The correlation between physiography and neotectonism in southeast Queensland

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Abstract

We tested for correlation between recent earthquake epicentre data and the distribution of major physiographic features, such as escarpments and river channels, in southeast Queensland. Preliminary results indicate that many of the known earthquake epicentres over the past century are distributed in several broad belts, corresponding in location and orientation to major structural discontinuities or narrow sedimentary basins bounded by faults. Other earthquake clusters show broad correlation with linear segments of major river systems where no major faults have been mapped. Several domains dominated by Palaeozoic-Triassic rocks, such as the North and South D'Aguilar blocks, are represented by high terrain flanked by faults that may have been active back to at least the mid-Mesozoic. Reactivation and subsidence along some of these faults may account for the local accumulation of thick sedimentary piles during the Paleogene. Modern earthquake epicentre distributions along the margins of these blocks suggest that recent and on-going tectonism may be enhancing the escarpments flanking the uplands. Unmapped, concealed or deep-seated geological discontinuities may exist where earthquake epicentres correspond to linear physiographic features but not to currently mapped faults or joints. Identification of such concealed geological structures will be important for developing accurate earthquake hazard maps into the future.

Introduction

Tectonism is one of the primary driving forces behind the structural and physiographic modification of land masses. For example, tectonism is largely responsible for terrain uplift and basin subsidence, which allow modification by secondary processes such as weathering and erosion. As tectonics is generally accepted to cause geomorphological change, it is logical to study geomorphological features to identify the influences of tectonics on the landscape (for example Burrato et al., 2003; Vannoli et al., 2004).

The Australian continent is situated within the Indo-Australia Plate. Compared to plate boundary earthquakes, intraplate earthquakes are few and shallow. However, the Global Seismic Hazard Map shows that Australian earthquake activity is moderate to high, relative to other intraplate regions (GSHAP, 1992-1997). The Indo-Australian Plate is presently under compressional stress (Hillis, 1998; Hillis and Reynolds, 2000) and modification of the land will occur in order to accommodate shortening of the continental mass where the stress exceeds the strength of the crust. For example, Neogene-Quaternary reverse faulting and compressional folding has clearly influenced landscape evolution in both central western (for example, Clark, 2005), and southeastern Australia (for example, Sandiford, 2003). Folds, faults, joints, shears and rock fabric alteration, resulting from tectonic movement, have long been known to control the formation of a variety of distinctive land surface features such as scarps and river channels (for example: Hobbs, 1904; Hobbs, 1911; Zernitz, 1932; Strahler, 1960, 1966; Twidale, 1980; Scheidegger, 1998, 2002; Ericson et al., 2005; Hodgkinson et al., in press). The relationship between Australia's geology and its earthquakes is poorly understood and many earthquakes cannot be assigned to known structures (Clark and McCue, 2003). Physiographic analysis in conjunction with recent seismic data will assist identifying those landscape features that are likely to be tectonically controlled and presently active; such analysis has the potential to refine zones hazardous to the population and infrastructure.

For dipping faults, earthquake epicentres will appear more distant from the surface trace with increasing hypocentral depth. As a consequence, epicentres may not be expected to align precisely with surface features, such as mapped faults, scarps and joint systems. Therefore, broad sectors in which earthquake epicentres are located should be identified to determine potentially active fault zones. Earthquake locations may also be inaccurate, particularly those identified from early records and, therefore, care must be taken when relating them to local physiographic features. Since the calculation of actual earthquake depth is typically inaccurate, this parameter should be treated with caution. Using available data, this study aims to provide evidence of tectonic control upon the landscape of southeast Queensland.

