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Identification of Neotectonic Features in the Gladstone Region, Central Queensland

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ABSTRACT

Neotectonic features in the Gladstone region of Central Queensland were indentified and assessed for activity within the context of the Australian Neotectonics Database at Geoscience Australia (Clark 2006). Following Clark (2006), within the Australian Neotectonics Database, "neotectonic deformation" is one which has hosted deformation under the current Australian crustal stress regime (estimated as having established in the last 10-5 Ma). This study identified structures with evidence of neotectonic deformation by interpreting geomorphologic expression (scarps, elevated terraces, offset drainages, shutter ridges) through interpretation of high-resolution LiDAR based DEMs, aerial photograph, published geologic mapping, and field reconnaissance mapping. The geomorphic interpretation was supplemented with assessment of temporal clustering of seismic events and, where available, from published studies, subsurface investigation and geophysics. In the Gladstone Region, the Australian Neotectonics Database identifies the West Basement fault as a Neotectonic Feature. A review of published geologic surface and subsurface mapping was compiled for this structure and an assessment of evidence for recent activity is presented. The assessment identified the Queenslander Fault, a north-northwest striking fault near Calliope, as a neotectonic feature with of evidence of potential movement in the early Quaternary.

Keywords: Neotectonic, Paleoseismology, West Basement Fault, Queenslander, Active Faulting

1. INTRODUCTION

An active fault is a discontinuity between two portions of the Earth's crust which shows evidence of movement during geologically recent time, association with earthquakes, and potential for recurrence. An active fault can produce surface rupture ground deformation that occurs along the surface trace of the causative fault during an earthquake.

Identification of fault activity is a key component of a seismic hazard assessment. The spatial extent and activity of faults will define seismic sources for input to probabilistic seismic hazard assessments (PSHA). Contribution to ground motions from the fault seismic sources will impact the design ground motion spectra and is needed for design of structures not covered by AS1170.4 (2007) including tall buildings with long natural frequencies, offshore structures, and large tanks. PSHA results in the form of a magnitude deaggregation are also used to derive design magnitudes for liquefaction assessments.

In addition, fault activity is critical to assess fault rupture hazard for infrastructure that may cross the fault. Long linear features such as rail, road, tunnels and pipelines cannot avoid faults as a practical option. Appropriate mitigation strategies for surface fault displacement are often required in identified active faults. Because the amount and frequency of surface displacement can vary significantly, it is important to estimate the degree of activity likely to be exhibited by a fault in the region of interest relative to the project.

Clark (2006) presented the Australian Neotectonics Database at Geoscience Australia a record of over 200 instances of potential neotectonic deformation. Following Clark (2006), "neotectonic deformation" is one which has hosted deformation under the current Australian crustal stress regime (estimated as having established in the last 10-5 Ma) and an "active fault" in the database is one that has hosted displacement since that time.

Structures in the Gladstone region were assessed for neotectonic deformation and active faulting in relation to a large linear infrastructure project.

2. IDENTIFICATION AND INTERPRETATION METHODOLOGY

Assessing the impact of potentially active faults involved four phases; identification, characterisation of the fault morphology, geologic field mapping and fault activity interpretation.

Identification

The initial task involved desk study review of geologic mapping, published literature and aerial photographs supplemented with reconnaissance level field mapping to indentify faults for more detailed study. Published geologic mapping, from the Queensland Government Department of Natural Resources and the Geological Survey of Queensland (GSQ), at various scales (1:100k and 1:250k) were used to locate known faults.

Fault Morphology Characterisation

Characterisation of the indentified faults within this region developed the geologic, structural/kinematic, geomorphologic and seismological setting from available information. GIS was used extensively to compile the various data sources and place the faults in a tectonic regional context. Characterisation tasks included; Data review of published geologic mapping and research, aerial photography interpretation (API), geomorphologic evaluation of digital elevation models (DEM) from both regional and LiDAR datasets, and spatial analysis of regional seismicity catalogue.

Geologic Mapping

This stage involved geologic mapping to investigate evidence of fault movement. The field efforts included the following activities; identification of fault in the field, geologic mapping of rock types and stratigraphic relationships, mapping geologic structure or kinematic relationships, geomorphologic mapping of Quaternary sediments and evidence of fault offset (if any) in younger geologic units.

