

MAGNITUDE - APPLES AND PEARS

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Abstract

A recent revision of large historical earthquake magnitudes by Geoscience Australia, guided by the new GEM-ISC database has three errors substantiated by instrumental and macroseismic information, and one omission. The original Gutenberg and Richter or PAS magnitudes or surface-wave magnitudes assessed by special studies of these events using the IASPEI formula should have precedence over the new proxy M_w values. Some of the revised magnitudes were computed from M_s measured from reported amplitudes and periods in station bulletins that were missed in the original study but the revised magnitudes reported only the missed information and did not include the original station readings.

Three earthquakes are substantially affected by the revision, the 1941 Meeberrie and 1968 Meckering earthquakes, two of the most important earthquakes in WA, the third an earthquake in the Simpson Desert in 1941. A list of preferred magnitudes of early West Australian earthquakes 1900-1968 is given with evidence from actual measurements of M_s and substantiated by their relative felt areas and fault dimensions where available. These are the values listed by the ISC and by Gibson (pers. comm.) and are those recommended for use for hazard assessments in Australia. The one earthquake that appears to have been upgraded in the GA list, a large earthquake in Central Australia in 1941, has probably been misidentified.

The largest Australian earthquake, omitted from the GA list, occurred in 1906 off the west coast of WA, magnitude 7.2. The largest onshore earthquake was at Meeberrie WA in 1941 magnitude 6.8 and the equal third largest earthquakes were at Meckering WA on 14 October 1968 and at Tennant Ck NT on 22 January 1988, both magnitude 6.6-6.8. The small Simpson Desert earthquake upgraded by GA was earlier than the mainshock, somehow the date must have been confused.

GA and the ISC should together correct their magnitudes accordingly.

Keywords: Earthquake magnitude, ISC, Large Australian earthquakes

INTRODUCTION

Magnitude is a measure of the relative size of earthquakes. There are a multiplicity of accepted magnitude scales based on the amplitude and period of seismic waves recorded on seismograms, the distance and depth of the earthquake and proxies including coda duration and felt area.



Figure 1. Charles Richter measuring magnitude (from <http://www.geo.mtu.edu/UPSeis/intensity.html>).

Australian earthquake magnitudes have been computed since about 1959 by Geoscience Australia (predecessors AGSO, BMR and MUN), state agencies such as PIRSA, GSQ, and private organisations such as ES&S, universities such as ANU, UQ, ADE, TasUni and RIV, researchers and ultimately the International Seismological Centre or ISC. Generally local agencies measure magnitude using their own version of the Richter scale ML, whereas ISC measured magnitudes using reported amplitudes and periods on the surface wave scale M_s and body wave scale mb, the scales overlap in the magnitude range 5.8 to 6. Moment magnitude M_w was introduced to overcome the limitation of M_s above magnitude 6.8 where that scale saturates. No Australian agency routinely reports M_w so it has to be converted from either ML or M_s .

Recently GA dramatically revised the magnitudes of some large earthquakes without actually looking at seismograms (Spiliopoulos, 2016): *As a result of a global project to more accurately measure historical earthquakes, Australia's list of largest recorded earthquakes has dramatically changed.* I assume that global project is ISC-GEM.

According to the ISC, *the ISC-GEM Global Instrumental Earthquake Catalogue (1900-2012) is the result of a special effort to adapt and substantially extend and improve currently existing bulletin data of large global earthquakes (magnitude 5.5 and above) to serve the requirements of the specific user group who assess and model seismic hazard and risk.*

On the 28 of January 2016, version 3.0 of the ISC-GEM catalogue was publicly released. The release marked the end of the second year of the Extension Project. During this year we added to the catalogue earthquakes listed in the ISS with phase data and surface wave amplitude measurements that occurred between 1935 and 1959.

To process earthquakes during 1935-1959 we digitized body wave arrival times as well as amplitudes and periods for various phases using a multitude of sources to allow relocation and magnitude re-computation (for this time period only M_s) using the same approaches described in Di Giacomo et al. (2015a). Compared to the first catalogue's release, for this version we were able to add amplitudes from printed station bulletins that were not available in the original ISC collection.

It is important to note that the ISC-GEM team measured only M_s , not M_w , but M_s was then used to convert to a proxy M_w . Previously unused station bulletin readings were used, the contemporary observations not amalgamated into their final magnitude revision.

A list of GA revisions is shown in Table 1, note that the scale is not identified e.g. the 6.9 for the Meckering earthquake was Richter magnitude ML concocted from mb and Ms by Everingham (in Gordon and Lewis, 1980) whereas the other pre-2016 values were Ms.

