Review paper: The 23rd March 2012 M_w 5.2 Pukatja surface rupturing earthquake, Australia

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Abstract

The 23rd March 2012 M_w 5.2 Pukatja earthquake produced an arcuate surface rupture 1.6 km long with a maximum vertical offset of 0.48 m. We reclassify its length to 1 km based on application of orientation and kinematic criteria used previously to measure other historic Australian surface ruptures. Epicentres are poorly constrained and inaccurate, located up to 17 km from the surface rupture with no reported uncertainties. Published interpretations of available seismological data do not provide constraints on rupture processes, hypocentre depth, and fault geometry. Sections of the surface rupture match the strike and dip of an intrusive contact as mapped in the field < 500 m from the rupture. This feature is evident as a linear magnetic anomaly co-located and parallel to the surface rupture, suggesting a strong bedrock control on the location and orientation of surface rupture. There is no topographic expression of prior rupture, and a shallow hand-dug trench shows evidence of only the historic rupture. However, erosion rates estimates suggest that residency time of any prior ruptures in the landscape may have been < 50 kyrs, and hence topographic evidence may have been removed prior to deposition of overlying sediments. Investigations of rock falls surrounding the historic rupture may provide estimates of strong ground motion recurrence in the absence of other paleoseismic data.

This document presents a review of available literature related to the 2012 Pukatja surface rupturing earthquake. It includes newly digitised data related to the rupture and new interpretations of controls on fault rupture. It supplements a manuscript reviewing all Australian surface rupturing earthquakes, submitted to Geosciences in August 2019.

Please contact authors on the content presented herein; we welcome constructive feedback.

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1. Geology

1.1 Regional / background

The 2012 Pukatja, 1986 Marryat Creek and 2016 Petermann surface rupturing earthquakes occurred within the Musgrave Block, a Mesoproterozoic basement assemblage that extends across the Northern Territory / South Australia border into Western Australia (Figure 1). This block is composed of high grade metamorphic and magmatic suites formed during the ~1200 Ma Musgrave orogen and reworked during the 580 - 520 Ma Petermann Orogeny (Aitken and Betts, 2009; Cawood and Korsch, 2008; Edgoose et al., 2004; Raimondo et al., 2010). Two large structures, the Woodroffe Thrust and Mann Fault, dominated uplift and deformation during the Petermann Orogeny (Lambeck and Burgess, 1992; Neumann, 2013; Stewart, 1995; Wex et al., 2019). The Woodroffe Thrust was responsible for significant exhumation of lower-crustal rocks, displacing the Moho by ~20 km associated with a present-day large gravitational and magnetic anomaly (Hand and Sandiford, 1999; Korsch et al., 1998; Wade et al., 2008). The Petermann and Pukatja surface ruptures occurred within 10 km of the Woodroffe Thrust (on the hanging-wall).

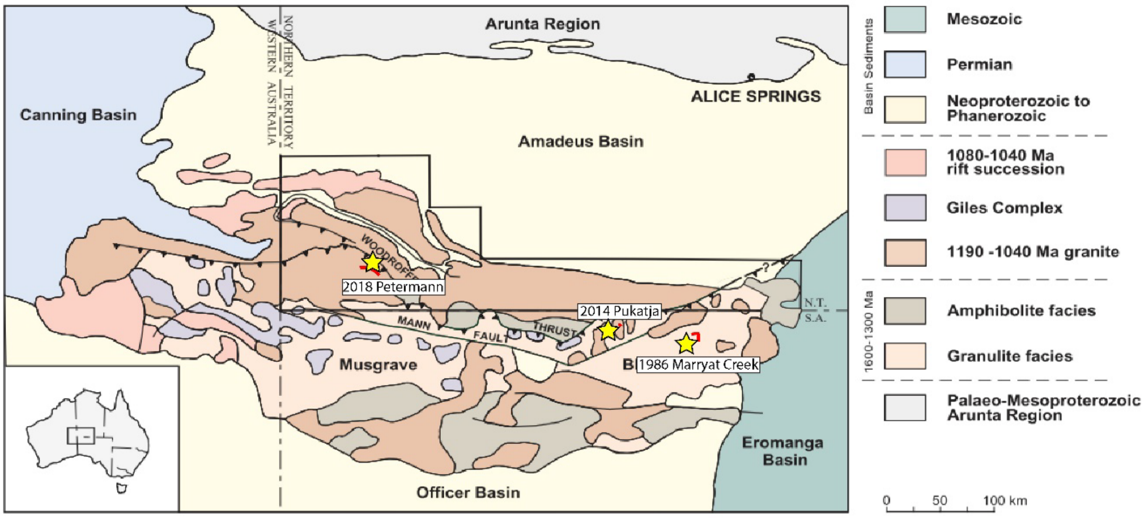

Figure 1: Musgrave Block geology from Figure 3 of Edgoose et al. (2004) with Petermann, Pukatja and Marryat Creek earthquakes (yellow star) and ruptures (red lines) overlaid. Note some authors locate the Mann Fault further south than this map, coincident with the location of the Marryat Creek rupture (Aitken and Betts, 2009; Raimondo et al., 2010). *(CC) NT GOV*

1.2 Local units / bedrock

The Pukatja surface rupture is located < 100 m away from a lithological bedrock boundary between a granite batholith and granulite facies gneiss (*Figure 2*). Gneissic foliation to the south and west of the rupture is orientated approximately N-S (see Fig. 2 of (Clark et al., 2014)), but is deformed around the granite batholith in the vicinity of the historic surface rupture. The Woodroffe Thrust is mapped ~ 9 km N - NW of the surface rupture with a NE-SW trend, and is associated with a ~1.5 km wide mylonitized shear zone (Clark et al., 2014).

