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Upper Pleistocene uplifted shorelines as tracers of (local rather than global) subduction dynamics

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ABSTRACT

Past studies have shown that high coastal uplift rates are restricted to active areas, especially in a subduction context. The origin of coastal uplift in subduction zones, however, has not yet been globally investigated. Quaternary shorelines correlated to the last interglacial maximum (MIS 5e) were defined as a global tectonic benchmark (Pedoja et al., 2011). In order to investigate the relationships between the vertical motion and the subduction dynamic parameters, we cross-linked this coastal uplift database with the "geodynamical" databases from Heuret (2005), Conrad and Husson (2009) and Müller et al. (2008). Our statistical study shows that: (1) the most intuitive parameters one can think responsible for coastal uplift (e.g., subduction obliquity, trench motion, oceanic crust age, interplate friction and force, convergence variation, dynamic topography, overriding and subducted plate velocity) are not related with the uplift (and its magnitude); (2) the only intuitive parameter is the distance to the trench which shows in specific areas a decrease from the trench up to a distance of ~300 km; (3) the slab dip (especially the deep slab dip), the position along the trench and the overriding plate tectonic regime are correlated with the coastal uplift, probably reflecting transient changes in subduction parameters. Finally we conclude that the first order parameter explaining coastal uplift is small-scale heterogeneities of the subducting plate, as for instance subducting aseismic ridges. The influence of large-scale geodynamic setting of subduction zones is secondary.

1. Introduction

Fossil shorelines (or strandlines) are generally packed and constitute staircase coastal geomorphologies or sequences of "terraces" (e.g. marine or reefal for example). They are tracers of the sea level at the time they formed. Current elevation of fossil shorelines results from the combination of sea level change (eustasy) and vertical ground motion (uplift or subsidence, Lajoie et al., 1991; Pirazzoli et al., 1993). Pedoja et al. (2011) exhaustively compiled the worldwide repartition and elevation of the shorelines formed during the last interglacial sea level highstand (Marine Isotopic Stage 5e, ~120 ka BP) and calculated apparent coastal uplift rates since that time. More recently, Pedoja et al. (2014), investigated other benchmarks (MIS 1, 3, 11 and upper shoreline of the sequences) in the coastal sequences including MIS 5e strandline. Their database highlights the contrast in tectonic uplift rates between active zones (mainly Pacific Ocean) and passive zones (Atlantic and Indian Oceans) (Fig. 1). Even if Pedoja et al. (2014) did a first-order exploration of uplift record on paleoshorelines in function of the rough geodynamic setting, vertical motion along the coasts located above subduction zones has never been extensively explored. In this paper, we look for possible geological parameters

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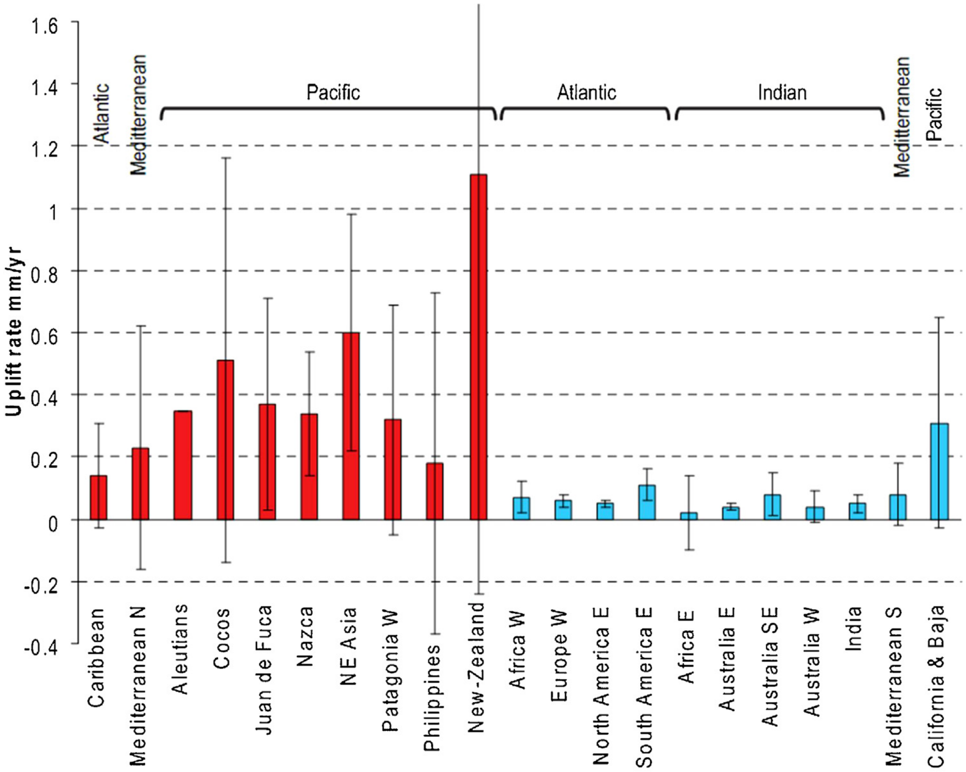