Background

Southeast Queensland's geology is complex and derived from several cycles of compressional and extensional tectonic activity since about 370 Ma. Palaeozoic to modern sedimentary and igneous rocks are interspersed with large belts of metamorphic rocks throughout the region. Many of the geological units (Queensland Government, 2003) are bounded by faults. Extensive regolith, vegetation and infrastructure conceal many of southeast Queensland's geological discontinuities including faults, joints and formation boundaries. Some areas appear to be relatively fault-free and, although this may be the case, the apparent dearth of these features may be attributable to concealment by ground cover or the lack of detailed mapping. Recent core logging in southeast Queensland has revealed discrepancies with the published geological maps (geological map, Queensland Government, 2003; Brisbane City Council, 2006 pers. comm.) and confirmed that faults and joints are common in the region. Fault distributions have been analysed recently (Humphries, 2003) but little has been published regarding age constraints on fault activity. Childs (1991) analysed Landsat images of the northern part of the region and showed that the main ranges and drainage systems are strongly concordant with the bedrock geology, and that faults also correspond with channel orientation. However, Humphries noted that some major faults and a shear zone on geological maps were not identifiable on the Landsat image, and may either lack surface expression or have had unfavourable illumination for Landsat (Childs, 1991). The region's elevation ranges from sea-level to 1360 m a.s.l. and the area can be divided into three general terrains: highlands (>300 m a.s.l.), hills (30-300 m a.s.l.) and lowlands (<30 m a.s.l.) (Fig. 1). The greatest portion of southeast Queensland is situated in the hilly to highland terrains. However, most of the population presently resides within the coastal lowlands, especially within the expanding cities of Brisbane, Ipswich and the Gold Coast. Three artificial reservoirs, Somerset, Wivenhoe and Samsonvale, provide southeast Queensland's main water supply: each is situated in known faulted and seismically active zones.

Earthquake monitoring

In order to compare neotectonism and its geomorphological effects, detailed earthquake data are needed. Earthquake monitoring in Queensland is generally sparse by international standards and has only operated intermittently. Earthquakes have been recorded since the late 1800's. In 1937, Queensland's first international monitoring station was opened in Brisbane, followed by the Charters Towers station in 1957. Subsequently, a seismic monitoring network developed slowly, broadening considerably after 1977, when more detailed instrumental monitoring was implemented around the large dams. Dam-site and other seismographs were integrated into a state-wide network, monitored by The University of Queensland (UQ) from 1993 (the QUAKES Centre) but since 1998, much of the operational instrumentation has been progressively discontinued from service. Monitoring is now restricted to southeast Queensland. Since 2000, 22 Queensland Government seismograph stations continue to collect data under commercial contract to Environmental Systems and Services (ES&S, Victoria,). As well as temporal discontinuities, data completeness is also affected by differences in the resolution of monitoring, spatially.

Methods

Digital topographic data at 25 m intervals (Queensland Government, 2005) (Fig. 1), geological and drainage (Fig. 2) maps for southeast Queensland were obtained from the Department of Natural Resources, Mines and Water (DNRM&W) (Queensland Government, 2003). Using the ArcGIS 9 software, a digital elevation map (DEM) was produced and slope maps (Fig. 3) created from which scarp features were extracted. Earthquake data retrieved from Geoscience Australia (2006) provided information for 100 earthquakes recorded in the region since 1872. Further data were supplied by the Earth Systems Science Computational Centre (ESSCC) at The University of Queensland, increasing the total number of earthquakes recorded in the region to 344 (Figs. 3,4,5). The digital maps were combined with seismic data for identification of concordant patterns of geomorphological lineaments and earthquake epicentres. Where 4 or more earthquake epicentres clustered or were well-aligned within a 12-15 kilometre wide corridor, they have been considered to possibly have a common source and be related to similar zones of seismic activity. Such clusters and alignments are referred to here as 'earthquake corridors'.

Results

Highlands and scarps

The highland areas are situated mainly in the west and north of the study area, and generally trend in a northwest-southeasterly direction. A discrete area of highlands, situated in the central region, is separated from the west by the Brisbane River valley. Some highland terrain is situated in the southeast, associated with the Mount Warning shield volcano. The physiography of the latter highland area does not correspond to the predominant northwest-southeast geological trends in southeast Queensland. Scarps are common across the region (Fig. 3). In places they coincide with the orientation of highlands, geological units, faults and drainage.

Drainage

Channel orientation in the region is predominantly northwest-southeasterly and northeast-southwesterly (Fig 2.). These trends are particularly strong in the Brisbane River system, which may be described as a trellis or rectilinear drainage pattern. Secondary trends occur in an east-west orientation and other trends are evident at a finer scale. Drainage in the southeast is radial, away from the centre of the Mount Warning volcanic complex.

Geological discontinuities

High angle dip-slip faults, joints, thrusts and shear zones have been mapped throughout the region (Queensland Government, 2003), although a large area in the southwest and on the coastal plains in the east appears to have few faults. Fault orientations in the remainder of the region strongly trend in a northwest-southeasterly orientation although various other trends are also evident (Fig. 4).

