Cadernos Lab. Xeolóxico de Laxe
Coruña. 2010. Vol. 35, pp. 209 - 220 ISSN: 0213-4497

Geomorphology of the Acraman impact structure, Gawler Ranges, South Australia

WILLIAMS, G.E.[1] and GOSTIN, V.A. [1]

(1) Discipline of Geology and Geophysics, School of Earth and Environmental Sciences, University of Adelaide, SA 5005, Australia

Abstract

The late Neoproterozoic Acraman impact structure occurs mostly in felsic volcanic rocks (Mesoproterozoic Gawler Range Volcanics) in the Gawler Ranges, South Australia, and strongly influences the topography of the region. The structure is expressed topographically by three main features: a near-circular, 30 km diameter low-lying area (Acraman Depression) that includes the eccentrically placed Lake Acraman playa; a partly fault-controlled arcuate valley (Yardea Corridor) at 85–90 km diameter; and arcuate features at 150 km diameter that are visible on satellite images. Geological and geomorphological observations and apatite fission-track data indicate that Acraman is eroded several kilometres below the crater floor, with the structure originally comprising a transient cavity about 40 km in diameter and a final structural rim 85–90 km in diameter. Ejecta of shock-deformed fragments of felsic volcanic rock up to 20 cm across derived from the Acraman impact form an extensive horizon ≤40 cm thick in Ediacaran (about 580 Ma) shale in the Adelaide Geosyncline 240–370 km to the east of the impact site. A correlative band ≤7 mm thick of sand-sized ejecta occurs in mudstone in the Officer Basin up to 540 km to the northwest of Acraman. The dimensions of the impact structure and the geochemistry of the ejecta horizon imply that the bolide was a chondritic asteroid >4 km in diameter. Acraman ranks among the largest 4% of known terrestrial impact structures, and the impact would have severely perturbed the Ediacaran environment.

Key words: Gawler Ranges, South Australia, Gawler Range Volcanics,
meteorite impact, geomorphology

INTRODUCTION AND GEOLOGICAL SETTING

The EARTH IMPACT DATABASE (2009) lists 176 craters and impact structures (eroded craters) caused by the impact of meteorites, asteroids and comets with the Earth. Acraman is the largest confirmed impact structure in Australia and ranks equal sixth largest in the world. This paper describes the geomorphology of Acraman, highlighted by satellite and digital terrain images, and discusses its erosional history and palaeoenvironmental effects.

The Acraman impact structure (WILLIAMS, 1986, 1987, 1994; WILLIAMS et al., 1996; WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005) occurs in the Gawler Range Volcanics, a Mesoproterozoic continental suite of mostly felsic lavas and ash flows (GILES, 1988; ALLEN et al., 2003) on the Gawler Craton, South Australia (figure 1). Acraman is underlain almost entirely by the 1592 ± 2 Ma Yardea

