A Closer Look at an Undersea Source of Alaskan Earthquakes

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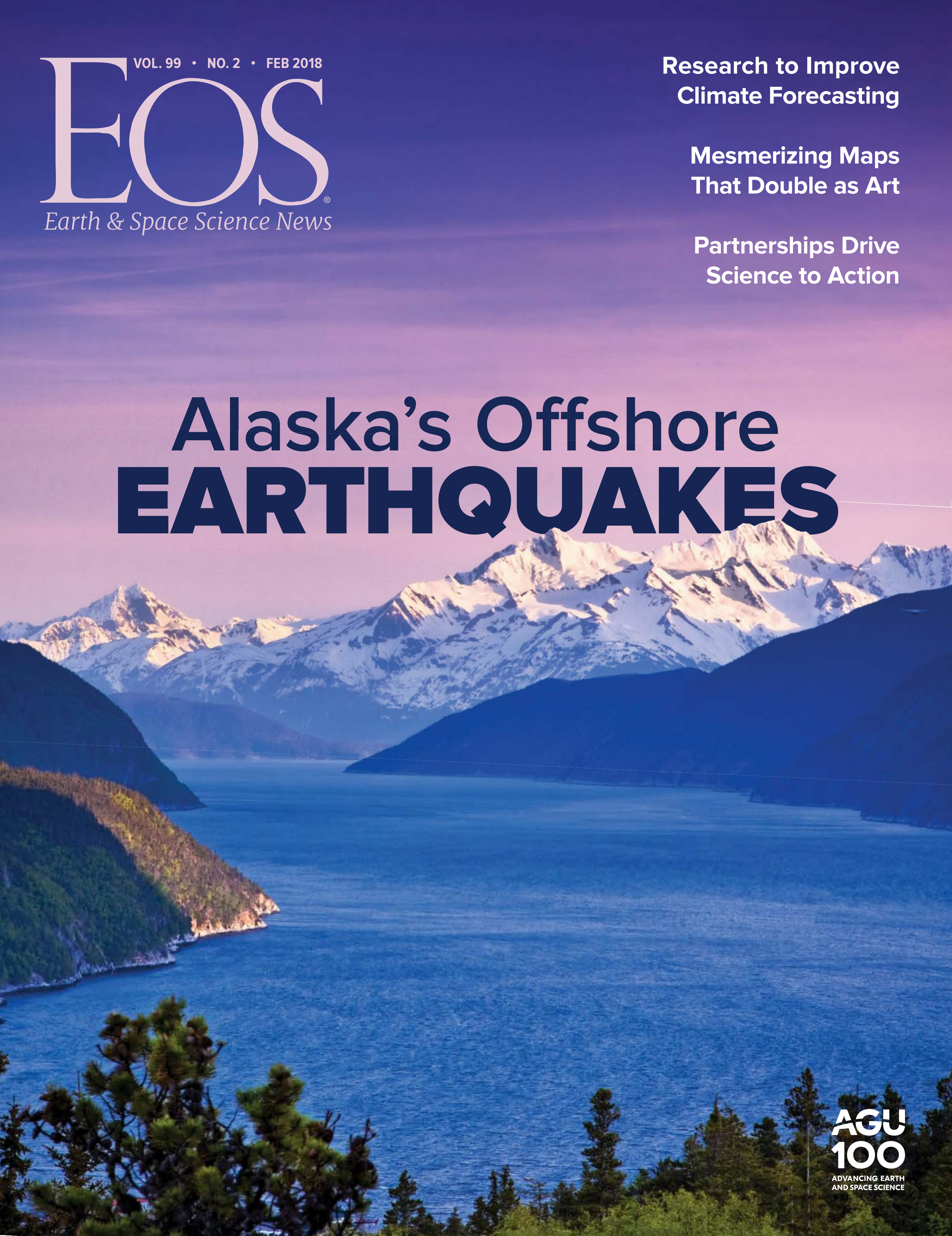

Research to Improve Climate Forecasting

Mesmerizing Maps That Double as Art

Partnerships Drive Science to Action

Alaska's Offshore EARTHQUAKES

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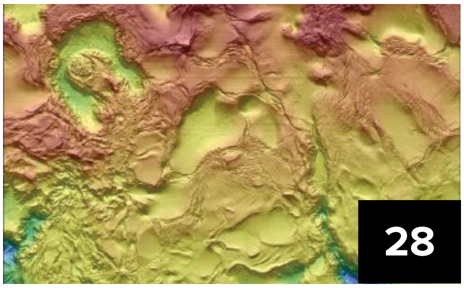

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A CLOSER LOOK AT AN UNDERSEA SOURCE OF ALASKAN EARTHQUAKES

A systematic survey offers a striking portrait of movement along a 500-kilometer-long undersea section of the Queen Charlotte–Fairweather fault off the coast of southeastern Alaska.