Fault Activity Interpretation

The findings from the fault characterisation and geologic mapping support an interpretation of fault activity. The interpretation methodology followed guidelines presented in the U.S. Nuclear Regulatory Commission publication "Techniques for Identifying Faults and Determining Their Origins" (NUREG/CR-5503).
Key components of the assessment include:

Intrinsic Fault Evidence and Stratigraphic Evidence

Faults commonly are associated with characteristic textures and structure that develop as a result of shearing. Analysis of fault-rock lithology and texture provided important information on the conditions of faults. The presence of a fault is commonly identified from the juxtaposition of rock types that do not belong together in ordinary geologic sequences. Discontinuity in geologic strata may be a result of fault displacement, stratigraphic discontinuity or intrusion.

Geomorphic Evidence

Geomorphic evidence of fault activity includes features preserved on the landscape as the results of surface deformation (e.g. fault rupture, folding) and subsequent erosional or depositional processes that result from deformation. Geomorphic features indicative of late Quaternary fault activity include, but are not limited to, fault scarps, triangular facets, fault rifts, pressure ridges, shutter ridges, offset or deflected drainages, enclosed depressions or sag ponds, sidehill benches, aligned saddles, spring lines, vegetation lineaments, and linear drainages or troughs.
Combinations of these features are present if a fault has experienced repeated late Quaternary activity. The identification, delineation, and evaluation of geomorphic features associated with faults is an effective method for recognising and characterising active faults.

Seismologic Evidence

If a fault can be shown to have generated an earthquake during historic time, it is considered an active fault. The historic and instrumental record of earthquakes is short and instrumental coverage is limited. The magnitude and location accuracy of the instrumental record is largely dependent on the number of seismometers, their sensitivity and spatial coverage (distribution density). In regions with low rates of seismicity, the instrumental record is rarely adequate in frequency or in the accuracy of epicentre location to confidently identify

an active fault. It is important to note that absence of seismic activity can not used to show that a fault is inactive.
Analyses of seismicity data provide important information on fault behaviour. The focal mechanisms describe the style and orientation of faulting slip and hypocentral depth provide information on seismogenic crust, thus maximum width of faulting.

3. GEOLOGIC SETTING

Tectonic Setting

The rigid outer shell of the earth (the lithosphere) is broken into a mosaic of some 15 major tectonic plates, which slide over the more plastic interior (the asthenosphere) at different rates. Boundaries between the plates are of four principal types: divergent zones; subduction zones; collision zones; and transform faults. The majority of the earthquakes, volcanic and mountain building activity around the world are associated with these plate boundaries.

Australia is a wholly intraplate region with the nearest plate boundary more than 500km north of Darwin. It has no major active fault systems. It is bounded on three sides by passive margins, and its northern edge is an active plate boundary, where the Australian plate is involved in a continent-arc collision with northern New Guinea and the Banda arc.

The geology of southeast Queensland developed primarily from a complex series of compressional and extensional events from the Late Palaeozoic onwards. A strong northwest trend is clearly evident in the structure and distribution of rock units located in southeast Queensland.This shows the geology of Queensland is divided into three main structural divisions: the Proterozoic shield in the northwest and north, the Palaeozoic-Mesozoic Tasman Orogenic Zone in the east, and the interposing and overlapping Mesozoic Great Australian Basin. The Palaeozoic-Mesozoic Tasman Orogenic Zone formed during the Late Devonian to Early Carboniferous period as convergence led to the development of a subduction zone and related volcanic arc dipping to the west. This led to the development of a marine forearc basin and an accretionary prism. Renewed subduction during the Early Permian led to block faulting and regional metamorphism. A further extensional episode took place in the late Cretaceous to Early Tertiary possibly associated with the opening of the Tasman Sea (Nash, 1988).

The Australian continent is currently under compressional stress and may experience warping and reverse faulting of the crust as the landmass shortens. Stress orientations and seismicity in Australia have been modelled and reveal a north-northeast to south-southwest trending stress field in the region of eastern to southeast Queensland (Hodgkinson et al., 2007). This stress regime is expressed as north-northwest to south-southeast trending structures.

Seismicity

The lower frequency of seismic activity in Australian compared with central New Zealand or western California, should not be taken as an indication that major earthquakes do not occur in Australia. The largest known earthquake in continental Australia had a magnitude of 7.2. The observed average frequency of an earthquake magnitude 6 or more in Australia over the last 110 years is about 1 every 5 years. The apparent magnitude 5 or greater earthquakes throughout Australia is 1 per year, and 1 in 2 years in the eastern Australian states. The probability of occurrence is lower than in plate boundary areas, but when one looks at very low probabilities, major earthquakes do need to be considered in the Australian context.