Seismicity

Earthquakes occur throughout the region on all terrains (Figs. 3,4,5). As depth to focus data are highly uncertain, earthquake epicentres only have been considered in this analysis. Their distribution shows some concurrence with drainage, structural features (Figs. 4,5) and scarp distributions (Fig. 3). The epicentres cluster most prominently within a broad northwest-southeast trend but subsidiary southwest-northeast and roughly east-west trends are also evident (Figs. 3,5)

Discussion

Physical relationships

There is some concurrence between the location and orientation of faults and rivers, especially the Brisbane River system (Fig. 4). The presence of a scarp may be due to surface displacement by faulting, mass wasting or by other surface processes such as fluvial erosion. Some scarps appear to have no correlation with present drainage or mapped faults and may represent features with historical controls such as retreating coastal escarpments. A relationship between drainage system pattern and highland location is present, although such definition would be expected due to normal down-cutting of rivers between resistant rock units. The lowland areas primarily consist of unconsolidated Cenozoic sediments, which may conceal faults or joints.

Seismic and physiographic relationships

Earthquake epicentre and drainage patterns commonly concur throughout the region (Figs. 4,5). North of Brisbane/Toowoomba, this association is also closely aligned with faults. However, south of Brisbane/Toowoomba, virtually no mapped faults coincide with earthquake and river-trends. In the north, this alignment suggests that mapped faults may be active and controlling drainage channel orientation and position. In the south however, where some earthquake zones align with drainage but do not coincide with mapped faults, other faults may be concealed and/or not yet mapped. Several scarps coincide spatially with earthquake-prone zones (Fig. 3) and an apparent alignment between some scarps, faults and drainage channels, suggests that these scarps may be fault and/or river controlled. Some earthquake epicentres cluster in close proximity to mapped faults, such as those flanking much of the South D'Aguilar Block (Figs. 4,7). However, some clusters do not appear to align with currently mapped faults despite their linear spatial distribution. The proximity of earthquake activity to channel location suggests that there may be a relationship requiring further investigation.

Seismic zones lacking physiographic relationships

There are several earthquake-prone zones in the region that are commonly located in flat or gently undulating terrain and free from scarps, large river channels and faults. The earthquake epicentres in these areas may be associated with very deep faults that presently have no surface expression, may be in areas that are poorly mapped due to ground cover or may be beyond the resolution of the DEM. Equally, they may be associated with mapped faults with very shallow angles of dip causing the surface expression to be far enough away from the epicentre to appear unrelated. Data may also inaccurately reflect the position of the epicentre.

General

Deep earth investigation such as drilling, reflection seismography or GPR, together with more accurate measurements of hypocentre depths may assist in identifying the faults with which recent earthquakes are associated. Such work may also identify unmapped faults where surface features and earthquakes suggest there is potential faulting in the vicinity. For example, topography, river orientation and earthquake activity suggests faulting occurs along the southern edge of the South D'Aguilar Block. Many of the rock units throughout the region are bounded by faults implying tectonism is responsible for their current position. Recent earthquake activity in the vicinity of these faults suggests continued or sporadic movement of these units is occurring.

Conclusions

This preliminary study suggests that geomorphological evidence, when combined with geological and earthquake data, may be used to successfully identify zones of current faulting. An important consideration in this study has been the scale of viewing both temporally and spatially. Earthquake corridors suggested in our results may not be apparent if each epicentre was viewed in isolation or at a less broad scale in time and space. Although features such as channels and slopes may be controlled by differential weathering, neotectonism may also be influential and this may pose a greater threat than geohazard maps imply. The most widely used seismic hazard map of southeast Queensland (McCue et al., 1998) is a classic representation of a probabilistic earthquake model (defined by Cornell, 1968). The hazard designations are a product of available data, which may be sparse, temporally and spatially. Equally, the earthquakes may not be probabilistic in nature (Clark and McCue, 2003). Consequently, the map may not fully represent actual hazards in the area. Therefore, more detailed, widespread, long-term monitoring programs would be a valuable addition to future hazard assessment and mitigation, together with deterministic seismic modelling. First motion studies are useful in determining the dip orientation of dip-slip faults and whether normal or reverse. Accurate focal depths would also better constrain fault locations. Broad 'zones' surrounding the implied epicentre positions should be used to relate earthquakes to potential, local, physiographic features, unless absolutely certain of the data accuracy. The most densely populated area in southeast Queensland is situated within the lowlands, which hosts a widespread veneer of unconsolidated Cenozoic sediments that may conceal potentially active faults. Better collection and availability of structural data, in combination with high resolution digital terrain models, would enable more thorough landscape analysis to identify potentially active fault zones, areas of concealed faults and deep sediment zones which are conducive to seismic amplification. Ultimately this would provide a better understanding of both neotectonism and localised seismic hazard zones in southeast Queensland.

