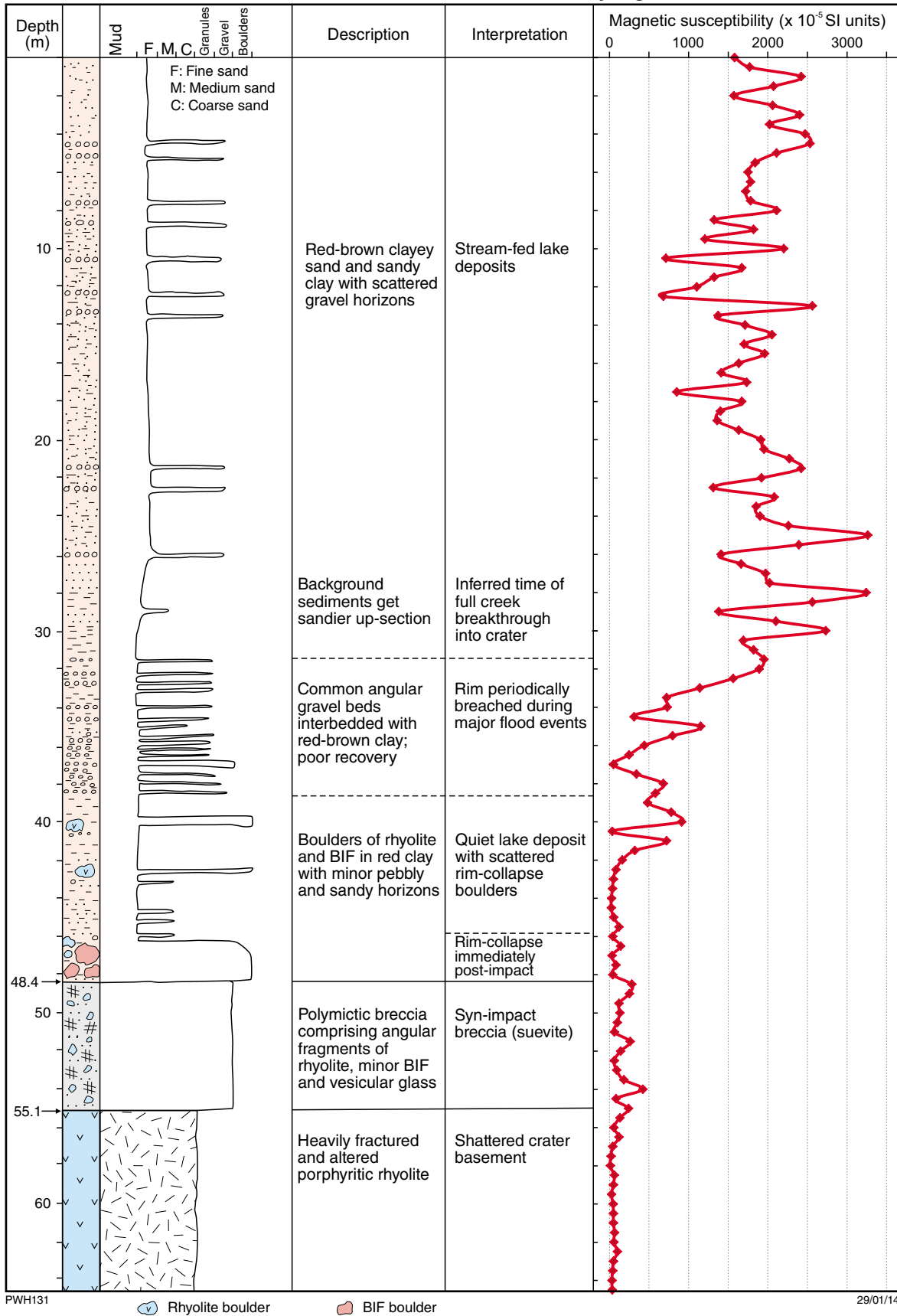


Figure 3. Lithological log of the Hickman Crater drillcore with basic descriptions, interpretations and magnetic susceptibility data (average spacing 0.5 m)

crater basement and boulders above the breccia, and with crater-fill clay and sand. Most notably, the enrichment in Ni, 295–2381 ppm, peaks about three orders of magnitude above background levels in Woongarra Rhyolite (<3 ppm, based on regional geochemical data; Trendall, 1995). Iridium ranges between 9 and 85 ppb in the same samples, but is below the 1 ppb detection limit in all samples outside the melt-bearing breccia (typical continental crust averages about 0.022 ppb Ir; Koeberl, 2007). PGE inter-element ratios are much closer to those in meteorites than to those in continental crust. The enriched elements behave in a coherent way through the impact breccia, with maximum enrichment near the base, proportionally decreasing towards the top, with the exception of one sample. The geochemical results indicate significant contamination of the breccia by disseminated meteoritic material, confirming an impact origin. The Ni abundance is consistent with an iron meteorite projectile (irons average about 8% Ni by weight; Buchwald, 1975). Iron projectiles are the most common type to produce small simple craters, even though chondrites are much more common among meteorite falls; chondrites and other stony projectiles of this size range typically disintegrate in an atmospheric airburst (French, 1998; Collins et al., 2005). Preliminary calculations suggest a meteoritic contribution to the impact breccia of 0.4 – 3 wt%, assuming an iron projectile with an average Ni content and minimal post-impact Ni mobilization. The meteoritic content of the breccia is unusually high; meteoritic contamination in impact breccias is usually well below 1% by weight (Koeberl, 2007). A possible explanation involves significant atmospheric slowing of the relatively small projectile, which Glikson et al. (2008) estimated at about 10 m diameter. In larger and more energetic impacts, where the projectile retains most of its cosmic velocity, the majority of the projectile is vapourized, and only a very small component is retained in the crater rocks.

A sample of shattered rhyolite basement 10 cm beneath the impact breccia shows a weak enrichment in some of the above elements (although some PGE were below detection), using an analysis of the centre of a fresh unfractured (and presumably uncontaminated) rhyolite boulder above the impact breccia as a proxy for unaltered basement. This is consistent with the injection of a small meteoritic component into the basement at the instant of impact, or minor post-impact mobility of enriched elements downward from the impact breccia.

Quartz and other mineral grains in the crater basement and breccia show intense irregular and sub-planar fracturing, but lack the optically distinct planar deformation features (PDFs) that are diagnostic of shock metamorphism in larger, more energetic impact craters. Such planar deformation features in quartz start to form at shock pressures of around 10 GPa (French, 1998). The absence of PDFs may constitute further evidence for significant deceleration of the projectile by atmospheric drag, potentially reducing shock pressures on impact to below this critical level.

Summary

Hickman Crater drillcore reveals the typical succession expected of a relatively small simple impact crater. Although no definitive shock metamorphism was observed, the melt-bearing breccia shows strong enrichment in Ni, Co, Au and PGE with respect to the basement and infilling sediments. PGE inter-element ratios in the breccia are much more like those in meteorites than average continental crust, confirming a significant meteoritic component and hence an impact origin for the crater. The particularly high Ni content is consistent with an iron meteorite projectile, the most common projectile type in such small craters. The lack of shock metamorphism and unusually high meteoritic component of the breccia may be explained by significant atmospheric deceleration of a relatively small projectile prior to impact. Drilling of the Hickman Crater represents the first scientific drilling of a simple impact crater of this size (<1 km) in Australia, and one of very few worldwide.

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