# Evaluation of the April 2011 Bowen $M_L$ 5.3 earthquake and aftershock sequence

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## Abstract

On the 16 April 2011 (05:31:18 UTC) a $M_L$ 5.3 earthquake occurred 50 km west of Bowen in central Queensland. This event was widely felt on the north Queensland coast and was followed by a number of aftershocks, which resulted in Geoscience Australia receiving more than 500 felt reports. Fifty earthquakes of M <5.0 have been recorded in the region between Charters Towers and Mackay since 1900. However, during this same period only one M >5.0 earthquake is recorded; a $M_L$ 5.7 event located north of Ravenswood in December 1913.

The main shock was followed by five smaller aftershocks ($M_L$ 3.2 to 4.1) on the 16, 17 and 19 of April. These initial aftershocks were recorded on permanent seismic stations (e.g. Charters Towers, Eidsvold, Quilpie and Roma). However, the location, magnitude and depth of over 300 smaller-magnitude aftershocks is improved by four temporary stations, which were installed within four days of the main shock. The temporary sites were located between 10 and 48 km from the epicentre of the main shock to maximise the azimuthal coverage. Three-component seismometer and accelerometer data were recorded for a total of six weeks.

**Keywords**: Bowen earthquake, aftershock, temporary seismometer, Queensland.

## INTRODUCTION

On 16 April 2011 (05:31:18 UTC) the largest earthquake to strike Queensland in almost 50 years occurred approximately 50 km west of Bowen. Five smaller aftershocks ranging in magnitude from $M_L$ 3.2 to 4.1 were recorded on 16, 17 and 19 April (Fig. 1). The main shock resulted in felt reports from local residents who contacted the Geoscience Australia (GA) Earthquake Hotline or completed the online earthquake reporting form. Within 24 hours of the main shock GA officers mobilised to deploy four temporary seismic recorders around the epicentre (Fig. 2). Aftershock data was recorded for a period of six weeks (19 April – 2 June), with multiple aftershocks occurring daily in the weeks following the main shock. This paper describes the preliminary aftershock distribution from the first two weeks of recorded

