Tectonophysics 507 (2011) 26–30

Contents lists available at ScienceDirect

Tectonophysics

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

Wedge geometry, mechanical strength, and interseismic coupling of the Hikurangi subduction thrust, New Zealand

Åke Fagereng *

Department of Geological Sciences, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa

ARTICLE INFO

Article history:
Received 11 August 2010
Received in revised form 23 February 2011
Accepted 12 May 2011
Available online 18 May 2011

Keywords:
Subduction
Interseismic coupling
Shear strength
Coulomb wedge
Accretionary prism
Hikurangi margin

ABSTRACT

The Hikurangi subduction thrust interface, east coast North Island, New Zealand, exhibits along-strike variations in seismic style: the southern segment is interseismically locked, while the plate boundary thrust slips aseismically in the north. The geometry of the offshore accretionary prism is also heterogeneous, changing from small to large taper angle (fault dip plus surface slope) from south to north. Along-strike variations in accretionary prism geometry generally reflect changes in Coulomb wedge critical taper angle. Such variations are controlled by the relative strengths of the subduction megathrust and the wedge material. In the southern Hikurangi margin, the small taper angle indicates a relatively weak subduction thrust interface where strong interseismic locking is inferred. In the northern margin, high taper angle reflects a strong shallow décollement relative to the south. Thus, based on critical Coulomb wedge theory, the shallow megathrust appears relatively weak in the locked segment, and stronger in weakly coupled regions.

1. Introduction

Why some fault segments slip aseismically and others fail in large earthquakes is a matter of on-going debate. A commonly held view is that displacement by aseismic shearing (weak coupling) occurs on low effective stress fault segments, while locked (coupled) fault patches experience a higher effective normal stress (McCaffrey et al., 2008; Scholz, 1998; Scholz and Campos, 1995; Sibson and Rowland, 2003; Song and Simons, 2003). Other studies, however, have pointed out that large megathrust earthquakes occur on mechanically weak faults under low effective stress (Brown et al., 2003; Fagereng and Ellis 2009; Lamb, 2006; Tassara, 2010; Tobin and Saffer, 2009; Wang, 2010; Wang et al., 1995). There is therefore a need for examples of how relative frictional strength varies along faults exhibiting along-strike changes in seismic style.

The Hikurangi subduction zone, along the east coast of the North Island, New Zealand, exhibits significant spatial variations in observed microseismic activity (Reyners and Eberhart-Phillips, 2009), and interseismic coupling (Fig. 1) (Wallace et al., 2004), where inter-seismic coupling is defined by the relative motion of rocks on opposite sides of the fault in the time between major earthquakes. According to best-fit inversions of geodetic and seismic data, the Hikurangi subduction thrust is interseismically locked to 35–50 km depth in the southern North Island, while the depth of the fully locked zone decreases to only 10–15 km offshore from Hawke's Bay and the Raukumara Peninsula (Fig. 1) (Wallace et al., 2004). Thus at depths of 10–15 km, the southern Hikurangi margin is interseismically locked, while north of Hawke's Bay this depth range corresponds to the down-dip limit of the locked zone and the slip zone of episodic slow slip events (Wallace et al., 2009). Two M_w 6.9–7.1 earthquakes occurred on the northern segment in 1947, with coseismic slip zones shallower than 20 km (Doser and Webb, 2003) indicating a shallow base of the seismogenic zone. Temperature has been excluded as a main controlling factor of the along-strike variation in coupling depth, based on negligible variation in modeled thermal structure (Fagereng and Ellis, 2009; McCaffrey et al., 2008).

