# Impact Ejecta Horizon Within Late Precambrian Shales, Adelaide Geosyncline, South Australia

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**A solitary layer of shattered crustal rock fragments has been traced over a distance of 260 kilometers within folded 600-million-year-old Precambrian marine shales of the Adelaide Geosyncline, South Australia. The fragments consist entirely of acid to intermediate volcanics (approximately 1575 million years old) displaying shattered mineral grains, shock lamellae in quartz, and small shatter cones. Fragments reach 30 centimeters in diameter and show evidence of vertical fall emplacement. Available evidence points to derivation of the rock fragments from a distant hypervelocity impact into the Gawler Range Volcanics at Lake Acraman, approximately 300 kilometers west of the Adelaide Geosyncline.**

THE IMPACT OF LARGE METEORITES and comets with the earth has been keenly researched and the geological and biological implications widely discussed (*1*). Most research has centered on the actual impact craters or their circular remnants of shattered rock (astroblemes). Impact ejecta are less commonly preserved, but include meteorite fragments, proximal impact breccia and glass, widely dispersed tektites, and possible worldwide chemical anomalies. We report the discovery of a widespread layer of shattered rock fragments ejected from a hypervelocity impact 250 to 300 km away. The ejecta layer occurs within folded late Precambrian marine shales approximately 600 million years (m.y.) old. To our knowledge, this is the first record of widely dispersed coarse impact ejecta preserved in a pre-Cenozoic sedimentary sequence.

In our search for datable volcanic material within the Adelaide Geosyncline, we discovered a coarse debris layer consisting of clasts of a relatively uniform volcanic lithology. The outcrop of the layer extends at least 160 km from north to south, and discovery of the same layer in a drill core extends its known occurrence another 100 km to the northwest (Fig. 1). It occurs on average about 80 m above the base of the Bunyeroo Formation (Fig. 2), a marine shale unit some 400 m thick. The debris horizon has only been observed near the western margin of available outcrop, suggesting a westerly source.

The Bunyeroo Formation generally consists of maroon and green clay shales, with minor concretionary carbonates. These shales were deposited from suspension below wavebase, following a regional transgression marking the start of the last Precambrian sedimentary cycle (*2*). Some coarse gravel and sand lenses occur in the vicinity of paleo-islands, but this locally derived material is polymict and petrographically distinct from the debris layer. Hence, this layer represents an unusual event in the otherwise quiet marine environment of the Bunyeroo Formation.

The debris layer varies from 0 to 40 cm in thickness, but is usually less than 10 cm thick. It is enveloped by green shales averaging 1 m in thickness. The layer is well developed near Bunyeroo Gorge (Fig. 1), where it has the following internal stratification (Fig. 3). Layer 1 is a basal layer of poorly sorted, angular, coarse, sand-sized grains and sparse, angular to subrounded blocks, the largest collected being 30 cm in diameter and weighing 6.4 kg. All blocks and most finer fragments were apparently derived from a single rock type, a pink to red porphyritic volcanic of dacite to rhyodacite (and rarely rhyolite) composition. The largest fragments are impressed into the underlying shale, suggesting a dropstone or vertical fall origin. Layer 2 is a thin green shale drape containing scattered sand-sized fragments. Layer 3 is a thin graded layer of finer sand-sized fragments, which also drapes the larger fragments of layer 1. Layer 4 is a lenticular layer of sand usually less than 10 cm thick, but locally reaching a maximum of 40 cm, showing multiple grain-size grading, cross-bedding, and occasional current ripples. This composite layer is separated from the underlying debris by a thin shale parting. The interpreted current direction is toward the east to northeast, similar to the interpreted depositional paleoslope of the overlying Wonoka Formation in this area.

In thin section, the larger fragments consist of 35 to 45% phenocrysts set in a finer devitrified groundmass. The phenocrysts are mainly feldspars with plagioclase dominant, lesser mafic minerals (altered largely to chlorite), opaques, and rare quartz. Most mineral grains display reticulate fracturing, with fractures showing offset of plagioclase twin lamellae and grain boundaries (Fig. 4A). In some specimens up to 90% of quartz phenocrysts exhibit multiple sets of planar features of the type described as shock-induced deformation lamellae from known impact structures (Fig. 4B) (*3*). Two sets are most common but up to four sets have been observed in a single grain. Examination of numerous grains within one quartz-rich clast revealed sets parallel to the $\omega\{10\bar{1}3\}$,

