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Cenozoic uplift of south Western Australia as constrained by river profiles

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ABSTRACT

The relative tectonic quiescence of the Australian continent during the Cenozoic makes it an excellent natural laboratory to study recent large-scale variations in surface topography, and processes that influence changes in its elevation. Embedded within this topography is a fluvial network that is sensitive to variations in horizontal and vertical motions. The notion that a river acts as a 'tape recorder' for vertical perturbations suggests that changes in spatial and temporal characteristics of surface uplift can be deduced through the analysis of longitudinal river profiles. We analyse 20 longitudinal river profiles around the Australian continent. Concave upward profiles in northeast Australia indicate an absence of recent surface uplift. In contrast, the major knickzones within longitudinal profiles of rivers in southwest Australia suggest recent surface uplift. Given the lack of recent large-scale tectonic activity in that region, this uplift requires an explanation. Applying an inverse algorithm to river profiles of south Western Australia reveals that this surface uplift started in the Eocene and culminated in the mid-late Neogene. The surface uplift rates deduced from this river profile analysis generally agree with independent geological observations including preserved shallow-marine sediment outcrops across the Eucla Basin and south Western Australia. We show that the interplay between global sea level and long-wavelength dynamic topography associated with south Western Australia's plate motion path over the remnants of an ancient Pacific slab is a plausible mechanism driving this surface uplift.

1. Introduction

The Australian continent displays remarkable intermediate (10^2 km) to long-wavelength (10^3 km) tectonic stability throughout the Cenozoic. Since its break-up from Antarctica along the Great Australian Bight and the opening of the Tasman Sea along the eastern margin in the Cretaceous (Veevers, 1984), Australia has been tectonically relatively quiescent, with vertical surface displacements of the northward-moving continent largely controlled by long-wavelength dynamic topography (Heine et al., 2010; Müller et al., 2000). Past Australian inundation patterns, deduced from preserved ancient shallow-water sediments (Langford et al., 1995), generally differ from global sea level trends and have commonly been attributed to the effects of mantle convection-induced dynamic topography (Czarnota et al., 2013; DiCaprio et al., 2009; Gurnis et al., 1998; Heine et al., 2010; Liu, 1979; Matthews et al., 2011; Sandiford, 2007; Veevers, 1984).

While subsidence over geological time scales is generally well preserved in the stratigraphic record, uplifting areas are subject to erosion and tend to have a poorer preservation potential (Flament et al., 2013; Olen et al., 2012). Here, tectonic geomorphology can be used to infer rates and patterns of surface uplift over geological timescales from information contained in the present-day fluvial network (Whipple and Tucker, 1999). In particular, longitudinal river profiles may indicate whether surface uplift with respect to sea level (England and Molnar, 1990) has affected a catchment area (Snyder et al., 2000). The analysis of longitudinal river profiles is generally applied to tectonically active regions where surface uplift rates can be estimated independently and compared with bedrock erosion rates (Schoenbohm et al., 2004; Snyder et al., 2000). Recently, Pritchard et al. (2009) and Roberts and White (2010) suggested that the present-day geometry of longitudinal river profiles contains time-dependent information pertaining to the evolution of landscape vertical motions over larger spatial and temporal scales (i.e., ~1–100+ Myr, 10–1000 km; Roberts et al., 2012) in tectonically quiescent regions. In this method, time-dependent surface uplift rates are estimated by parameterizing the elevation of a river profile as a function of its length (Pritchard et al., 2009). Indeed, surface uplift results in rapid changes in gradient near the river mouth that, over time, migrate upstream as knickpoints (Whipple and Tucker, 1999). Depending on retreat rate, knickpoints may be preserved in present-day longitudinal river profiles, providing information on past uplift events.

Here, we analyse 20 longitudinal river profiles across the Australian continent (Fig. 1). While profiles from northern Australia do not show evidence for anomalous vertical motions, the shape of river profiles in south Western Australia suggests that recent surface uplift on regional