By Daniel S. Brothers, Peter Haeussler, Amy East, Uri ten Brink, Brian Andrews, Peter Dartnell, Nathan Miller, and Jared Kluesner

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During the past century, movement along the Queen Charlotte–Fairweather fault, which lies for most of its length beneath the waters off southeastern Alaska and British Columbia, has generated at least seven earthquakes of magnitude 7 or greater. These include a magnitude 8.1 earthquake in 1949, the largest ever recorded in Canada.

Other events include a magnitude 7.8 earthquake in 1958 that dislodged a massive landslide above Lituya Bay in Alaska. The earthquake generated a tsunami that sent water 525 meters up the mountainside, a world record run-up [*Miller*, 1960]. The 2012 magnitude 7.8 Haida Gwaii earthquake, centered on Moresby Island, British Columbia, and the 2013 magnitude 7.5 earthquake near Craig, Alaska [*Walton et al.*, 2015], increased awareness of the potential geologic hazards posed to residents of southeastern Alaska and western British Columbia.

Together, these events highlight the need for a greater understanding of the Queen Charlotte–Fairweather fault and its history.

Yet despite the dramatic effects of this fault's activity, a near absence of high-resolution marine geophysical and geological data limits scientific understanding of its slip rate, earthquake recurrence interval, paleoseismic history, and rupture dynamics.

The U.S. Geological Survey (USGS) has now completed a systematic examination of the tectonic geomorphology along a 500-kilometer-long undersea section of the