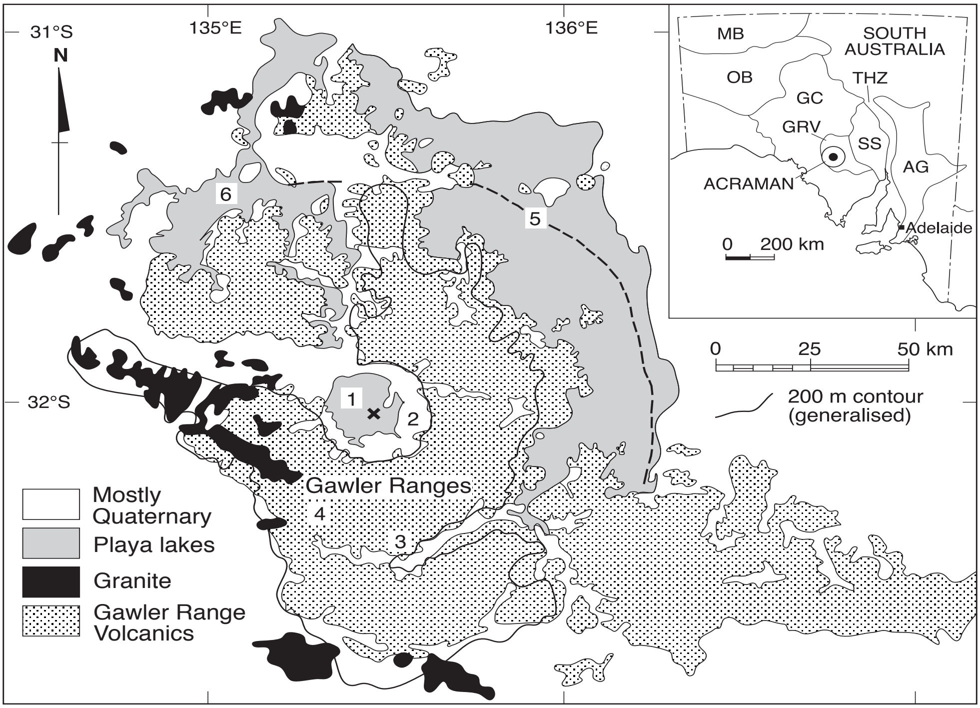

Fig. 1. Geological map of the Gawler Ranges, South Australia, showing the 1.59 Ga Gawler Range Volcanics and related granites of the Hiltaba Suite. 1, Lake Acraman; 2, Acraman Depression; 3, Yardea Corridor; 4, area of closely jointed Gawler Range Volcanics; 5, Lake Gairdner, with dashed line marking an arcuate topographic feature at 150 km diameter conspicuous on Landsat scenes (Figure 2; DOUGLAS, 1980); 6, Lake Everard. The cross (×) in Lake Acraman marks the position of a central dipolar magnetic anomaly (SCHMIDT and WILLIAMS, 1996; WILLIAMS et al., 1996). Inset: AG, Adelaide Geosyncline; THZ, Torrens Hinge Zone; SS, Stuart Shelf; GRV, Gawler Range Volcanics; GC, Gawler Craton; OB, Officer Basin; MB, Musgrave Block.

Dacite (FANNING et al., 1988; CREASER and WHITE, 1991; PARKER and FLINT, 2005), the uppermost and most extensive formation of the Gawler Range Volcanics. The Yardea Dacite is flat-lying and crops out within an area of 12,000 km^2; it has an exposed thickness of 250 m but is likely much thicker in the subsurface. An unknown amount has been removed by erosion. Low islands of Yardea Dacite in the southeastern part of Lake Acraman near the centre of the impact structure display classic features of shock metamorphism, including planar deformation features (PDFs) in quartz grains that indicate shock pressures of up to 15 GPa, shatter cones, intense brecciation, and melt rock (WILLIAMS, 1986, 1994).

The age of the impact is constrained by stratigraphy. Acraman is the source of an ejecta horizon 0–40 cm thick of shock-deformed, sand-sized material and fragments of felsic volcanic rock up to 20 cm across that occurs widely in shale 40–80 m above the base the 400 m thick Bunyeroo Formation in the Adelaide Geosyncline (now represented by folded strata of the Flinders Ranges) 240–370 km to the east of Acraman. The ejecta horizon also occurs as thin (0–7 mm) bands of sand-sized volcanic rock fragments in the correlative Dey Dey Mudstone in the Officer Basin up to 540 km to the west of the impact site (GOSTIN et al., 1986, 1989; WALLACE et al., 1989, 1990, 1996; WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005; HILL et al., 2004, 2007). Palaeomagnetic data for the Bunyeroo Formation and melt rock from Acraman, together with modelling of the subsurface source of the dipolar magnetic anomaly at the centre of Acraman (SCHMIDT and WILLIAMS, 1991, 1996; WILLIAMS et al., 1996) and zircon U–Pb geochronology of the ejecta material (COMPSTON et al., 1987), support correlation of Acraman and the ejecta horizon in the Bunyeroo Formation. The Bunyeroo Formation and Dey Dey Mudstone are of late Neoproterozoic age and assigned to the recently established Ediacaran System and Period, which has its Global Stratotype Section and Point (GSSP) in the central Flinders Ranges (KNOLL et al., 2004, 2006). Rb–Sr whole-rock dating of Ediacaran strata in the Adelaide Geosyncline (COMPSTON et al., 1987) and the Neoproterozoic time-scale of WALTER et al. (2000) suggest an age of about 580 Ma for the Bunyeroo Formation, which is a best estimate for the age of the Acraman impact.

