NUMERICAL MODELLING OF THE FORMATION OF THE YALLALIE IMPACT STRUCTURE.
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Introduction: The Yallalie structure is located in the Perth Basin about 200 km north of Perth, Australia. It has recently been confirmed to be a 14-16 km complex impact crater [1]. The structure is buried below ~100-300 m of undisturbed sediments [2,3]. However, the allocthonous "Mungedar Breccia" [4], outcrops 4 km west of the buried structure (Fig. 1), and it is the only exposed geological unit known that is associated with the confirmed structure.

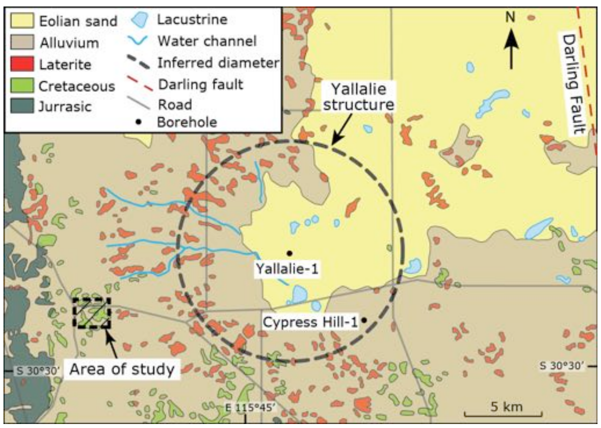

Fig. 1. Location and generalized geology of the area around the Yallalie structure (after [5]). The Mungedar breccia study area is located in the lower left.

Airborne magnetic surveys [2] reveal a 12-km diameter, circular feature consisting of concentric positive magnetic anomalies. These anomalies suggest the presence of a complex structure (Fig. 2).

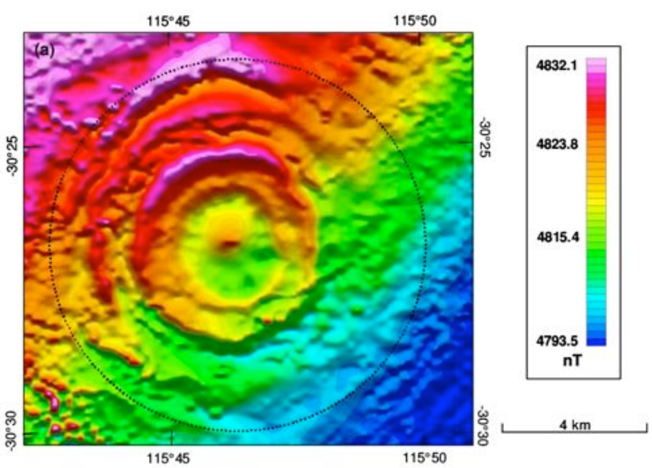

Fig. 2. Aeromagnetic anomaly map from [3].

Seismic surveys across the structure show a zone of disruption that extends to ~1500 m below the surface, with an abrupt contact between the structure and overlying, sedimentary units [2,3,5]. A small positive gravity anomaly of 30 gu [5] was detected based on north-south transects across the Yallalie structure, and is attributed to uplifted bedrock (Fig 3, and contours in Fig. 4).

Earlier works [i.e., 5] interpreted the Mungedar breccia as an allocthonous polymictic breccia that formed from material ejected during the Yallalie impact, even though no confirmed shocked minerals were documented at that time. A new study [1] has reported shocked quartz grains containing planar fractures (PFs) and planar deformation features (PDFs) in the Mungedar breccia. Furthermore, the estimated shock pressures of clasts in the Mungedar breccia range from unshocked, to 5-10 GPa based on quartz grains exhibiting PFs, and up to 10-20 GPa for quartz grains with PDFs.

Methods: The iSALE shock physics hydrocode [6-8] was used to model the formation of the Yallalie structure in order to predict (1) the geometry and distribution of shocked material that remains *in situ*, and (2) the relative proportions differently shocked ejecta material (or 'ejecta shock provenance') within the area of study in the Mungedar breccia.

The cell resolution in a 2D numerical mesh was 25 by 25 m. The projectile used in the simulation was 1.2 km in diameter, impacting Earth at 12 km/s vertical speed; this speed also represents faster speeds at moderately oblique impact angles (e.g., [9]). The impactor was modelled using a dunite analytical equation of state (ANEOS) [10], representative of a stony asteroid. The target was simulated using a granite ANEOS equation of state [11]. Although granite is not present among the target rocks where the Yallalie structure formed, it may more accurately represent the target rock mineralogy than monomineralic quartzite [1,12]. We acknowledge some level of uncertainty of the material properties of the Perth Basin target rocks at the time of the Yallalie structure formation, and further material models are being explored.