Table 1 The GA (Spiliopoulos (2016) Revised Australian magnitudes

Magnitude post-2016 revisions	Magnitude pre-2016 revisions	Location	Date
6.6	6.7	Tennant Creek, NT	1988
6.5	6.9	Meckering, WA	1968
6.4	5.6	Simpson Desert, NT	1941
6.3	6.4	Tennant Creek, NT	1988
6.3	7.2	Meeberrie, WA	1941
6.2	6.3	Collier Bay, WA.	1997
6.2	6.3	Tennant Creek, NT	1988
6.1	6.2	Cadoux, WA	1979
6.1	N/A	Petermann Ranges, NT	2016
6.0	6.0	West Lake Mackay, WA	1970

Surface Wave Magnitude Ms

According to Johnson (1996): *the Gutenberg-Richter magnitude, M_{GR} is essentially equivalent to the Prague M_S (Geller & Kanamori 1977; Lienkaemper 1984), except for most of the early time period 1900-1917, as identified and corrected by Abe (1981) and Abe with subsequent co-workers. For a fuller discussion of early instrumental M_{GR} and M_S the reader should consult Ambraseys & Melville (1982) or Pacheco & Sykes (1992).*

THE LARGER WA EARTHQUAKES, 1906, 1941, 1968 & OTHERS

ISC Bulletin Search summary: Rectangular search

Latitude range: -35 to -16, Longitude range: 105 to 125

Start date: 1900-01-01 00:00:00, End date: 1968-12-31 00:00:00

Magnitude ≥ 6 and ≤ 9

Events found: 6

1906 Sonja Ridge Offshore Central West Australia

Event 914285 (ISC)

Date	Time	Lat	Long	Depth	Author	OrigID
1906/11/19	07:18:18.00	-22	109	0	CENT	02318577
1906/11/19	07:18:18	-22.0	109.0	35	uk GUTE	1961916
		-19.1	111.8		Stover	

The first worldwide seismograph network was established by 1901 and this earthquake was large enough to be recorded on low-gain seismographs around the world, its magnitude subsequently computed, then revised, from measured amplitudes and periods of seismic waves. Gutenberg and Richter originally assessed the magnitude as $M_s 7\frac{3}{4}$. Abe and Noguchi (1983) re-evaluated the magnitude to $M_s 7.2$ (see Table 2). This 1906 WA earthquake is still the largest known earthquake to have occurred in intraplate Australia since European settlement. It occurred offshore and within the Australian Plate (Figure 2) near the continent-ocean boundary and is important for PSHA analyses in Australia. If it could occur there then it could occur at any other equivalent location. The location uncertainty is about 300km with the marked estimates of the epicentre discussed by Gregson and Everingham 1991

