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A Holocene sedimentary record of tectonically influenced reduced channel mobility, Skokomish River delta, Washington State, USA

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ABSTRACT

At the Skokomish River delta in Washington State's Puget Lowland, coseismic uplift and tilting trapped the river against a valley wall, resulting in little to no channel migration for the last 1000 years. The most recent earthquake occurred before AD 780–990, based on stratigraphic evidence such as sand blows and abrupt facies changes. Since the hypothesized tilting a 5-km-long section of the river has not migrated laterally or avulsed, resulting in reduced migration and a muddy intertidal flat that is 2 km wider in the east than on the west side of Annas Bay. A ridge running perpendicular to the river may also have restricted channel mobility. The ridge may be either the surface expression of a blind thrust fault or a relict, uplifted and tilted shoreline. The uplift and tilting of the delta can be ascribed to any of three nearby active fault zones, of which the most likely, based on the orientation of deformation, is the Saddle Mountain fault zone, which produced a surface rupture 1000–1300 years ago. The delta has experienced submergence since the earthquake. A forest that colonized an uplifted part of the delta about 800–1200 years ago was later submerged by at least 1.6 m and is now a brackish-water marsh.

1. Introduction

A variety of factors can lead to reduced channel mobility (low rates of migration and avulsion) including human influence, tectonics, topographic features and substrate (Holbrook and Schumm, 1999; Aslan et al., 2005). Rivers avulse for a variety of reasons, including a gradient advantage for the river to take another course (Slingerland and Smith, 1998), channel aggradation (King and Martini, 1984), and favorable substrate or geomorphology along another course (Aslan et al., 2005). Tectonically driven channel mobility is the result of river channels preferentially migrating away from uplift and/or toward subsidence (Holbrook and Schumm, 1999). This study illustrates a case where tectonic uplift dominates over other factors that can control the location of fluvial channels, resulting in reduced channel mobility, due to a bounding valley wall, and the delta building into only one side of the receiving basin.

In modern and ancient fluvial and deltaic systems, tectonically induced migration and avulsion is studied as an indicator for tectonic environment and for the subsequent depositional pattern (Schumm, 1986; Alexander and Leeder, 1987; Holbrook and Schumm, 1999; Gouw, 2007; Matteo and Siringan, 2007); the signal from the interplay of tectonics and river dynamics is not always straightforward. Increased rates of avulsion in rivers and lobe switching in deltas often indicate tectonic activity when other variables are constant (Gouw, 2007). In contrast, in locations where a river runs parallel to the trend of a graben, lower rates of migration can occur if rates of subsidence are high enough to overcome other river characteristics (e.g., stream power, sedimentation) and trap the river against the graben wall (Alexander and Leeder, 1987). Changes to river systems by earthquakes are often transient (Schumm, 1986; Attal et al., 2008), making stratigraphic and geomorphic studies necessary to understand the tectonic history.

Faults and fluvial systems can interact in complex ways and create complicated records in the geomorphology and stratigraphy of the landscape (Schumm, 1986). This study examines a moderately simple fluvial-deltaic system affected by both coseismic uplift and long-term subsidence. The study covers a time period over which sea level and climate has remained almost stable (Eronen et al., 1987; McLachlan and Brubaker, 1995). The system itself is small (4-km wide delta at the river mouth), mesotidal, and experiences little wave activity and longshore drift (Schwartz, 1991). Additionally, in the study area the valley floor consists of alluvium so the river is not affected by changes in lithology.