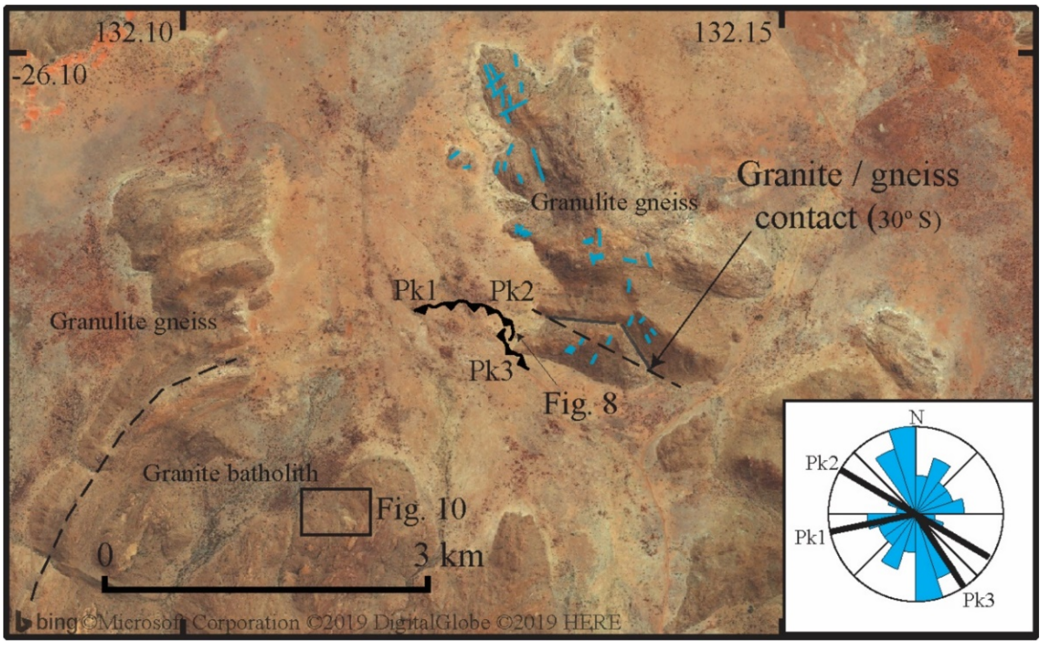

Figure 2: Bedrock intrusive boundary and foliation/joint orientations mapped from satellite imagery (© Bing, DigitalGlobe, HERE, Microsoft). Inset shows rose diagram of structural orientations in bedrock close to the surface rupture (blue) relative to the three orientations of the arcuate surface rupture trace (black). Strike and dip measurement of the granite and gneiss contact in the outcrop east of the rupture from (Clark et al., 2014). Eolian sands cover the area between bedrock outcrops. Location of Figures 8 and 10 shown.

The arcuate historic surface rupture aligns with an arcuate magnetic anomaly (*Figure 3*) associated with the intrusive boundary of the granite batholith mapped in *Figure 2*, showing a strong correlation between the historic rupture and basement structure. Available gravity maps are too low in resolution to show any anomalies at the scale of the historic rupture.

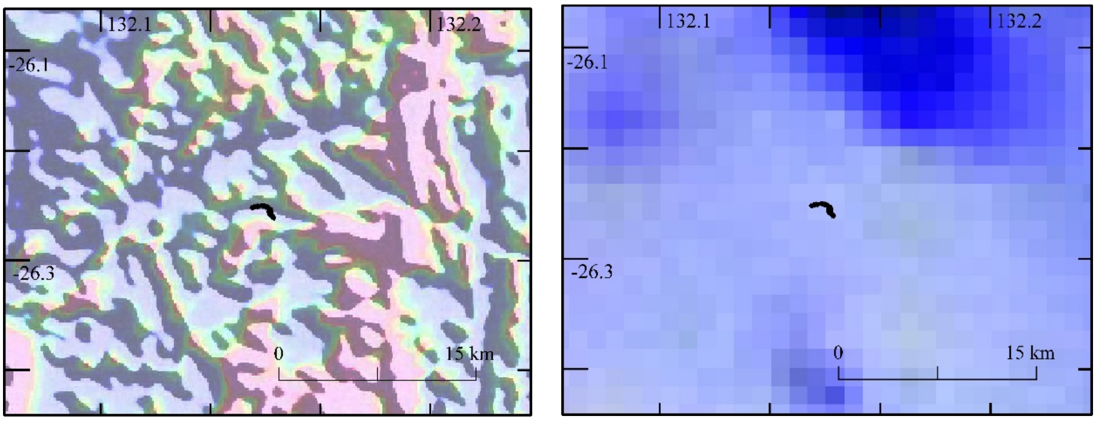

Figure 3 Pukatja scarp (black lines) relative to magnetic intensity and bouguer gravity anomaly maps. National bouguer gravity anomaly map: http://pid.geoscience.gov.au/dataset/ga/101104; National total magnetic intensity map: http://pid.geoscience.gov.au/dataset/ga/89596

1.3 Surficial deposits

Bedrock is covered with a low-relief colluvial, fluvial and sheet wash sand plain of unknown thickness (Clark et al., 2014). A ~ 1 m deep trench dug across the rupture did not expose bedrock (Clark et al., 2014).

2. Seismology

2.1 Epicentre

Clark et al. (2014) publish four epicentre locations (*Table 1*, *Figure 4*). The GA_online catalogue location was revised in 2015 to lie on the hanging-wall of the surface rupture. The original GA location (Clark et al., 2014) lies 17 km to the west of the surface rupture, which is the also the current location in the USGS online catalogue (assumedly updated since the USGS location in Clark et al. (2014) was published). The other three solutions (GCMT, USGS, and St Louis University) are 4, 7, and 6 km N and NW from the most proximal part of the surface rupture. The recently published NSHA18 catalogue (Allen et al., 2018) epicentre is located ~ 2 km SE of the original GA location; it is unknown how this location was derived.