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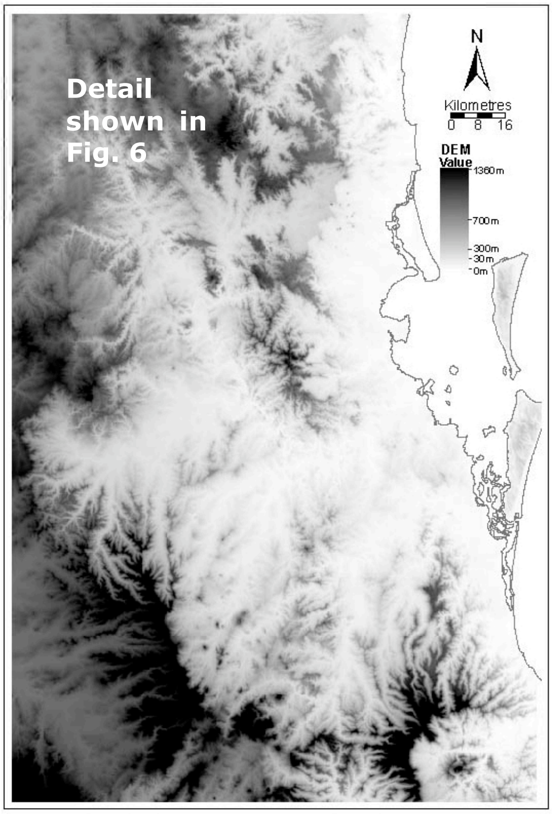