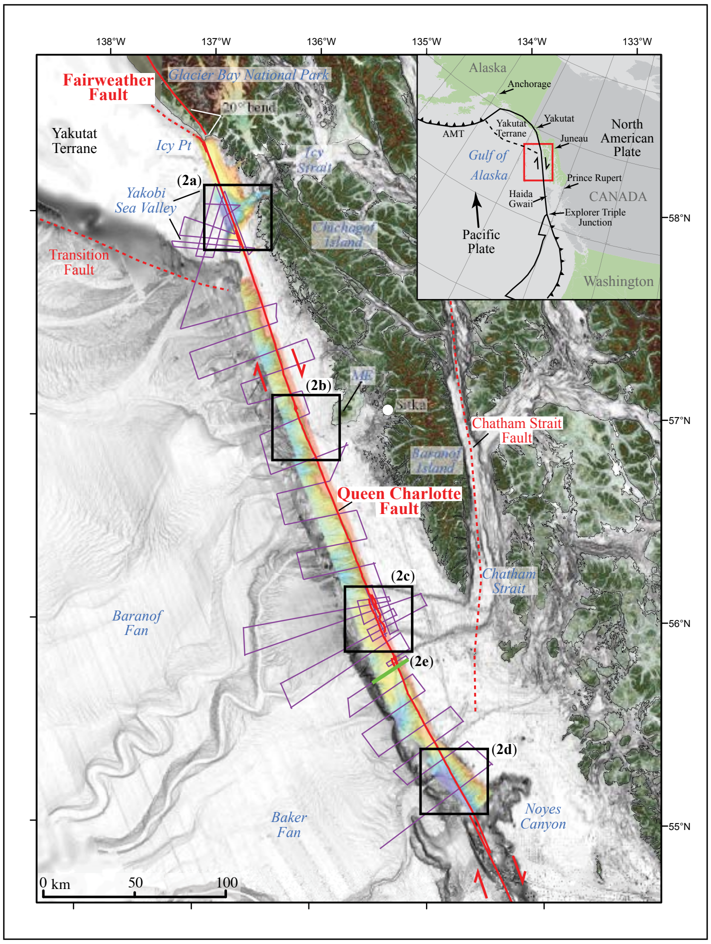

Fig. 1. Recent geophysical surveys provided high-resolution seafloor depth data for the northernmost undersea portion of the Queen Charlotte–Fairweather fault (area outlined in red). The colored seafloor relief represents multibeam echo sounder data acquired along the continental shelf and slope in 2015 and 2016; the gray seafloor relief in deeper water west of the fault was acquired by the University of New Hampshire in 2005. Black boxes are locations of depth imagery shown in Figures 2a–2d. Purple lines represent high-resolution seismic reflection profiles that were acquired in 2016 aboard the R/V Norseman. *One such profile (green line) is shown in Figure 3. AMT represents the Alaska–Aleutian megathrust, and ME indicates Mount Edgecumbe.*

Queen Charlotte–Fairweather fault that offers new insights into activity at this strike-slip boundary, where the North American and Pacific plates slide horizontally past each other.

A Complicated Boundary

The Queen Charlotte–Fairweather fault system and its better known counterpart, the San Andreas Fault (which is highly visible on land in California), form the boundary between the North American and Pacific tectonic plates. The Queen Charlotte–Fairweather fault system defines this plate boundary for a distance of more than 1,200 kilometers, from Yakutat, Alaska, to the Queen Charlotte Triple Junction, a confluence of three faults west of British Columbia (Figure 1). Within this system, the Queen Charlotte fault represents the underwater section and is widely recognized as one of the world's most seismically active continent-ocean transform faults [*Plafker et al.*, 1978; *Bruns and Carlson*, 1987; *Nishenko and Jacob*, 1990; *Walton et al.*, 2015].

The northern part of the boundary between the North American and Pacific plates is complicated by the collision of the Yakutat terrane, a block of crustal material surrounded by faults, with southern Alaska. In this region, the Pacific plate begins to subduct, or plunge beneath, the North American plate along a boundary known as the Alaska-Aleutian megathrust.

The Fairweather fault is the only stretch of the fault system accessible by land. To the south of Icy Point, the Fairweather fault runs offshore, becoming the Queen Charlotte fault, which extends about 900 kilometers southward along the continental slope.

Earlier studies estimated the Fairweather fault's slip rate to be 41–58 millimeters per year [*Plafker et al.*, 1978; *Bruns and Carlson,* 1987; *Elliot et al.*, 2010], but few direct observations of horizontal seafloor displacement existed [*Bruns and Carlson,* 1987] because of the absence of high-resolution seabed data.

Geophysical Surveys

In 2015, our team conducted two marine geophysical surveys, one aboard R/V *Solstice* and a second on R/V *Alaskan Gyre* (see https://on.doi.gov/2ynQo7h). We collected high-resolution seafloor depth data using multibeam sonar along the northernmost section of the fault. We also used a chirp subbottom profiler, which returns detailed images down to 50 meters beneath the seafloor.

In 2016, two additional cruises (aboard R/V *Medeia* and R/V *Norseman*) extended data coverage of the Queen Charlotte–Fairweather fault an additional 325 kilometers southward (see https://on.doi.gov/2ABWXt4). We again used multibeam sonar to map the ocean floor and multichannel seismic reflection to image deeper layers of sediment. Most recently, seismic reflection and chirp surveys were completed in July 2017 aboard the R/V *Ocean Starr*.

In total, during 95 days of seagoing operations, we collected more than 5,000 square kilometers of high-resolution depth data, 9,400 kilometers of high-resolution multichannel seismic reflection profiles, and 500 kilometers of subbottom chirp data.

A Clearer View of the Fault System

Imagery from the surveys shows the fault in pristine detail, cutting straight across the seafloor, with offsetting seabed channels and submerged glacial valleys (Figure 2). The continuous knife-edge character of the fault is evident over the entire 500-kilometer-long survey area. At the same time, we can see several previously unknown features, including a series of subtle bends and steps in the fault that appear to form basins within the fault zone.

