Tectonophysics 474 (2009) 449–462

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

The lithospheric geodynamics of plate boundary transpression in New Zealand: Initiating and emplacing subduction along the Hikurangi margin, and the tectonic evolution of the Alpine Fault system

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ARTICLE INFO

Article history:
Received 28 December 2008
Received in revised form 18 April 2009
Accepted 20 April 2009
Available online 24 April 2009

Keywords:
Plate tectonics of New Zealand
Subduction initiation
Basin formation
Transpression
Alpine Fault
Southern Alps
Hikurangi subduction
Puysegur subduction
Delamination

ABSTRACT

In contrast to the normal 'Wilson cycle' sequence of subduction leading to continental collision and associated mountain building, the evolution of the New Zealand plate boundary in the Neogene reflects the converse—initially a period of continental convergence that is followed by the emplacement of subduction. Plate reconstructions allow us to place limits on the location and timing of the continental convergence and subduction zones and the migration of the transition between the two plate boundary regimes. Relative plate motions and reconstructions since the Early to Mid-Miocene require significant continental convergence in advance of the emplacement of the southward migrating Hikurangi subduction—a sequence of tectonism seen in the present plate boundary geography of Hikurangi subduction beneath North Island and convergence in the Southern Alps along the Alpine Fault. In contrast to a transition from subduction to continental convergence where the leading edge of the upper plate is relatively thin and deformable, the transition from a continental convergent regime, with its associated crustal and lithospheric thickening, to subduction of oceanic lithosphere requires substantial thinning (removal) of upper plate continental lithosphere to make room for the slab. The simple structure of the Wadati–Benioff zone seen in the present-day geometry of the subducting Pacific plate beneath North Island indicates that this lithospheric adjustment occurs quickly. Associated with this rapid lithospheric thinning is the development of a series of ephemeral basins, younging to the south, that straddle the migrating slab edge. Based on this association between localized vertical tectonics and slab emplacement, the tectonic history of these basins records the effects of lithospheric delamination driven by the southward migrating leading edge of the subducting Pacific slab. Although the New Zealand plate boundary is often described as simply two subduction zones linked by the transpressive Alpine Fault, in actuality the present is merely a snapshot view of an ongoing and complex evolution from convergence to subduction.

1. Introduction

The development of a new plate boundary requires fundamental tectonic changes in the lithosphere—perhaps most profoundly during the formation and emplacement of a new subduction zone. From the initial concepts of the Wilson Cycle, in which ocean basins shrink and disappear as subduction zones initiate along their margins and consume the produced oceanic lithosphere, to the more recent focus on the processes at work along the subduction megathrust interface, it has been recognized that understanding how subduction zones form and evolve is of first-order importance. In contrast to transform and ridge/rift plate boundary development, subduction zone initiation has eluded our full understanding in part because the subduction process itself destroys much of the key evidence of the initial stages.

A variety of studies have focused on the geologic record of subduction initiation. Many of these studies developed geodynamic models of subduction initiation (e.g. Cloetingh et al., 1982; Mitrovica et al., 1989; Gurnis, 1992; Toth and Gurnis, 1998), used those models to predict a geologic response, and compared model predictions to observations. In general the focus was on the large-scale response, often with a focus on the role of upper mantle dynamics in driving vertical tectonics. On a regional scale however, much of the tectonic activity recorded in the geology of the crust will reflect the interaction between the two lithospheric plates, as the system moves toward the nearly universal geometry of the Wadati–Benioff zone.

In any transition to subduction, the over-riding plate's lithosphere, which initially may be over-thickened by pre-subduction convergence, is transformed into a wedge-shaped margin during the initial stages of subduction. How space is created in the upper plate to accommodate the emplaced slab and produce this lithospheric geometry remains largely unanswered. In practice many of the modeling studies cited above assume an inclined initial interface between the

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0040-1951/$ – see front matter
doi:10.1016/j.tecto.2009.04.023

two plates at subduction initiation. For most subduction zones this initial stage occurred in the distant geologic past—there are few current examples of unambiguously young subduction initiation—and so the record of this process is lost or overprinted by subsequent subduction tectonics. However, the Hikurangi subduction regime beneath northern New Zealand is a young, actively emplacing subduction zone. The timing of subduction initiation and plate kinematics throughout its history, including the subsequent southward migration of the subducted slab, are all constrainable, and have occurred post-30 Ma. Much of the geologic record of the ongoing event is extant, and the migrating nature of the emplacement (and a space-for-time substitution) allows us to determine the geophysical (primarily seismological) structure before, during, and after subduction emplacement.