The only published uncertainty values are in the GA_online catalogue (± 4 - 6 km) which describe statistical uncertainty (precision) but not epistemic (accuracy). The mis-location of seismological epicentres up to 17km from the surface rupture is a considered to be a combination of epistemic uncertainties including the velocity model used by each agency. These large epistemic uncertainties in epicentre location also effect foreshock and aftershock locations (discussed below).

This paper prefers the magnitude (M_W 5.2) of the recently published NSHA18 catalogue (Allen et al., 2018) as they conduct a thorough and consistent reanalysis of Australian magnitude values. This is slightly lower than the originally published M_w value (5.4), but they are likely within error of each other (no magnitude uncertainty values are published).

Table 1 : Published epicentre locations, depths and magnitudes

Reference	Agency	Latitude	± (km)	Longitude	± (km)	Depth (km)	± (km)	M1	M2
Clark et al (2014)	GA	-26.16		131.95		4		5.4 Mw	5.7 ML
GA online	GA	-26.124	~6	132.124	~4	0	16	5.4 Mw	5.7 ML
Clark et al (2014)	GCMT	-26.11		132.08		12		5.3 Mw	5.6 mb
Allen et al (2018)	NSHA18	-26.178		131.971		10		5.18 Mw	
Clark et al (2014)	St Louis University	-26.07		132.12		20		5.3 Mw	
Clark et al (2014)	USGS	-26.06		132.12		11		5.3 Mw	5.6 Mb
USGS online	USGS	-26.163		131.955		7		5.3 Mwc	5.7 ML

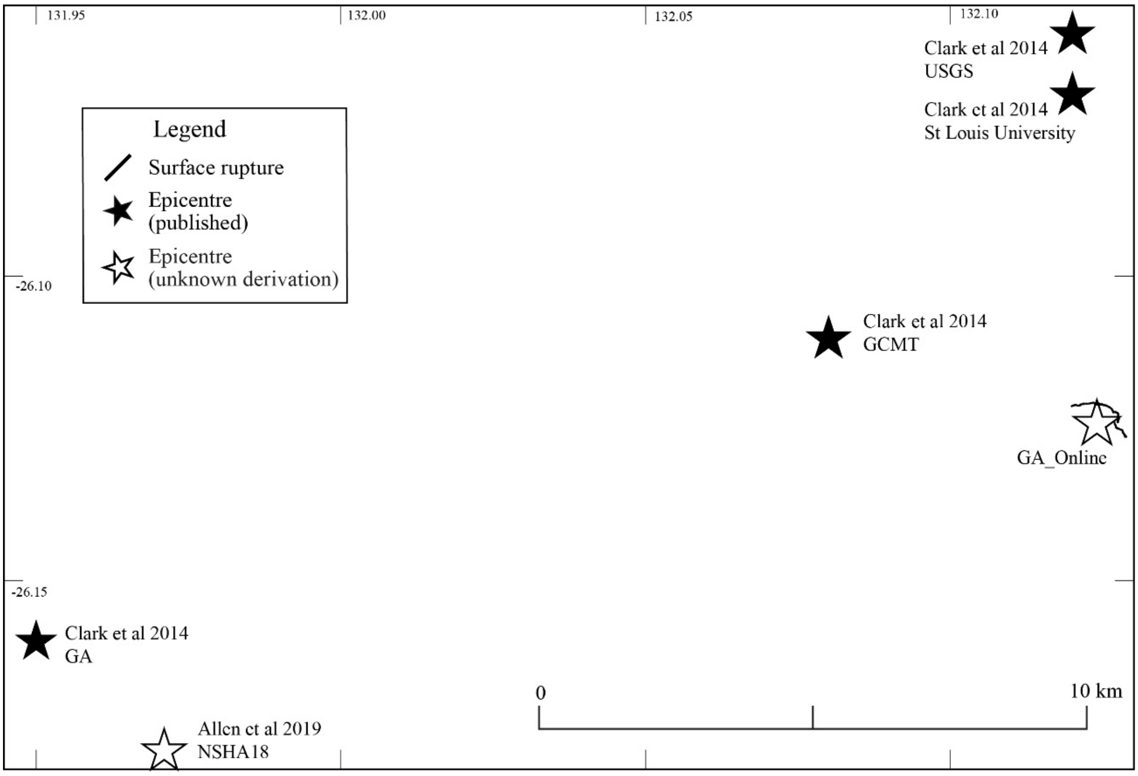

Figure 4: Published epicentre locations around the surface rupture

2.2 Focal mechanisms

Three focal mechanisms have been published for the Pukatja earthquake, from GA, CMT and St Louis University, all with consistent reverse movement on a NW-SE trending plane. It is assumed that all of these are CMT solutions using teleseismic body-waves inversion (Ekström et al., 2012). Surface rupture suggests a SW dipping fault, aligning to the steepest plane in each focal mechanism (72°, 45° and 70° respectively).