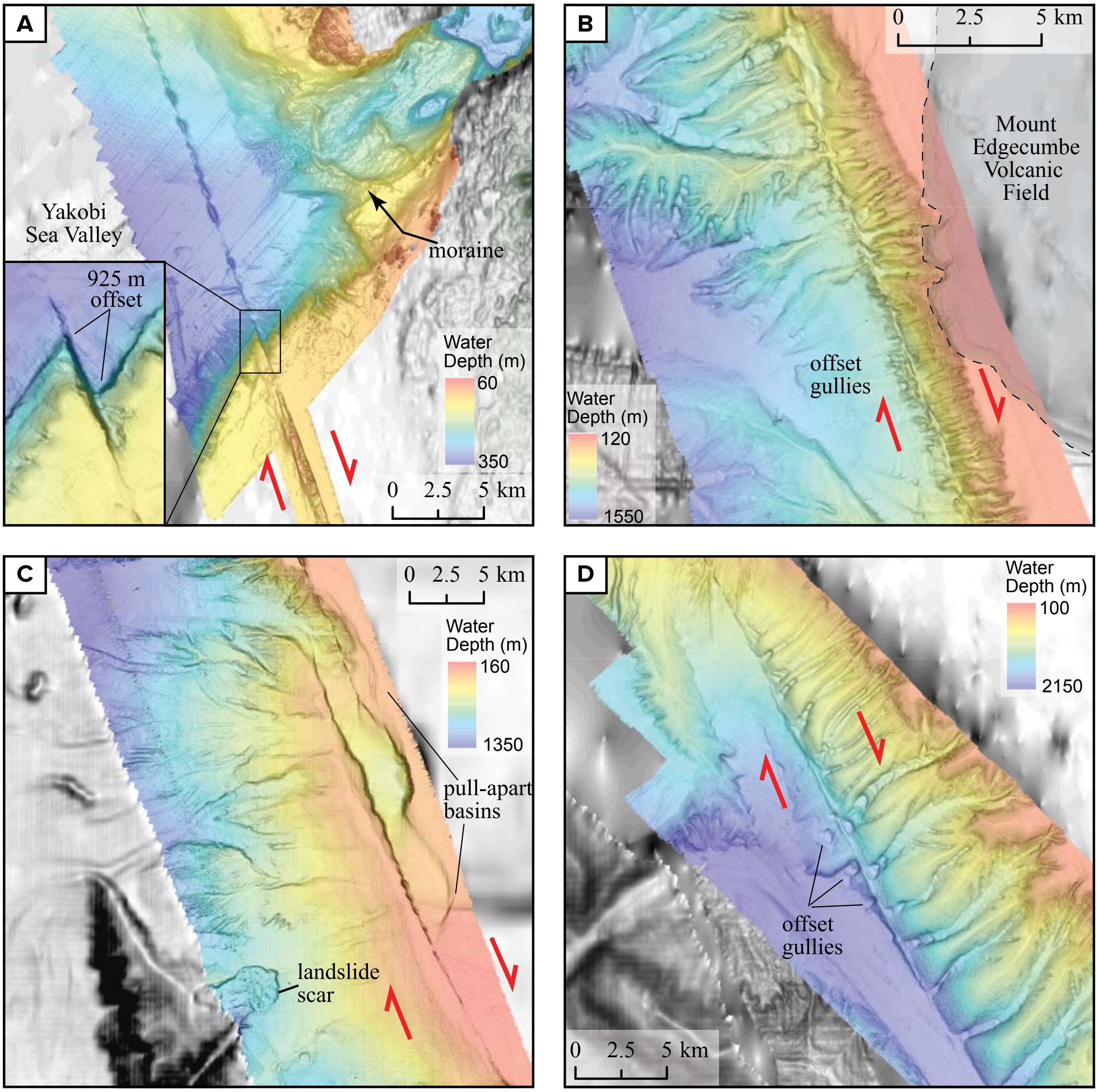

Fig. 2. High-resolution depth images at four locations along the Queen Charlotte fault show the morphological features of the fault and the continental slope. Red arrows indicate the relative sense of motion (see Figure 1 for locations).

Because the surveys spanned four sections of the fault that ruptured in significant historical earthquakes, the results provide a unique catalog of geomorphic features commonly associated with active strike-slip faults.

The Fairweather fault bends 20° as it extends southward across the shoreline near Icy Point (Figures 1 and 2a) and then continues southward at a 340° strike along the shelf edge as a single fault trace for another 150 kilometers.

Numerous submarine canyons, gullies, and ridges have been displaced or warped along the fault. Fault valleys parallel to the margin locally separate geomorphically distinct upper and lower sections of the continental slope (Figures 2b and 3). A Pleistocene basaltic-andesitic volcanic edifice exposed at the seabed extends from Mount Edgecumbe to the shelf edge (Figure 2b).

