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Fore-arc mantle wedge seismicity under northeast New Zealand

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ABSTRACT

Relocated upper mantle seismicity, using a 3D velocity model, delineates three tightly clustered (about 12 km diameter) zones of seismicity that occur in the mantle wedge under the fore-arc region of the northern Hikurangi margin, North Island, New Zealand. These clusters extend from the subducting plate at about 55 km depth up to about 35 km, and coincide with strong seismic reflectivity recorded active source seismic reflection measurements, suggesting a fluids association. They have maximum magnitudes of about Mw 4.5. The clusters correspond closely with a change from low to high Vp and Qp, and with average Vp/Vs that is interpreted to be caused by the transition from serpentinised to normal peridotite. The location of this transition appears to correspond to the locus of dehydration of peridotite, suggesting that the seismicity is caused by dehydration embrittlement. The release of these fluids where the serpentinised mantle wedge reaches the locus of dehydration may provide a mechanism for transferring additional fluids or fluid fluxed partial melt into the adjacent back-arc basin and facilitate the generation of voluminous magmas that are erupted there. The occurrence of serpentinite in the fore-arc mantle under northeastern North Island may influence the shallow extent of interplate coupling under the region. The location and spacing of the clusters is consistent with thermally driven diapiric or fluid upwellings, but they also show a spatial relationship with proposed lithospheric fractures and associated volcanic seamounts on the subducting Hikurangi plateau.

1. Introduction

Seismicity at subducting plate margins is focussed in the subducting slab or in the overlying brittle crust. Seismicity in the mantle wedge, lying between these regions, is generally low and diffuse (Hasegawa et al., 2009; Kirby et al., 1996; Reyners et al., 2006), but clusters of seismicity have been detected at regular intervals within the fore-arc mantle wedge in northeast New Zealand. What is their cause? Tomographic studies (e.g. Eberhart-Phillips et al., 2008; Hasegawa et al., 2009; Reyners et al., 2006) demonstrated that the seismic character of the mantle wedge (including Vp, Vp/Vs, Qp and anisotropy) varies between subduction zones and also along these zones. Viscous drag on the overlying mantle along the top of the subducting slab drives asthenospheric corner-flow bringing hot mantle rocks up to the base of crust at back-arc basins and giving rise to extension and back-arc volcanism. This upwelling is associated with mantle melts arising from fluids from the top of the subducted plate at depths of about 100 km, generated by sediment subduction and dewatering and with dehydration phase transitions in the subducted rocks with increasing temperature and pressure (e.g. Gerya et al., 2006; Wada and Wang, 2009) that also results in dehydration embrittlement related seismicity in the subducting lithosphere (e.g. Kirby et al., 1996). The increased mutual solubility between fluids and silicate melts at high temperatures and pressures means that the distinction between fluids and melts vanishes (Liebscher, 2010). In some subduction systems the fore-arc mantle wedge is formed of low seismic velocity, highly serpentinised peridotite (e.g. Bostock et al., 2002) resulting from the hydration of mantle peridotite by water from the subducting slab and sediments (e.g. Gerya et al., 2006). Where no volcanic line or back-arc basin exists, seismic tomographic images indicate that rocks in the mantle wedge may not take part in the asthenospheric circulation (e.g. Reyners et al., 2006).

Clusters of seismicity in the fore-arc mantle have recently been reported from Japan (Okada et al., 2004; Uchida et al., 2010) where they are called supraslab earthquakes (Kirby et al., 2005). The clusters are randomly distributed spatially above the subducting slab and occur up to 60 km deep. The clusters cross the crust–mantle boundary and have been interpreted as caused by the fracturing of subducted seamounts which have been detached from the subducting slab and underplated onto the overlying crust (Uchida et al., 2010). Seismicity clusters within the fore-arc mantle wedge have also been delineated in northeast New Zealand, between the active Hikurangi subduction slab in the east and the actively extending Taupo Volcanic Zone back-arc basin in the west (Figs. 1 and 2), but do not appear to be randomly distributed spatially. Active source crustal seismic reflection data across the eastern Bay of Plenty and Raukumara Peninsula margin (Figs. 1 and 3) image a localised zone of strong reflectivity at a depth