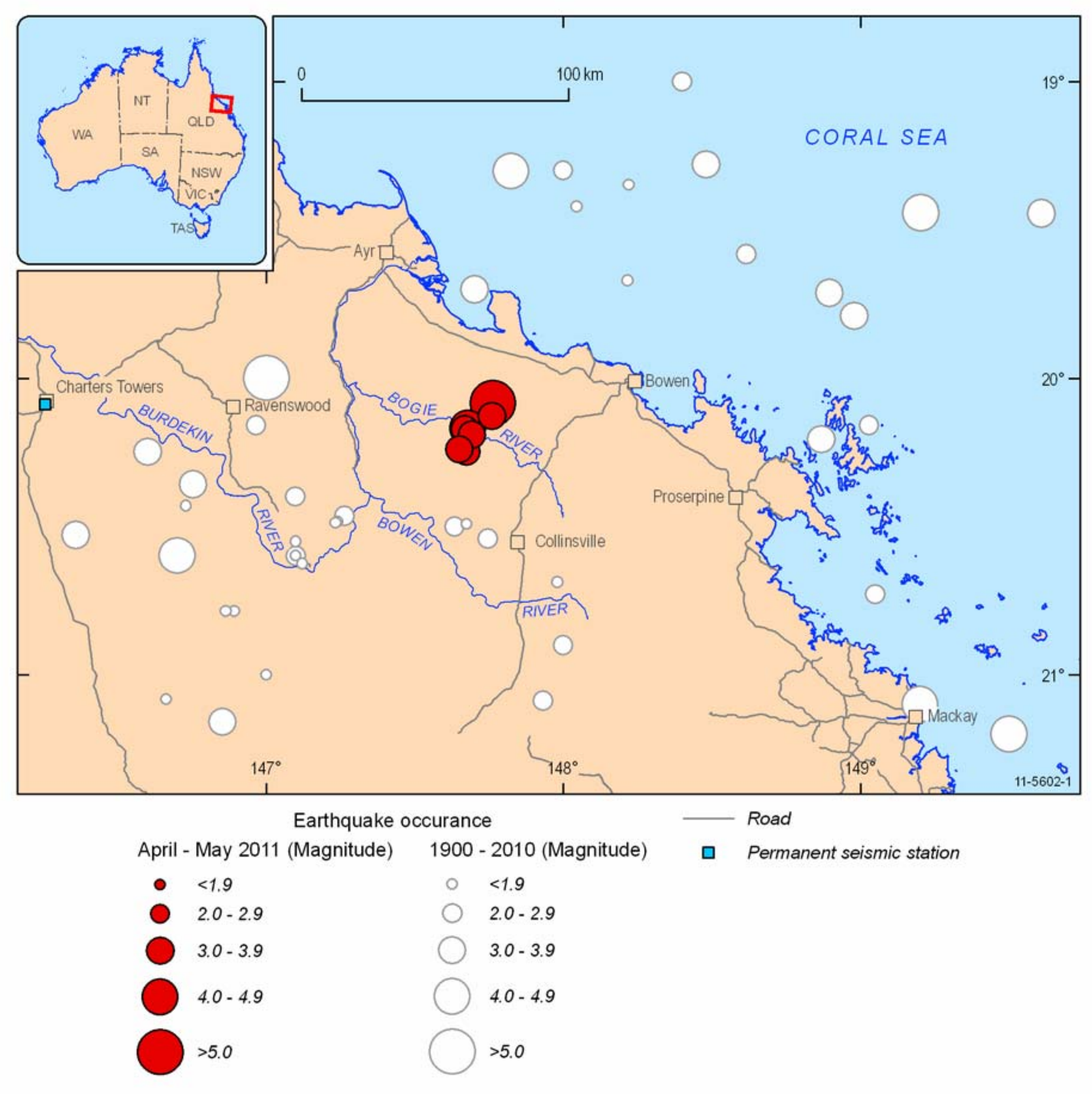


**Figure 1**. Map showing location of Bowen earthquake and first aftershocks (red circles) relative to historical earthquakes recorded in central Queensland (white circles). The permanent Australian National Seismic Network (ANSN) station at Charters Towers (CTA) is shown in blue.

data. The response spectra, isoseismal radius and focal mechanism of the main shock are also presented.

Prior to the $M_L$ 5.3 event only 12 earthquakes of M > 5.0 are recorded in the onshore and offshore parts of Queensland between 1900 and March 2011. One of the largest events was a $M_L$ 5.7 in 1913, which was located north of Ravenswood (80 kilometres west of the Bowen epicentre). Despite the apparent paucity of moderate-sized events, earthquakes are known to occur in central Queensland, with more than 50 events (M 0.5-5.7) having been recorded in the Bowen region since 1900 (Fig. 1). A M 3.6 earthquake recorded offshore Innisfail on 25 March 2011 was one of 18 earthquakes in Queensland recorded by GA in 2011. This is much higher than the number recorded by GA in recent years (Glanville 2011).

