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A Neogene history of mantle convective support beneath Borneo

Gareth G. Roberts [a,*], Nicky White [b,*], Mark J. Hoggard [b], Patrick W. Ball [b], Conor Meenan [b]

[a] Department of Earth Science and Engineering, Imperial College London, London, UK
[b] Bullard Laboratories, Department of Earth Sciences, University of Cambridge, Cambridge, UK

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ABSTRACT

Most, but not all, geodynamic models predict 1–2 km of mantle convective draw-down of the Earth's surface in a region centered on Borneo within southeast Asia. Nevertheless, there is geomorphic, geologic and geophysical evidence which suggests that convective uplift might have played some role in sculpting Bornean physiography. For example, a long wavelength free-air gravity anomaly of +60 mGal centered on Borneo coincides with the distribution of Neogene basaltic magmatism and with the locus of sub-plate slow shear wave velocity anomalies. Global positioning system measurements, an estimate of elastic thickness, and crustal isostatic considerations suggest that regional shortening does not entirely account for kilometer-scale regional elevation. Here, we explore the possible evolution of the Bornean landscape by extracting and modeling an inventory of 90 longitudinal river profiles. Misfit between observed and calculated river profiles is minimized by smoothly varying uplift rate as a function of space and time. Erosional parameters are chosen by assuming that regional uplift post-dates Eocene deposition of marine carbonate rocks. The robustness of this calibration is tested against independent geologic observations such as thermochronometric measurements, offshore sedimentary flux calculations, and the history of volcanism. A calculated cumulative uplift history suggests that kilometer-scale Bornean topography grew rapidly during Neogene times. This suggestion is corroborated by an offshore Miocene transition from carbonate to clastic deposition. Co-location of regional uplift and slow shear wave velocity anomalies immediately beneath the lithospheric plate implies that regional uplift could have been at least partly generated and maintained by temperature anomalies within an asthenospheric channel.

1. Introduction

It is generally agreed that convective circulation of the Earth's mantle generates and maintains some component of surface topography (e.g. Pekeris, 1935; Richards and Hager, 1984; McKenzie, 2010; Müller et al., 2018). This component is often referred to as dynamic topography and it is expected to vary as a function of space and time. A significant corollary is that the history of vertical motions of the Earth's surface are indirectly recorded by the stratigraphic record. Despite more than 30 yr of geodynamic modeling, there is considerable debate about the amplitude and wavelength of present-day dynamic topography (see e.g. Steinberger, 2007; Spasojevic and Gurnis, 2012; Yang and Gurnis, 2016; Steinberger et al., 2017; Müller et al., 2018). A significant example of this lack of consensus concerns the history of regional epeirogeny across southeast Asia.

The present-day plate tectonic setting of this region is undoubtedly complex (see, e.g., Hall and Nichols, 2002; Replumaz et al., 2004; Hall, 2009; Cullen, 2010; Hall and van Hattum, 2010). Numerous fragments of subducted oceanic lithosphere, volcanic arcs, back-arc sedimentary basins, and flexural foreland basins form a kalaeidoscopic framework that has undoubtedly had a rapidly evolving history during Mesozoic and Cenozoic times. Global dynamic topographic models consistently predict that vertical motions of this region are dominated by a long wavelength (i.e. 10^3–10^4 km) convectively maintained depression or draw-down that is up to 2 km deep (Fig. 1; Lithgow-Bertolloni and Gurnis, 1997; Steinberger, 2007; Spasojevic and Gurnis, 2012; Flament et al., 2013; Yang and Gurnis, 2016). This draw-down is thought to be maintained by the presence of many cold slabs of subducted oceanic lithosphere (e.g. Yang et al., 2016). According to Stokes' law, the resultant mass excess generates and maintains large-scale downwelling within the viscously deformable mantle, which produces and maintains surface draw-down (compare Fig. 1c and d). It is important to emphasize that this topic is a rapidly evolving one and that several alternative dynamic topographic models predict

* Corresponding authors.
E-mail addresses: gareth.roberts@imperial.ac.uk (G.G. Roberts), njw10@cam.ac.uk (N. White).