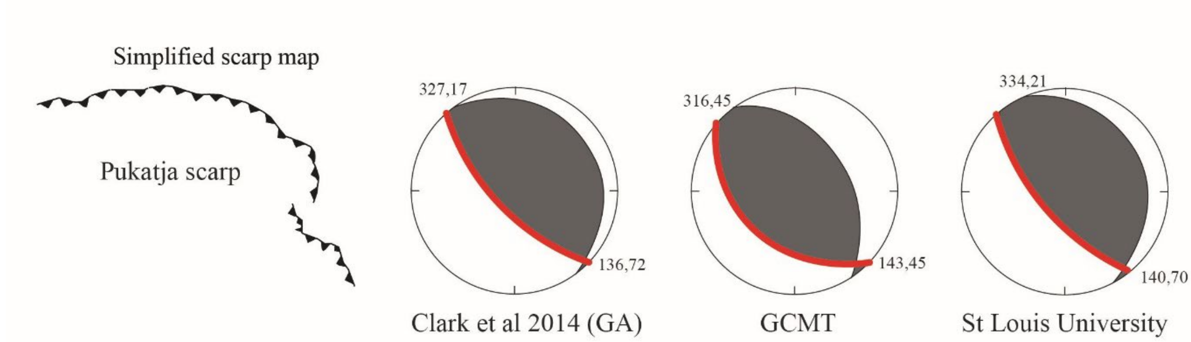

Figure 5: Published focal mechanism and simplified scarp map

2.3 Depth

Seismologically derived depth estimates range from 4 to 20 km between agencies. Clark et al. (2014) note that certain characteristics of the waveforms (lack of depth phases and abundance of surface waves) suggest a shallow hypocentre in line with previous observations for historic Australian surface rupturing earthquakes. No specific seismological analysis of hypocentral or centroid depth is available for this event.

2.4 Foreshock / aftershocks

Prior to 2012, the GA online catalogue shows five events in the 30 km surrounding the Pukatja earthquake with four in 1985-1986, and one in 1995. Three of the events from 1986 have no magnitude estimates, and were likely poorly recorded earthquakes following the 1986 Marryat Creek surface rupturing earthquake. Clark et al. (2014) report two foreshocks of M_L 3.9 and 4.3 in the two weeks prior to the mainshock, though only one of these events (M_L 3.8, three days prior) is recorded in the GA catalogue.

In the fourteen months following the Pukatja earthquake, five earthquakes of M_L 2.97 - 3.66 are recorded in the GA catalogue within a 22 km radius, with the closest 6.5 km to the south of the rupture. Clark et al. (2014) report 39 small unlocatable aftershocks in the first 24 hrs following the mainshock, and many subsequent aftershocks that cannot be accurately located.

Fifteen months after the Pukatja earthquake, another M_w 5.7 event known as the Mulga Park earthquake occurred 13 km to the west (Clark and Mcpherson, 2013). Three M_L 2.9 - 3.3 2013 earthquakes are located 14 – 25 km north of both the Pukatja and Mulga Park earthquakes. Four more earthquakes between M_L 2.9 - 3.3 occurred in 2015, between 18 and 25 km north of the two 2012-2013 events. In 2017, M_L 2.9 and 3.6 earthquakes were recorded 4 and 6 km west of the Mulga Park earthquake location. No seismicity has been recorded in the area since 2017.

3. Surface Rupture

3.1 Authors / map quality

The Pukatja surface rupture occurred 17 km north of Pukatja community (also called Ernabella), 420 km south of Alice Springs, which is within the Anangu Pitjantjatjara Yankunytjatjara (APY) area of South Australia, making access dependant on permits. The Pukatja surface rupture is described in Clark et al. (2014) with additional details in a conference paper (Clark and Mcpherson, 2013). No InSAR was derived for this event due to poor coverage over the earthquake location at the time. The map from Clark et al. (2014) is digitised and available in GAs Neotectonics Database (Clark, 2012). The rupture is not visible on Google or Bing satellite imagery. Bing satellite imagery does record rockfalls related to the 2012 earthquake (*Figure 10*).

3.2 Length and shape

The Pukatja surface rupture has a highly arcuate concave shape (relative to the hanging-wall) and the published length based on visible rupture is 1.6 km. Approximately 30 m from its eastern most tip, the rupture has a ~55 m wide step-over, before continuing in a concave direction towards the north and west.

A review of all historic Australian surface rupturing earthquakes (King et al., 2019) (in review), found most published lengths for historic ruptures were derived from a simplification of rupture lengths rather than a direct measure of the mapped surface rupture trace. Conversely, the published length of the Pukatja rupture by Clark et al. (2014) is derived from a near exact measure of the visible surface rupture without any simplification (*Figure 6*a,b), making it anomalous within the literature.

*Figure 6*c shows length derived by simplifying the rupture trace in a way similar to original length measurements of other Australian arcuate surface ruptures (1968 Meckering, 1986 Marryat Creek). This reduces the length by 20 %. We also apply a criteria which defines distinct faults where mapped primary rupture has gaps/steps > 1 km and/or where strike changes by > 20° for distances > 1 km (e.g. (Quigley et al., 2017)). This results in a single fault describing the Pukatja rupture, with a total length of 1 km (*Figure 6*c) (explored in more detail in King et al. (2019) (in review)).

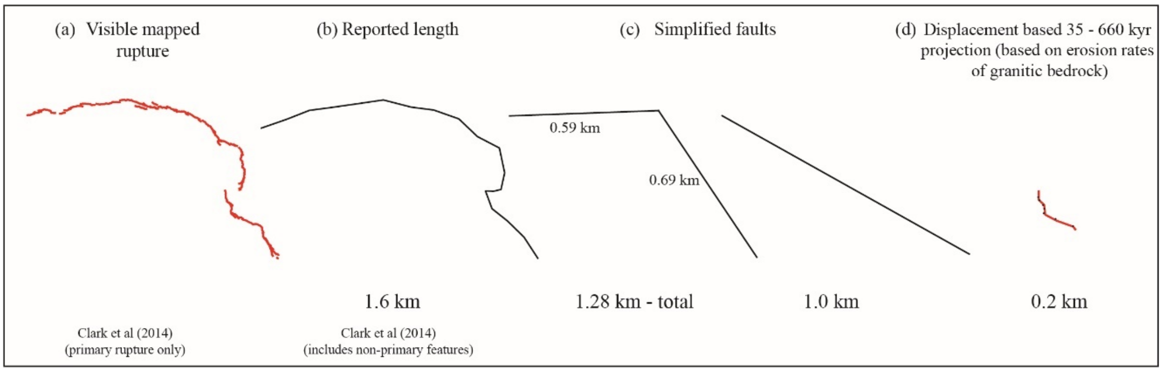

Figure 6: Measures of length for the Pukatja surface rupture and underlying faults.