A brief review of instrumental and historical earthquakes in the study area is presented in this section and on Figure 1. Earthquakes can be identified from instrumental recordings or from reports of historical "observed" or "felt" effects. A preliminary catalogue of earthquake events around the region was compiled from Geosciences Australia for earthquakes from 1960 to 2009, and from a historical catalogue of events reported by EPRI (1994).

Historical Earthquakes

A review of historical earthquakes shows that low to intermediate events have occurred within the study area over the previous 120 years. The earliest recorded event was documented in 1872, though, recent research has identified the possibility of a significant earthquake (possibly around M_L 6.0) felt in the Noosa area of south-east Queensland in 1862 (Jones et al., 2001). The largest earthquake in Queensland occurred offshore of Gladstone in 1918 with a M_L 6.3. Structural damage to buildings was reported form this Gladstone earthquake. In Queensland earthquakes > M_L 5.0 happened every 5 years during the last century. The most recent moderate sized earthquake struck in Bundaberg in 1985 with M_L 3.1.

The published literature of recent tectonic activity in the region documents thrust faulting on the Midgee (Dee Range) Fault from a M 2.9 earthquake sequence 60km west-northwest of the site, and 7km north of Bajool (McKavanagh et al. 1993). This consisted of a main shock and a number of aftershocks defining a NW-SE structure dipping 45 degrees to the northeast. This orientation is consistent with dominate structural trend in the region and the current Australasian stress-regime. This event did not produce a surface rupture.