Fig. 1 25m DEM of southeast Queensland

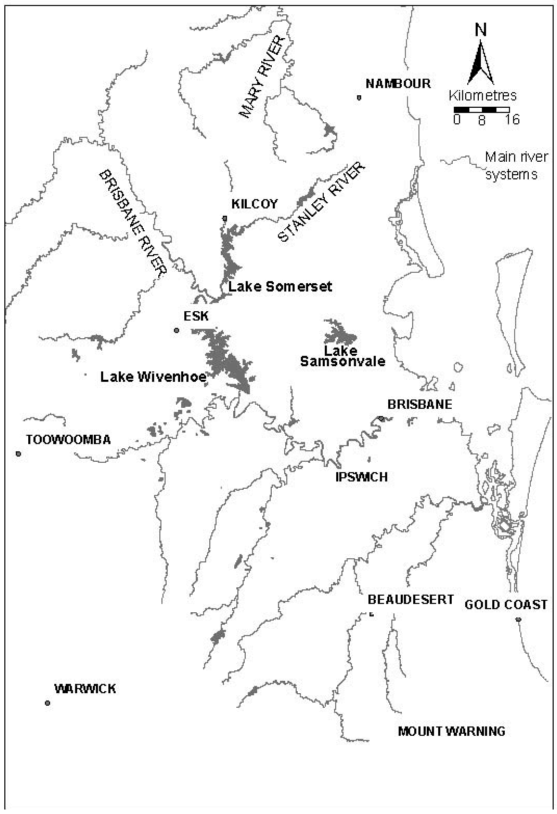

Fig 2 Main drainage systems and locations of southeast Queensland

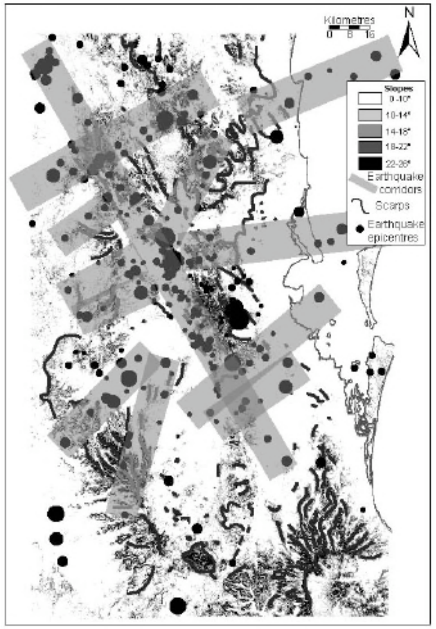

Fig. 3

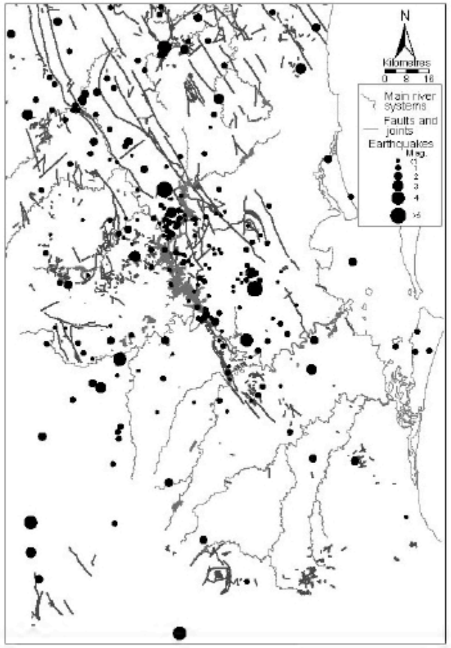

Fig. 4

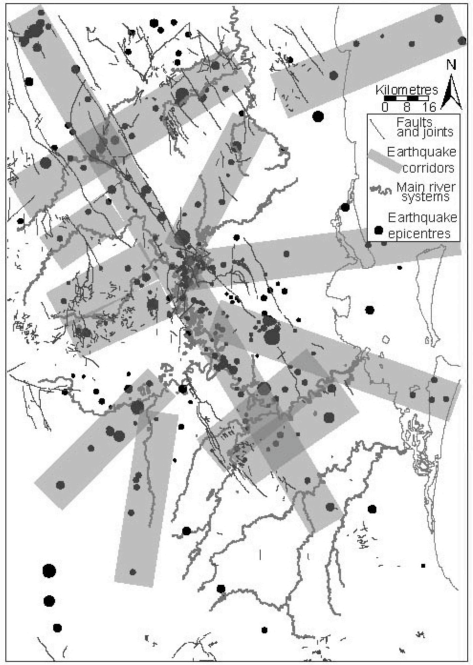

Fig. 5

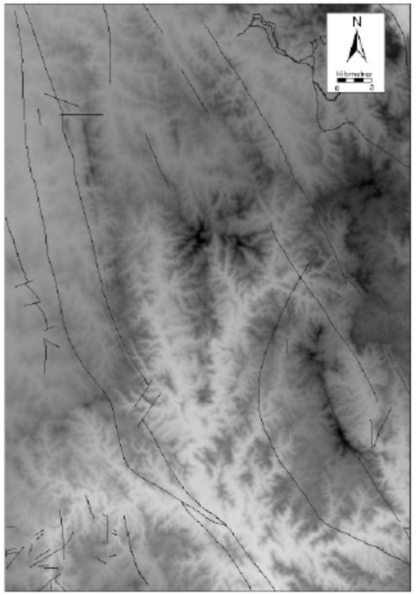

Fig. 6

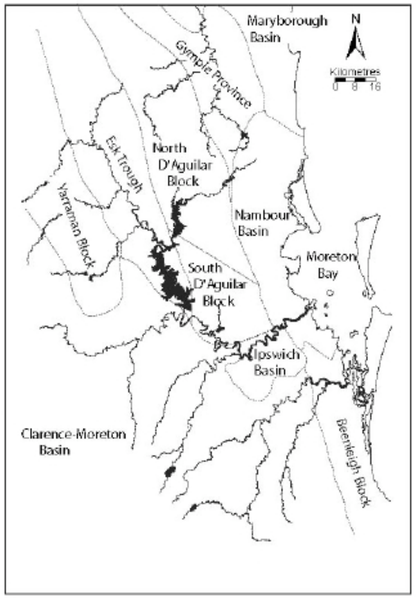

Fig. 7

Fig. 3 Earthquake epicentre corridors superimposed onto slope map. Scarps highlighted in black

Fig. 4 Main drainage, structural features and earthquake epicentres in southeast Queensland

Fig. 5 Data from 'Fig. 4' superimposed with earthquake corridors

Fig. 6 DEM detail (northwest of region) showing linear escarpments with mapped faults superimposed

Fig. 7 Stable geological blocks and basins of southeast Queensland