Within the fluvial/deltaic system of the Skokomish River, this study aimed to determine the geomorphic and stratigraphic effects of Recent faulting on a fluvial deltaic system including the origin of a bight and shore-parallel berm. The results demonstrate a combination of differential uplift (tilting) and receiving basin geometry resulted in reduced channel mobility of the Skokomish River and delta out-building only in the eastern half of Annas Bay (Figs. 1, 2). Tilting, probably associated with the earthquake uplift, resulted in the river channels consistently on the eastern side of the delta for the last 1000 years. To the east, large (~150 m tall) bluffs of glacial sediment slow river migration, with the result that all sediment is discharged to the eastern side of the delta. Thus, the bight on the western side of the delta is interpreted to be an area of non- or low deposition. Interpretation of the shore-parallel berm (herein

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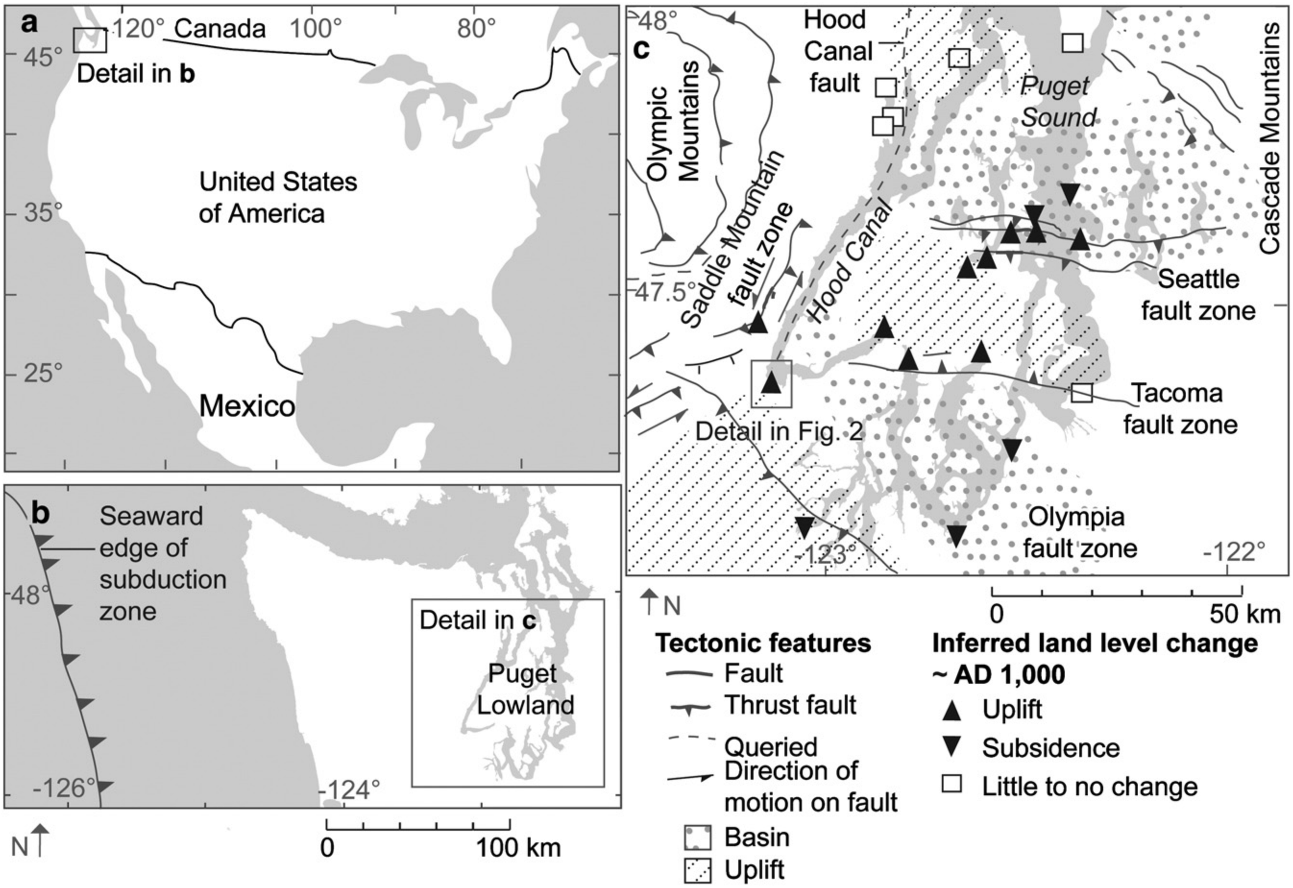