West of southern Baranof Island, the fault takes a series of subtle 3°–5° right steps and bends that form en echelon pull-apart basins along the shelf edge (Figure 2c). The fault continues southward as a single lineament but exhibits a subtle warp and series of westward steps displacing submarine canyon valleys (Figure 2d) before crossing Noyes Canyon and extending southward into Canadian waters [see, e.g., *Barrie et al.*, 2013].

Fault Slip Rates

The offset features along the seabed provide important information for reconstructing past fault motion. From the ages of these features we can calculate the average rate of motion along the fault, then estimate the typical recurrence interval for large earthquakes.

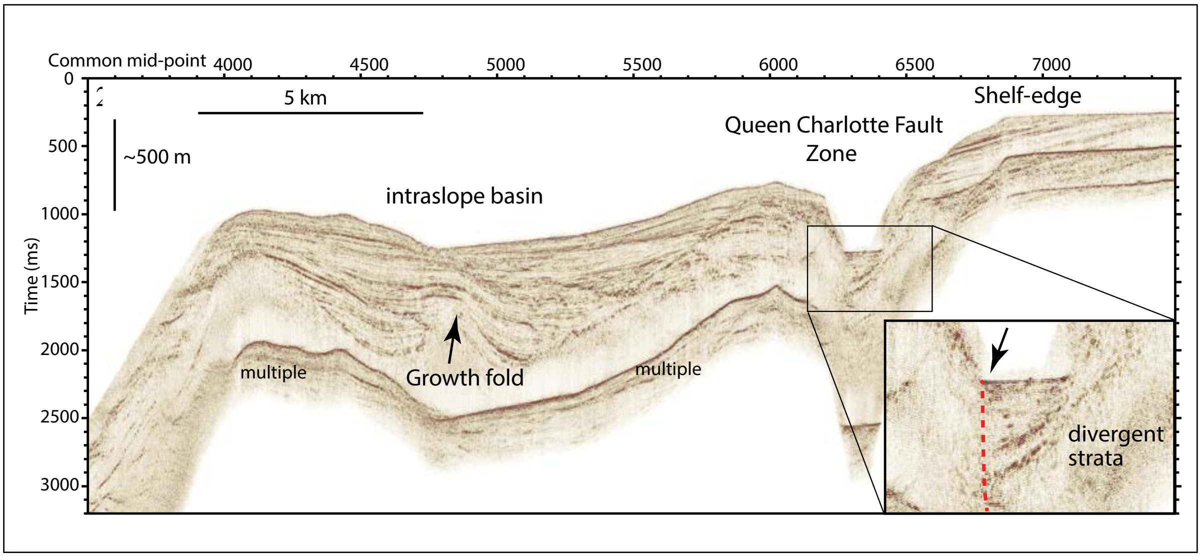

Fig. 3. A seismic reflection profile acquired in August 2016 highlights the structure and stratigraphy of the continental slope.

For example, the southern margin of the Yakobi Sea Valley has been sliced and translated about 925 meters by the linear, knife-edge fault trace (Figure 2a). Ice likely retreated from the valley about 17,000 years ago. Thus, the slip rate of the Queen Charlotte–Fairweather fault across the Yakobi Sea Valley exceeds 50 millimeters per year. It is one of the fastest slipping continent-ocean transform faults in the world [*Brothers et al.*, 2015].

Furthermore, we observe coincidence between the pull-apart basins shown in Figure 2c and the northernmost extent of the 2013 Craig earthquake, implying that changes in fault geometry likely influenced the length of rupture propagation [e.g., *Walton et al.*, 2015].

A Real-World Laboratory

The USGS, the Geological Survey of Canada, the Sitka Sound Science Center, and the University of Calgary jointly led a research cruise in September 2017 to collect sediment cores along the Queen Charlotte–Fairweather fault in Canadian and U.S. territories to constrain the sedimentation history along the margin and date features offset by fault motion (see https://on.doi.gov/2pesZGp).

Overall, this project has shown that the Queen Charlotte–Fairweather fault is an ideal laboratory for examining the tectonic geomorphology of a major strike-slip fault and the associated processes responsible for generating offshore hazards.

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