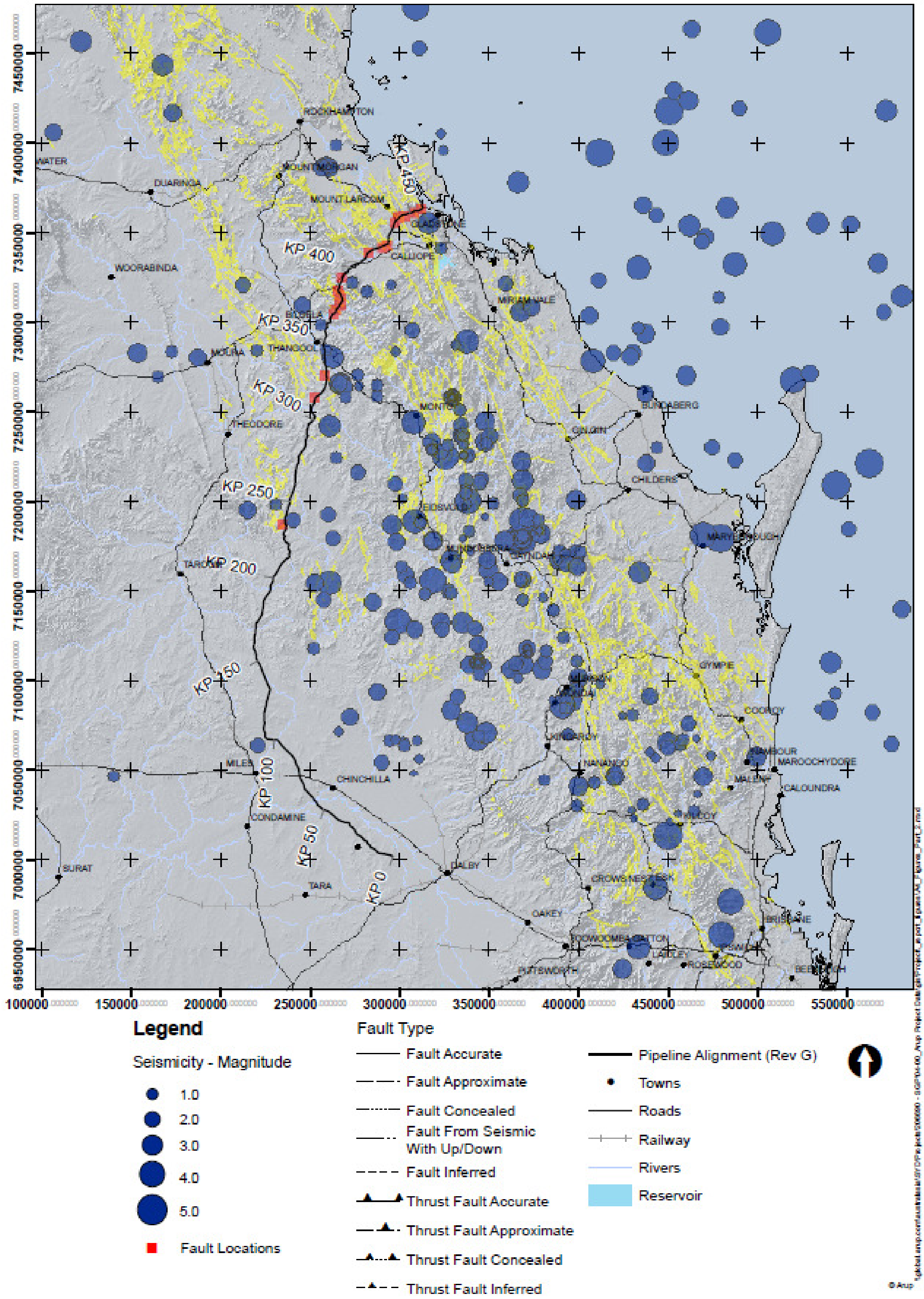

Figure 1 Seismicity in the Gladstone, Queensland Area

4. WEST BASEMENT FAULT

Map Expression

The Western Basement Fault (WBF) is shown on the published geological maps trending NNW to SSE and defines the western boundary of the Narrows. This structure separates Devonian arenite/mudrock rocks to the west and Tertiary rocks and sediments to the east. This fault has been extensively investigated as part of the investigations of the Stuart Oil Shales (Pope, 2000). In the shallow sub-surface the WBF is interpreted to be a parallel set of steeply-dipping normal faults, which marks the western boundary of the Narrows half-graben (Mclver et al. 1991).