The established variations in interseismic coupling, depth of slow slip events, and a variety of well-studied parameters varying in 3-d, make the Hikurangi margin a suitable natural laboratory for study of the relative impact of various factors on seismic style, although the lack of well-documented megathrust ruptures restricts interpretation to the current interseismic period. Fagereng and Ellis (2009) and Reyners and Eberhart-Phillips (2009) suggested that the fluid pressure state on the interface may be a significant control on megathrust mechanical behavior, although it is likely that multiple factors affect the degree of interseismic coupling (Wallace et al., 2009). To assess whether variations in interface strength (caused by a heterogeneous fluid pressure distribution) occur along the margin, and the correlation (if any) between interface strength and inter-seismic coupling, we apply a critical Coulomb wedge model to recently published offshore geometrical data for the accretionary prism (Barker et al., 2009; Barnes et al., 2010; Bell et al., 2010). The analysis is restricted to the offshore prism, thus to depths in the 10–15 km range, which corresponds to depths at and below the down-dip

* Tel.: +27 21 650 2926.
E-mail address: ake.fagereng@uct.ac.za.

0040-1951/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2011.05.004

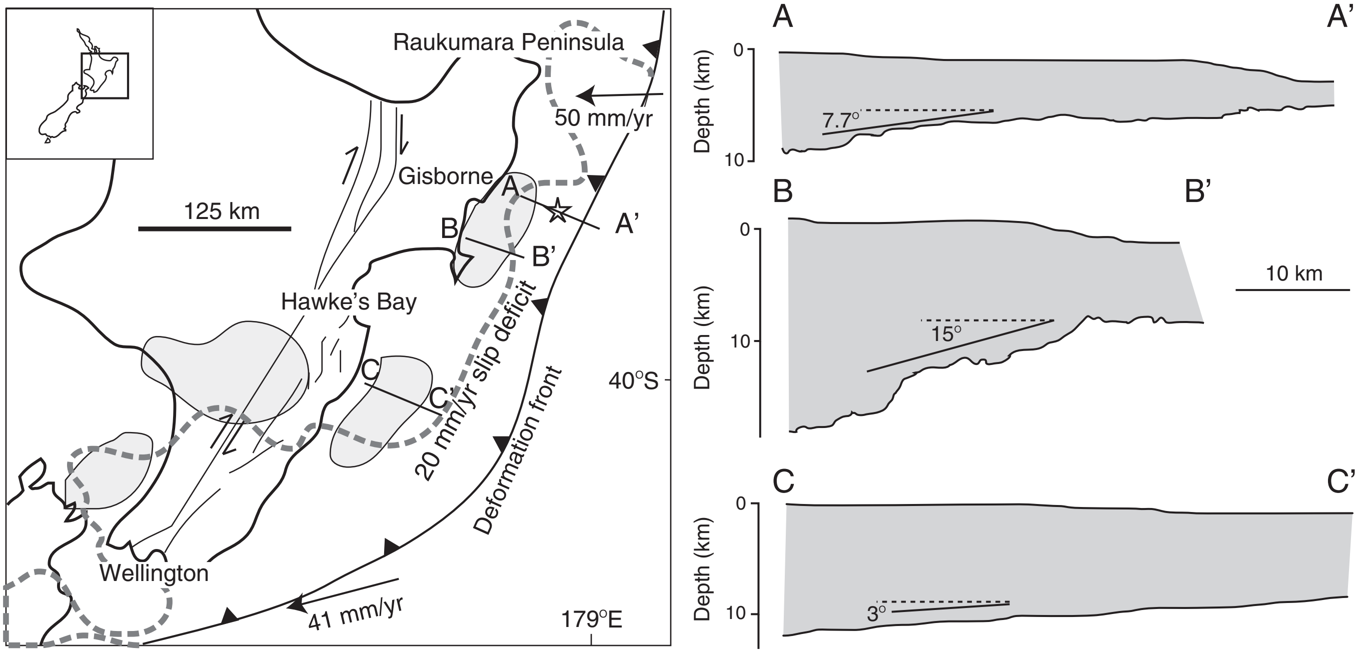

Fig. 1. Map of the North Island of New Zealand with tectonic and seismic features. Arrows represent plate convergence vectors and convergence velocities from Anderson and Webb (1994). The dashed contour of 20 mm/year slip deficit is taken from Wallace et al. (2004), and the area of strong interseismic coupling is between this contour and the deformation front. Shaded areas represent areas of slip in slow slip events, after McCaffrey et al. (2008). The star shows the location of the 1947 tsunami earthquakes offshore Gisborne (Doser and Webb, 2003). Vertical cross-sections of accretionary wedge geometry offshore Gisborne, north of Hawke's Bay (both after Bell et al., 2010), and south of Hawke's Bay (after Barnes et al., 2010) are drawn to the right of the map. Profiles A and B are representative for the range of wedge geometries seen north of Hawke's Bay, whereas C is typical of the imbricate wedge developed in the southern, locked segment (Barnes et al., 2010), although C is located at the edge of the transition from the southern locked zone to the weakly coupled northern segments.

limit of the locked zone in the north, and lies within the locked zone in the south.