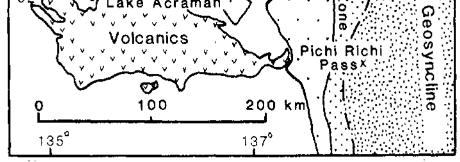
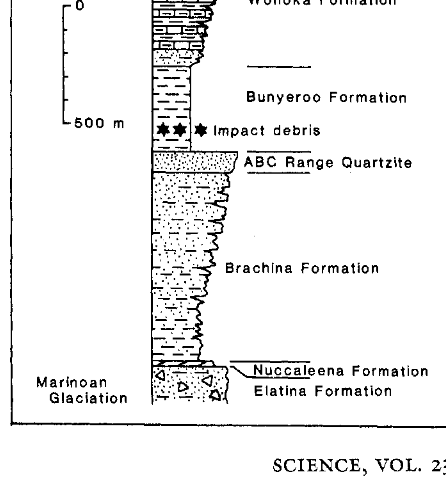



Fig. 1 (left). Locality map showing outcrop areas of impact ejecta within sediments of the Adelaide Geosyncline. The impact ejecta layer has also been recognized in drill core WMC WWD 1. The Lake Acraman impact structure is favored as the impact site for the described ejecta (*9*). Fig. 2 (right). Partial stratigraphic section of late Precambrian sediments exposed along the western margin of the central Adelaide Geosyncline, showing the position of the impact debris layer within shales of the Bunyeroo Formation.

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$\xi\{11\bar{2}2\}$ and $\{22\bar{4}1\}$ crystallographic directions, with the greatest concentration around $\omega\{10\bar{1}3\}$. These lamellae directions are characteristic of type C shock deformation of quartz, which indicates shock pressures of approximately 150 kbar (*4*). Hypervelocity impact is the only known natural mechanism capable of producing such shock pressures. Lamellae are also present in fine-grained quartz within the devitrified groundmass, indicating that shock deformation postdated devitrification, and are sometimes observed within feldspars and other mineral grains. Some hand specimens are intensely fractured, and one 12-cm block shows small shatter cones on a fractured surface (Fig. 5).

The enclosing Bunyeroo Formation was deposited about 600 m.y. ago (*5*). However, U-Pb dating by the ion microprobe SHRIMP of single euhedral zircons separated from one large dacite clast gives an age of $1587 \pm 52$ m.y. for all grains combined, or $1558 \pm 28$ m.y. if one apparently older grain is excluded as a probable xenocryst. Euhedral zircons from sand-sized debris at two other localities give ages of $1578 \pm 12$ m.y. and $1556 \pm 53$ m.y., respectively. These ages contrast both with the age of sedimentation and with $1135 \pm 25$ m.y. for the majority of abraded detrital zircons found elsewhere within the Bunyeroo Formation (*6*). The age of the dacite fragments is similar to that of the youngest presently exposed unit of the Gawler Range Volcanics (Yardea Dacite), most recently dated at $1592 \pm 2$ m.y. (*7*), although earlier results indicated somewhat younger ages. The Yardea Dacite is petrographically similar to clasts from the debris layer. The Gawler Range Volcanics were exposed to the west of the Adelaide Geosyncline during the late Precambrian (*8*); however, because of subsequent erosion, ages from present outcrops of these volcanics are expected to be somewhat older than ages obtained from ancient debris.

Several possible mechanisms of transport may account for the presence of coarse debris within shales. These include rock-fall from a nearby escarpment, debris flow, fluvial transport, ice rafting, cryptovolcanic ejection, and meteorite impact ejection. The lateral extent and thinness of the layer precludes the rock-fall, debris flow, and fluvial mechanisms. The dropstone character of large clasts also argues against the fluvial and debris flow modes of emplacement. The solitary nature of the layer, its monomict lithology, and the absence of glacial sculpturing of the larger fragments does not support the ice rafting hypothesis. The isotopic age of the clasts, far in excess of the age of the enclosing shales, militates against a

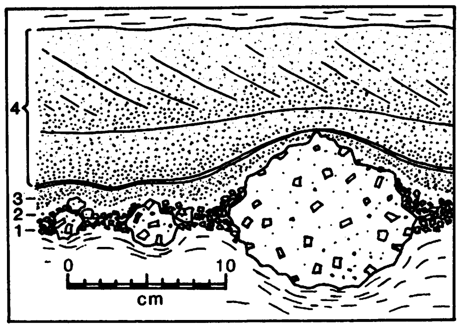


Fig. 3. Sketch of representative section through impact ejecta layer, Bunyeroo Gorge area.

penecontemporaneous volcanic source. Furthermore, none of the larger fragments display volcanic bomb features, and shards characteristic of volcanic tuff layers are absent from the finer debris. The only mechanism that can satisfactorily account for all the sedimentological observations is the subaqueous deposition of ejecta derived from a hypervelocity impact on dacites similar to those of the Gawler Range Volcanics west of the Adelaide Geosyncline. An impact origin is further supported by the intense fracturing and shock metamorphism of the debris.