Fig. 1. Worldwide distribution of apparent coastal uplift rates (since MIS 5e): in red and blue the average uplift rate for, respectively, the actively deforming zones (mostly subduction zones) and the stable zones (mostly passive margins; data from Pedoja et al. (2011). Brackets represent the data standard deviation. Note the zone named California and Baja, corresponds to a passive margin very close to a rift/transform setting. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

that may explain why coastal areas located above subduction zones are uplifting so fast (Fig. 1).

The compilation from Pedoja et al. (2011) records only emerged terraces with few exceptions. As discussed in Pedoja et al. (2011), the worldwide distribution of shoreline sequences suggests that there are much less subsiding areas along subduction coastlines than uplifting ones, a fact that shall not be considered as an observational bias (see Pedoja et al., 2011, 2014). Then, the database may reflect a global tendency to coastal uplift during late Pleistocene (Pedoja et al., 2011), and also partly results from the fact that Pleistocene to present-day coastal subsidence is more difficult to quantify than coastal uplift. In any case, this database shows that the average coastal uplift is faster above subduction zones than at passive margins. In the following, we look for possible links between Late Pleistocene (posterior to MIS5) coastal uplift and subduction geodynamics. In particular, we investigate the uplift dependence on some geodynamic parameters, chosen for their driving effect. Some are obvious, like: distance to the trench, trench motion, age of the subducting plate, subduction obliquity, overriding and subducting plate velocities, and dynamic topography. The others are suspected to act on the vertical motion but with magnitudes and direction that deserve exploration: interplate force and friction force, position along the trench (i.e. distance to the subducting plate edge), slab dip, tectonic setting of the overriding plate (see Heuret (2005)).

2. Materials and methods

2.1. Databases: paleoshorelines and geodynamics

The compilation by Pedoja et al. (2014), Pedoja et al. (2011) focuses on coastal geomorphic indicators correlated to the Marine Isotopic Stage 5e (125 ky BP). Indeed, corresponding terraces are the most extensively preserved and dated. Moreover, MIS 5e is purportedly the last analogue to the current interglacial and the time span is enough to largely exceed several seismic cycles such that the uplift rate is not significantly affected by an individual seismic event. Using the MIS 5e shoreline elevation, we calculated the average uplift rate using the following formula: $U = (z - e)/t$, with U the shoreline uplift rate, z the MIS 5e terrace elevation, t the age of the terrace and e the relative elevation of the MIS 5e sea level with respect to the current sea level. In accordance to Pedoja et al. (2014) and Pedoja et al. (2011), we use $e = 0 \pm 10$ m, which is conservative in the sense it takes into account the different debated evaluations of the last interglacial sea-level (e.g., Waelbroeck et al., 2002; Kopp et al., 2009; O'Leary et al., 2013) and the way the shorelines are fossilized (e.g., Lajoie et al., 1991). In addition, this elevation value is of little interest to the current study as it uniformly offsets uplift rates while our analysis considers relative vertical displacements from one site to another. Besides the elevation of the uplifted shorelines, Pedoja et al. (2014, 2011) deliver some additional information like the geographic location of the sequences. Noteworthy, the spatial repartition of the data over South America, Japan and Cascadia subduction allow investigating the coastal uplift distribution as a function of the distance to the trench up to 800 km away (in the Japan and South America transects). In addition, it is noticeable that some places have not been investigated for marine terraces, like the Aleutian subduction zone where the Ostrov Beringa and Seguam islands exhibit marine terraces visible on satellite images but not studied in the field or even the Mariana subduction zone (Stafford et al. (2005) observed uplifted karst in Guam).

Subduction zone geodynamic parameters are sourced from Heuret (2005) (parts of the data base have been published in Heuret and Lallemand (2005), Lallemand et al. (2005) and Funiciello et al. (2008)). He provides every 2 degrees multiple geodynamic parameters like the overriding plates tectonic regime, the trench