Marine Geology 384 (2017) 103–119

Contents lists available at ScienceDirect

Marine Geology

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

Paleoseismic potential of sublacustrine landslide records in a high-seismicity setting (south-central Alaska)

Nore Praet [a,*], Jasper Moernaut [b,c], Maarten Van Daele [a], Evelien Boes [a], Peter J. Haeussler [d], Michael Strupler [a,c], Sabine Schmidt [e], Michael G. Loso [f,g], Marc De Batist [a]

[a] Renard Centre of Marine Geology, Ghent University, Krijgslaan 281 (S8 WE13), Ghent, Belgium
[b] Instituto de Ciencias de la Tierra, Universidad Austral de Chile, Campus Isla Teja, Valdivia, Chile
[c] Geological Institute, ETH Zürich, Sonneggstrasse 5, Zürich, Switzerland
[d] U.S. Geological Survey, Anchorage, 4210 University Drive, Anchorage, United States
[e] EPOC, UMR CNRS 5805, Univ. Bordeaux, Allée Geoffroy St Hilaire, Pessac 33615, France
[f] Department of Environmental Science, Alaska Pacific University, Anchorage, AK 99508, United States
[g] Wrangell-St. Elias National Park and Preserve, Copper Center, AK 99573, United States

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form 30 April 2016
Accepted 9 May 2016
Available online 11 May 2016

Keywords:
Sublacustrine paleoseismology
Landslide record
South-central Alaska

ABSTRACT

Sublacustrine landslide stratigraphy is considered useful for quantitative paleoseismology in low-seismicity settings. However, as the recharging of underwater slopes with sediments is one of the factors that governs the recurrence of slope failures, it is not clear if landslide deposits can provide continuous paleoseismic records in settings of frequent strong shaking. To test this, we selected three lakes in south-central Alaska that experienced a strong historical megathrust earthquake (the 1964 M_w9.2 Great Alaska Earthquake) and exhibit high sedimentation rates in their main basins (0.2 cm yr^{-1}–1.0 cm yr^{-1}). We present high-resolution reflection seismic data (3.5 kHz) and radionuclide data from sediment cores in order to investigate factors that control the establishment of a reliable landslide record. Seismic stratigraphy analysis reveals the presence of several landslide deposits in the lacustrine sedimentary infill. Most of these landslide deposits can be attributed to specific landslide events, as multiple landslide deposits sourced from different lacustrine slopes occur on a single stratigraphic horizon. We identify numerous events in the lakes: Eklutna Lake proximal basin (14 events), Eklutna Lake distal basin (8 events), Skilak Lake (7 events) and Kenai Lake (7 events). The most recent event in each basin corresponds to the historic 1964 megathrust earthquake. All events are characterized by multiple landslide deposits, which hints at a regional trigger mechanism, such as an earthquake (the synchronicity criterion). This means that the landslide record in each basin represents a record of past seismic events. Based on extrapolation of sedimentation rates derived from radionuclide dating, we roughly estimate a mean recurrence interval in the Eklutna Lake proximal basin, Eklutna Lake distal basin, Skilak Lake and Kenai Lake, at ~250 yrs., ~450 yrs., ~900 yrs. and ~450 yrs., respectively. This distinct difference in recording can be explained by variations in preconditioning factors like slope angle, slope recharging (sedimentation rate) and the sediment source area: faster slope recharging and a predominance of delta and alluvial fan failures, increase the sensitivity and lower the intensity threshold for slope instability. Also, the seismotectonic setting of the lakes has to be taken into account. This study demonstrates that sublacustrine landslides in several Alaskan lakes can be used as reliable recorders of strong earthquake shaking, when a multi-lake approach is used, and can enhance the temporal and spatial resolution of the paleoseismic record of south-central Alaska.

1. Introduction

The sedimentary record of subaquatic landslide deposits in lakes has been used as a proxy of past earthquakes in paleoseismological studies in a variety of tectonic settings. The reasoning behind this approach is that seismic shaking in lake basins can cause widespread and coeval (i.e. in different locations of the lake at the same time) failure of sediment-covered slopes. In Swiss perialpine lakes (intraplate collisional setting) this approach was successfully applied to reconstruct a regional seismic history (Schnellmann et al., 2002; Monecke et al., 2004; Strasser et al., 2007, 2011). It has also been applied in lakes in subduction zone (Chile; Moernaut et al., 2007; Bertrand et al., 2008), continental transform fault (southern Patagonia; Waldmann et al., 2011), intraplate graben (Canada; Doughty et al., 2013) and half-graben (Lake Tahoe; Smith et al., 2013) settings.