Figure 6d displays portions of the scarp where more than two vertical displacement measurements of greater than 0.2 m occur within a distance of 1 km (data from Clark et al. (2014)). Applying cosmogenic erosion rates from lithologically and climatically analogous settings of Australia (0.3 – 5 m/Myr; Bierman and Caffee, 2002) suggests that 0.2 m of scarp height could be removed within 35 – 660 kyrs, leaving just 0.2 km of rupture length (i.e., 0.2 km of residual surface rupture with relief ≥ 0.2m) visible in the landscape. This suggests that the surface scarp may not persist within this landscape as a mappable scarp, unless recurrence intervals are < 0.05 to 0.5 Myr. In this calculation we assume that the scarp is shallowly underlain by granitic bedrock and that the scarp erodes more rapidly than the surrounding terrain at rates commensurate with Bierman and Caffee (2002). We do not account for erosion rates of any duricrust which may overlie granitic bedrock or anthropogenically- and/or climatically-modulated variations in erosion rates.

3.3 Strike

Due to the concavity of rupture, the strike is highly variable along the surface rupture. A line drawn between each end of the surface rupture strikes ~122°, while the general trend of the western, central and eastern portions of the scarp are 082°, 121° and 153° respectively. Preferred strikes of focal mechanisms range from 136 °- 143°.

3.4 Dip

The only available measurement of the surface rupture dip comes from a shallow hand-dug trench exposing a rupture plane dipping 25° SW (Clark et al., 2014). This is significantly shallower than dips derived from focal mechanisms (72°, 45° and 70°), but matches well with the dip of a nearby intrusive contact between granite and gneiss (*Figure 2*). It is possible that this contact steepens at depth, relating to the steeper focal mechanism dips.

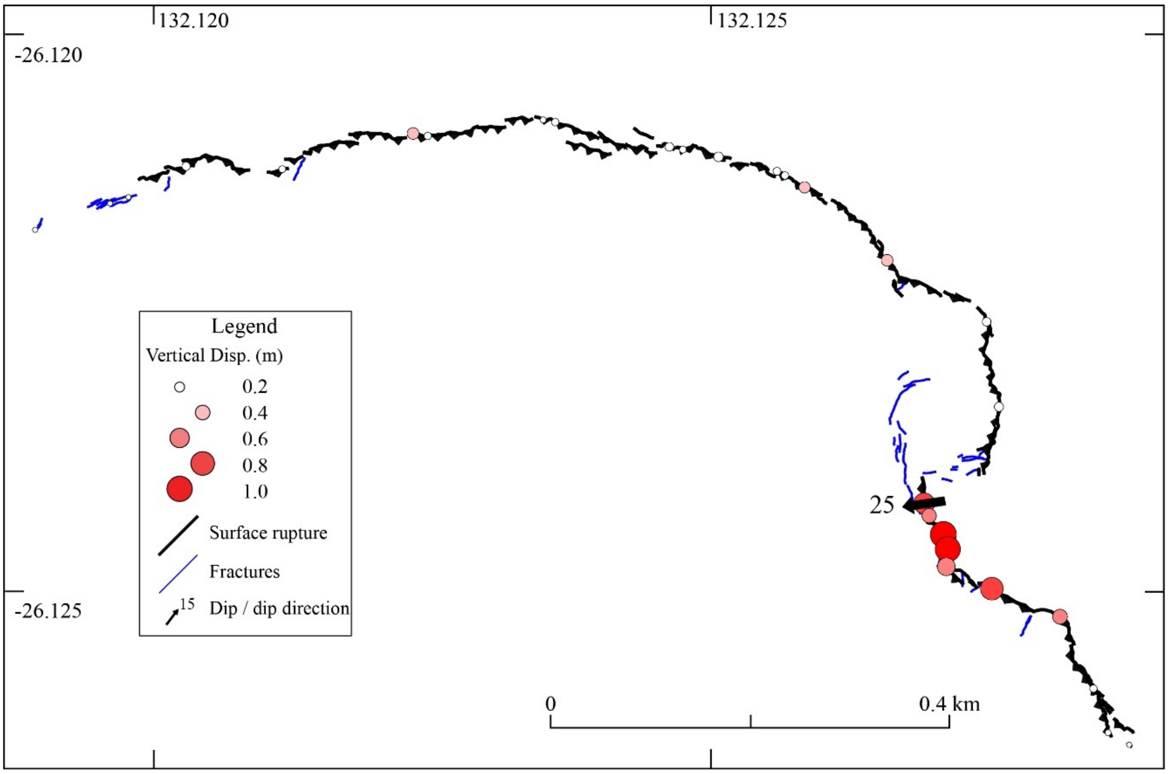

Figure 7: Map of the Pukatja scarp, fractures, vertical offset measurements along the rupture, dip measurement (all from Clark et al. (2014))

3.5 Morphology

The western limb is typified by mole-track rupture, where the surficial sediments are broken into A-tent forms, with very minimal visible offset of the hanging-wall and footwall (< 0.1 m) (Clark et al., 2014). In the central portion, as the scarp turns to the SE it forms discrete ruptures with visible offset of the hanging-wall and footwall (Clark et al., 2014).

The rupture was re-visited in 2016, and while hanging-wall / foot-wall offset was still evident, the rupture trace was very hard to see in the field due to vegetation growth and smoothing of the rupture face through erosion (*Figure 8*).

