Physics of the Earth and Planetary Interiors 186 (2011) 49–58

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

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

Control of high oceanic features and subduction channel on earthquake ruptures along the Chile–Peru subduction zone

Eduardo Contreras-Reyes[a,*], Daniel Carrizo[a,b]

[a] Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[b] Advanced Mining Technology Center AMTC, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile

ARTICLE INFO

Article history:
Received 8 September 2010
Received in revised form 8 March 2011
Accepted 8 March 2011

Edited by: George Helffrich.

Keywords:
Bathymetry
Asperity
Barrier
Subduction channel
Earthquake rupture
1960 and 2010 megathrust earthquakes

ABSTRACT

We discuss the earthquake rupture behavior along the Chile–Peru subduction zone in terms of the buoyancy of the subducting high oceanic features (HOF's), and the effect of the interplay between HOF and subduction channel thickness on the degree of interplate coupling. We show a strong relation between subduction of HOF's and earthquake rupture segments along the Chile–Peru margin, elucidating how these subducting features play a key role in seismic segmentation. Within this context, the extra increase of normal stress at the subduction interface is strongly controlled by the buoyancy of HOF's which is likely caused by crustal thickening and mantle serpentinization beneath hotspot ridges and fracture zones, respectively. Buoyancy of HOF's provide an increase in normal stress estimated to be as high as 10–50 MPa. This significant increase of normal stress will enhance seismic coupling across the subduction interface and hence will affect the seismicity. In particular, several large earthquakes ($M_w \geq 7.5$) have occurred in regions characterized by subduction of HOF's including fracture zones (e.g., Nazca, Challenger and Mocha), hotspot ridges (e.g., Nazca, Iquique, and Juan Fernández) and the active Nazca-Antarctic spreading center. For instance, the giant 1960 earthquake ($M_w = 9.5$) is coincident with the linear projections of the Mocha Fracture Zone and the buoyant Chile Rise, while the active seismic gap of north Chile spatially correlates with the subduction of the Iquique Ridge. Further comparison of rupture characteristics of large underthrusting earthquakes and the locations of subducting features provide evidence that HOF's control earthquake rupture acting as both asperities and barriers. This dual behavior can be partially controlled by the subduction channel thickness. A thick subduction channel smooths the degree of coupling caused by the subducted HOF which allows lateral earthquake rupture propagation. This may explain why the 1960 rupture propagates through six major fracture zones, and ceased near the Mocha Fracture Zone in the north and at the Chile Rise in the south (regions characterized by a thin subduction channel). In addition, the thin subduction channel (north of the Juan Fernández Ridge) reflects a heterogeneous frictional behavior of the subduction interface which appears to be mainly controlled by the subduction of HOF's.

1. Introduction

Along the Chile–Peru Trench the oceanic Nazca plate subducts beneath the South American plate at a current rate of ~6.5 cm/year (Khazaradze and Klotz, 2003). The Nazca plate hosts a large population of high oceanic features (HOF's) including hotspot tracks and oceanic fracture zones (FZ's). Perhaps the most striking feature of the oceanic plate is the Chile Rise, an active spreading center that marks the boundary between the oceanic Nazca and Antarctic plates and is currently subducting at ~46°S beneath the South American plate. Bathymetric data show four main oceanic hotspot tracks: Nazca, Iquique, Copiapó and Juan Fernández Ridges (Fig. 1). The Nazca Ridge (NR) was formed at the Easter Island hotspot on the Pacific-Farallon/Nazca spreading center (Pilger, 1984), while the Juan Fernández Ridge (JFR) is an off-ridge hotspot formed at the JFR hotspot onto 27 Myr old oceanic crust (Yáñez et al., 2001). The oceanic Nazca plate is further segmented by several oceanic fracture zones formed at the Pacific-Nazca and Antarctic-Nazca spreading centers (Tebbens et al., 1997).

Most of the seafloor features hosted by the oceanic Nazca plate are in the throes of being subducted (Herron et al., 1981; Yáñez et al., 2001; Rosenbaum et al., 2005). Subduction of a HOF may modify the geodynamics and tectonic setting of the outer forearc region, and disrupt and erode material from the overriding plate. In addition, subduction of a HOF is expected to influence dramatically the degree of coupling across the subduction interface and may affect seismicity, in particular the size and frequency of large

* Corresponding author. Tel.: +56 2 9784296; fax: +56 2 6968686.
E-mail address: econtreras@dgf.uchile.cl (E. Contreras-Reyes).