An impact origin permits interpretation of the internal structure of the debris horizon (Fig. 3) in the following way. Layer 1 was deposited by vertical fall of ballistic ejecta through the water column shortly after impact. Layer 2 probably represents resettling of sea-floor sediments put into suspension by seismic waves propagating from the impact and disturbance by infall of coarse debris. Layer 3 represents finer impact debris which took longer to settle

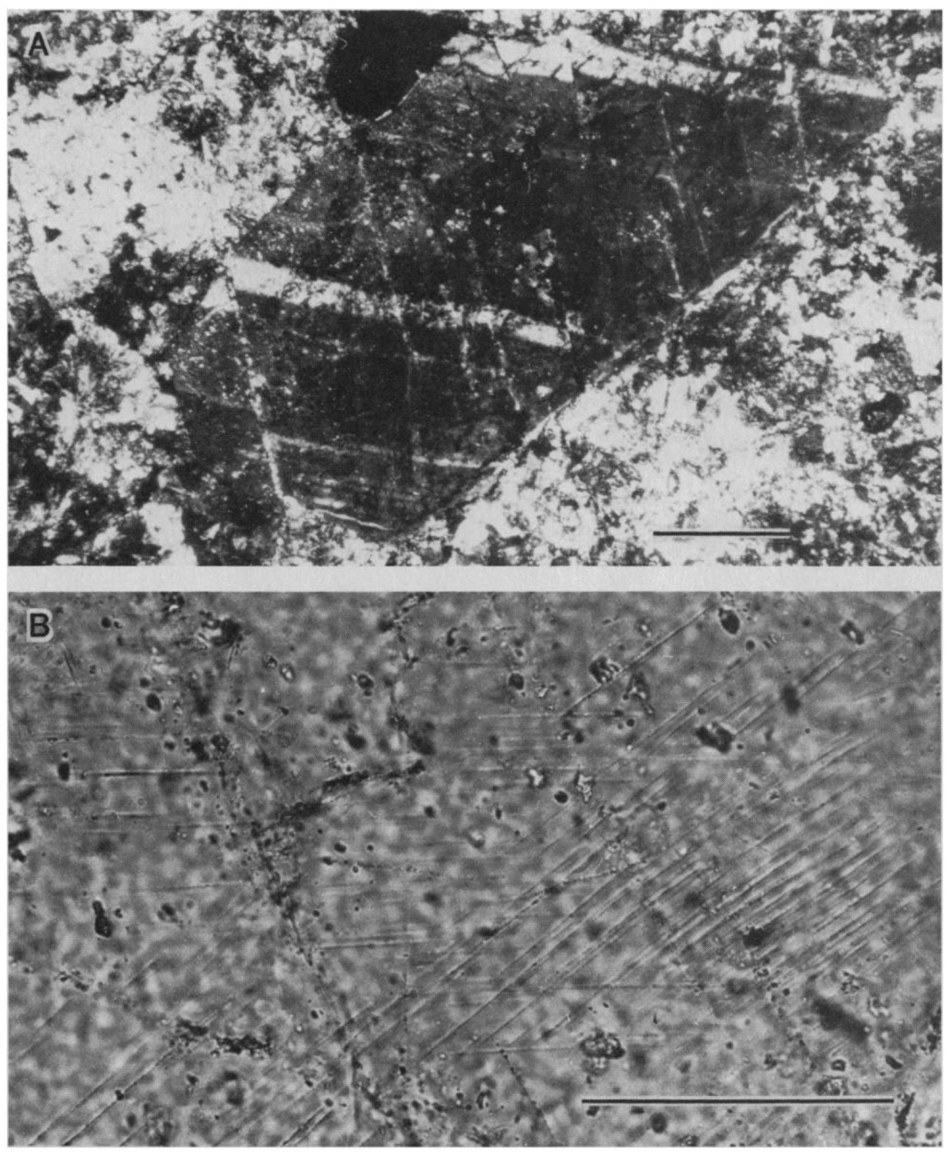


Fig. 4. Photomicrographs of thin sections of coarse impact debris showing (A) a fractured feldspar grain with repeated displacement of twin lamellae and grain boundary (scale bar, 0.5 mm); (B) two sets of shock-induced lamellae in quartz, both parallel to $\omega\{10\bar{1}3\}$ (scale bar, 100 μm).

through the atmosphere and water column. Layer 4 was deposited by traction currents, possibly in distinct episodes, at an undetermined time after impact. It represents proximal debris reworked into distal areas by storms or turbidity currents. Recognition of the ejecta has been facilitated by the timing and location of the impact. Had the debris been ejected into a vigorous sedimentary environment, such as characterizes many of the formations in the Adelaide Geosyncline, mixing with surrounding sediments would have masked its distinctive character. Likewise, impact into an area of diverse lithologies would have hindered recognition of this event.

