Quaternary Science Reviews 105 (2014) 209–238

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Coastal tectonics on the eastern margin of the Pacific Rim: late Quaternary sea-level history and uplift rates, Channel Islands National Park, California, USA

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A R T I C L E I N F O

Article history:
Received 21 July 2014
Received in revised form
20 September 2014
Accepted 24 September 2014
Available online

Keywords:
Marine terraces
Uplift rates
Sea-level history
Channel Islands
California
Uranium-series dating
Aminostratigraphy
Glacial-isostatic adjustment processes
Tectonics
Pacific Rim

A B S T R A C T

The Pacific Rim is a region where tectonic processes play a significant role in coastal landscape evolution. Coastal California, on the eastern margin of the Pacific Rim, is very active tectonically and geomorphic expressions of this include uplifted marine terraces. There have been, however, conflicting estimates of the rate of late Quaternary uplift of marine terraces in coastal California, particularly for the northern Channel Islands. In the present study, the terraces on San Miguel Island and Santa Rosa Island were mapped and new age estimates were generated using uranium-series dating of fossil corals and amino acid geochronology of fossil mollusks. Results indicate that the 2nd terrace on both islands is ~120 ka and the 1st terrace on Santa Rosa Island is ~80 ka. These ages correspond to two global high-sea stands of the Last Interglacial complex, marine isotope stages (MIS) 5.5 and 5.1, respectively. The age estimates indicate that San Miguel Island and Santa Rosa Island have been tectonically uplifted at rates of 0.12–0.20 m/ka in the late Quaternary, similar to uplift rates inferred from previous studies on neighboring Santa Cruz Island. The newly estimated uplift rates for the northern Channel Islands are, however, an order of magnitude lower than a recent study that generated uplift rates from an offshore terrace dating to the Last Glacial period. The differences between the estimated uplift rates in the present study and the offshore study are explained by the magnitude of glacial isostatic adjustment (GIA) effects that were not known at the time of the earlier study. Set in the larger context of northeastern Pacific Rim tectonics, Channel Islands uplift rates are higher than those coastal localities on the margin of the East Pacific Rise spreading center, but slightly lower than those of most localities adjacent to the Cascadia subduction zone. The uplift rates reported here for the northern Channel Islands are similar to those reported for most other localities where strike-slip tectonics are dominant, but lower than localities where restraining bends (such as the Big Bend of the San Andreas Fault) result in crustal shortening.

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1. Introduction

The Pacific Rim is highly active tectonically, with its margins characterized by spreading centers, subduction zones, and transform faults. On the eastern margin of the Pacific Rim, the coast of western North America is situated at the boundary between the Pacific plate and the North American plate (Fig. 1). The nature of this plate boundary changes from south to north. In the Gulf of California, the East Pacific Rise (spreading ridge) separates the two plates, whereas farther north in California, the San Andreas transform fault forms the boundary. Still farther north, from northern California to southwestern Canada, smaller subplates (Juan de Fuca and Gorda plates) are being subducted under the North American plate. Coastal geomorphic evolution in western North America is influenced strongly by tectonic processes, but the nature and rates of those processes differ along the coastline because of the changing nature of the plate boundary. Coastal uplift rates, a reflection of this tectonic activity, can be ascertained by the study of emergent marine terraces (Keller and Pinter, 2002; Murray-Wallace and Woodroffe, 2014).

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http://dx.doi.org/10.1016/j.quascirev.2014.09.017
0277-3791/Published by Elsevier Ltd.

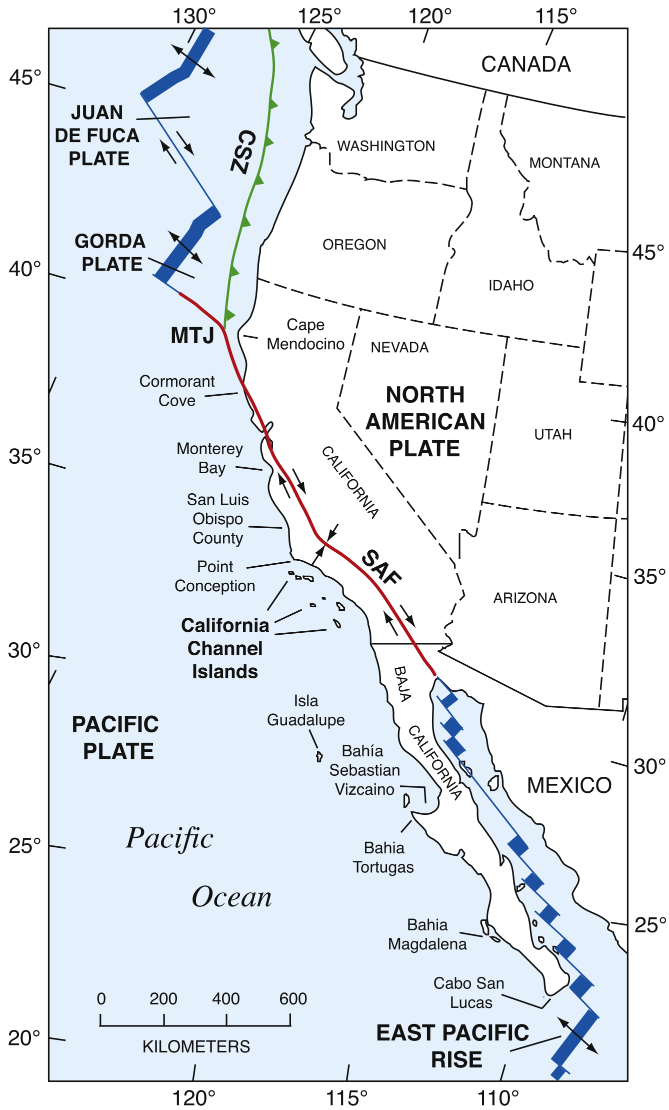

Fig. 1. Map showing the plate tectonic setting of western North America (simplified from Drummond (1981) and Simkin et al. (2006)), location of the California Channel Islands, and other localities referred to in the text. SAF, San Andreas Fault; MTJ, Mendocino Triple Junction; CSZ, Cascadia subduction zone.