An apatite fission-track apparent age of 319 ± 19 Ma was obtained for shattered Yardea Dacite from the centre of Acraman (WILLIAMS, 1994; WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005). Assuming that the present geothermal gradient for the region can be applied to the past, the result suggests erosion of 2–5 km at the impact site since 320 Ma. KOHN et al. (2002) gave apatite fission-track data for the Gawler Craton, finding (p. 710) that the denudation chronology “shows a fairly uniform rate of ca 10 m per million years over the last 300 million years.” This implies about 3 km of erosion of the Gawler Craton since 300 Ma. KOHN et al. (2002, p. 703) stated, however, “if palaeogeothermal gradients were elevated at the time of a particular period of denudation compared to those of the present day then the magnitude of denudation would be lower (as would the calculated long-term denudation rate).” A more conservative interpretation of the apatite fission-track data, using a possible higher palaeogeothermal gradient for the Gawler Cra-

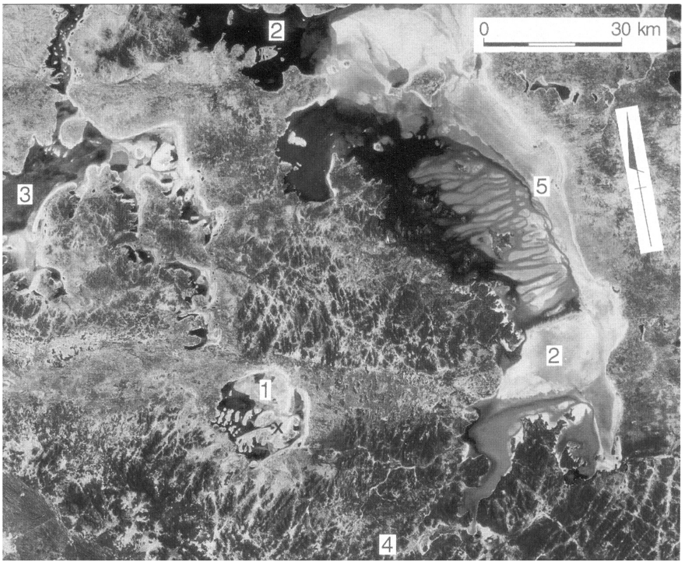

Fig. 2. Landsat scene covering most of the Acraman impact structure, showing: 1, Lake Acraman within the Acraman Depression; 2, Lake Gairdner; 3, Lake Everard; 4, the Yardea Corridor at 85–90 km diameter. Surface water (darker tone) in Lake Gairdner helps define an arcuate trend (5) at about 150 km diameter that continues westward to Lake Everard. Crosses mark the location of the dipolar magnetic anomaly at the centre of the Acraman structure; shattered and shock-deformed Yardea Dacite is exposed in adjacent islands. (Landsat scene 15 February 1973, scene centre S31-30 E135-51; seen also in issue cover illustration.)

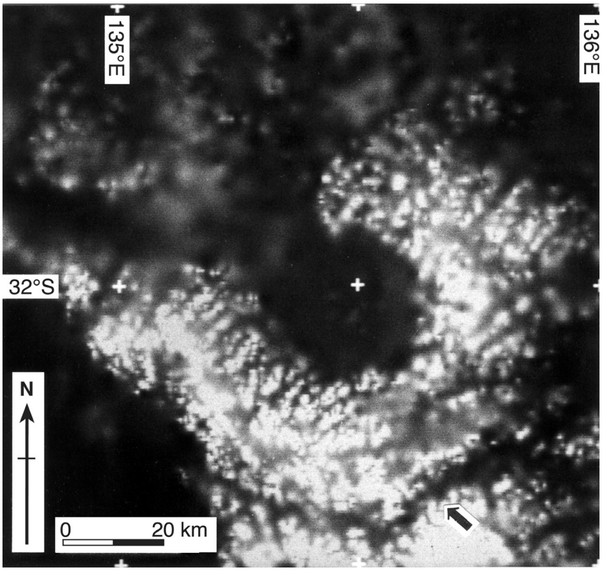

Fig. 3. Digital elevation image (light tone = high elevations, dark tone = low elevations) of the Gawler Ranges, showing Lake Acraman (133–138 m elevation) and the Acraman Depression (140–200 m) surrounded by more elevated country (up to 450 m) and the Yardea Corridor (arrow). Scale bar 20 km. (Image derived from data supplied by the Australian Surveying and Land Information Group (AUSLIG), Canberra, Australian Capital Territory).