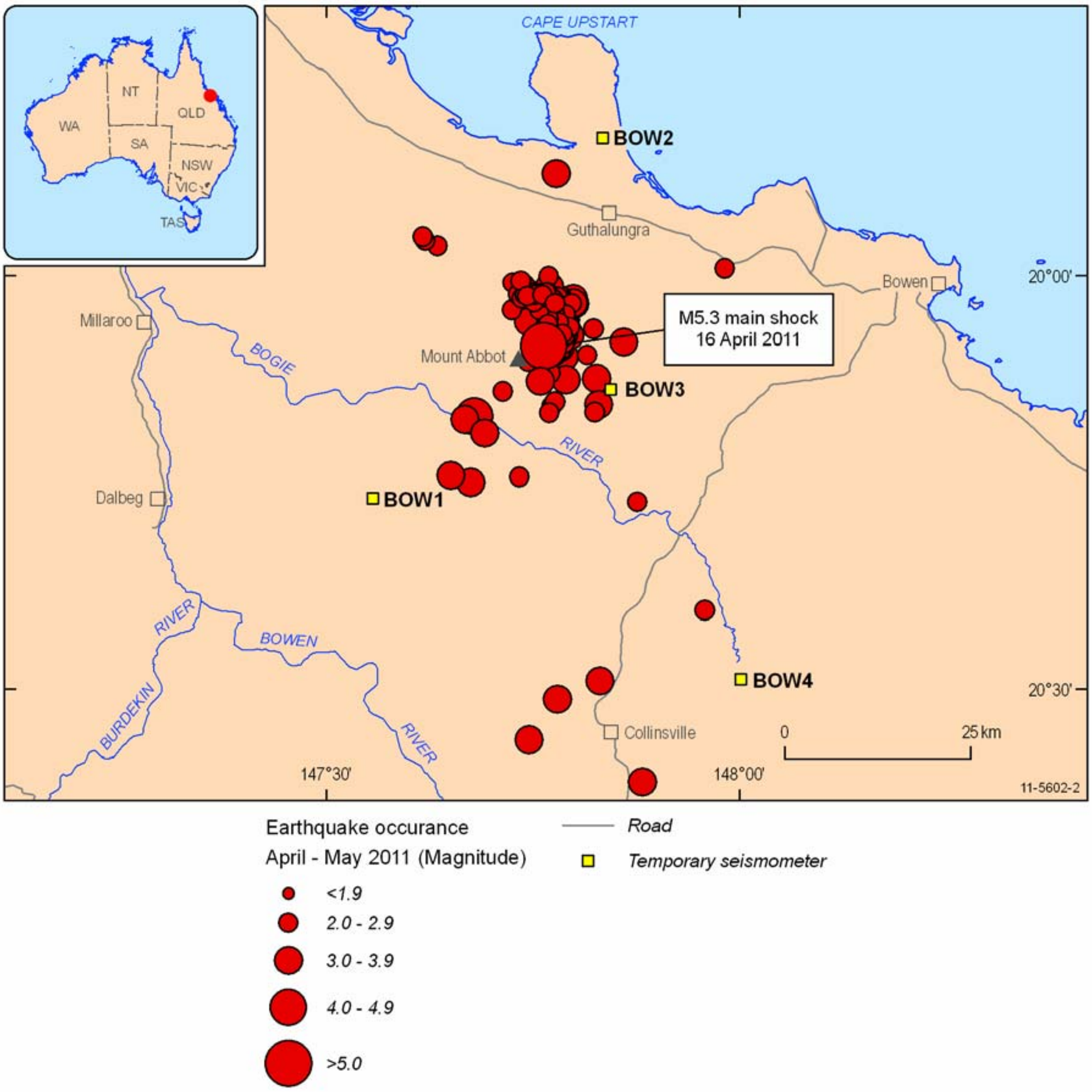


**Figure 2**. Distribution of aftershocks (solutions using more than 3 stations) showing the cluster north and east of Mount Abbot. The location of the temporary seismometers (BOW1-BOW4) are shown in yellow. Note: epicentres in the south may be associated with Collinsville mine.

The Burdekin region to the north has been identified as a seismic source zone (e.g. Gaull *et al*. 1990), while the Bowen Basin region to the south is considered to be comparatively aseismic (Hillis *et al.* 1999).

## MAIN SHOCK

GA detected and analysed a $M_L$ 5.3 earthquake using seismic arrivals identified on several permanent Australian National Seismic Network (ANSN) stations in central Queensland, with strong arrivals at Charters Towers (CTA), Eidsvold (EIDS) and Quilpie (QLP), and was recorded at a depth of 7 kilometres.

A preliminary moment magnitude ($M_W$) of 5.2 was calculated for the main shock. Five percent damped response spectra were calculated for the strong-motion recording at Charters Towers (CTAO). The CTAO response spectra were subsequently compared to several ground-motion prediction equations (GMPEs) at an equivalent magnitude and distance (Fig. 3). The data suggest a good correlation with the Atkinson & Boore (2006) GMPE for eastern North America. The Somerville *et al.*