Fig. 1. The tectonic setting of the Puget Lowland and crustal fault locations. a. Regional map. b. Map of Cascadia subduction zone and coastline. c. Map of the Puget Lowland showing active faults and locations of paleoseismic studies. Modified from Blakely et al., 2009. Paleoseismic studies: Eronen et al., 1987; Beale, 1990; Bucknam et al., 1992; Bourgeois and Johnson, 2001; Sherrod, 2001; Blakely et al., 2009; Brian Sherrod, personal communication; Arcos, 2012.

termed the Ridge) remains unresolved, but the geomorphology cannot be explained by south-dipping thrust fault with a back thrust as proposed by Polenz et al. (2010). An alternative interpretation is that the Ridge is an uplifted and tilted former beach berm, with additional alluvial/fluvial modifications.

1.1. Tectonics and fluvial systems

The effects of tectonic deformation on rivers and deltas depend on the characteristics of the fluvial system, the type of faulting, and the orientation of the fault or faults to the river system (Miall, 1981). The effects can include offset stream channels, beheaded channels, changes in sinuosity, abandoned channels, ponding, steering, and variation in erosion rates (Keller et al., 1982; Rockwell et al., 1984; Schumm, 1986; Johnston and Schweig, 1996; Leeder et al., 1996; Peakall, 1998; Kim et al., 2010). For tectonic deformation to steer a river, the tilting rate must be great enough to outweigh the influence of sedimentation, erosion, and river slope (Holbrook and Schumm, 1999; Kim et al., 2010). On a delta, tectonic uplift effectively lowers base level. In response, the grade of the river steepens and, the channel can incise, or sinuosity may increase to maintain river gradient (Schumm, 1993).

Tectonic, climate, and anthropogenic effects can produce similar effects on river systems including increased sedimentation, changes in grade, and downcutting (Schumm, 1986; Gouw, 2007; Attal et al., 2008) but these processes have changed little over the time scale of this study. River channels typically respond more quickly to perturbations than other geomorphic features such as hillslopes and catchments (Fernandes and Dietrich, 1997; Whipple and Tucker, 1999). Climatic changes that influence the stream power such as increased precipitation or landsliding that adds sediment load can drive changes in a river's grade, deposition, or incision (Skylar and Dietrich, 2001; Zaprowski et al., 2005). Increased deposition in the channel can lead to channel migration and avulsion and delta lobe switching (Bryant et al., 1995; Gouw, 2007) During the time period this study covers, the last 2000 years, climate in the Puget Lowland has remained relatively stable, and until widespread logging there was only variation in vegetation in the most sensitive environments (McLachlan and Brubaker, 1995; Gavin and Brubaker, 1999). A stable climate history indicates it is unlikely the study area has experienced changes in sediment budget and stream power due to climate. Few changes to the coastline and river path since the first maps (Fig. 2C) indicated anthropogenic influences including logging and damming of one of the river forks, have not created large-scale changes in the geomorphic features in this study.

1.2. Regional setting

The Skokomish delta lies at the nexus of the Cascadia accretionary wedge and forearc basin—the Olympic Peninsula and Puget Lowland (Fig. 1). Progressive accretion and exhumation of mostly marine sedimentary and volcanic rocks along the subduction zone formed the Olympic Mountains along east verging thrust faults (Cady, 1975; Tabor and Cady, 1978a, 1978b; Brandon et al., 1998; Fig. 1). In contrast, faults in the Puget Lowland are typically east–west trending to accommodate shortening provoked by oblique subduction and by a rotating and northward-moving Oregon forearc (Wells et al., 1998; Mazzotti et al., 2002; McCaffrey et al., 2007). The difference in these regimes generates long-term emergence in the Olympic Mountains and subsidence in the Puget Lowland, with the boundary between this uplift and