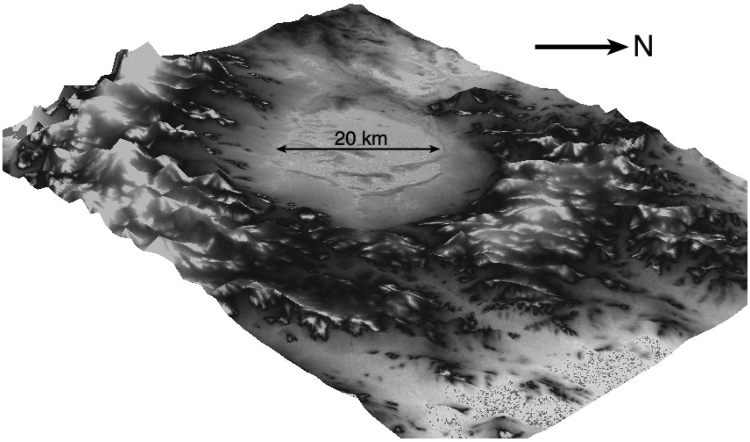

Fig. 4. Digital terrain image with viewer looking obliquely northwest over Lake Acraman (20 km across, 133–138 m elevation) and the Acraman Depression (30 km diameter, 140–200 m elevation) within the Gawler Ranges, which attain elevations of 430–450 m south of Lake Acraman and 300–330 m north of the Lake. (Image by courtesy of Malcolm Wallace).

ton in the late Palaeozoic, suggests as much as 2 km of erosion of the Acraman impact structure since 320 Ma (WILLIAMS, 1994; WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005).

GEOMORPHOLOGY

The main topographic features of the Gawler Ranges region up to 150 km from the centre of Acraman and beyond are shown in Landsat scenes (figure 2; DOUGLAS, 1980) and also revealed by digital terrain images (figures 3 and 4). A National Oceanographic and Atmospheric Administration (NOAA) satellite thermal infra-red night image of central South Australia (figure 5) shows Acraman and its relation to principal ejecta sites in the Bunyeroo Formation in the Flinders Ranges to the east.

The climate of the region is semi-arid, with mean annual rainfall of <300 mm within the Gawler Ranges (PARKER and FLINT, 2005). Maximum daily temperatures near 40°C are common in the summer months. Vegetation on hills within the Gawler Ranges includes mulga, wattle, mallee, black oak, and spinifex, and in the wider valleys is mostly bluebush and saltbush with scattered clumps of trees.

Lake Acraman (20 km diameter, elevation 133–138 m) is a playa lake eccentrically placed within a near-circular low-lying area 30 km across, termed the Acraman Depression (140–200 m elevation). The Depression is ringed on most sides by the Gawler Ranges that rise up to 300 m above the lake bed. This elevated ground, as outlined by the generalised 200 m contour (figure 1), forms an annulus 25–30 km wide that is breached in the northwest. The Gawler Ranges are flanked to the east and north by a low-lying area that includes Lake Gairdner, a highly saline playa or salina (113–121 m). The Lake