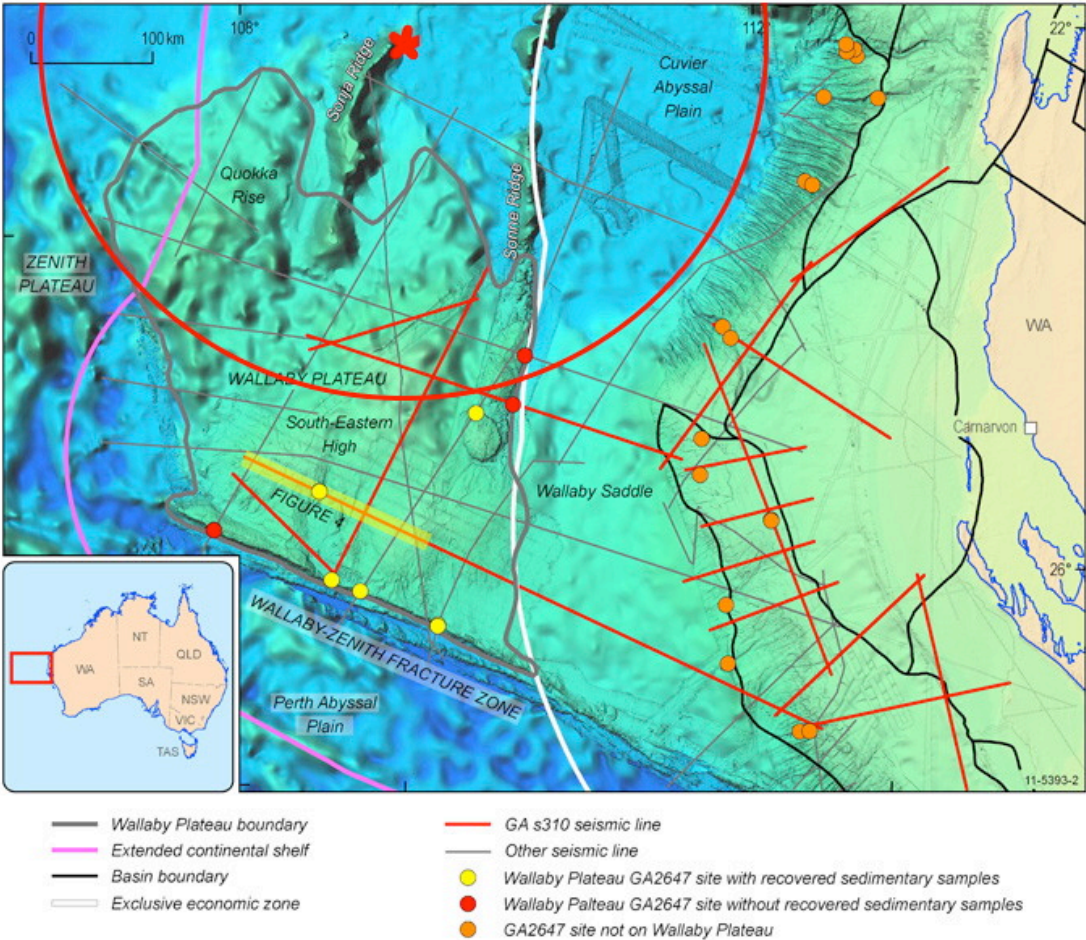


Figure 2 The Gutenberg and Richter location on the Sonja Ridge (red asterisk with red semi-circle of radius 300km, the approximate uncertainty). Basemap from GA.

Table 2 Magnitudes for the 1906 earthquake offshore central WA

Magnitude		Author	Orig ID
mB	7.5	ABE1	02318577
Ms	7.2	AN2	02318577
Mw	7.2	P&S	02318577
UK	7.8	GUTE	02318577
UK	7.8	PAS	02318577
MS	7.8	PAS	1961916

The instrumental magnitude is backed up by the macroseismic magnitude. The earthquake was felt out to 1700km across the state as summarized in the isoseismal map Figure 3 by Gregson and Everingham, 1991. Undoubtedly it was larger than those at Meeberrie WA in 1941, Meckering WA in 1968 or Tennant Creek NT in 1988.

1920 Offshore southwest of Australia

Event 912424 (ISC)

Date	Time	Latitude	Longitude	Depth	Author	OrigID
1920/02/08	05:24:12	-35.0	111.0		uk ISS	1959637
1920/02/08	05:24:30	-35.0	111.0	35.0	uk GUTE	19596
1920/02/08	05:24:28.7	-35.81	109.54	15.0f	ke ISC	05951338

(Depth fixed to depth of a reported hypocentre)

Table 3 Magnitudes of the 1920 earthquake offshore SW WA.

Magnitude		Nsta	Author	OrigID
MS	6.2		PAS	1959636
MS	6.3	4	ISC	05951338

This magnitude Ms 6.2 event was not reported felt in Australia. The epicentre was ~370km off the SW coast. Both instrumental and lack of macroseismic data attest that it was much smaller than the three largest WA earthquakes of 1906, 1941 and 1968.

1929 Northwest of Australia off Broome

Event 908268 (ISC)

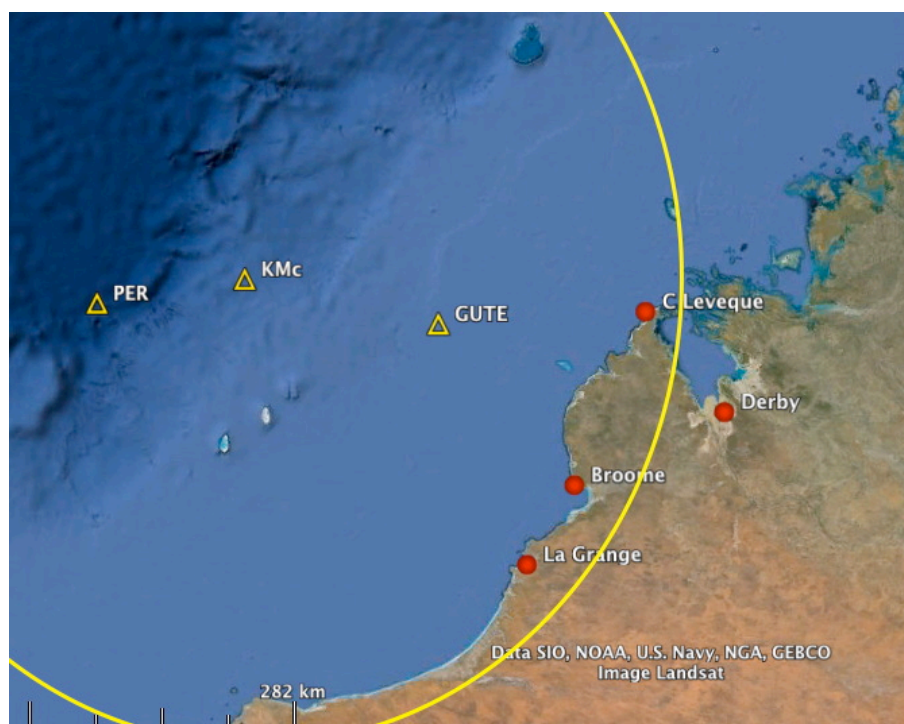
Date	Time	Latitude	Longitude	Depth	Author	OrigID
1929/08/16	21:28:12	-16.30	122.40		uk DJA	1954708
1929/08/16	21:28:25	-16.50	121.00	35.0	uk GUTE	1954707