Results: Impact simulation of the Yallalie crater formation produced a good match with sub-surface structural maps from published seismic surveys and borehole stratigraphy [2,5] (Fig. 3). The simulation shows a central uplift that is approximately 4 km in diameter and vertically displaces stratigraphy by up to 2 km. The final crater depth is up to 1 km. Fault traces previously interpreted from seismic data match well with faults traces suggested by the simulation in Fig. 3. The iSALE simulation suggests that the crater rim diameter may be larger than previously estimated, about 14 km (if measured at pre-impact surface level) or a 16 km rim-to-rim diameter. The transient crater is approximately 10 km in diameter, assuming that the transient crater is reached at the moment of maximum excavation volume [e.g., 13].

The spatial distribution and shock-level provenance of material forming the ejecta deposit are calculated from the iSALE simulation (Fig. 3). The Mungedar Breccia sample site (Fig. 1) is located about 10 km away from the centre of the crater. In the iSALE simulation, the ejecta blanket geometry at the breccia sample site was taken to be 200 m wide and 100 m deep (as denoted by the grey box in Fig. 3).

Each numerical cell was tracked by a tracer particle noting the amout of mass it represented. Analysis of each tracer particle inside the grey box (Fig. 3) shows that the ejecta at this site is composed of 75% mass that is shocked to peak pressures lower than 5 GPa, 17% of mass shocked to 5-10 GPa, and 8% mass shocked to peak pressures above 10 GPa. Higher cell size resolution, larger number of tracers as well as variable tracer sample area caused up to 10% variation in the results of shocked material mass distribution; This confirmed the robustness of results.

Conclusions: The Mungedar Breccia is confirmed to be a product of impact due to the presence of shocked quartz grains. Impact simulation of the Yallalie crater formation also suggested Mungedar breccia to belong to the proximal ejecta.

Shock levels experienced by clasts in the breccia, as diagnosed through shock microstructures in quartz grains, are consistent with the results of modelled simulations of the ejecta blanket at the locations of the exposed breccia, relative to the impact structure.

References: [1] Cox, M.A. et al. (2018) *Meteorit. & Planet. Sci.*, under minor revision. [2] Hawke, P.J. et al. (2003) *ASEG Extended Abstracts* (2): 1–4. doi:10.1071/aseg2003ab066. [3] Hawke, P.J. (2004) *Ph.D. thesis*, University of Western Australia, Australia. [4] Bevan A. (2012) Field Excursion. Excursion Guidebook for the *75th Annual Meeting of the Meteoritical Society*, Cairns, Australia. [5] Dentith, M.C. et al. (1999) *Geological Magazine* 136 (6): 619–632. [6] Amsden, A.A. et al. (1980) *Report LA-8095*. Los Alamos National Laboratories, N. Mex. 105 pp. [7] Collins, G.S. et al. (2004) *Meteorit. & Planet. Sci.* 39, 217–231. [8] Wünnemann, K. et al. (2006) *Icarus* 180, 514–527. [9] Pierazzo, E. and Melosh, H.J. (2000) *Ann. Rev. Earth Planet. Sci.* 28, 141–16. [10] Benz, W. et al. (1989) *Icarus* 81, 113–131. [11] Pierazzo, E. et al. (1997) *Icarus* 127 408–423. [12] Timms, N.E. et al. (2015) *Marine and Petroleum Geology* 60 (February): 54–78. [13] Melosh, H.J and Ivanov, B.A. (1999) *Annu.Rev. Earth Planet. Sci.* 27:285–415.

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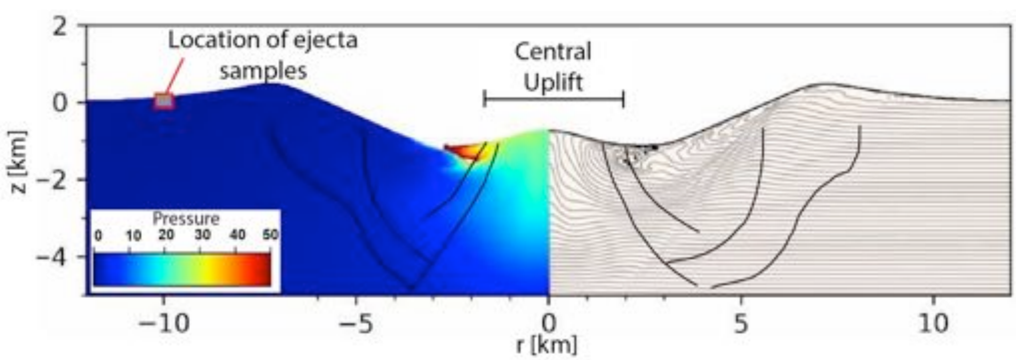

Fig. 3. Numerical simulation of the Yallalie impact crater. Peak pressure is shown on the left and partial displacement is shown on the right (r = radius, z = height relative to the paleo surface). The grey box at the surface denotes the sampled ejecta site. The grey image below the model is a previously published interpreted seismic line across the Yallalie structure [4]. The interpreted fault traces from the seismic line were added to the iSALE model at the same scale. Bottom figure shows the peak shock pressure distribution of tracers in the sample area (gray box).