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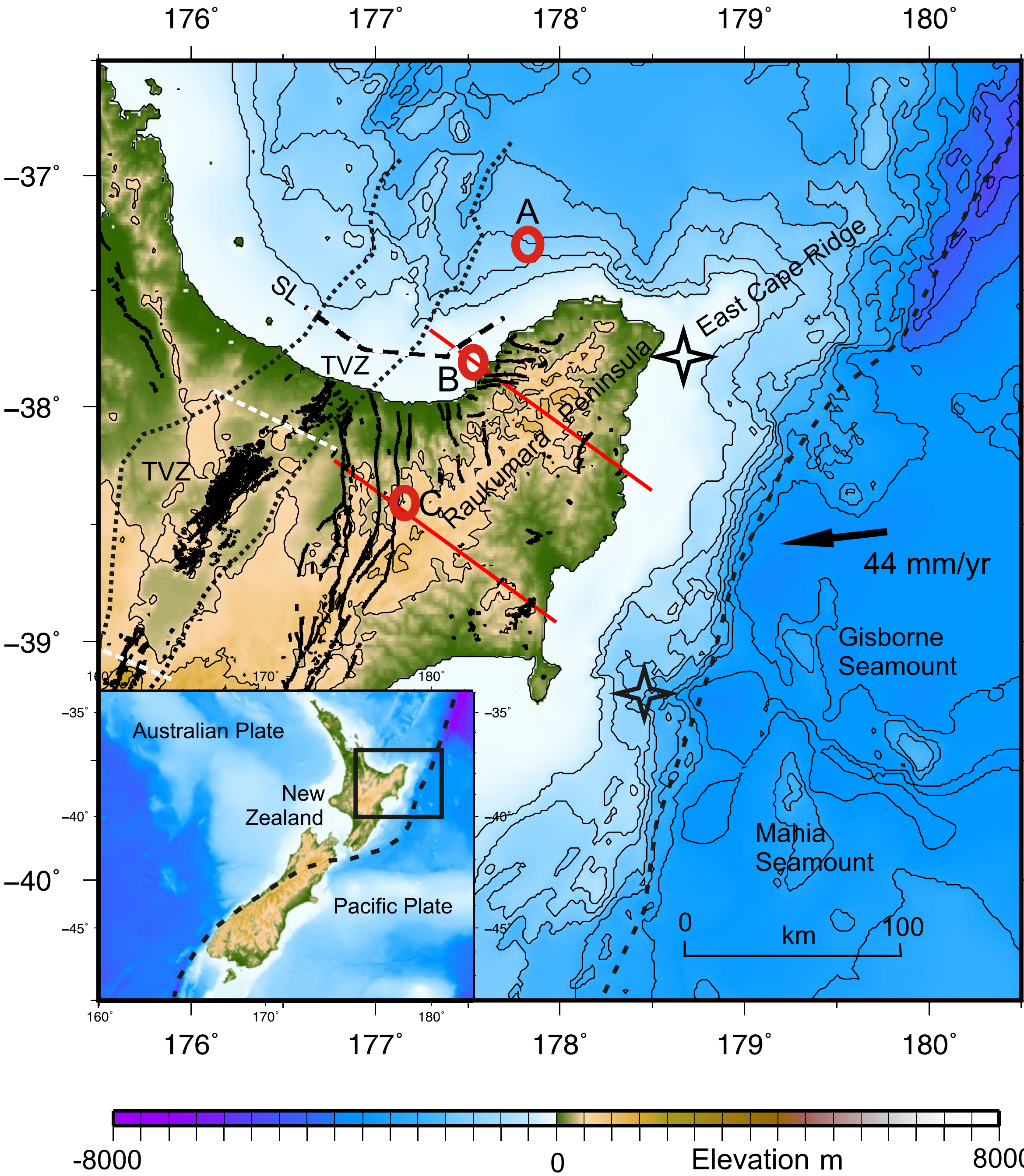

Fig. 1. Northeastern North Island, New Zealand. Topography and bathymetry. Location of seismicity clusters (red circles labelled A, B and C), seismic reflection profile shown in Fig. 3 (thin black dashed line labelled SL), earthquake tomography profiles shown in Fig. 5 (thin red lines), seamounts on the oceanic plate labelled and inferred subducted seamounts shown by black open stars. Active faults on land from GNS Science active faults data base (thick black lines). Taupo Volcanic Zone (back-arc basin TVZ) delineated by dotted lines, white dashed lines delimit the central rhyolite sector. Arrow is the plate convergence direction, annotated with rate. Inset: regional setting of New Zealand and the Pacific and Australian plates, plate boundary marked by dashed line and main figure by black outline box.

of about 35–50 km (12 to 16 s two-way-travel time (s twt)) across the margin of one of these seismicity clusters, suggesting the presence of fluids or partial melt (Davey, 2009). The reflective zone, and associated seismicity cluster, lie within the mantle wedge as Moho is imaged on the seismic reflection data and the top of the subducting Pacific slab, clearly defined by seismicity (Fig. 5), lies below the depth extent of Fig. 3. We use these active source crustal seismic data and tomographic models of Vp, Vp/Vs, and Q (Eberhart-Phillips and Chadwick, 2002) to examine possible causes of the seismicity clusters and their relationship to the movement of fluids through part of the subduction system.

2. Regional Tectonic Setting

The eastern part of the North Island, New Zealand corresponds to the Hikurangi subducting margin where the Pacific plate is being subducted under the North Island at rates of about 44 mm/yr (DeMets et al., 1994). The rate and relative convergence direction varies from almost normal (80°) in the northeast of North Island to highly oblique (45°) in the southeast, and this is reflected in how the margin deforms and accommodates the convergence (Wallace et al., 2009). At the surface, dip-slip and strike slip motions are decoupled (Nicol and Wallace, 2007), with dip-slip largely along the subduction interface