0031-9201/$ – see front matter
doi:10.1016/j.pepi.2011.03.002

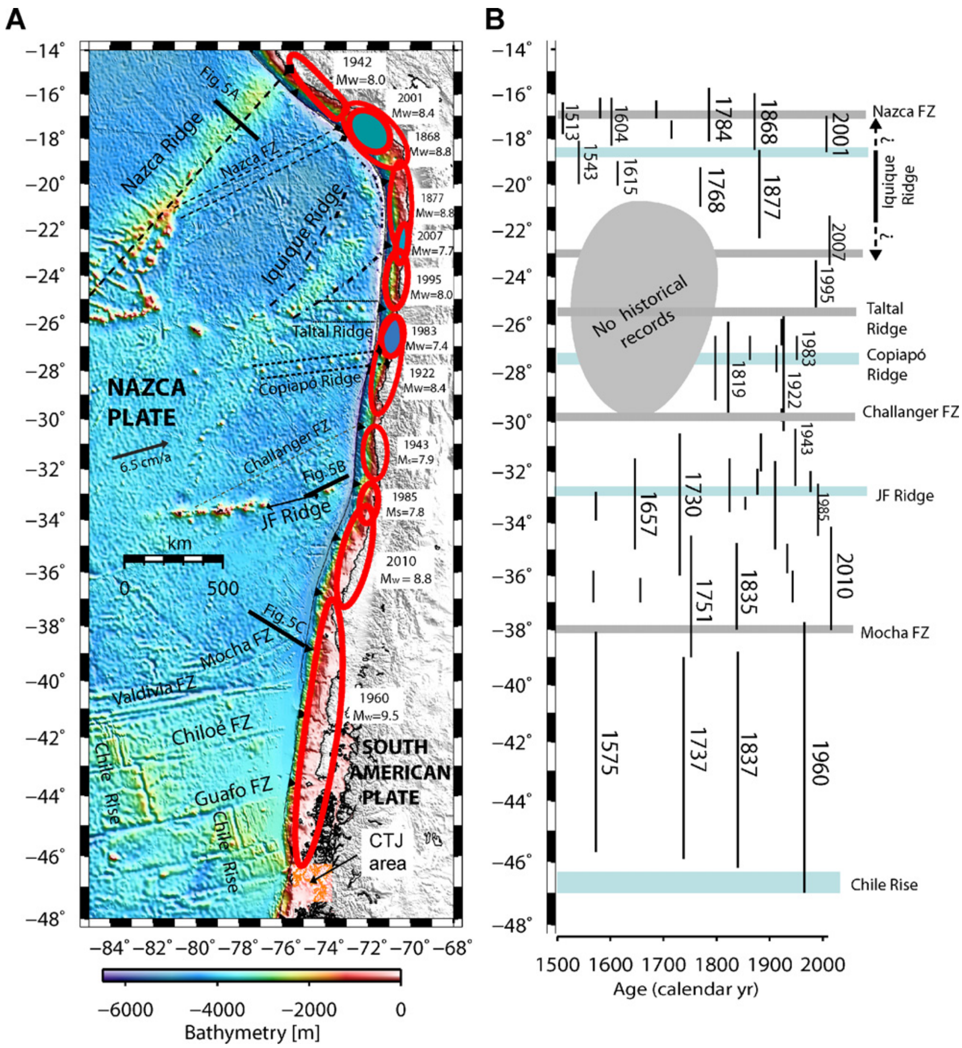

Fig. 1. (A) Main oceanic bathymetric features and most significant earthquakes (red elipses) from the 19th to 21st centuries are shown. Bathymetry is taken from Sandwell and Smith (1997) and main oceanic fracture zones are taken from Tebbens et al. (1997). (B) Earthquake ruptures (M_w > 7.0) were compiled from Beck et al. (1998), Comte and Pardo (1991), Cisternas et al. (2005) and Bilek (2010). (For interpretation of the references to color in this sentence, the reader is referred to the web version of the article.)

earthquakes (Kelleher and McCann, 1976; Cloos, 1992; Scholz and Small, 1997).

The slip distribution at the subduction interface is highly heterogeneous in terms of the strength or frictional characteristics of the material in the fault zone. These stress heterogeneities have been recognized as asperities (Kanamori, 1994) and barriers (Das and Aki, 1977) to earthquake rupture which control the seismic moment release and rupture area. A seismic asperity is an area with locally increased friction and exhibits little aseismic slip during the interseismic period relative to the surrounding regions. Once the shear yield stress τ_o (critical shear stress required for failure) along these heterogeneities is reached by the accumulated interseismic shear stress τ_1, the asperity concentrates the coseismic moment release and slip during the earthquake. The regions with little or no slip during rupture propagation are generally called barriers and control the size of the earthquake rupture area (ERA) (Aki, 1979; Kanamori and McNally, 1982).

Once the earthquake initiates ($\tau_1 \geq \tau_o$), the rupture front propagates through regions where the dynamic stress associated with the rupture process is larger than τ_o. If the rupture front encounters an obstacle where the dynamic stress is lower than τ_o, the fault motion slows down and eventually stops (barrier zone). In other words, the interplay between the amount of dynamic stress and τ_o will define whether a region behaves as an asperity with large slip or behaves as a barrier with no slip. Therefore, it is fundamental investigate the shear yield stress distribution along the subduction interface. A heterogeneous distribution of τ_o might be useful to predict the location of local barriers and asperities before occurrence of an earthquake. τ_o varies over time and depends on frictional properties, fluid pore-pressure, and state stress anomaly. For example, subduction of a rigid seamount will result in an increase of normal stress σ_n and hence τ_o preventing eventual rupture (strong coupling). Likewise, buoyancy of HOF's will enhance seismic coupling and anomalous increase of τ_o. In contrast, an increase of fluid pore pressure will reduce τ_o facilitating rupture propagation.

Since HOF's dramatically modify the geodynamics of the outer forearc and interplate boundary conditions, they are probably the most obvious candidates for asperities and/or barriers. The frictional behavior of HOF's is clearly influenced by the increase of normal stress at the subduction interface caused by the excess buoyancy of these features (Scholz and Small, 1997). Furthermore, Scholz and Small (1997) claim that the "geometric" normal stress effect due to the need of the overriding plate to accommodate the shape of the HOF is a significant additional source of increasing normal stress at the subduction interface. Thus, the anomalous strong coupling associated with HOF's (buoyancy and geometry) might