Table 4 Magnitude of the 1929 earthquake offshore NWWA.

Magnitude		Author	OrigID
MS	6.2	PAS	1954707

Figure 3 Isoseismal map of the earthquake of 16 August 1929 offshore Broome WA. The triangles indicate the reported epicentres computed by three different authorities.

The yellow circle is the MMIV isoseism. It was only reported felt at Broome and La Grange, not Derby. At the time, 5:32am local time, any shaking warranting only



intensity 3 would not stir most people from sleep. Both instrumental and macroseismic data are consistent with a magnitude of at least 6.2.

1941 Meeberrie Western Australia

Event 900787

Date	Time	Latitude	Longitude	Depth	Author	OrigID
1941/04/29	01:35:40.29	-26.8	116.2	25	CENT	02319755
1941/04/29	01:35:42	-27.0	117.0		uk CGS	1942859
1941/04/29	01:35:42	-26.9	116.3		uk ISS	1942860
1941/04/29	01:35:43	-26.5	117.0	60	uk GUTE	1942858
1941/04/29	01:35:38.82	-26.91	116.25	15	ke ISC	05952548

(Depth fixed at 15km)

Table 5 Magnitudes of the 1941 Meeberrie WA earthquake.

Magnitude		Err	Nsta	Author	OrigID
UK	6.6			PAS	02319755
MS	6.8			PAS	1942858
MS	6.3	0.1	3	ISC-GEM	05952548

Interestingly only the bulletins from the **3** rediscovered stations (Nsta in Table 5), Bombay and Agra (India), and La Pas (Bolivia) were used by GEM-ISC in their revision of the magnitude down to Ms6.3. The average Ms with a reported error of 0.1 did not include PAS, WEL or RIV readings, all reporting Ms6.8. Both the Ms magnitude and felt area (Figure 3) label this the largest onshore earthquake in Australia, though quite a bit smaller than the 1906 earthquake off the west coast.