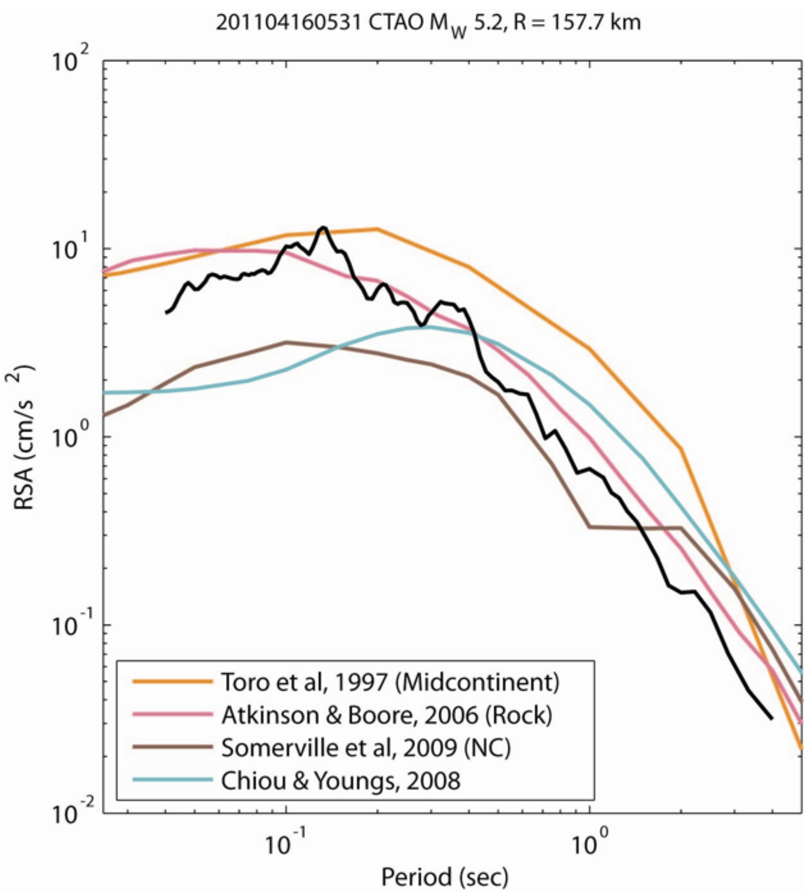


**Figure 3**. Five percent damped response spectra calculated from the CTAO accelerogram for the $M_W$ 5.2 (preliminary) Bowen main shock. The black line indicates the geometric mean of the horizontal components, which is compared to published Ground-Motion Prediction Equations.

(2009) GMPE developed for non-cratonic Australia performs well at longer periods. However, this model appears to underestimate short-period ground shaking for the $M_W$ 5.2 CTAO record.

## AFTERSHOCK DEPLOYMENT

Four temporary seismometers (BOW1-BOW4) were installed by Geoscience Australia officers within four days of the main shock (18-20 April; Fig.2). The aim of the temporary seismometers was to record aftershock activity in order to obtain more precise data on the location, magnitude and depth of smaller magnitude aftershocks. This data was intended to assist in better understanding the source of the main shock.

The temporary recording stations were located between 10 and 48 kilometres from the epicentre of the main shock (Fig. 2). The sites were arranged to maximise the azimuthal coverage relative to the epicentre and the locations of permanent sites in the ANSN. The site coordinates were predefined, with final locations determined by access to the land. Where possible, the stations were preferentially located on or adjacent to *in situ* bedrock.

The instrumentation at these sites consisted of a Lennartz LE-3Dlite Mk II seismometer and a Kelunji Echo digitiser with on-board accelerometer. Data was recorded on six channels at a sample rate of 100 samples per second.

## AFTERSHOCK DATA

The aftershock data described is focused on the first two weeks of recorded data. Multiple small ($M < 2.0$) aftershocks occurred each day, with a total of 326 separate events recorded during this period. The number of aftershocks averaged 20 per day, with more frequent events occurring on 19-22 April, shortly after the recorders were installed. During this period, the maximum number of aftershocks reached 56 events on 21 April.

Most earthquakes cluster in an area 10 x 20 kilometres near Mt Abbot (see Fig. 2), south of Cape Upstart. The main shock and series of aftershocks generally display a trend towards the north-west. This trend includes events analysed with more than three stations. Events where two stations were involved in the final solution also occur within this overall trend. Prior to installation of the temporary seismometers, initial aftershocks recorded on the permanent ANSN were located south of the main cluster (near the Bogie River). The temporary station distribution was not optimal as three of the four temporary stations are located in a north-south alignment. Consequently, aftershock hypocentres are biased by this station configuration smearing the hypocentre distribution towards the north-west. However, difficulties in accessing preferred sites and the absence of rock outcrop in preferred azimuths meant the aftershock deployment configuration was not optimal.