The present-day plate tectonics of New Zealand (Fig. 1) are typically described as simply two subduction zones linked by a transpressive transform fault, the Alpine Fault. This view is not only oversimplified, but also misses key aspects of the plate boundary structures and their evolution that bear on fundamental questions in lithospheric geodynamics. Even the existence of a transpressional plate boundary through New Zealand is a geologically recent phenomenon, having developed since the Early Miocene as the relative motions between the Australia and Pacific plates changed. Since the Euler poles describing Australia–Pacific motion are quite near to the New Zealand landmass, relatively small changes in the pole position reflect substantial changes in the tectonics of Australia–Pacific interactions through New Zealand. This has been recognized for more than three decades (Chase, 1978), and the details of Australia–Pacific plate kinematics (Fig. 2) are now reasonably well constrained (Cande and Stock, 2004). Post-25 Ma, Pacific subduction beneath the Australia plate began along the Hikurangi margin, eastern North Island (the northern subduction) and Australia subduction beneath the Pacific plate began along the Puysegur (or Fiordland) margin, southwestern South Island (the southern subduction). A proto-Alpine Fault developed at this time to link these two nascent subduction zones. However it is important to recognize that because plate motion (and hence the plate boundary) since the Miocene is dominated by significant translation, the configuration of crustal elements at the initiation of the New Zealand plate boundary was substantially different from today.

2. Formation of the New Zealand plate boundary

Prior to approximately 30–35 Ma, the New Zealand land mass (termed Zealandia by Luyendyk, 1995; Landis et al., 2008) was all a part of a single plate, albeit experiencing significant internal deformation. Between 30 Ma and 20 Ma, this changed with the development of a plate boundary structure through New Zealand and the evolving

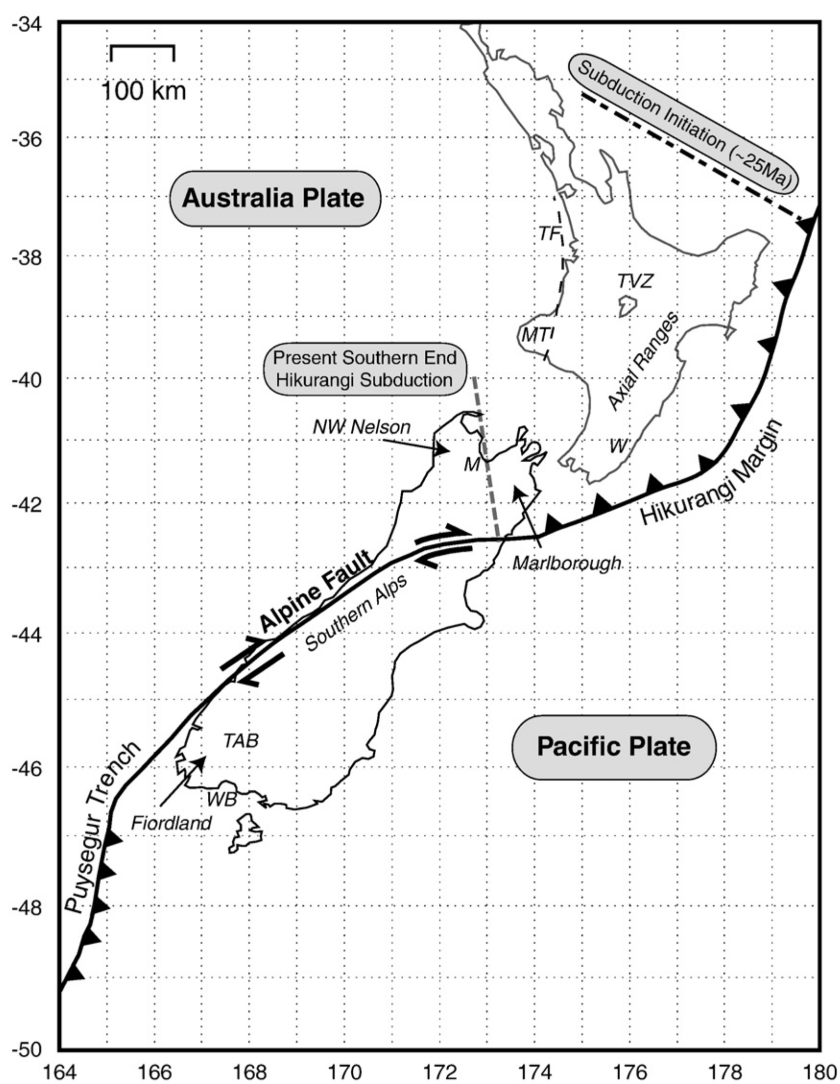

Fig. 1. Present plate boundary structure (schematic) through New Zealand, separating the Australia and Pacific plates. Locations of Hikurangi subduction initiation and present extent of subducted slab are shown. Locations TVZ (Taupo Volcanic Zone), MT (Mount Taranaki), TF (Taranaki Fault), TAB (Te Anau Basin), WB (Waiau Basin), M (Motueka) and W (Wairapa) are indicated.