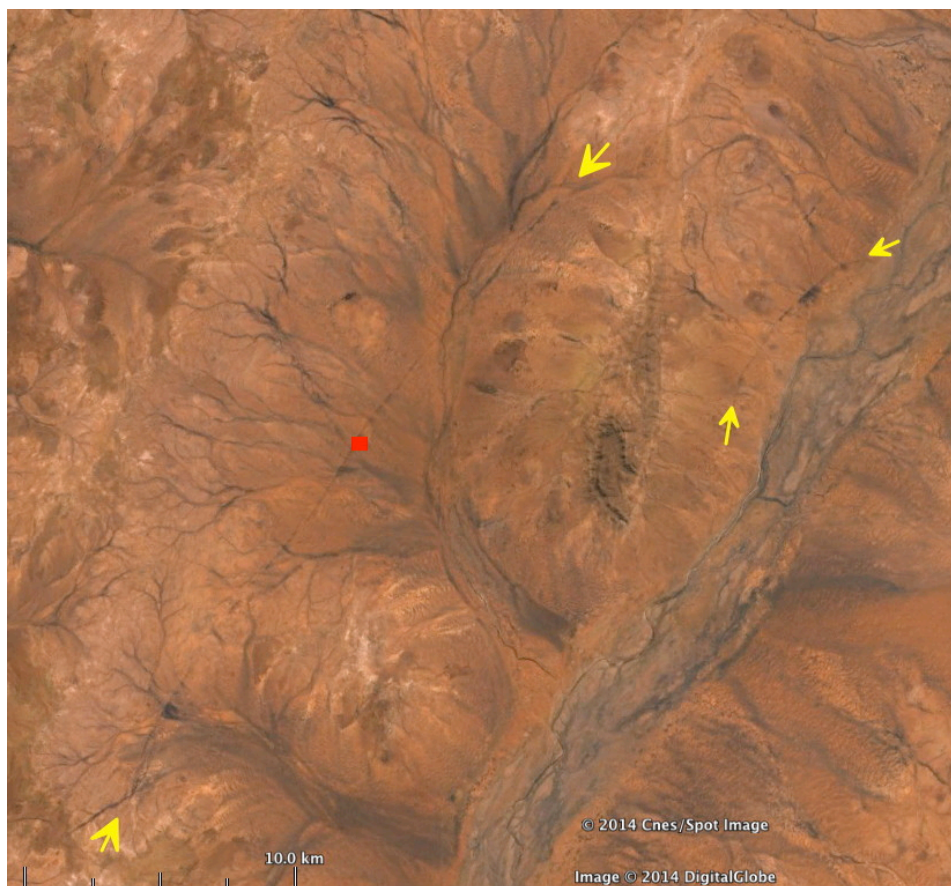


Photo 1. Google Earth photo of Recent fault scarps near Meeberrie W.A., the fault breaks outlined between the yellow arrows. Note the scale.

Google map images clearly delineate Recent fault scarps in the epicentral area. These prominent fault scarps are near both the computed epicentre and the macroseismic epicentre. Near Meeberrie Homestead, the segments are up to 70km long. Whitney and others (2015) trenched the scarps in several places and concluded that they formed prior to the 1941 earthquake during at least 4 similar sized events.

They did not observe surface deformation that they could attribute to the 1941 Meeberrie earthquake in any of the three structures they trenched, and suggested either they had not found the fault or that the earthquake did not rupture to the surface. If it was as deep as Gutenberg and Richter reported, 60km in the mantle, that

might be a reason for the lack of surface deformation but the ISC have fixed the depth at 15km which is a typical focal depth of Australian earthquakes. No other Australian earthquake is known to have occurred below the crust in the mantle.

Such a large shallow earthquake should have surface expression and of the expected dimensions of some of the fault scarps observed near Meeberrie. The coincidence of this prominent recent-looking rupture and the 1941 epicentre (within the location errors) would beg some association and further ground studies should be undertaken to look for more evidence of co-seismic surface rupture or to conclusively rule it out. Either way this earthquake was larger than Ms6.3 reported by GA in their reassessment.

