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Changes in plate boundary kinematics: Punctuated or smoothly varying — Evidence from the mid-Cenozoic transition from lithospheric extension to shortening in New Zealand

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ABSTRACT

The marine magnetic anomaly record and plate kinematics derived from that data provide evidence of numerous cases of significant changes in plate motions and plate interactions. However, in most cases the temporal resolution provided by the marine record does not discriminate between punctuated (abrupt) or smooth variations in plate motions. During a 10 million year period (~30 Ma to 20 Ma), the Euler poles (stage poles) describing Australia–Pacific relative plate motion migrated more than 20° in latitude. The New Zealand segment of the plate boundary is close to the location of the Euler poles and their migration making the tectonics of its plate boundary structures particularly sensitive to the history of plate kinematics. Based on the rapid southward migration of the Euler (stage) poles from north of New Zealand to south of the landmass, there is an expected rapid, migrating transition from an extensional (stage pole north of the site) to transpressional (stage pole south of the site) plate boundary system. The geologic signature of this rapid change in plate boundary kinematics is preserved in the stratigraphic record of a suite of basin deposits that span the latitudinal sweep of the migrating Euler poles. Analyses of these deposits indicate that the timing of the transition from extensional to transpressional tectonics shows a continuous and systematic southward sweep, indicating that the changes in Australia–Pacific plate motions during the 30 Ma–20 Ma interval were smoothly continuous and not punctuated.

1. Introduction

Tectonism along plate boundaries varies in time and space as changing plate motions lead to changing plate boundary kinematics. In some cases it is clear that these changes are spatially systematic but temporally quite abrupt, for example with passage of a triple junction. Such is the situation in northern California, where the North America plate boundary has systematically changed from subduction to translation in response to the northward migration of the Mendocino triple junction (Furlong, 1984; Furlong and Schwartz, 2004). However, in the absence of a triple junction, the changes might be expected to be less fundamental or abrupt. However, standard methodology for determining the history of plate motions (and the discrete nature of correlative features such as marine magnetic anomalies) produces the histories that often contain abrupt changes in plate motion. How rapidly such changes actually occur (geologically instantaneous or smoothly over a finite time period) is not generally resolved. This can lead to a (possibly specious) correlation between specific tectonic events and assumed abrupt changes in plate motion. However, with improved and finer temporal resolution leading to the time interval represented by individual Euler stage poles decreasing, what have previously been thought to be abrupt changes in motion are revealed to be clearly more gradual — for example with improved temporal resolution what was previously seen as an abrupt change in Pacific–North America plate motion in the Late Miocene is now identified to be a more gradual increase in transpression along that boundary (cf. Atwater and Stock, 1998; Engebretson et al., 1985). Two key questions arise in assessing the history of plate boundary kinematics: (1) Is a smoothly varying change in relative plate motions the norm or are abrupt changes in plate boundary kinematics more likely, and (2) is there a discernible geologic signature of such a plate boundary evolution?

The Cenozoic to Present relative motions between the Australia and Pacific plates, as described by the Euler rotation (stage) poles, change substantially, particularly during the period between 30 Ma and 20 Ma. Based on the finite reconstruction poles of Cande and Stock (2004), stage poles describing Australia–Pacific motion migrate almost 20° (arc distance) over that 10 million year time interval (Furlong and Kamp, 2009; Hayes et al., 2009). In the Cande and Stock (2004) analysis, this interval of substantial plate motion change was described by four

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finite reconstruction poles at the times of anomalies 15o (35.0 Ma), 11o (30.1 Ma), 8o (26.6 Ma), and 6o (20.1 Ma), generating three stage poles (15o–11o, 11o–8o, and 8o–6o) each representing 5–6 Ma of time, each on the order of 8° or more distant from the others, and each implying significantly different plate interactions across the boundary.

The evolution of the plate boundary through New Zealand during this time interval provides an opportunity to observe whether relative motions between the Australia and Pacific plates underwent systematic or punctuated changes. Because the New Zealand continent is located near the rotation (stage) poles describing relative Australia–Pacific motion, any changes in relative motion between those two plates (equivalent to changes in the position of the rotation pole) may have a significantly greater effect on plate boundary kinematics than would be seen if the pole describing that relative motion were distant (e.g. Zatman et al., 2001). We have used these ~5 m.y. duration stage poles to determine a suite of 1 m.y. duration stage poles that reproduce the finite rotations/reconstructions determined by Cande and Stock (2004), at the specified times (e.g. at anomaly 11o), and smoothly vary between those specified time points (Furlong and Kamp, 2009; Hayes et al., 2009). The resulting 1 m.y. duration stage poles for the period between 30 Ma and 24 Ma are shown in Fig. 1 (on a 27 Ma reconstruction, Australia fixed reference frame). These poles (which are part of a 40 Ma–Present set of poles; Furlong and Kamp, 2009) provide a smooth transition from the position north of the New Zealand continent prior to 30 Ma to south of the continent by about 24 Ma. Does the geologic record within the New Zealand continent reflect such a systematic change, or as implied by the longer duration reconstruction poles, did the plate boundary kinematics abruptly change at approximately 26 Ma (anomaly 8o)?