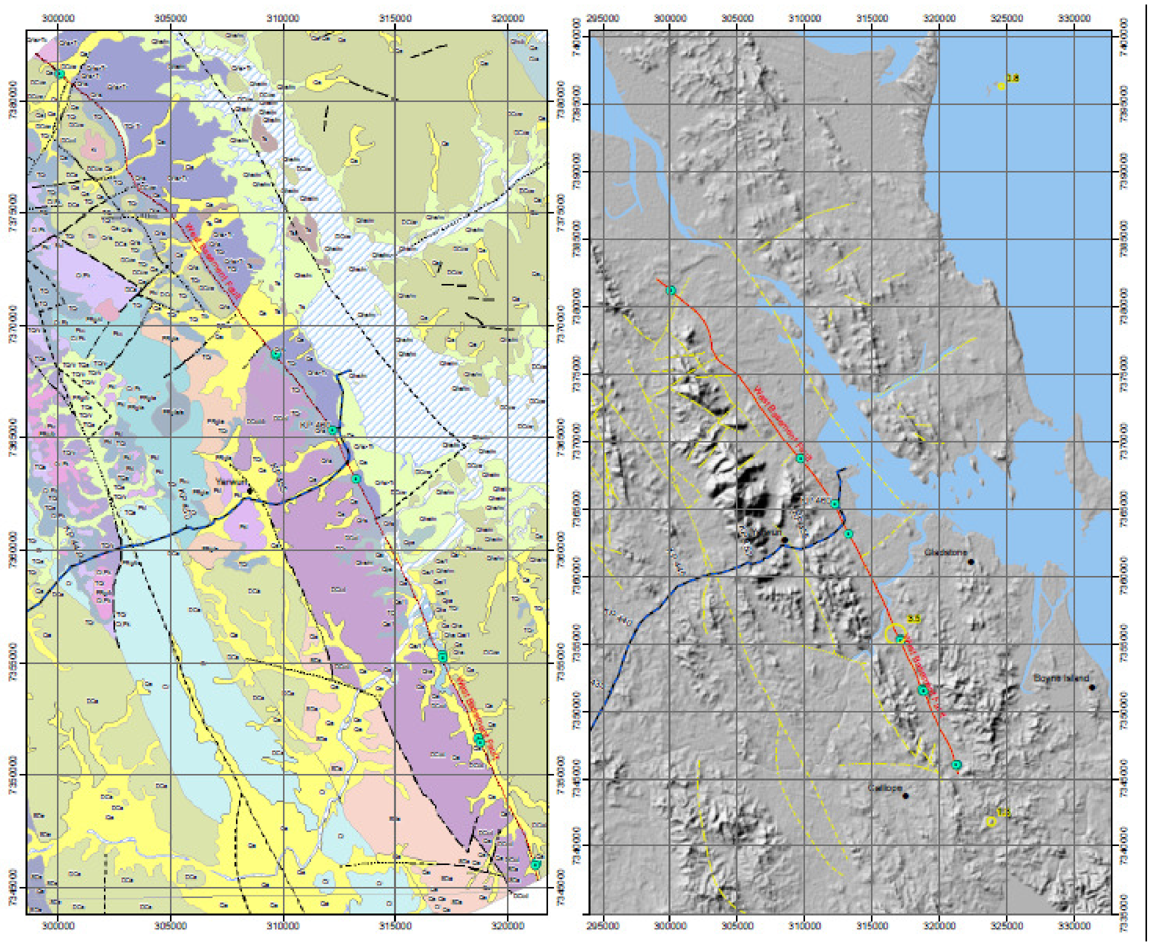

Figure 2 Geologic Map (left) and Shaded Relief Map of the Western Basement Fault

Geomorphic Expression

Aerial photograph interpretation (API) carried out on photographs from 1973 and 2007 provide evidence of the WBF as a major bedrock controlling structure in the present topography. Various geomorphological indicators of potentially more recent activity observed include: structural control of Quaternary drainages (offset and straight sections); topographic depressions which could be sag ponds; topographic highs which could be shutter ridges, and over steep breaks in topography that potentially could be scarp features.

Field Comments

A total of 7 sites were mapped along the fault trace spanning over 50km along its trace (Figure 2). The sites were in either Quaternary deposits or Tertiary gravels and showed little to no expression of the fault trace (Figure 3). The field mapping was unable to demonstrably locate the fault trace in the Tertiary and Quaternary sediments along its mapped trace. In a few instances there were local breaks in slope that were subparallel to the fault trace. These features were short, relative to the fault trace and could be explained by normal alluvial processes of deposition and erosion. The published geologic mapping shows the fault defining a major contact between distinct rock units, this contact was not observed at any of the field sites.

Figure 3 Photograph showing the typical subdued geomorphic expression along the “mapped” WBF trace.

Associated Seismicity

There was a magnitude 3.6 event located in 1912 located on the southern end of the WBF (Figure 2). The location of this 1912 event is before the implementation of the global network of seismographs in ~1960s. The evidence for this specific event most likely comes from historic records which would be concentrated in the populated areas and could bias the location. This event is not considered reliable enough to be associated with one specific structure definitively, but may be considered as evidence of potential neotectonic activity in the region.

The catalogue reports one earthquake near the southern terminus of the fault attributed to mine blasts (M1.3 on 12 Feb 1992). This event is not seismogenic and therefore not considered in this study.

Fault Activity Interpretation

The WBF is a major structure that defines The Narrows Graben. Its existence and vertical offset is confirmed by exploration drilling for the Stuart Oil Shale (Pope, 2000) and it is indentified by Geoscience Australia as a Neotectonic Feature (Clark, 2007).

Various geomorphological indicators observed in aerial photographs from 1973 and 2007 are observed including; structural control of drainages (offset and straight sections), potential sag ponds interpreted from topographic depressions, potential shutter ridges interpreted from topographic highs, and potential fault scarps along over steep topographic breaks.

Pope (2000) indicates that normal faulting on the WBF took place up to late-Miocene (10.5 – 5.5 Ma) as The Narrows developed. Finegan (1990) states that oblique-slip reactivation of the WBF took place and has offset Miocene to early Pliocene (~14 – 4Ma) aged gravel beds. Finegan (1990) and Pope (2000) imply that reactivation of the WBF took place following lateritisation of gravel beds. Lateritisation is estimated to have taken place during the Miocene and early-Pliocene (~14 – 4Ma) which places the earliest reactivation of the WBF during the early-Pliocene (~ 4Ma).

The most recently published geological mapping Gladstone 1:100,000 sheet (2006) does not indicate any offset of Quaternary sediments, but the earlier Rockhampton 1:250,000 sheet (1976) does show offset in the Quaternary sediments with strike-slip motion along the WBF. A 1:10,000 scale geological map of the Gladstone to Targinie area (Finegan, 1990) clearly shows strike-slip displacement of Quaternary Residual Soils along the WBF. These Quaternary units are residual soils of Miocene to early Pliocene aged gravel beds and therefore relation to timing of fault is unknown.

Based upon the published information, the WBF has been reactivated as an oblique-slip fault in the current stress regime of Australia. The reactivation is inferred to have taken place in the early-Pliocene (~ 4 Ma) expressed in offset Teritary aged gravels. Field mapping at 7 sites along the fault show no evidence of Quaternary activity, in-fact the fault trace was difficult to recognize in Tertiary and Quaternary sediments along a 50 km length.