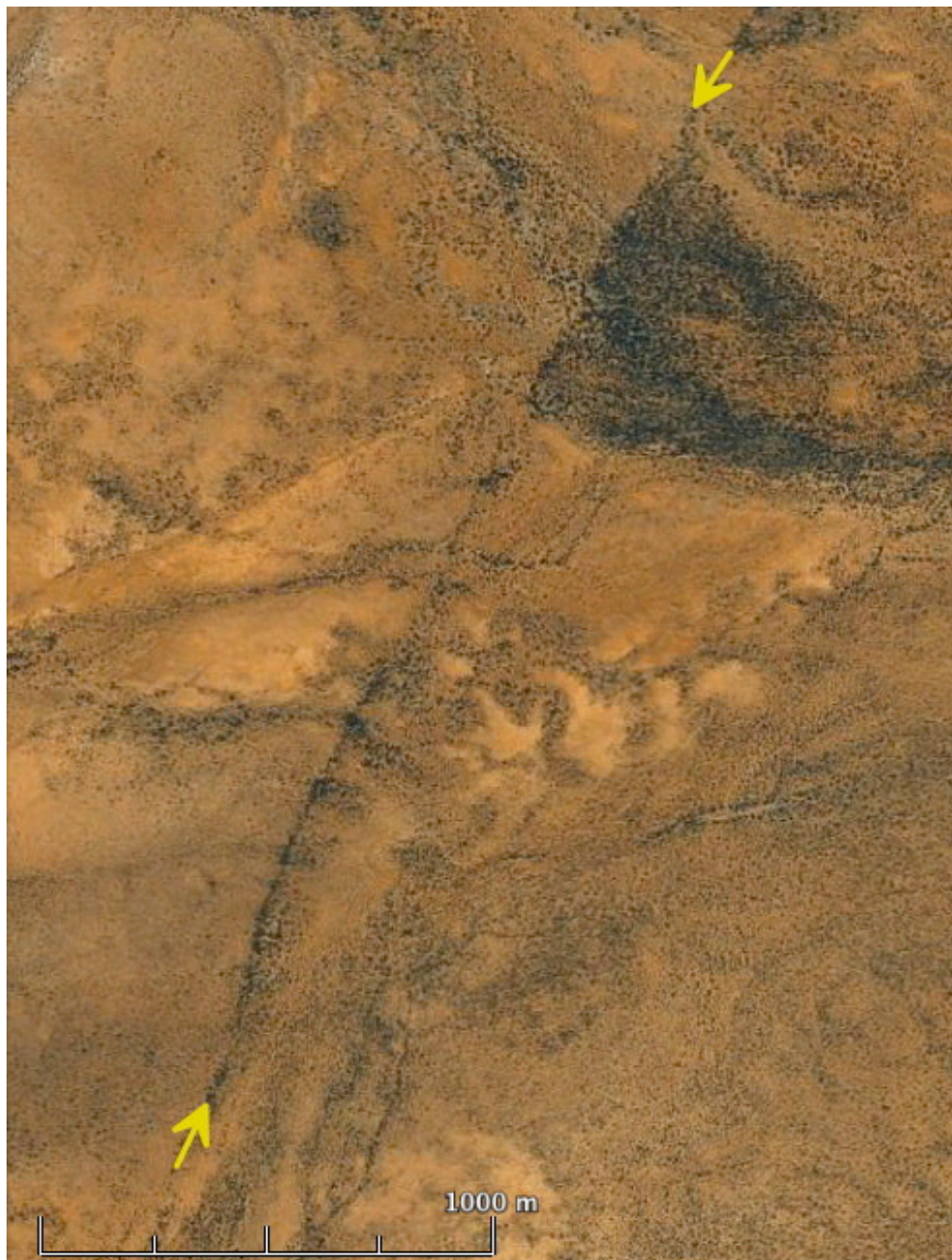


Photo 2. Google Earth photo of Recent fault scarps near Meeberrie W.A., the fault breaks outlined between the yellow arrows. Vegetation outlines the scarp due to the change of drainage caused by faulting. Note the scale.

1968 Meckering Western Australia

Miraculously no lives were lost in this major earthquake at 10am local time during school holidays though there were several injuries and nearly every brick house in the small town of Meckering was destroyed. Some damage occurred in Perth, the state capital, more than 100km away from the epicentre.

A 37km long fault scarp was generated with up to 2m of vertical uplift, 2.4m heave and 1.5m dextral strike-slip, in the process buckling the main railway line to eastern states and cutting the road and water pipeline to the goldfields (Gordon and Lewis, 1980). One of the interesting details is the focal depth, 18 (± 2)km obtained by the ISC from identification of depth phases on seismograms at distant stations. This earthquake was not confined to the top 6km of the crust (Langston, 1987) and other modellers using teleseismic data (Song and others) agree. The latter study also reported its magnitudes as Mw 6.5 to 6.7.

The ISC Solution:

Date	Time	Latitude	Longitude	Depth	Author	
1968/10/14	02:58:47.80		-31.50	117.00	1.0	de USCGS
(Severe damage at Meckering)						
1968/10/14	02:58:50.50		-31.59	116.99	0.0	uk AUST
1968/10/14	02:58:50.85		-31.521	116.980	5.0f	ke EHB
1968/10/14	02:58:50.85		-31.522	116.978	5.0	CENT
1968/10/14	02:58:51.00		-30.900	116.700	33.0	uk MOS
1968/10/14	02:58:51.80		-31.54	117.00	18.0d	de ISC

(Depth 18km fixed to depth phase depth) (#PARAM pP_DEPTH=18 \pm 2)

Table 6 Reported magnitudes of the 1968 Meckering WA earthquake.

Magnitude		Nsta	Author	OrigID
mb	6.0	13	USCGS	1796283
MS	6.8	13	USCGS	1796283
	6.8		AUST	1796284
mb	6.0		USCGS	02321944
mb	6.1		ISC	02321944
Ms	6.8		USCGS	02321944
UK	7.0		B&D	02321944
UK	7.4		PAS	02321944
MS	6.6	24	MOS	1796285
	6.9	9	MOS	1796285
mb	6.1	18	ISC	1796286

Ms magnitudes with an average of 6.8 are most relevant, mb magnitudes are meaningless as the scale saturates about mb 6. Obviously from the measured Ms and the felt area this is the smallest of the three earthquakes, both the 1906 and 1941 earthquakes were larger, the 1906 earthquake is the largest. Fredrich and others (1988) computed the moment as $10.4 \pm 0.53 \times 10^{18}$ Nm which converts to an Mw 6.6 to 6.7. There is no basis for reducing the Ms magnitude of this earthquake to Ms 6.5, the IASPEI definition has not changed.

A LARGE SOUTH AUSTRALIAN EARTHQUAKE

The 1941 South Australian event that GA has upgraded in the list, Table 1, is perhaps

overstated. There were several large earthquakes in central Australia in the late 1930s and early 1940s, two of them in 1941 are listed by the ISC as shown below. The earlier earthquake on 4 May was assigned magnitude Ms 5.6, the second on 27 June was a large earthquake Ms 6.4 (average reported) but this event is not listed in Table 1 from GA.