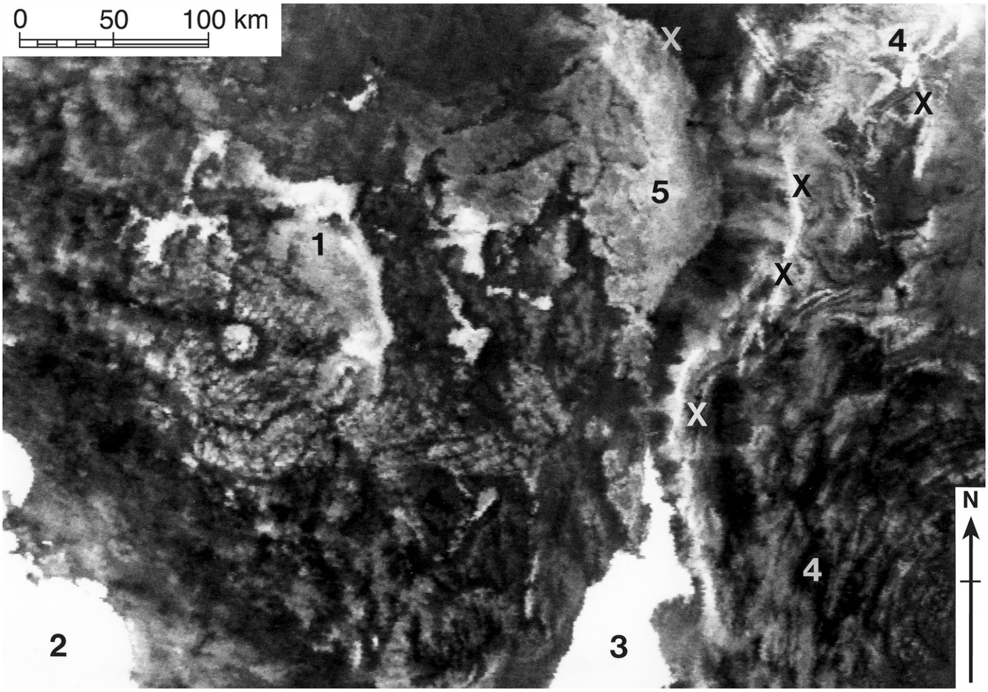

Fig. 5. NOAA satellite thermal infra-red night image of central South Australia. 1, Lake Gairdner; 2, Great Australian Bight; 3, Spencer Gulf; 4, Flinders Ranges; 5, Lake Torrens. Acraman forms a conspicuous concentric structure west of Lake Gairdner. The Acraman Depression at 30 km diameter and the Yardea Corridor at 85–90 km diameter appear cool (darker tone). Arcuate features at 150 km diameter comprise the southern limit of the Gawler Ranges south of Lake Acraman and a line running through Lake Gairdner. Crosses mark principal ejecta localities in the Flinders Ranges. NOAA9-AVHRR Band 3, Orbit no. 2246, 21 May 1985, 2200 hours. (Image geometrically corrected; Lambert conic conformal projection).

Everard and Lake Harris playas (121–124 m) occur to the northwest. The Gawler Ranges are bordered on the south and west by irregular terrain (90–200 m) marked by granite inselbergs, quartzose longitudinal (seif) dunes, and saline and gypsiferous playa lakes (TWIDALE and CAMPBELL, 1985; PARKER and FLINT, 2005).

The topography of the Gawler Ranges reflects several erosional cycles since the Mesozoic and the strong influence of bedrock structure. The Nott Surface (TWIDALE et al., 1976; CAMPBELL and TWIDALE, 1991) — a high-level summit surface of Cretaceous age — rises to 430–450 m south of Lake Acraman and 300–330 m north of the Lake. This feature was initiated by weathering of a peneplain in the Jurassic; northward tilting of the peneplain during the Early Cretaceous was followed by stripping of the Jurassic regolith to form the Nott Surface as an etch surface (CAMPBELL and TWIDALE, 1991). The Nott Surface is now dissected to depths of 250 m below summit levels in the Gawler Ranges south of Lake Acraman and to depths of 150 m north of the Lake.

The surface of the Acraman Depression slopes inward from an elevation of 180–200 m at the base of the Gawler Ranges to 140 m near the edge of Lake Acraman. The Depression is floored by brecciated and weathered Yardea Dacite mantled by Miocene–?Early Pliocene silcrete and ferruginous duricrust and Pleistocene–Holocene colluvium, alluvium and calcrete (BLISSETT et al., 1988). This duricrusted plain is similar to late Tertiary surfaces flooring valleys elsewhere on the Gawler Craton (TWIDALE et al., 1976; HOU et al., 2003). During the Tertiary, drainage from the Acraman Depression had an outlet via the low-lying country (≤150 m elevation) northwest of Lake Acraman (figures 1, 2 and 3).

The bed of Lake Acraman is ≤6 m lower than the level of the immediately adjacent plain. An observer on the Lake viewing the distant Gawler Ranges has the impression of being within a vast amphitheatre (figure 6). Like many other playa lakes in southern Australia, Lake Acraman developed by aeolian deflation during Pleistocene arid intervals (BOWLER, 1986). The Lake is now a closed basin where saline ground waters emerge, and is floored by damp, gypsiferous clays that in many places are veneered by a thin (millimetre) crust of halite. Through the action of prevailing westerly winds during the late Pleistocene, sandy clay and fine-grained gypsum blown from the dry lake bed were built into a series of mostly transverse gypsiferous dunes (or “kopi”) rising up to 30 m above the lake bed on the upwind (western and northwestern) margins of the islands of shattered dacite in the southeastern part of Lake Acraman. By the same mechanism, a crescentic dune or “lunette” (BOWLER,

Fig. 6. View across the halite encrusted bed of Lake Acraman toward the distant Gawler Ranges on the skyline.