This study did not include any subsurface investigation to definitively test the WBF fault. The authors are aware of on-going infrastructure development in the Gladstone Area and across the Narrows. Interpretative of the findings from these studies will subsequently refine this interpretation.

5. QUEENSLANDER FAULT

Map Expression

The Queenslander Fault is a thrust fault striking NW-SE dipping to the northeast (Figure 4). The thrust fault marks a boundary between Late Devonian – Early Carboniferous sandstone/siltstone/conglomerate on the NE and Quaternary alluvium on the SW. The thrust fault is mapped as approximate where is defines the contact between the rock and alluvium. Where the fault crosses alluvium it is mapped as concealed.

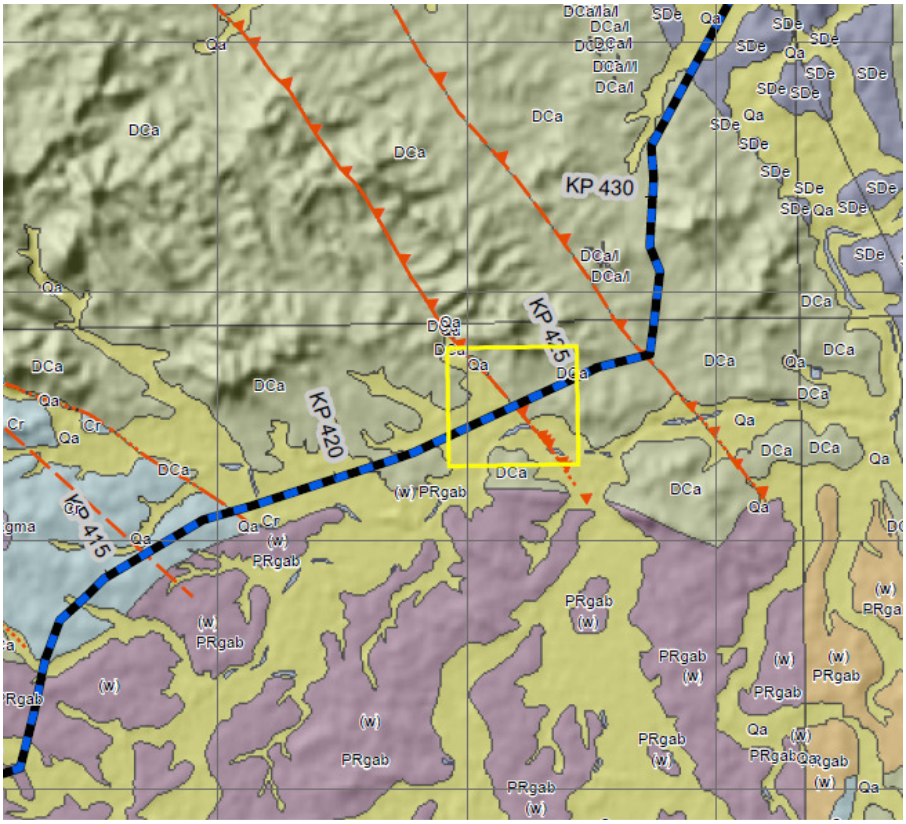

Figure 4 – Geologic map of the southern end of the Queenslander Fault. The yellow box defines the detailed map areas of Figure 5.

Geomorphic Expression

From the northwest, the fault parallels the lower slope of a prominent ridgeline. The orientation of the ridge on the hanging wall of the fault is consistent with a thrust. The fault appears to be structurally controlling parts of a small local creek until it crosses the Calliope River (Figure 5). This creek has an abnormally wide channel with shallow slopes. The creek marks the boundary between rock and alluvium (Figure 4).