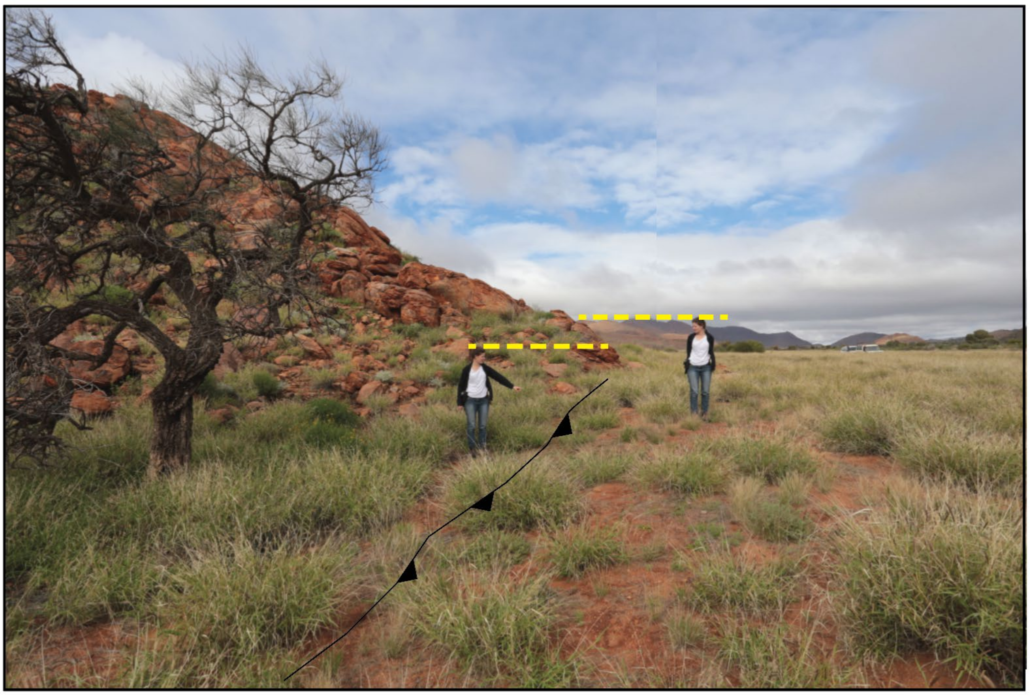

Figure 8: Composite of two images taken in 2016 showing offset across the 2012 Pukatja rupture (looking south-east). While offset is still evident 4 years after the event, the rupture itself is very difficult to see due to erosion. See Figure 2 for location of photos.

3.6 Lateral displacement

As the scarp turns to the SE through the central section, cracks on the hanging-wall of the rupture indicated a dextral component to the slip (Clark et al., 2014). Where the scarp steps over, extensional cracks extend between the scarps with a dominant east to north-east orientation, in line with the compressional and extensional fields implied by the focal mechanisms (Clark et al., 2014).

3.7 Displacement

Vertical displacement measurements along the rupture are presented in Clark et al. (2014). These are presented in *Figure 9* and show generally minimal offsets along the majority of the rupture, with a maximum of 0.48 m close to the step over. Clark et al. (2014) also present data from three profiles ~ 40 to 70 m long, close to the area of maximum rupture offset. They find vertical displacements between the hanging-wall and footwall of 0.36 to 0.51 m (figure 4 in Clark et al. (2014)).

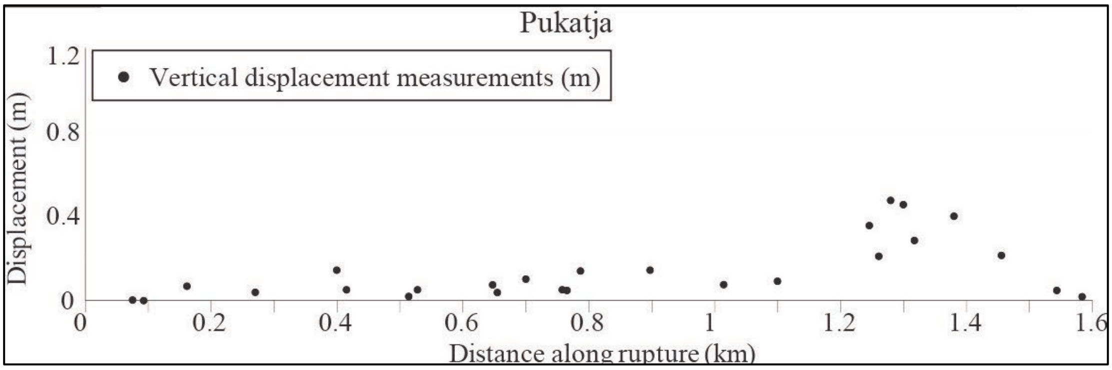

Figure 9: Vertical displacement measurements along the Pukatja scarps, digitised from (Clark et al., 2014).

3.8 Environmental damage

Clark et al. (2014) note a number of features that fall into the ESI-07 scale (Michetti et al., 2007) including surface rupture, rock falls and cracking. While they note vegetation damage in the form of grass killed by root-tear, no other vegetation damage relevant to the ESI-07 scale is recorded, and no hydrological effects are recorded. The surface rupture falls between ESI VII - IX, with rupture extending for only “several hundred meters” (VII), but demonstrating “offsets generally in the order of several cm” (IX) (Michetti et al., 2007). Surface cracking falls between ESI VI - VII but is mapped only in immediate proximity to the surface rupture, which places it within the ESI IX contour. Seven rockfalls were noted by Clark et al. (2014) up to 15 km from the scarp, all on the hanging-wall side of faulting. We classify the six rock falls close to the rupture as ESI VII, with one distal rockfall classified as ESI V. Two of these rockfalls were visited in 2016, and are visible on Bing satellite imagery (*Figure 10*).