Continuous recording at the temporary sites was occasionally interrupted, resulting in data gaps at various time intervals. The analysis resulted in events where any given final solution may have involved two, three, four or more stations (where any number of ANSN stations was used). Accordingly the location of the final earthquake solution may be impacted by the available coverage.

## ISOSEISMAL MAP

Following the $M_L$ 5.3 main shock, over 500 felt reports were received through GA's Earthquake Hotline and online reporting forms. A Modified Mercalli Intensity (MMI) was established from each report and the intensity distribution was contoured to produce an isoseismal map (Fig. 4). It shows the distribution of ground shaking and illustrates the degree of attenuation of seismic energy with distance away from the epicentre. A maximum intensity of MMI V was experienced in Ravenswood and Bowen, with some reports of slight damage in Guthalungra and Bowen. The felt reports indicate that the earthquake was felt as far north as Cairns (~400 km from the epicentre) and as far west as Hughenden (~370 km from the epicentre). The average felt radius distance for an MMI III ranges from 200-300 kilometres for an earthquake of this magnitude (Dent *et al.* 2007). Few felt reports were received from the south-western areas, which is in part due to lower population. Following the $M_L$ 5.3, a fresh landslide was observed by locals on the western side of Mt Abbot. This may provide an indication of the intensity of ground-shaking in the epicentral region that was associated with the main shock.