Some of these studies (e.g. Moernaut et al., 2007, 2009) demonstrate that the sublacustrine landslide deposit record in some high-seismicity

* Corresponding author.
E-mail address: nore.praet@ugent.be (N. Praet).

http://dx.doi.org/10.1016/j.margeo.2016.05.004

regions is incomplete and may not have captured all large past earthquakes. This is attributed to the low sedimentation rates (~1 mm yr^{-1}) in these lakes, which prevent the accumulation of sufficient sediment on a potential sliding surface in between two seismic events (e.g. average recurrence rate of ~140 years for M_w > 7 3/4 events in south-central Chile). This observation raises the question whether sublacustrine landslide deposit records from lakes with higher sedimentation rates could be better suited for paleoseismological studies in high-seismicity regions.

In this paper we investigate which factors define the quality and completeness of the sublacustrine landslide deposit record for paleoseismicity in three lakes in south-central Alaska. These three lakes were selected because i) they are located in a high-seismicity subduction zone setting, ii) they experienced a strong historical megathrust earthquake (the 1964 M_w9.2 Great Alaska Earthquake), the effects of which are well-known and have been reported in detail in literature (e.g. Plafker, 1965), iii) they cover a wide range of morphologies and sedimentary regimes, and iv) they exhibit overall significantly higher modern sedimentation rates (~0.5 cm yr^{-1}; Rymer and Sims, 1976) in comparison with the Chilean lakes studied by Moernaut et al. (2007, 2009), possibly reducing the effect of under-representation.

This study investigates the distribution of landslide deposits and megaturbidites attributed to the historic 1964 megathrust earthquake in the three lakes and compares their distribution to prehistoric landslide events using seismic stratigraphy analysis. Variable slope angles and sedimentation rates allow investigation of the influence of these factors on the generation of subaquatic landslides, and discussion of the landslide deposit record for each lake. In this paper, we show that a multi-lake approach will allow construction of a landslide record that can be used for paleoseismological purposes in south-central Alaska.

2. Setting

2.1. Tectonic setting and earthquake history

South-central Alaska is located on top of the Alaska-Aleutian megathrust, a 4000-km-long convergent plate margin where the Pacific Plate subducts beneath the North American Plate at approximately 5.5 cm yr^{-1} in a northwesterly direction (343°) (DeMets et al., 1990). On March 27, AD 1964, a M_w 9.2 megathrust earthquake ruptured an 800-km-long segment of the megathrust, extending from Prince William Sound (PWS) to Kodiak Island (Plafker, 1969) (Fig. 1A and B). It remains the largest instrumentally recorded earthquake in North America and the second largest worldwide. The resulting land-level changes created a region of subsidence and a parallel region of uplift, both with a SW-NE orientation (Fig. 1B). Coseismic uplift of the sea floor produced a large and destructive near-field tsunami along the adjacent Alaska coast and a trans-Pacific tsunami that propagated southeastward towards California, Pacific Northwest and Hawaii (Plafker, 1969). The earthquake involved a complex rupture pattern with an along-strike variation in coseismic slip. The areas beneath PWS and Kodiak Island (orange area on Fig. 1A) showed a significant coseismic slip, up to 20 m and 15 m, respectively. In contrast, the area beneath Cook Inlet, offshore the Kenai Peninsula (blue area on Fig. 1A), experienced a relatively low amount of slip of <5 m (Christensen and Beck, 1994; Holdahl and Sauber, 1994; Johnson et al., 1996; Santini et al., 2003; Suito and