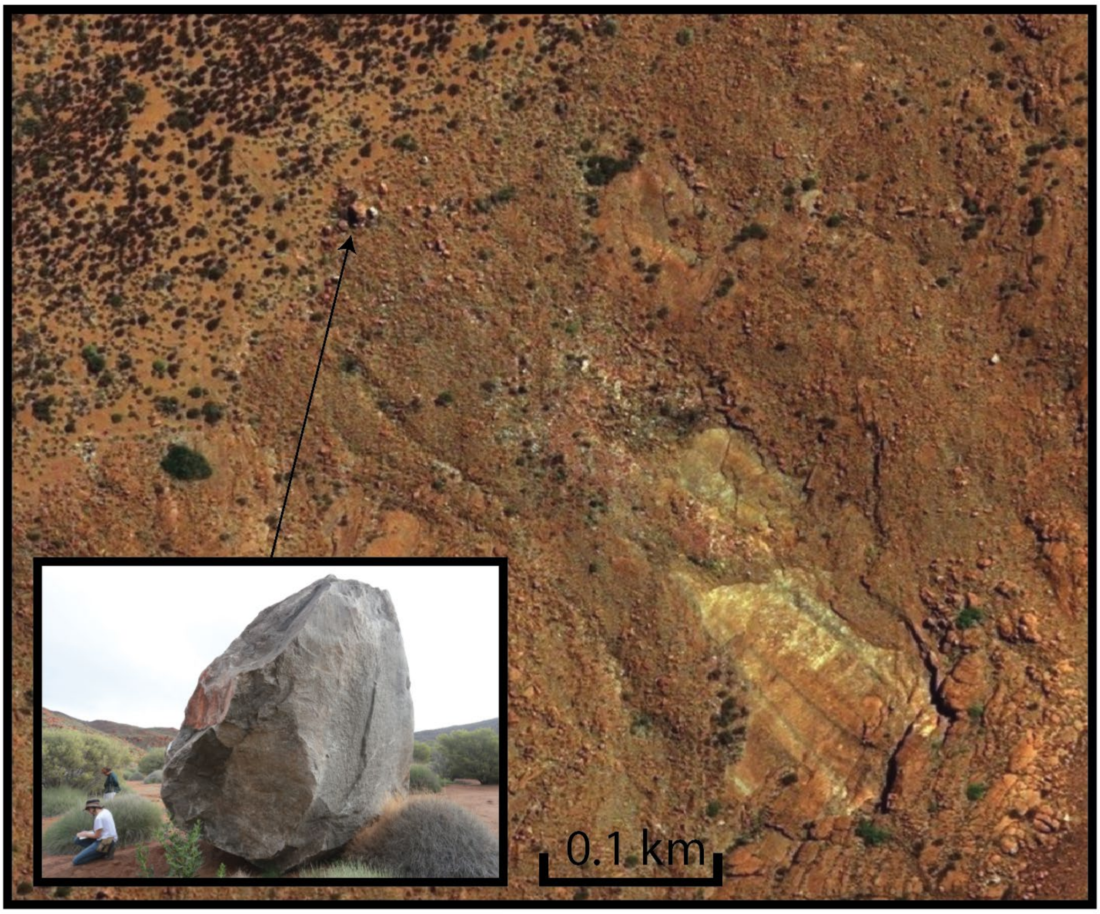

Figure 10: Satellite image (© Bing, DigitalGlobe, HERE, Microsoft) of rock fall (see Figure 2 *for location) and image of large fallen boulder from the 2012 earthquake*

4. Paleoseismology

Clark et al. (2014) note no evidence of prior activity in the landscape and no evidence of prior rupture in a small hand-dug trench. However, they describe the surficial sediments in the trench as young (“on the order of a few thousands of years old”) and thus this evidence of absence of a penultimate earthquake is unlikely to extend beyond the mid-Holocene.

While there is no evidence to support prior rupture along the Pukatja scarp, vertical displacements < 0.2 m combined with erosion rate estimates suggest that prior ruptures of a similar height would not be persistent features in this landscape. Prior rupture may have been removed through erosion before deposition of overlying sediments. The distribution and age of past rockfalls may help to constrain the rate or recurrence for strong ground motions in the area exceeding a certain threshold, providing some constraint on recurrence in the absence of topographic or trenching evidence.

5. Summary

5.1 Surface rupture relationship to Geology

At the eastern edge of the rupture, a large outcrop of granite occurs in a hill on the footwall, with a smaller outcrop on the hanging-wall. The step over in the rupture occurs coincident with this gap between the main outcrop and smaller outcrop. A lithological contact between the granitoid and granulite facies gneisses is mapped in the outcrop, dipping SW 30°. A projection of this lithological contact coincides with where rupture curves from a northerly trend (the eastern segment) to an E-W trend (central and western segments), matching the strike of the intrusive contact as seen in outcrop and as a arcuate magnetic anomaly. Surface geology and geophysical data suggest a strong bedrock lithological control on the historic rupture.

5.2 Relationship to Seismology

Clark et al. (2014) derive a fault area in the order of 4.3 (L) × 3.4 (W) km (14.6 km^2) using scaling relationships of Leonard (2010). This length is 63 – 77% longer than observed surface rupture length. There is also a discrepancy between the dip measured along the surface rupture (25°) and the fault dip derived by focal mechanisms (72°, 45° and 70°).

Other historic surface rupturing events that are highly arcuate (1968 Meckering, 1986 Marryat Creek) have P-wave first motion focal mechanisms that suggest rupture may have initiated on a minor fault before propagating through a fault intersection to produce the centroid moment tensor, mainshock event and surface rupture. Available focal mechanism for the Pukatja event describe a centroid that best matches the SE section of scarp. No P-wave first motion focal mechanisms are published, but they may help to constrain a rupture model for the Pukatja event. There are currently no published seismological or slip modelling data which help to constrain a fault rupture model for this event, or to resolve the discrepancies between surface observations and available seismological data.