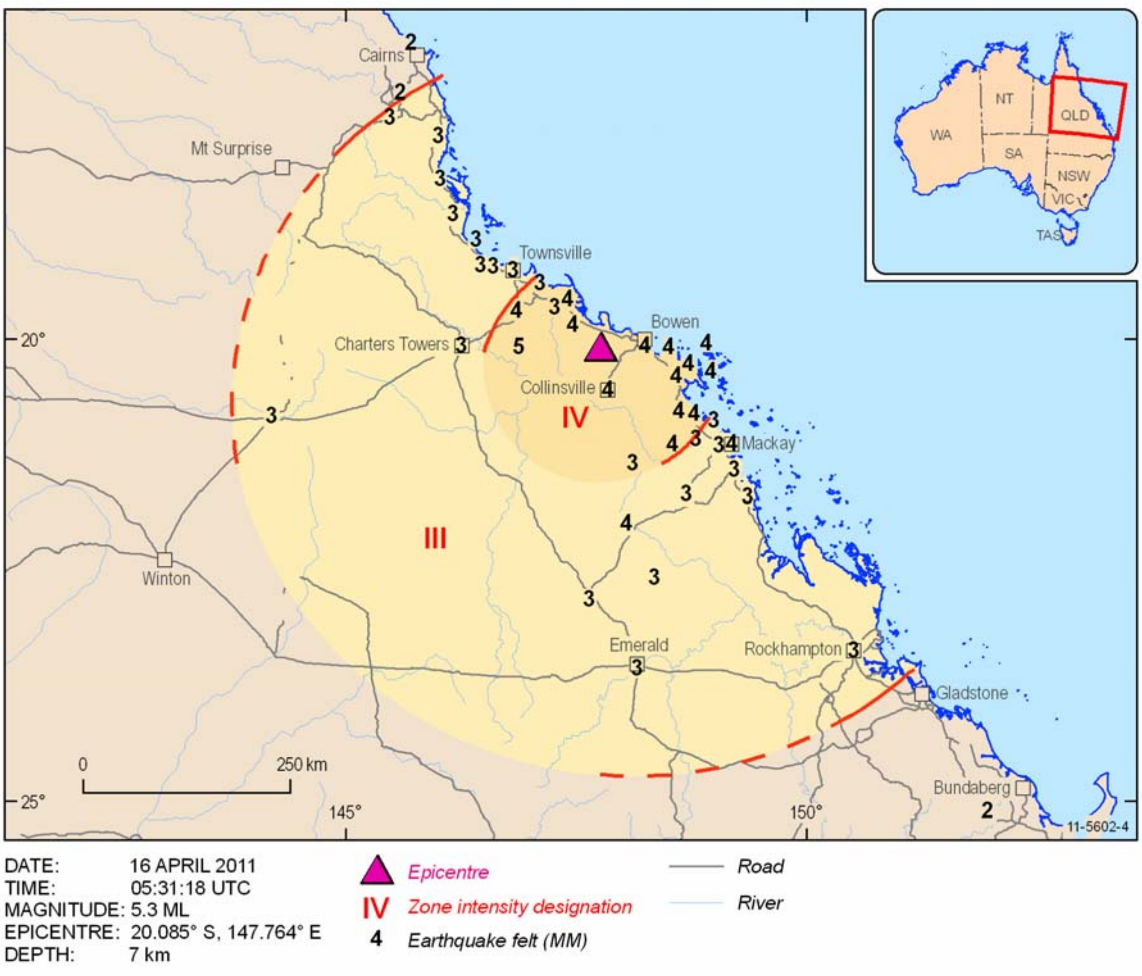


**Figure 4**. Isoseismal map for the Bowen main shock. MMI is a descriptive measure of the effects of ground shaking at a given location.

## GEOLOGICAL INTERPRETATION

The aftershock sequence occurred in the northern New England Fold Belt, east of the Bowen Basin (Champion *et al.* 2009; Fig. 5). Typical of intraplate seismicity, the recent earthquakes occurred in the upper crustal seismogenic zone (e.g. Denham 1988). Epicentres overlap Carboniferous intrusive rocks and Permian extrusives in the vicinity of Mount Abbot (i.e. Mount Abbot Igneous Complex). The complex is Mesozoic in age and consists of two intrusive stocks with sharp sub-vertical contacts, separated by steeply dipping local faults (Paine *et al.* 1974). Carboniferous granites and granodiorites situated to the west of Mount Abbot contain a set of closely spaced