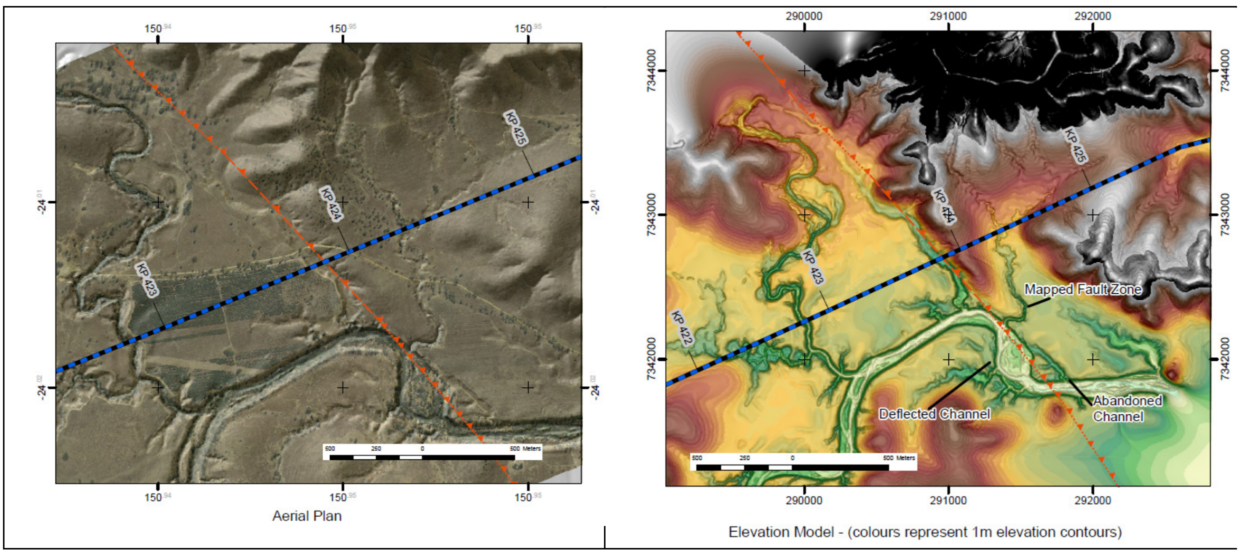

Figure 5 – Aerial Photograph and Hillshade DEM of the Queenslander Fault.

Where the fault crosses the Calliope River, the river takes a sharp bend, abandons an older more direct channel and bends back on itself heading up against the regional topographic gradient (Figure 5). This expression of a failed channel and the river bending back heading up gradient is the only example of this morphology observed along a 66km trace of Calliope River (Figure 6).

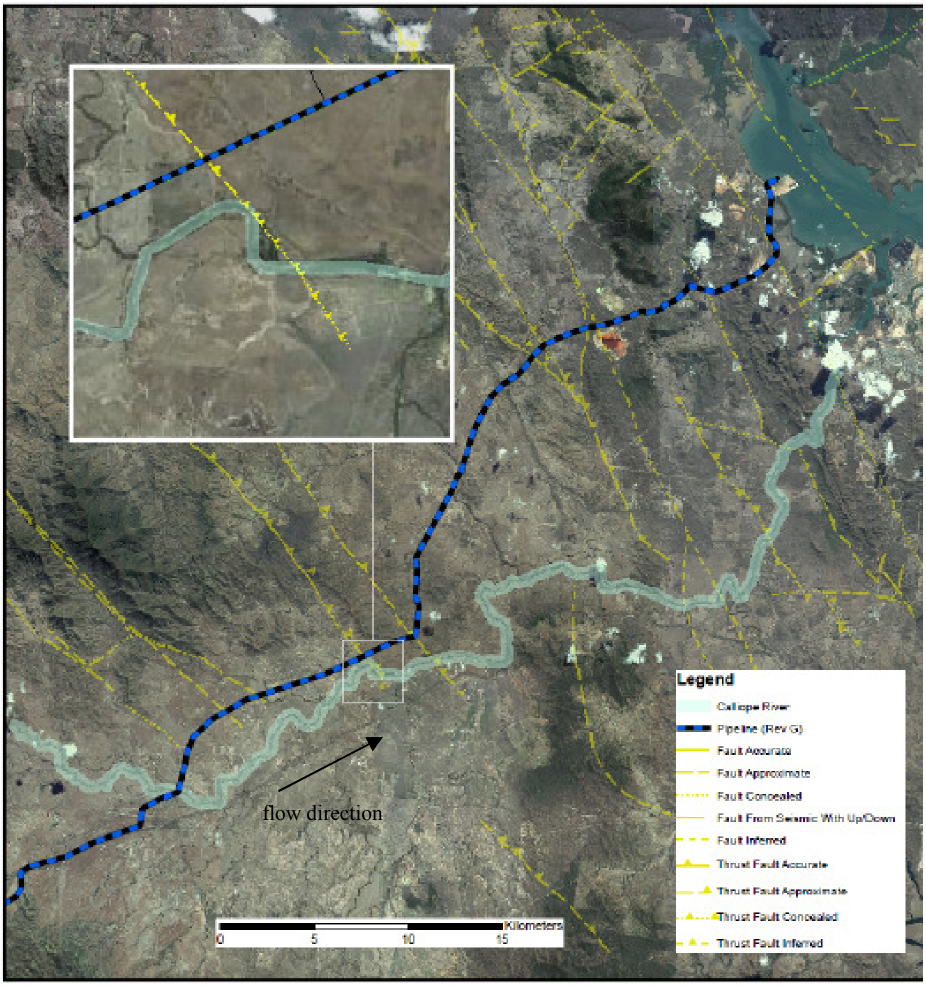

Figure 6 Aerial photograph showing the Calliope crossing the Queenslander Fault.