1968; CAMPBELL, 1968) that rises up to 25 m above the lake bed formed at the eastern and southeastern margins of the Lake.

Joints and structural lineaments in the Gawler Range Volcanics have strongly influenced the dissection of the Nott Surface. The dominant trend of joint-controlled valleys in the Yardea Dacite is northeast–southwest, with other trends between north–south and northwest–southeast. In addition, several linear valleys or structural corridors 3–10 km wide, marked by subdued exposures of bedrock and small depressions with playa lakes, traverse the Gawler Ranges. Two such lineaments intersect at the palaeodrainage outlet northwest of Lake Acraman (figures 2 and 5). The joint and fracture patterns in the Gawler Range Volcanics are of great antiquity, having influenced the weathering and morphology of a palaeosurface buried by Mesoproterozoic (1400 Ma) sandstone in the eastern Gawler Ranges (CAMPBELL and TWIDALE, 1991).

The Yardea Corridor 30 km south of the Acraman Depression (WILLIAMS, 1986, 1994) consists of several near-linear valleys up to 3 km wide that extend for at least 70 km roughly parallel to the southern margin of the Depression (figures 1, 3 and 5). A fault borders the Yardea Corridor for 35 km (BLISSETT, 1987; BLISSETT et al., 1988). The history of this fault is uncertain, but it may be an ancient structure that was reactivated by the Acraman impact.

ACRAMAN IMPACT EVENT

Original crater dimensions

The volcanic bedrock beneath the Acraman Depression is strongly brecciated and jointed, rendering it susceptible to weathering and erosion. Furthermore, there is neither geological nor geophysical evidence that the Depression is bordered by faults that might mark the boundary of the transient cavity or excavated area that formed immediately after the impact. These observations, and the >2 km of erosion subsequent to the impact, imply that the 30 km diameter Acraman Depression provides only a minimum estimate of the extent of the transient cavity. A transient cavity diameter of up to 40 km is consistent with the geological, geomorphological and apatite fission-track data (WILLIAMS, 1994). The plot of ejecta thickness versus distance from the centre of Acraman accords with a transient cavity diameter of 40 km (WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005).

The final structural rim marking the extent of the collapse crater may be marked by the partly fault-controlled Yardea Corridor at 85–90 km diameter (Figs. 1, 3 and 5). Arcuate features at about 150 km diameter that are visible on satellite images (Figs. 1, 2 and 5) may mark the outer limit of disturbance beyond the final structural rim. GRIEVE (2001) and the EARTH IMPACT DATABASE (2009) give the diameter of Acraman as 90 km, placing it among the largest 4% of known terrestrial impact structures.

Environmental effects

The anomalous platinum group element geochemistry of the ejecta horizon in the Bunyeroo Formation suggests that the bolide was a chondritic asteroid (GOSTIN et al., 1989; WALLACE et al., 1990) which could have been >4 km in diameter (WILLIAMS, 1994). The estimated impact energy of 5.2×10^6 Mt (megatons TNT) for an impact structure the size of Acraman exceeds the threshold of 10^6 Mt nominally set by others for global catastrophe (TOONE et al., 1997), and the impact probably caused a severe perturbation of the Ediacaran environment (WILLIAMS and WALLACE, 2003; WILLIAMS and GOSTIN, 2005). The occurrence of the impact at a palaeolatitude of 12.5 +7.1/–6.1° (SCHMIDT and WILLIAMS, 1996; WILLIAMS and WALLACE, 2003) may have magnified the environmental effects by perturbing the atmosphere in both the northern and southern hemispheres (WILLIAMS and GOSTIN, 2005). These findings accord with data from the Ediacaran palynology of Australia and from isotope and biomarker chemostratigraphy suggesting that the Acraman impact induced major biotic change (GREY et al., 2003; GREY, 2005).

ACKNOWLEDGMENTS

Discussions with Peter Haines, Malcolm Wallace, Phil Schmidt and many other colleagues provided valuable insights during the course of the research. We thank Wallace for providing the image used in Figure 4.

REFERENCES

ALLEN, S. R., SIMPSON, C. J., McPHIE, J. and DALY, S. J. (2003). Stratigraphy, distribution and geochemistry of widespread felsic volcanic units in the Mesoproterozoic Gawler Range Volcanics, South Australia. *Australian Journal of Earth Sciences*, **50**: 97-112.

