Earth and Planetary Science Letters 483 (2018) 1–12

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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High sedimentation rates and thrust fault modulation: Insights from ocean drilling offshore the St. Elias Mountains, southern Alaska

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ARTICLE INFO

Article history:
Received 25 May 2017
Received in revised form 17 November 2017
Accepted 17 November 2017
Available online 8 December 2017
Editor: R. Bendick

Keywords:
climate–tectonic interaction
fold-thrust belt
accretionary margin
temperate glaciation
syntectonic sedimentation
ocean drilling

ABSTRACT

The southern Alaskan margin offshore the St. Elias Mountains has experienced the highest recorded offshore sediment accumulation rates globally. Combined with high uplift rates, active convergence and extensive temperate glaciation, the margin provides a superb setting for evaluating competing influences of tectonic and surface processes on orogen development. We correlate results from Integrated Ocean Drilling Program (IODP) Expedition 341 Sites U1420 and U1421 with regional seismic data to determine the spatial and temporal evolution of the Pamplona Zone fold-thrust belt that forms the offshore St. Elias deformation front on the continental shelf. Our mapping shows that the pattern of active faulting changed from distributed across the shelf to localized away from the primary glacial depocenter over ∼300–780 kyrs, following an order-of-magnitude increase in sediment accumulation rates. Simple Coulomb stress calculations show that the suppression of faulting is partially controlled by the change in sediment accumulation rates which created a differential pore pressure regime between the underlying, faulted strata and the overlying, undeformed sediments.

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1. Introduction

Syntectonic sedimentation can exert first-order controls on internal deformation in accretionary margins, with increased sediment thickness leading to a more widely-spaced thrust system and shutdown of previously active faults underlying the additional sediment load (e.g., Fillon et al., 2013; Malavieille, 2010; Simpson, 2010; Storti and McClay, 1995). Numerical and analog models demonstrate specifically that deformation will focus away from loci of deposition when sedimentation outpaces the rate of deformation (Konstantinovskaya et al., 2009; Simpson, 2006). Field examples from the northern Appalachians (Konstantinovskaya et al., 2009) and the Pyrenees (Coney et al., 1996) provide additional evidence for extreme syntectonic sedimentation shutting off deformation or focusing strain elsewhere. However, the range of time-scales over which tectonic processes can respond to changes in surface processes remains a subject of debate. Model-based estimates for the mechanical response time of fold-thrust belts to changes in sedimentation range from 0.2–0.4 Myr (Fillon et al., 2013) to ∼1.5 Myr (Mannu et al., 2016), but there are few field examples with high-precision age constraints to explore the lower limits of response time. As a result, quantitative understanding of how increased sedimentation affects behavior on individual faults in a natural setting is largely unconstrained.

At the orogen scale, global and hemisphere-wide climate transitions can drive changes in surface processes that effectively redistribute mass within the system. The distal record of the St. Elias orogen in southern Alaska provides perhaps the clearest example of this phenomenon on timescales of climate transitions. After the change from 41 kyr to 100 kyr glacial–interglacial cycles that defines the mid-Pleistocene transition (MPT; 1.2–0.7 Ma) (Clark et al., 2006), mass flux leaving the orogen outpaced mass flux entering the collisional zone (Gulick et al., 2015). The local structural response to this mass redistribution remains ambiguous. Some studies suggest that an increase in erosion rates at the MPT led to tectonic reorganization onshore (Berger et al., 2008; Pavlis et al., 2012). Others suggest a structural shift after ∼2 Ma as a response to the high sedimentation rates since the PPT (Enkelmann et al., 2015a). Offshore, structural response to changes in depositional patterns has been documented (Worthington et al., 2010), but this study was based on very limited age control.