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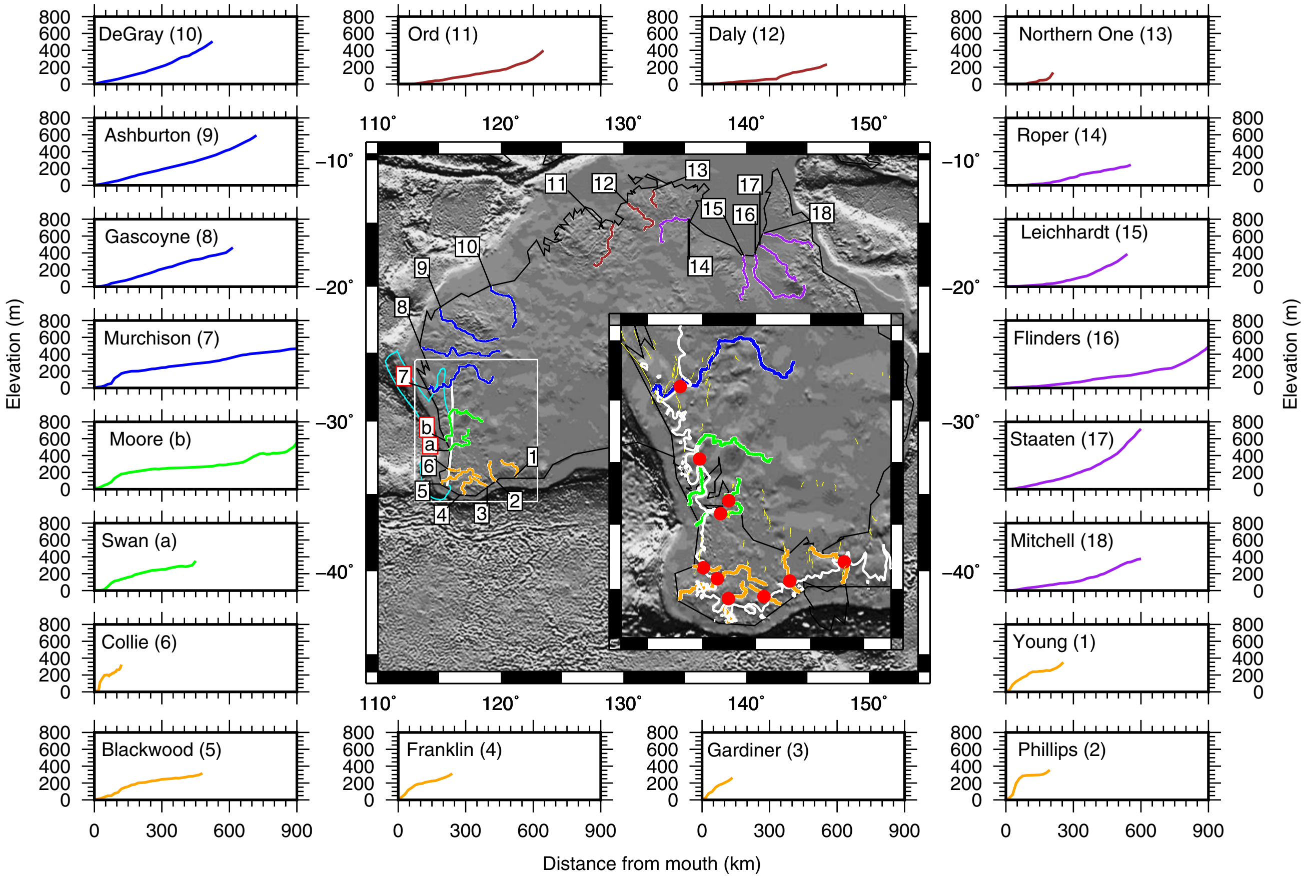

Fig. 1. Longitudinal river profiles (labelled 1–18 and a–b) extracted from an SRTM 3 s DEM (Rabus et al., 2003). Profiles are colour-coded by regions. South Western Australia (SWA) — orange, rivers that underwent documented drainage reversal — green, north Western Australia (NWA) — blue, Northern Territories (NT) — red, north Queensland (NQLD) — purple. Profile geometry varies across the continent. River profiles in Western Australia are underlain by the Darling Fault (white line) and the Perth Basin (cyan outline). SWA river profiles show major knickzones (Whipple and Tucker, 1999) that become less pronounced in NWA, from where profiles are concave. Inset: south Western Australian river profiles, major knickzones (red dots), 200 m contour elevation (white), and reactivated Late Neogene–Quaternary faults (yellow; Clark et al., 2012).

scale may have occurred. This was previously recognised by Cope (1975). The main proposed mechanisms for this regional-scale uplift in south Western Australia is long-wavelength dynamic topography and associated continent-wide tilting (Jakica et al., 2011; Quigley et al., 2010; Sandiford, 2007).

We apply the method of Pritchard et al. (2009) to south Western Australian rivers to constrain the timing of surface uplift in that region. We then discuss potential driving mechanisms of this uplift, integrating geological constraints on seismicity, marine deposition, tectonic activity and the northward motion of the Australian plate since the Eocene.

2. Methodology

We analyse 20 individual longitudinal river profiles grouped into five representative regions: south Western Australia, Pilbara, north Western Australia and Northern Territories, and north Queensland (Fig. 1). To ensure that our study focuses on the effects of mantle-driven processes on landscape evolution, we have excluded the South-east Highlands (Wellman, 1974; Wellman, 1979), Flinders Ranges (Célérier et al., 2005) and Tasmania (Solomon et al., 1962) where this effect is considered eclipsed by shorter-wavelength tectonic processes. Tectonically induced vertical motions are generally much larger than that produced by mantle convective processes, making the latter difficult to identify (e.g. Flament et al., 2014).

2.1. Extraction, selection and geometry of longitudinal river profiles

2.1.1. Profile extraction

Each river profile was extracted from an SRTM 3 arc second DEM (Rabus et al., 2003). The DEM was segmented and reprojected into its respective UTM zones (50, 52 and 54) ensuring a consistent cell size of 90 m. A global assessment of the SRTM data indicates an absolute height error of 6.0 m, and relative height error of 4.7 m for the Australian continent (Rodriguez et al., 2006). We followed standard protocols to extract river profiles using the *Hydrology Tool* in ESRI ArcGis 10.0®. We first removed all anomalous spikes and troughs, ensuring a hydrologically sound DEM. Next; we established a drainage network using a standard flow-routing algorithm that determines the direction of flow via the steepest slope from each cell. This was then used to calculate the flow accumulation based on the cumulative weight of all cells flowing into each downslope cell. All profiles exceed Strahler stream order >4 (Strahler, 1957) which defines stream size based on a hierarchy of tributaries. All rivers drain to the coastline, which is assumed to be the fixed reference level in this approach (Pritchard et al., 2009).

2.1.2. Profile selection

Rivers draining internally are excluded as they may experience changes in reference levels at their mouth, which is not located at sea level. Furthermore, rivers draining expansive inland regions may cross different swells and depressions, which would not be consistent with