BLISSETT, A. H. (compiler) (1987). *Geological setting of the Gawler Range Volcanics*. Geological Atlas Special Series, 1:500,000. South Australian Department of Mines and Energy, Adelaide.

BLISSETT, A. H., PARKER, A. J. and CROOKS, A. F. (1988). *Yardea, South Australia.* Sheet SI 53-3, 1:250,000 Geological Series. South Australian Department of Mines and Energy, Adelaide.

BOWLER, J. M. (1968). Australian landform example 11. Lunette. *The Australian Geographer*, **10**: 402-404.

BOWLER, J. M. (1986). Spatial variability and hydrologic evolution of Australian lake basins: analogue for Pleistocene hydrologic change and evaporite formation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **54**: 21-41.

CAMPBELL, E. M. (1968). Lunettes in southern South Australia. *Transactions of the Royal Society of South Australia*, **92**: 85-109.

CAMPBELL, E. M. and TWIDALE, C. R. (1991). The evolution of bornhardts in silicic volcanic rocks in the Gawler Ranges. *Australian Journal of Earth Sciences*, **38**: 79-93.

COMPSTON, W., WILLIAMS, I. S., JENKINS, R. J. F., GOSTIN, V. A. and HAINES, P. W. (1987). Zircon age evidence for the Late Precambrian Acraman ejecta blanket. *Australian Journal of Earth Sciences*, **34**: 435-445.

CREASER, R. A. and WHITE, A. J. R. (1991). Yardea Dacite — large-volume, high-temperature felsic volcanism from the Middle Proterozoic of South Australia. *Geology*, **19**: 48-51.

DOUGLAS, J. (1980). *South Australia from Space*. Rigby, Adelaide.

Earth Impact Database (2009: updated 30 January 2009). http://www.unb.ca/passc/

ImpactDatabase/CIDiameterSort3.htm

FANNING, C. M., FLINT, R. B., PARKER, A. J., LUDWIG, K. R. and BLISSETT, A. H. (1988). Refined Proterozoic evolution of the Gawler Craton, South Australia, through U–Pb zircon geochronology. *Precambrian Research*, **40/41**: 363-386.

GILES, C. W. (1988). Petrogenesis of the Proterozoic Gawler Range Volcanics, South Australia. *Precambrian Research*, **40/41**: 407-427.

GOSTIN, V. A., HAINES, P. W., JENKINS, R. J. F., COMPSTON, W. and WILLIAMS, I. S. (1986). Impact ejecta horizon within late Precambrian shales, Adelaide Geosyncline, South Australia. *Science*, **233**: 198-200.

GOSTIN, V. A., KEAYS, R. R. and WALLACE, M. W. (1989). Iridium anomaly from the Acraman impact ejecta horizon: impacts can produce sedimentary iridium peaks. *Nature*, **340**: 542-544.

GREY, K. (2005). Ediacaran palynology of Australia. *Memoirs of the Association of Australasian Palaeontologists*, **31**.

GREY, K., WALTER, M. R. and CALVER, C. R. (2003). Neoproterozoic biotic diversification: "Snowball Earth" or aftermath of the Acraman impact? *Geology*, **31**: 459-462.

GRIEVE, R. A. F. (2001). The terrestrial cratering record. In: *Accretion of Extraterrestrial Matter Throughout Earth's History*. E. B. Peucker and B. Schmitz (Eds). Kluwer, New York, p. 379-402.

HILL, A. C., GREY, K., GOSTIN, V. A. and WEBSTER, L. J. (2004). New records of Late Neoproterozoic Acraman ejecta in the Officer Basin. *Australian Journal of Earth Sciences*, **51**: 47-51.

HILL, A. C., HAINES, P. W., GREY, K. and WILLMAN, S. (2007). New records of Ediacaran Acraman ejecta in drillholes from the Stuart Shelf and Officer Basin, South Australia. *Meteoritics and Planetary Science*, **42**: 1883-1891.

HOU, B., FRAKES, L. A., ALLEY, N. F. and CLARKE, J. D. A. (2003). Characteristics and evolution of the Tertiary palaeovalleys in the northwest Gawler Craton, South Australia. *Australian Journal of Earth Sciences*, **50**: 215-230.

KNOLL, A. H., WALTER, M. R., NARBONNE, G. M. and CHRISTIE-BLICK, N. (2004). A new period for the geologic time scale. *Science*, **305**: 621-622.