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https://doi.org/10.1016/j.epsl.2017.11.041
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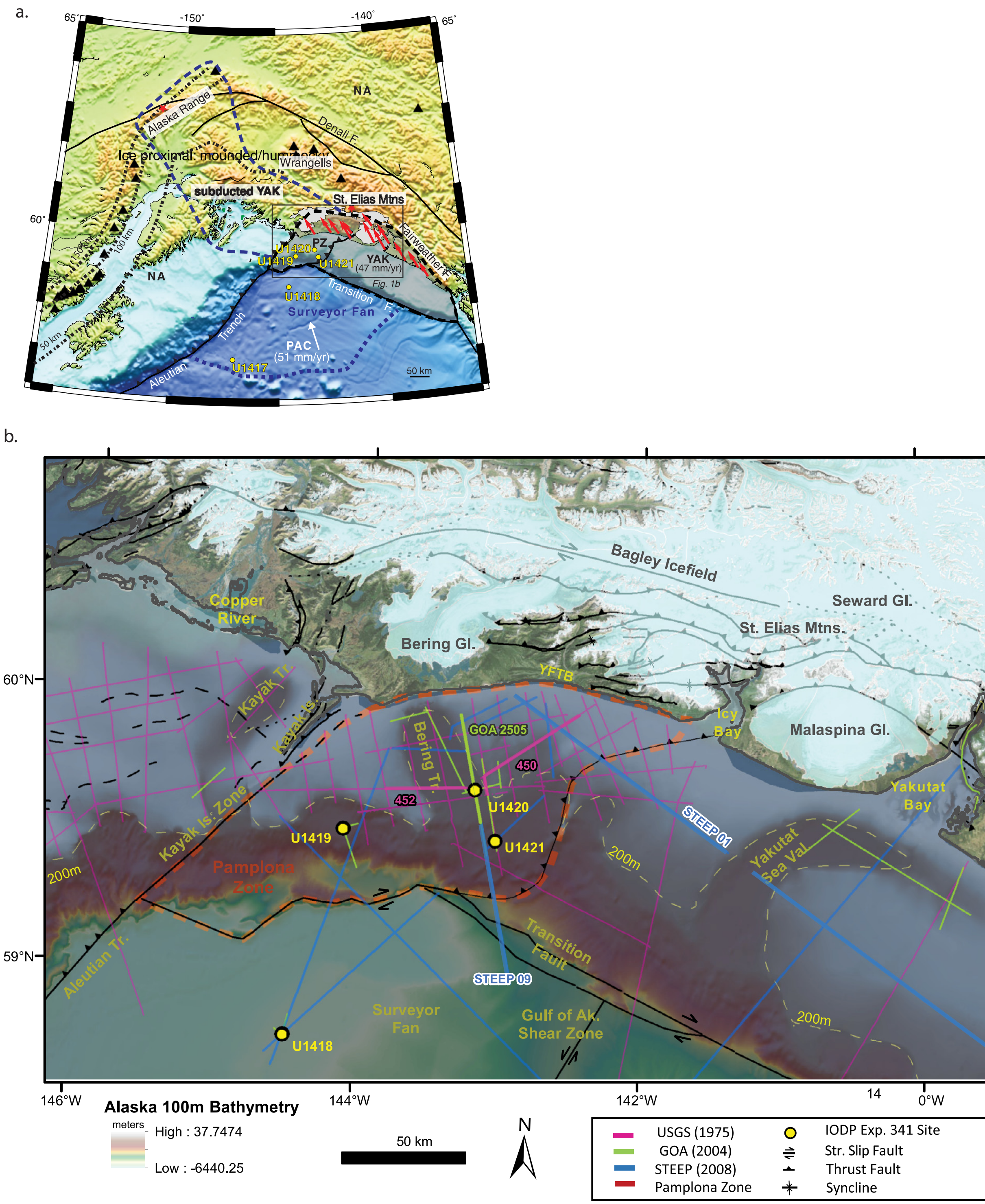

Fig. 1. a) Regional view of study area showing northern Gulf of Alaska, major tectonic elements and contours of Benioff zone seismicity. Plate motion vectors shown with respect to North America (NA). Pacific plate (PAC) motion from DeMets et al. (2010); Yakutat plate (YAK) motion from Elliott et al. (2010). Subducted Yakutat extent from Eberhart-Phillips et al. (2006). Integrated Ocean Drilling Program Expedition (IODP) 341 sites shown in yellow; PZ = Pamplona Zone fold-thrust belt. b) Pamplona Zone study area. The Pamplona Zone area is outlined in bold dashed red. Geologic structures modified from the Alaska quaternary fault and fold database. Transition fault geometry modified after Gulick et al. (2013). Seismic reflection profiles shown in pink (1975 USGS; e.g., Bruns and Schwab, 1983), blue (2008 STEEP; e.g., Worthington et al., 2010), and green (2004 IODP Site Survey (GOA)). Glacial extents shown from Global Land Ice Measurements from Space glacier database GLIMS in light blue. Smoothed 200 m bathymetric contour is shown dashed yellow. Imagery compilation source: Esri, DigitalGlobe, GeoEye, Earthstar, Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. USGS, STEEP and GOA profiles depicted in Figs. 4 and 5 labeled with heavier lines. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

Properly addressing these potential climate–tectonic interactions requires information on the time-dependent behavior of both surface and rheological processes that can only be accessed offshore through scientific ocean drilling.

Here, we investigate the history of deformation in the Pamplona Zone fold-thrust belt, offshore the St. Elias Mountains in southern Alaska (Fig. 1), since the intensification of Northern Hemispheric glaciation at the Plio–Pleistocene transition (PPT), ∼2.6 Ma

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