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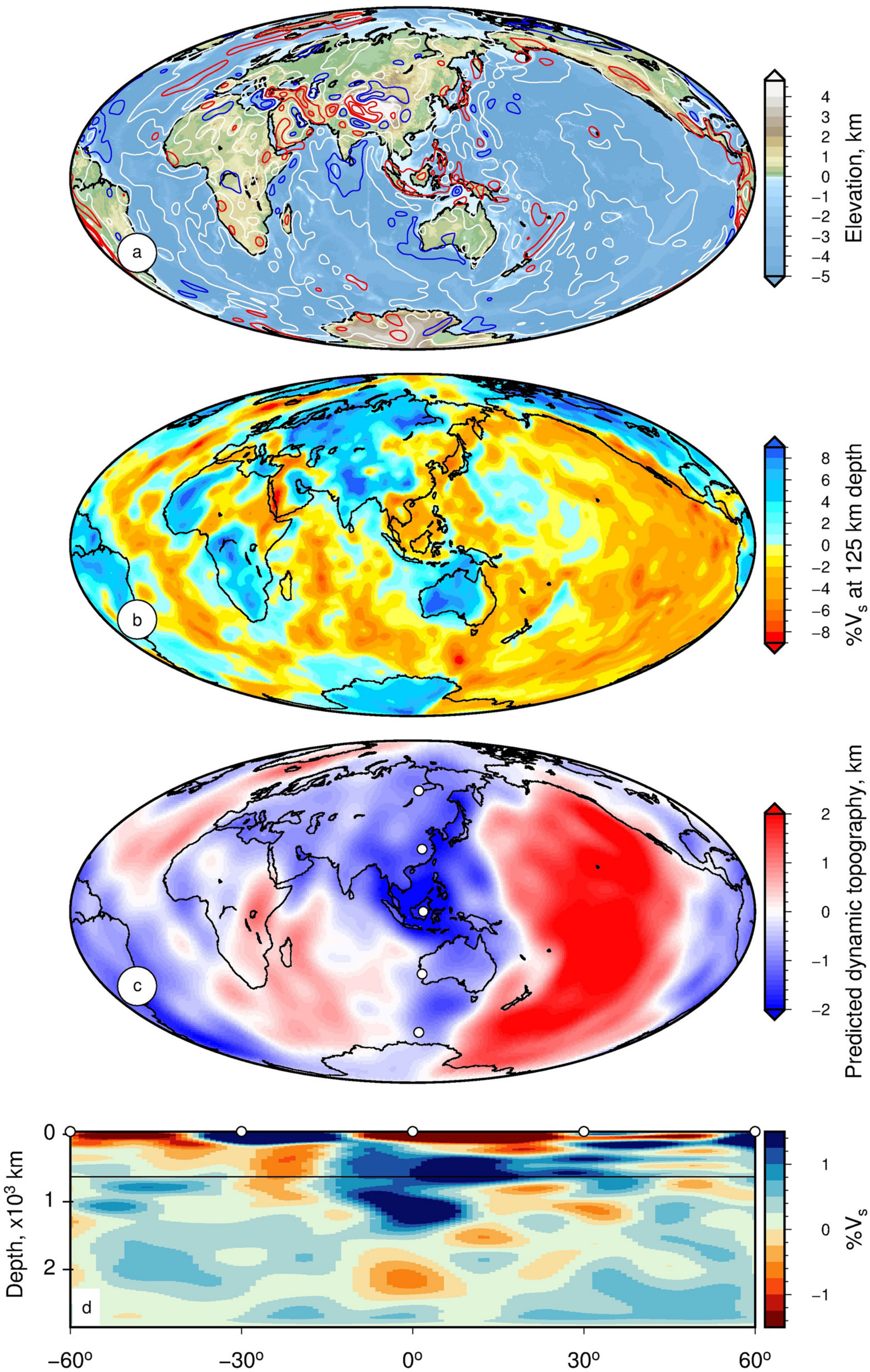

Fig. 1. (a) Global topographic map superimposed with long wavelength (730–9000 km) free-air gravity field from ETOPO5 and GGMO3C databases, respectively (Tapley et al., 2005; Hoggard et al., 2016). Red/white/blue contours = positive/zero/negative gravity anomalies at 30 mGal intervals. (b) Horizontal slice through SL2013sv shear velocity tomographic model where percentage anomaly is with respect to AK135 model (Schaeffer and Lebedev, 2013). (c) Predicted dynamic topography calculated by Steinberger (2007), which is broadly representative of other models (e.g. Müller et al., 2018). Open circles = positions along transect shown in panel (d). (d) Vertical slice along transect highlighted in panel (c) which shows shear wave velocity anomalies from S20RTS model of Ritsema et al. (1999) that was used to calculate panel (c). Black line = 670 km mantle discontinuity. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)