KNOLL, A. H., WALTER, M. R., NARBONNE, G. M. and CHRISTIE-BLICK, N. (2006). The Ediacaran Period: A new addition to the geologic time scale. *Lethaia*, **39**: 13-30.

KOHN, B. P., GLEADOW, A. J. W., BROWN, R. W., GALLAGHER, K., O'SULLIVAN, P. B. and FOSTER, D. A. (2002). Shaping the Australian crust over the last 300 million years: insights from fission track thermotectonic imaging and denudation studies of key terranes. *Australian Journal of Earth Sciences*, **49**: 697-717.

PARKER, A. J. and FLINT, R. B. (2005). *Yardea, South Australia. Sheet SI 53-3, 1:250,000 Geological Series – Explanatory Notes*. Primary Industries and Resources South Australia, Adelaide.

SCHMIDT, P. W. and WILLIAMS, G. E. (1991). Palaeomagnetic correlation of the Acraman impact structure and the Late Proterozoic Bunyeroo ejecta horizon, South Australia. *Australian Journal of Earth Sciences*, **38**: 283-289.

SCHMIDT, P. W. and WILLIAMS, G. E. (1996). Palaeomagnetism of the ejectabearing Bunyeroo Formation, late Neoproterozoic, Adelaide fold belt, and the age of the Acraman impact. *Earth and Planetary Science Letters,* **144**: 347-357.

TOON, O. B., ZAHNLE, K., MORRISON, D., TURCO, R. P. and COVEY, C. (1997). Environmental perturbations caused by the impacts of asteroids and comets. *Reviews of Geophysics*, **35**: 41-78.

TWIDALE, C. R., BOURNE, J. A. and SMITH, D. M. (1976). Age and origin of palaeosurfaces on Eyre Peninsula and the southern Gawler Ranges, South Australia. *Zeitschrift für Geomorphologie*, **20**: 28-55.

TWIDALE, C. R. and CAMPBELL, E. M. (1985). The form of the land surface. In: *Natural History of Eyre Peninsula*. C.R. Twidale, M.J. Tyler and M. Davies (Eds). Royal Society of South Australia, Adelaide, p. 57-76.

WALLACE, M. W., GOSTIN, V. A. and KEAYS, R. R. (1989). Discovery of the Acraman impact ejecta blanket in the Officer Basin and its stratigraphic significance. *Australian Journal of Earth Sciences*, **36**: 585-587.

WALLACE, M.W., GOSTIN, V.A. and KEAYS, R.R. (1996). Sedimentology of the Neoproterozoic Acraman impact-ejecta horizon, South Australia. *AGSO Journal of Australian Geology and Geophysics*, **16**: 443-451.

WALLACE, M.W., WILLIAMS, G.E., GOSTIN, V.A. and KEAYS, R.R. (1990). The Late Proterozoic Acraman impact – towards an understanding of impact events in the sedimentary record. *Mines and Energy Review South Australia*, **57**: 29-35.

WALTER, M. R., VEEVERS, J. J., CALVER, C. R., GORJAN, P. and HILL, A. C. (2000). Dating the 840–544 Ma Neoproterozoic interval by isotopes of strontium, carbon, and sulfur in seawater, and some interpretative models. *Precambrian Research*, **100**: 371-433.

WILLIAMS, G. E. (1986). The Acraman impact structure: source of ejecta in late Precambrian shales, South Australia. *Science*, **233**: 200-203.

WILLIAMS, G. E. (1987). The Acraman structure – Australia's largest impact scar. *Search*, **18**: 143-145.

WILLIAMS, G. E. (1994). Acraman: A major impact structure from the Neoproterozoic of Australia. *Geological Society of America Special Paper*, **293**: 209-224.

WILLIAMS, G. E. and GOSTIN, V. A. (2005). Acraman–Bunyeroo impact event (Ediacaran), South Australia, and environmental consequences: twenty-five years on. *Australian Journal of Earth Sciences*, **52**: 607-620.

WILLIAMS, G. E. and WALLACE, M. W. (2003). The Acraman asteroid impact, South Australia: magnitude and implications for the late Vendian environment. *Journal of the Geological Society of London*, **160**: 545-554.

WILLIAMS, G. E., SCHMIDT, P. W. and BOYD, D. M. (1996). Magnetic signature and morphology of the Acraman impact structure, South Australia. *AGSO Journal of Australian Geology and Geophysics*, **16**: 431-442.