2. Regional Setting

Along the east coast of the North Island, the oceanic Pacific Plate is subducted obliquely westward beneath continental lithosphere of the Australian Plate (Fig. 1). Convergence occurs at ~40 mm/year in the southern North Island, increasing to ~50 mm/year in the north (Fig. 1) (Wallace et al., 2004). The angle between the plate convergence vector and the Hikurangi Trough decreases from near-orthogonal in the north to ~40° in the south (Fig. 1) (Anderson and Webb, 1994).

Along-strike variations in various physical properties were reviewed by Wallace et al. (2009). Differences between strongly and weakly coupled segments are listed in Table 1. Major differences include a change in the subducting slab from an oceanic plateau with smooth sediment cover in the southern, coupled segment, to significant topography and seamount subduction in creeping segments further north (Davy et al., 2008). The upper plate is experiencing compression and active reverse faulting in the south, but extension and active normal faulting in the north (Wallace et al., 2004). From seismic velocity models, the hanging wall in the south has been inferred to be relatively dry and impermeable, whereas the upper plate in the north is inferred to be relatively permeable (Eberhart-Phillips et al., 2008).

Table 1
Table comparing observations and inferences for interseismically strongly (locked) and weakly (creeping) coupled segments of the Hikurangi subduction thrust interface, (Wallace et al., 2009, and references therein).

	Locked	Creeping
Convergence rate	<40 mm/year	40–50 mm/year
Convergence obliquity	Oblique to trench	Near orthogonal to trench
Heat flow	<50 mW/m2	>50 mW/m2
Thickness of oceanic crust	~15 km	~10 km
Roughness of subducting slab	Relatively smooth	Significant topography
Prism taper angle	<4°	>10°
Upper plate tectonic regime	Compressional	Extensional
Margin type	Accretionary	Erosional
Inferred hanging wall permeability	Low	High
Inferred relative shear strength	Low	High

3. Accretionary Prism Geometry

In the south (south of Hawke's Bay), an up to 150 km wide, well-developed imbricated accretionary prism is present between the Hikurangi Trough and the North Island dextral fault belt (Fig. 1) (Barker et al., 2009; Barnes et al., 2010). This prism comprises an inner wedge of deformed, pre-subduction basement covered by deformed Miocene–Recent sediments, and an outer wedge of Pliocene–Pleistocene turbidite sequences (Fig. 1) (Barnes et al., 2010). Wedge taper is relatively constant south of Hawke's Bay (Barker et al., 2009); on average, the surface slope of the wedge is 0.7°, and the shallow décollement dips at about 3.0° (Fig. 1) (Barker et al., 2009; Barnes and de Lepinay, 1997; Barnes et al., 2010).

In the central margin at Hawke's Bay, the wedge is narrower than in the south, with a maximum width of ~80 km (Fig. 1) (Barker et al., 2009). This part of the accretionary wedge is cut by major thrust faults, some of which are inferred to splay from the main décollement (Barker et al., 2009; Barnes et al., 2010). Within this region there is a kink in the subduction thrust interface, and its dip increases to >8° (Barker et al., 2009). This increase in décollement dip coincides with an increase in accretionary wedge surface slope to >3° (Barker et al., 2009).

While the southern and central parts of the subduction system are accretionary, the northern Hikurangi margin has a much smaller sediment supply, and is currently experiencing subduction erosion as seamounts are subducted below Raukumara Peninsula (Fig. 1) (Barker et al., 2009; Barnes et al., 2010). The décollement dip is