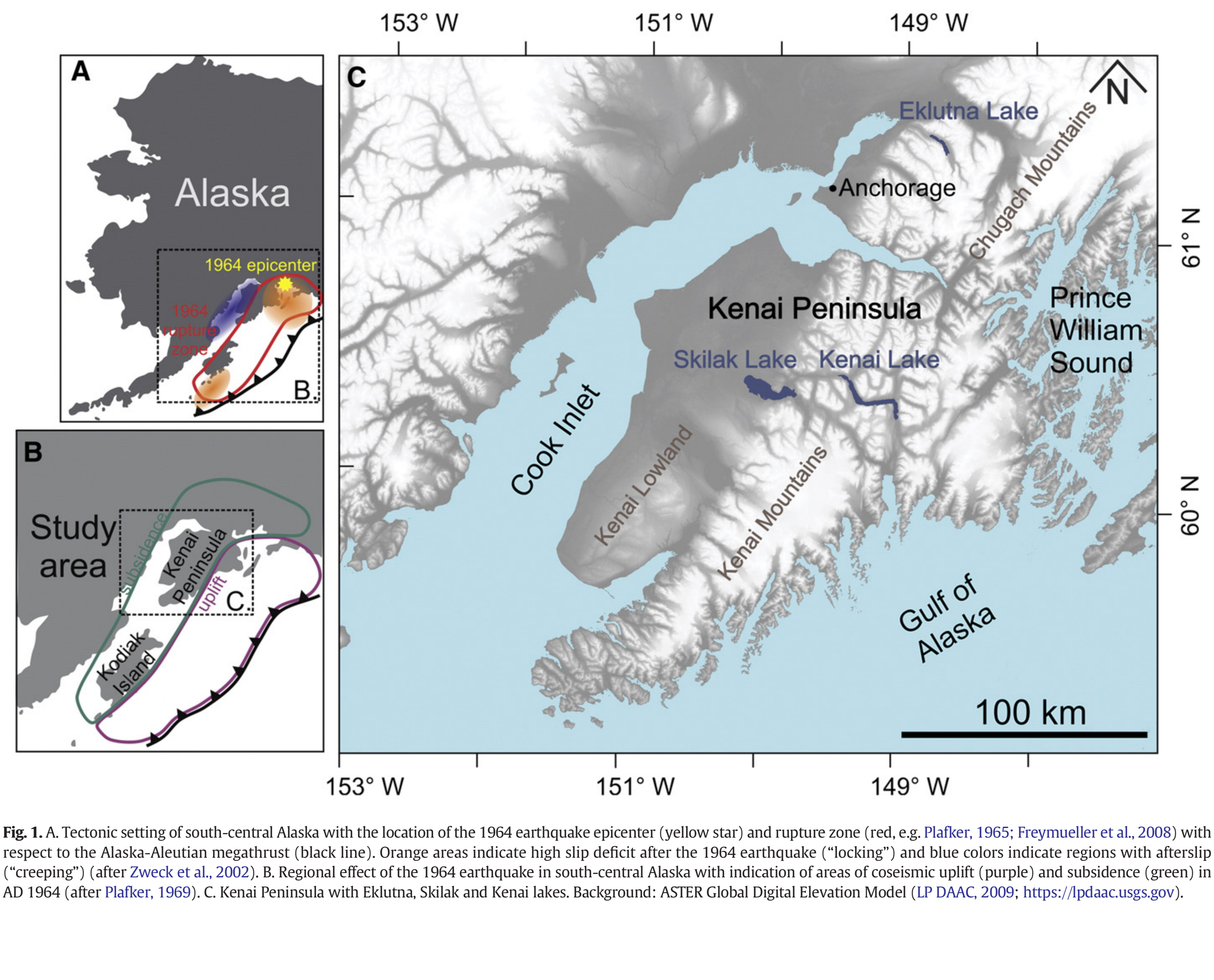

Fig. 1. A. Tectonic setting of south-central Alaska with the location of the 1964 earthquake epicenter (yellow star) and rupture zone (red, e.g. Plafker, 1965; Freymueller et al., 2008) with respect to the Alaska-Aleutian megathrust (black line). Orange areas indicate high slip deficit after the 1964 earthquake ("locking") and blue colors indicate regions with afterslip ("creeping") (after Zweck et al., 2002). B. Regional effect of the 1964 earthquake in south-central Alaska with indication of areas of coseismic uplift (purple) and subsidence (green) in AD 1964 (after Plafker, 1969). C. Kenai Peninsula with Eklutna, Skilak and Kenai lakes. Background: ASTER Global Digital Elevation Model (LP DAAC, 2009; https://lpdaac.usgs.gov).