Event 900793 South Australia

Date	Time	Latitude	Longitude	Depth	Author	OrigID
1941/05/04	22:07:32	-25.8	137.0		uk ISS	1942871
1941/05/04	22:07:42	-23.0	142.0		uk CGS	1942872
1941/05/04	22:07:31	-26.5	137.5	35.0	uk GUTE	1942870

Table 7 Magnitude of the 1st earthquake in Central Australia 1941

Magnitude		Author	OrigID
MS	5.6	PAS	1942870

Event 900865 Northern Territory

Date	Time	Latitude	Longitude	Depth	Author	OrigID
1941/06/27	07:55:48	-26.0	137.0		uk CGS	1943006
1941/06/27	07:55:48	-26.2	137.5		uk ISS	1943007
1941/06/27	07:55:49	-26.5	137.5	35	uk GUTE	1943005
1941/06/27	07:55:55.1	-25.94	137.48	15f	ke ISC	05952556

(Depth fixed to depth of a reported hypocentre)

Table 8 Magnitude of the 2nd earthquake in Central Australia in 1941

Magnitude		Err	Nsta	Author	OrigID
MS	6.5			PAS	1943005
MS	6.3	0.2	4	ISC	05952556

There certainly was a large earthquake in Central Australia in 1941 (McCue, 2012) but only one in June, and it was reported as 6.4 ± 0.1 by the ISC, the earlier earthquake in May should not be upgraded from 5.6.

DISCUSSION

The three largest earthquakes in Western Australia are listed in table 9 using the Ms scale and IASPEI formula so that their relative size can be ranked aka apples vs apples. The same ranking is obtained by comparing their felt areas (the MM4 isoseismal areas in Figure 4). Inspection of the ISC on-line database shows that the ISC has not downgraded the magnitudes. Johnson's list of Stable Continental Crust SCR earthquakes includes the 1906 earthquake and supports these magnitudes. Gibson's database (pers. comm.) does not reflect the GA change and supports these magnitudes.

As Spiliopoulos (2016) said: *There is still a lot to learn about intraplate seismic events such as the ones that occur on the Australian continent, and we are constantly seeking to improve our knowledge.* To improve our knowledge objectively all the available data must be used, seismological (phase arrival times and the latest Earth models), macroseismic data (felt reports and isoseismal map), and paleo-seismological data (including geophysics such as LIDAR, and comprehensive trenching).

Table 9 The three largest earthquakes in WA since 1900.

Date UTC	Time	Latitude S	Longitude E	Ms IASPEI	Place
1906 11 19	0719	-22	109	7.2	Offshore Carnarvon
1941 04 29	01 35	-26.8	116.1	6.8	Meeberrie
1968 10 14	02 58	-31.60	117.00	6.7	Meckering

From this table of Ms magnitudes, the Mw can be computed using any agreed formula but whatever formula is used there should be no change in the ranking. On this basis the largest of the three Tennant Creek earthquakes on 22 January 1988, average magnitude Ms 6.5 IASPEI according to ISC, is smaller than the Meckering earthquake, though the fault scarp has a similar length and offset, and its felt area MMIV is larger. The two were of similar size within the uncertainty of the magnitude assessment, about ± 0.2 .