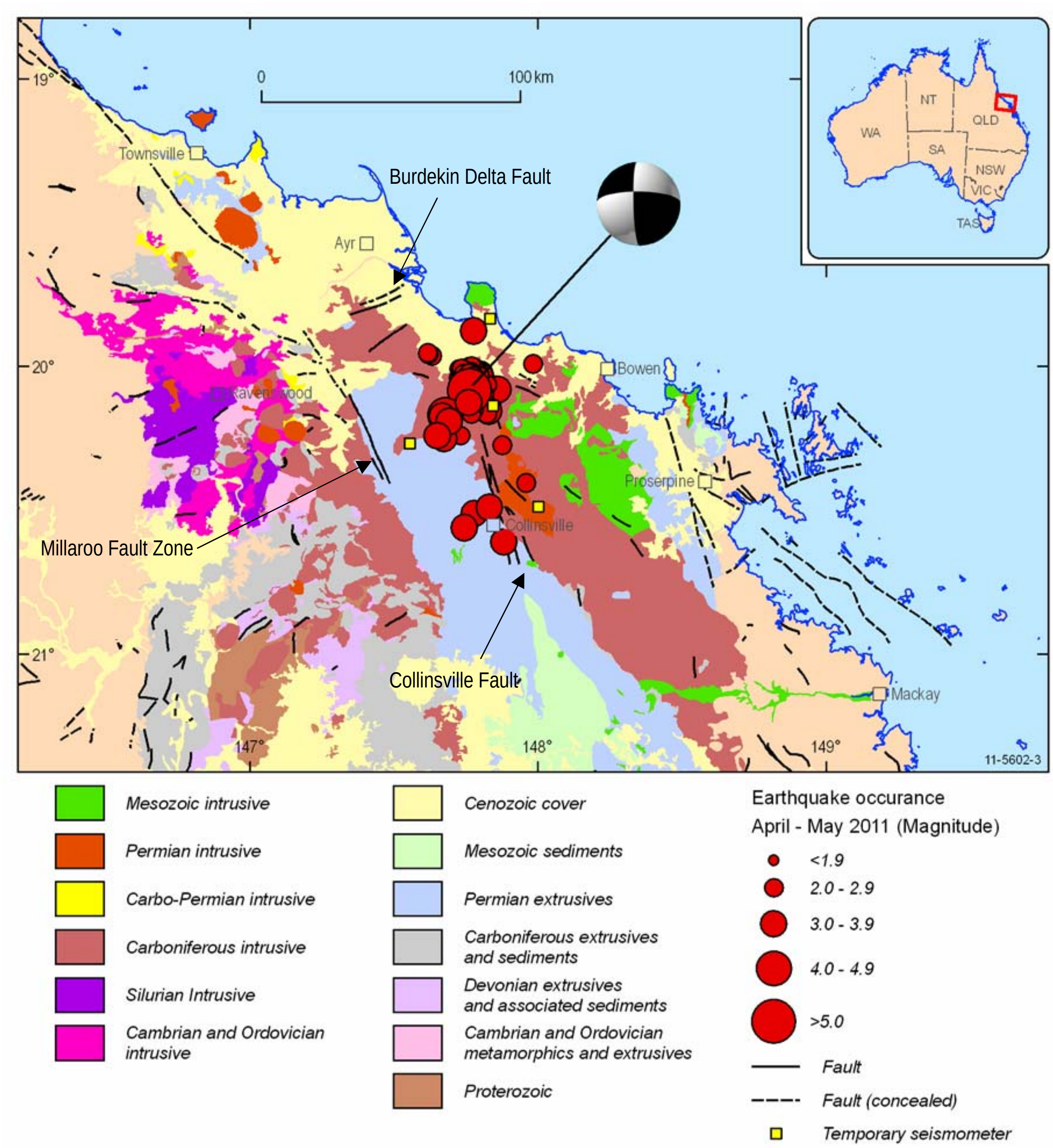


**Figure 5**. Regional geological map of the earthquake zone showing major lithologies and structural trends, including the Millaroo and Collinsville Faults. The April-May 2011 earthquake epicentres are primarily associated with Carboniferous intrusive rocks in the northern New England Fold Belt. The focal mechanism for the main shock shows a strike-slip solution.

dykes, which form a series of semi-circular of ridges and hills. Mapped structural geometry of Upper Carboniferous to Permian rocks shows that existing faults are steeply dipping to vertical (Paine *et al.* 1974).

The main structural features in the epicentral region include the Millaroo Fault Zone (MFZ) and the Collinsville Fault. There is a regional structural trend towards the north-northwest, with regional faults east of the MFZ oriented in a north-northwest direction. Faults in the Bowen Basin also reflect this broad structure (Korsch *et al.* 1992; Hillis *et al.* 1999). It is possible that the apparent north-westerly trend of aftershocks, which is consistent with the strike of regional structures, may highlight a pre-existing fault, fault complex or shear zone. The magnitude of the Bowen earthquake implies a rupture length in the order of 2-3 km, and accordingly the event is unlikely to have produced any surface rupture, although field mapping would be required to confirm this. Northwest of the earthquake zone, the east-northeast trending Burdekin Delta Fault is the only potential neotectonic feature recorded in the area (Clark *et al.* 2011). This feature is mapped as occurring in the same Carboniferous intrusive rocks as the recent earthquakes (Fig. 5).

A preliminary moment tensor solution derived using ANSN data from the main shock indicates a strike slip motion (Fig. 5). Orientation of the focal planes differs from the dominant north-northeast stress orientations in the adjacent Bowen Basin (Hillis *et al.* 1999) and could suggest a northerly stress direction in the northern New England Fold Belt (NEFB). This focal mechanism is also in reasonable agreement with the north to north-westerly trend of major faults in the NEFB.

## SUMMARY

The $M_L$ 5.3 Bowen earthquake and aftershock sequence were widely felt in the northernmost parts of central Queensland, with the main shock being the largest to occur for many years in both the region and in Queensland as a whole. Many local residents experienced significant ground-shaking, with an MMI IV felt around the epicentre. The response spectra of the main shock from CTAO show a good fit to modelled ground motion prediction equations. A focal mechanism produced for the main shock indicates that movement along the fault was strike slip. Such events are important for understanding earthquake activity in intraplate regions. The rapid deployment of aftershock recording equipment has provided more detailed information about the earthquake sequence than could be obtained from only using ANSN station data.

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