In attempting to locate the site of impact in the Gawler Range Volcanics, our attention was drawn through discussions to the large circular structure now occupied by the sand-plain and salt-lake depression of Lake Acraman (Fig. 1). This major impact structure, the largest known in Australia, was independently discovered by G. E. Williams (*9*). Rocks from the impact site match the ejecta fragments described, even though the present land surface at Lake Acraman is below that of the original crater floor. Lake Acraman lies 300 km west of Bunyeroo Gorge, the locality where the largest fragments have been recorded. This would have been a minimum distance at the time of impact because subsequent folding and thrust faulting within the Adelaide Geosyncline would have shortened the crust between these sites, possibly by tens of kilometers.

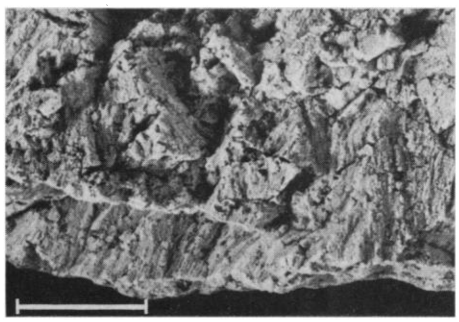

Fig. 5. Photograph of small shatter cones on a fractured surface of a 12-cm dacite fragment collected from the base of the impact ejecta horizon north of Bunyeroo Gorge (scale bar, 1 cm).

The Bunyeroo ejecta horizon represents an ancient widely dispersed ejecta blanket of known source which can provide valuable information on the nature and effects of large terrestrial impacts.


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6. For a detailed discussion of the isotopic dating, see W. Compston, I. S. Williams, R. J. F. Jenkins, V. A. Gostin, P. W. Haines, in preparation.
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8. The presence of clasts derived from the Gawler Range Volcanics in the glacial Elatina Formation (Fig. 2) indicates that these rocks were exposed during the late Precambrian. During the time of deposition of the Bunyeroo Formation, these volcanics did not crop out further east of their present margin because a cover of late Precambrian sediment was already present on the Stuart Shelf. The Gawler Range Volcanics could have extended further north, west and south of their present outcrop.
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# The Acraman Impact Structure: Source of Ejecta in Late Precambrian Shales, South Australia


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**A major probable impact structure occurs in middle Proterozoic dacitic volcanics in the Gawler Ranges, central South Australia. The structure has an inner depressed area about 30 kilometers in diameter that contains the Lake Acraman salina, an intermediate depression or ring about 90 kilometers in diameter, and a possible outer ring approximately 160 kilometers in diameter. Outcrops of dacite in Lake Acraman are intensely shattered and contain shatter cones and multiple sets of shock lamellae in quartz grains. The Acraman structure is the largest probable impact structure known in Australia and is the likely source of dacitic ejecta found in late Precambrian marine shales some 300 kilometers to the east.**


THE ACRAMAN STRUCTURE IN THE Gawler Ranges, South Australia, is the largest probable impact structure known in Australia (*1*) and the likely source of coarse, shock-metamorphosed ejecta found in late Precambrian shales some 300 km away (*2*). The linking of a large terrestrial circular structure with widely dispersed coarse ejecta may throw light on ejecta dynamics and transport and provide other data valuable to meteoritics.

Lake Acraman (latitude 32°01′S, longitude 135°26′E) is a hexagonal-shaped salina (elevation 133 to 138 m) about 20 km in diameter (Figs. 1 and 2) surrounded by a roughly circular alluvial depression (elevation, 140 to 200 m) about 30 km across. The principal lithological unit in the region is the coarsely porphyritic Yardea Dacite which, with minor rhyodacites, rhyolites, and basalts, constitutes the middle Proterozoic Gawler Range Volcanics, about 1590 million years old (*3*). The Yardea Dacite is the uppermost layered member of the Gawler Range Volcanics and has a thickness of at least 250 m. Around the Acraman depression the dacite forms prominent ridges and hills that rise up to about 280 m above the bed of the lake. This high ground, as defined by the generalized 200-m contour, forms a broad "horseshoe" with a full width of about 90 km that opens to the west-northwest (Fig. 1). The elevated terrain is bordered to the east and northeast by the arcuate western margin of the Lake Gairdner salina; to the southeast and south it is traversed by a broadly arcuate depression about 2 to 4 km wide and about 75 km long, termed here the "Yardea corridor."

The geomorphological elements around Lake Acraman suggest a multiringed structure with Lake Acraman at its center. The Yardea corridor marks an intermediate ring about 90 km in diameter, and a possible outer ring 150 to 160 km in diameter is suggested by the eastern margin of Lake Gairdner and the southern limit of the


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