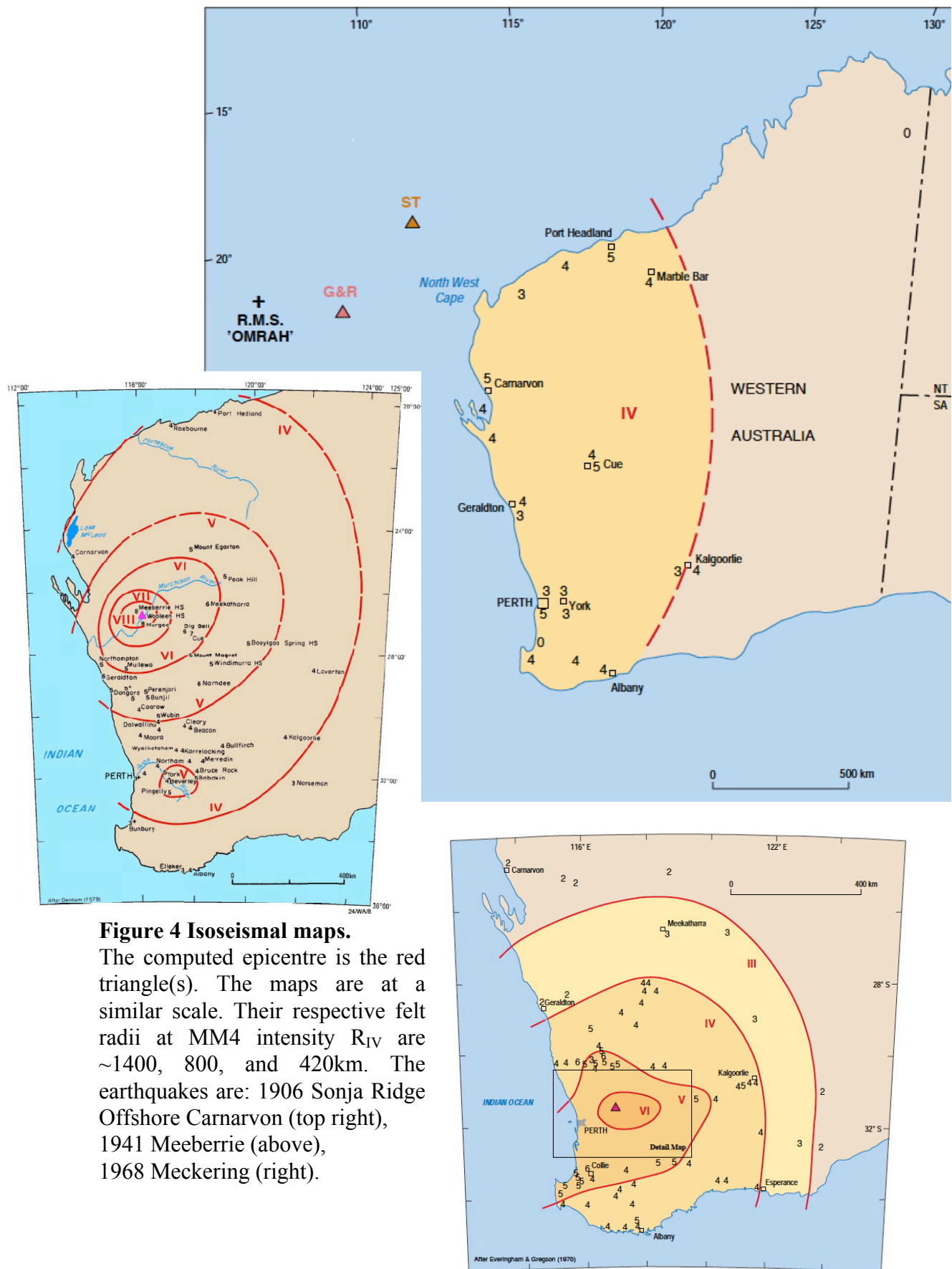
Care must be taken when comparing magnitudes that similar definitions are used, that you are comparing apples with apples and not apples with pears. For good reason, the previous and current Australian practice of measuring ML for small and moderate earthquakes within $\sim 1000\text{km}$ of the seismograph station and Ms for large earthquake recorded at $20^\circ - 130^\circ$ range should be continued. These magnitudes can be converted to Mw later if everyone agrees on the process which at the moment they don't.

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APPENDIX

GA Media Release: Shaking Up Australia's Earthquake Sizes

11 May 2016

As a result of a global project to more accurately measure historical earthquakes, Australia's list of largest recorded earthquakes has dramatically changed - placing Tennant Creek at the top of the table.

A magnitude 6.6 earthquake recorded near Tennant Creek in 1988 is now considered Australia's largest ever recorded earthquake. It was one of three very large earthquakes all occurring on 22 January 1988, followed by thousands of aftershocks felt throughout the Northern Territory.

Geoscience Australia has revised a number of Australia's most notorious earthquakes as part of an international effort to more accurately reflect the true size of historic earthquakes across the globe. One of the most significant changes from this project was to the 1941 Meeberrie earthquake, Western Australia - previously considered Australia's largest onshore earthquake.

The Meeberrie earthquake was originally recorded as a magnitude 7.2 based on personal accounts of those who felt its effects. Now, through an improved understanding of Australia's seismicity and by applying modern techniques to a vast database of international seismic events, the magnitude has been revised to 6.3.

"It's quite a common understanding amongst seismologists that this earthquake, and others of the time, may have been overestimated and are in fact considerably smaller than historically reported", said Spiro Spiliopoulos, Senior Seismologist at Geoscience Australia. "There were minimal recordings of the Meeberrie earthquake given its remote location and the technology available in 1941. Seismologists at the time resorted to calculating the size of the earthquake primarily by deciphering entries in the local homestead owner's diary."

"There is still a lot to learn about intraplate seismic events such as the ones that occur on the Australian continent, and we are constantly seeking to improve our knowledge by participating in international projects such as this one", Spiro said.