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6. References

Aitken, A., Betts, P.G., 2009. Constraints on the Proterozoic supercontinent cycle from the structural evolution of the south-central Musgrave Province, central Australia. Precambrian Res. 168, 284–300. https://doi.org/10.1016/j.precamres.2008.10.006

Allen, T., Leonard, M., Ghasemi, H., Gibson, G., 2018. The 2018 National Seismic Hazard Assesment: Earthquake epicentre catalogue (GA Record 2018/30). Geoscience Australia, Commonwealth of Australia, Canberra, ACT. https://doi.org/http://dx.doi.org/10.11636/Record.2018.030

Bierman, P.R., Caffee, M.W., 2002. Cosmogenic exposure and erosion history of Australian bedrock landforms. Bull. Geol. Soc. Am. 114, 787–803. https://doi.org/10.1130/0016-7606(2002)114<0787:CEAEHO>2.0.CO;2

Cawood, P.A., Korsch, R.J., 2008. Assembling Australia: Proterozoic building of a continent. Precambrian Res. 166, 1–35. https://doi.org/10.1016/j.precamres.2008.08.006

Clark, D., 2012. Neotectonic Features Database. Geoscience Australia, Commonwealth of Australia, Canberra, Australia.

Clark, D., Mcpherson, A., 2013. A tale of two seisms: Ernabella 23/03/2012 (Mw5.4) and Mulga Park 09/06/2013 (Mw 5.6). Aust. Earthq. Eng. Soc. Newsl.

Clark, D., Mcpherson, A., Allen, T., De Kool, M., 2014. Coseismic surface deformation caused by the 23 March 2012 Mw 5.4 Ernabella (Pukatja) earthquake, central Australia: Implications for fault scaling relations in cratonic settings. Bull. Seismol. Soc. Am. 104, 24–39. https://doi.org/10.1785/0120120361

Edgoose, C.J., Scrimgeour, I.R., Close, D.F., 2004. Geology of the Musgrave Block, Northern Territory (NTGS Report 15). Northern Territory Geological Survey, Darwin, Australia.

Ekström, G., Nettles, M., Dziewoński, A.M., 2012. The global CMT project 2004-2010: Centroid-moment tensors for 13,017 earthquakes. Phys. Earth Planet. Inter. 200–201, 1–9. https://doi.org/10.1016/j.pepi.2012.04.002

Hand, M., Sandiford, M., 1999. Intraplate deformation in central Australia, the link between subsidence and fault reactivation. Tectonophysics 305, 121–140. https://doi.org/10.1016/S0040-1951(99)00009-8

King, T.R., Quigley, M.C., Clark, D., 2019. Surface-rupturing historical earthquakes in Australia and their environmental effects: new insights from re-analyses of observational data. Geosciences.

Korsch, R.J., Goleby, B.R., Leven, J.H., Drummond, B.J., 1998. Crustal architecture of central Australia based on deep seismic reflection profiling. Tectonophysics 288, 57–69. https://doi.org/10.1016/S0040-1951(97)00283-7

Lambeck, K., Burgess, G., 1992. Deep crustal structure of the musgrave block, central australia: Results from teleseismic travel-time anomalies. Aust. J. Earth Sci. 39, 1–19. https://doi.org/10.1080/08120099208727996

Leonard, M., 2010. Earthquake fault scaling: Self-consistent relating of rupture length, width, average displacement, and moment release. Bull. Seismol. Soc. Am. 100, 1971–1988. https://doi.org/10.1785/0120090189

Michetti, A.M., Esposito, E., Guerrieri, L., Porfido, S., Serva, L., Tatevossian, R.E., Vittori, E., Audemard M., F.A., Azuma, T., Clague, J., Comerci, V., Gurpinar, A., McCalpin, J.P., Mohammadioun, B., Morner, N.A., Ota, Y., Roghozhin, E., 2007. Intensity Scale ESI 2007, Memorie Descrittive della Carta Geologica d'Italia, Special Volume 74. APAT, Rome 2007.

Neumann, N.L., 2013. Yilgarn Craton – Officer Basin – Musgrave Province Seismic and MT Workshop (GA Record 2013/28). Geoscience Australia, Commonwealth of Australia, Canberra, ACT. https://doi.org/http://pid.geoscience.gov.au/dataset/ga/76664

Quigley, M.C., Mohammadi, H., Duffy, B.G., 2017. Multi-fault earthquakes with kinematic and geometric rupture complexity : how common ? INQUA Focus Group Earthquake Geology and Seismic Hazards.

Raimondo, T., Collins, A.S., Hand, M., Walker-Hallam, A., Smithies, R.H., Evins, P.M., Howard, H.M., 2010. The anatomy of a deep intracontinental orogen. Tectonics 29. https://doi.org/10.1029/2009TC002504

Stewart, A.J., 1995. Western extension of the Woodroffe Thrust, Musgrave Block, central Australia.

AGSO J. Aust. Geol. Geophys. 16, 147–153.

Wade, B.P., Kelsey, D.E., Hand, M., Barovich, K.M., 2008. The Musgrave Province: Stitching north, west and south Australia. Precambrian Res. 166, 370–386. https://doi.org/10.1016/j.precamres.2007.05.007

Wex, S., Mancktelow, N.S., Camacho, A., Pennacchioni, G., 2019. Interplay between seismic fracture and aseismic creep in the Woodroffe Thrust, central Australia – Inferences for the rheology of relatively dry continental mid-crustal levels. Tectonophysics 758, 55–72. https://doi.org/10.1016/j.tecto.2018.10.024