Specifically we test whether or not there is a geologic record of a systematic north to south change in plate boundary tectonic character in sync with the southward transit of the rotation poles and the implied transition from dominantly extensional to transpressional tectonism. The specific signature that such a transition leaves in the geologic record can help to constrain the nature of other plate boundary transitions for which the underlying plate kinematics are less well known.

2. Plate tectonic setting

The present plate boundary through the New Zealand continent is a relatively young feature having developed only since the Middle to Late Eocene. Its initial form was as a predominantly extensional structure. This early extensional phase has affected both the subsequent lithospheric response once transpression began, and also the spatial distribution of basins, marine surfaces, and refuge 'islands' during the late Oligocene and into the Neogene. South of the New Zealand continent, this extension was localized within the Emerald Basin

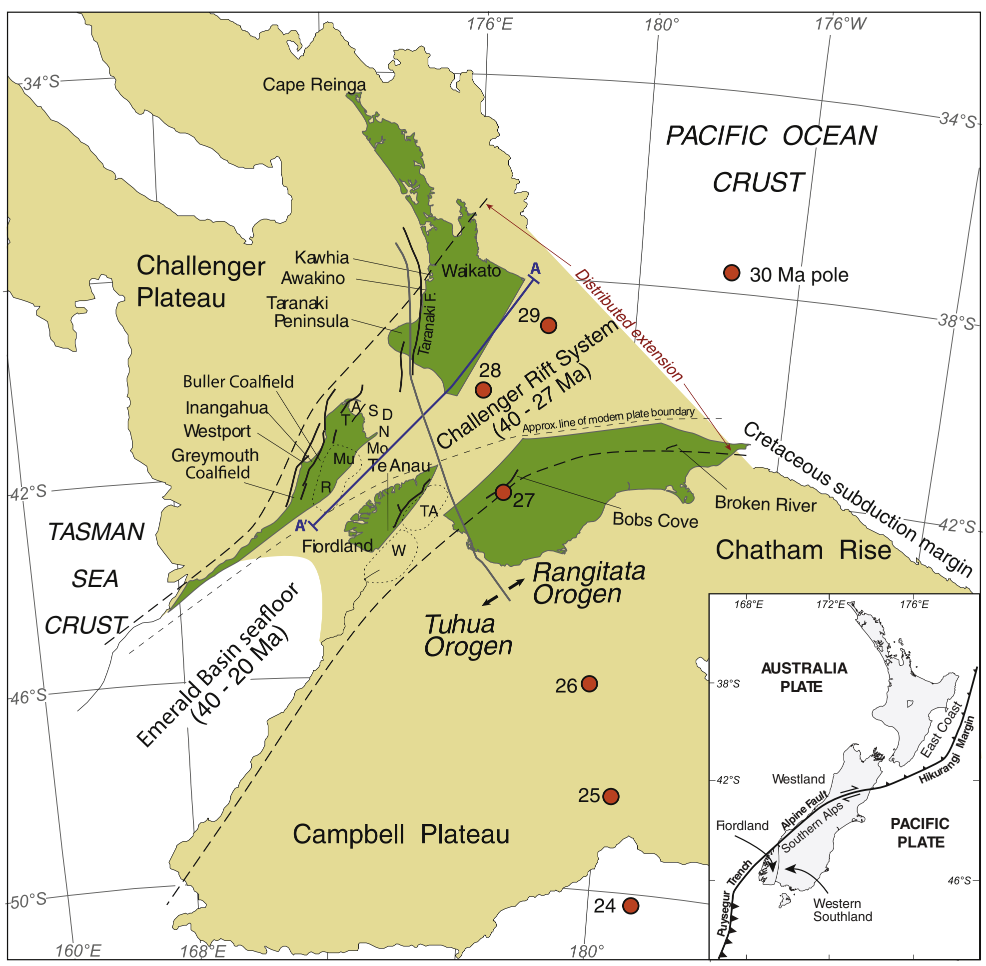

Fig. 1. Map of the New Zealand subcontinent at 27 Ma showing the extent of sea floor in the Emerald Basin and the limits of the Challenger Rift System (Kamp, 1986b) through continental crust. Also shown are the stage pole locations (circles) at 1 m.y. intervals for 30–24 Ma (in Australia fixed reference frame). Uncertainties on pole positions (derived from Cande and Stock, 2004 finite rotation poles) are approximately twice the size of the symbol indicating the pole position. A–A′ refers to the profile shown in Fig. 10. Place names referred to in the text are shown in relation to the present coastline and present plate configuration. Abbreviations for sub-basins: A, Aorere; S, Surville; N, Nelson; M, Moutere; Mu, Murchison Basin; R, (Rappahannock Group) Maruia Basin; TA, Te Anau Basin; W, Waiau Basin. Inset, the generalized location of the Australia–Pacific plate boundary through the New Zealand region.