Southern California is divided by the San Andreas Fault (Fig. 2). Much crustal deformation along the San Andreas and other faults in coastal California is horizontal, due to the dominance of a strike-slip movement. Thus, along much of the southern California mainland coast and the adjacent islands, late Quaternary uplift rates are expected to be modest. There are exceptions to this generalization, however. An area in southern California where dramatic upward movement has been documented in late Quaternary time is the western Transverse Ranges physiographic province, an east–west-trending series of fault-bounded mountain ranges and intervening valleys. Although right-lateral, strike-slip movement characterizes much of the San Andreas Fault zone, there is considerable crustal contraction and shortening adjacent to the "Big Bend" of this fault (Fig. 2). Thus, south of this major restraining bend, faults of the western Transverse Ranges strike east–west and fold axes also strike east–west. Along the coast between Goleta/Santa Barbara and Ventura, which is part of this major fault and fold belt, there are numerous geomorphic indicators of rapid crustal deformation, including uplifted, faulted, and folded marine terraces (Wehmiller et al., 1978, 1979; Lajoie et al., 1979; Wehmiller, 1982; Sarna-Wojcicki et al., 1987; Trecker et al., 1998; Minor et al., 2009; Gurrola et al., 2014).

The northern Channel Islands (San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands) are situated in Santa Barbara Channel, south of the Big Bend area of the San Andreas Fault zone and also south of the Santa Barbara–Ventura fault and fold belt region (Fig. 2). The crustal platform on which these islands are located has also been studied for estimating rates of tectonic uplift. Using estimated marine terrace ages from Santa Rosa Island, Sorlien (1994) suggested that the northern Channel Islands could have been uplifted at rates of 0.5–1.0 m/ka. Because these estimates were based on assumed ages of marine terraces, they were, however, presented as hypothetical. Pinter et al. (1998a, 1998b, 2003) studied marine terraces on the western portion of Santa Cruz Island. The lowest of three terraces mapped by these investigators dates to the ~120 ka high-sea stand of the Last Interglacial period, or marine isotope stage (MIS) 5.5 (nomenclature of Martinson et al. (1987)), based on U-series analyses of fossil corals. Elevation measurements indicate that the maximum uplift rate of Santa Cruz Island is ~0.1 m/ka, and the westernmost part of the island could have experienced little or no uplift since the Last Interglacial high-sea stand. In contrast, Chaytor et al. (2008) infer rapid uplift of a submerged marine terrace they mapped around the southern, submarine portion of the northern Channel Islands crustal block. Radiocarbon ages of fossil shells associated with the submerged terrace give a Last-Glacial-period age (~23–12 ka). Chaytor et al. (2008) used the terrace age, elevation (~95–120 m below present sea level), and the Last-Glacial-to-Holocene sea level curve of Lambeck et al. (2002) to generate an uplift rate. Because the Lambeck et al. (2002) curve indicates a Last Glacial maximum (LGM) paleo-sea level of ~140 m below present, Chaytor et al. (2008) calculated an uplift rate of ~1.5 m/ka for the past ~23 ka in the northern Channel Islands region. This uplift rate is more than an order of magnitude higher than the highest possible uplift rate derived from the data of Pinter et al. (1998a, 1998b, 2003) for nearby Santa Cruz Island.

The emergent marine terraces on the northern Channel Islands were studied in the present effort in order to evaluate the competing hypotheses of low (Pinter et al., 1998a, 1998b, 2003) versus moderate (Sorlien, 1994) versus high (Chaytor et al., 2008) uplift rates for the northern Channel Islands region. The highly divergent estimates of late Quaternary uplift rate for the northern Channel Islands crustal block have quite different implications for seismic hazard, assuming that high uplift rates imply a region with more frequent earthquakes. The present paper reports new mapping, elevation measurements, and ages of emergent marine terraces on the northern Channel Islands that allow new estimates of late Quaternary uplift rates. The resulting uplift rates for this part of California are also compared to those calculated from uplifted marine terrace data from other tectonic settings in the northeastern part of the Pacific Rim, on the west coast of North America.

2. Field and laboratory methods

2.1. Field and GPS methods

Marine terrace deposits and other surficial sediments were mapped on San Miguel Island and Santa Rosa Island, in part modified from mapping conducted by Weaver et al. (1969). Unlike Weaver et al. (1969), however, the present work distinguishes between low terraces (less than ~30 m elevation), hypothesized to be of probable late Quaternary age (based on elevation, stratigraphic position, and faunal assemblages) and high terraces (greater than ~30 m elevation), hypothesized to be of middle-to-early Quaternary