Field Observations

The northern edge of the channel follows the mapped fault trace. The northeast bank is rock, where the southwest bank is alluvium (Figure 7). The creek was observed to have gentle banks with a flat wide bottom. This morphology is not observed in other creeks in the region. Following the trace south across a terrace to the south of the channel is a slight change in gradient of across the alluvial terrace.

Figure 6 View along the Queenslander Fault trace looking north. The slope on the right is Devonian aged rock. The slope on the left is Quaternary Alluvium.

Further to the south is a tributary, entering the main drainage from the north. There is a prominent shear zone within the incised creek (Figure 7). The shear zone is not evident on the surface of the terrace. The presence of this deformation zone confirms the existence of the fault at this location. At a junction where the fault meets the Calliope River, there is a 3m over steepened scarp parallel to the projected fault trace.

Figure 7 Fault shear and gouge zone of the Queenslander Fault.

Associated Seismicity

The Bajool earthquakes on the Midgee Fault defined movement on a NW-SE trending thrust fault. The earthquake event is approximately 55km from the Queenslander fault crossing. Projection of this fault to the southwest would suggest that it could potentially be part of a larger regional structure connecting to the Queenslander Fault (Figure 4). Between the mapped expressions of the Midgee Fault and the Queenslander Fault are numerous subparallel lineaments. Although there is not one continuous pervasive lineament a thrust fault would not be expected to be exactly straight because of its low angle.

Fault Activity Assessment

The Queenslander thrust fault shown on the geologic mapping is well defined in this area. The mapped evidence includes:

1. Shear zone with gouge.
2. Up thrown ridge on NE of fault.
3. Structural control on river sections
4. Offset or dissected terraces.
5. Over steepened creek banks.
6. Defined contact between Quaternary Alluvium and Devonian Rocks.

The expression of recent activity includes:

1. Expression of fault prominent in the present geomorphology
2. Defines sharp contact between Quaternary Alluvium and Devonian Rocks.
3. At the area where this fault crosses the Calliope River, the river meanders back on itself up-gradient (Figure 8). This area shows the Calliope River quickly meandering back to the west. A thrust on this NW-SE fault, with the up thrown block on the NE thrusting to the SW is a plausible explanation for this feature.
4. Potential association with Bajool Earthquake.

Based on the findings of this assessment the Queenslander Fault should be considered a "neotectonic" feature following Clark (2007). The combination of mapped and stratigraphic relationships, strong geomorphic expression and potential associated seismicity suggests the fault shows displacement at least in the early Quaternary and therefore should be considered an "active fault" following Clark (2007).

7. CONCLUSIONS

Identification of neotectonic features in the Gladstone Region used published mapping, the seismologic record, available aerial photography, high resolution DEMs and field mapping to interpret recent activity.

Published research suggests that Western Basement Fault has been reactivated as an oblique-slip fault in the current stress regime of Australia. The reactivation is inferred to have taken place in the early-Pliocene (~ 4 Ma) expressed in offset Tertiary aged gravels. Field mapping and review of existing literature did not recognise definitive activity in the Quaternary along a 50 km length. This study did not include any subsurface investigation to definitively test the WBF fault.

The Queenslander Fault should be considered a "neotectonic" feature following Clark (2007). Furthermore the combination of mapped and stratigraphic relationships, strong geomorphic expression and potential associated seismicity suggests the fault shows displacement at least in the early Quaternary and therefore should be considered an "active neotectonic feature" following Clark (2007).

This study did not include any subsurface investigation (borings or fault trenching) to definitively test these faults. The authors are aware of on-going infrastructure development in the Gladstone Area and across the Narrows. Interpretation of the findings from these investigations will subsequently refine this interpretation.

A thorough palaeoseismologic investigation of these structures would be required to definitively characterise the activity of these faults. The study at the least should include fault trenching and may include dating techniques if appropriate datable mineralogy is present.

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