Prepared in cooperation with the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory and the National Center for Airborne Laser Mapping

Sculpted by Water, Elevated by Earthquakes

The Coastal Landscape of Glacier Bay National Park, Alaska

By

Robert C. Witter,[1] Adam LeWinter,[2] Adrian M. Bender,[1]
Craig Glennie,[3] and David Finnegan[2]

[1]U.S. Geological Survey;
[2]U.S. Army Corps of Engineers;
[3]National Center for Airborne Laser Mapping

Introduction

Within Glacier Bay National Park in southeastern Alaska, the Fairweather Fault represents the onshore boundary between two of Earth's constantly moving tectonic plates: the North American Plate and the Yakutat microplate. Satellite measurements indicate that during the past few decades the Yakutat microplate has moved northwest at a rate of nearly 5 centimeters per year relative to the North American Plate. Motion between the tectonic plates results in earthquakes on the Fairweather Fault during time intervals spanning one or more centuries. For example, in 1958, a 260-kilometer section of the Fairweather Fault ruptured during a magnitude 7.8 earthquake, causing permanent horizontal (as much as 6.5 meters) and vertical (as much as 1 meter) displacement of the ground surface across the fault. Thousands to millions of years of tectonic plate motion, including earthquakes like the one in 1958, raised and shifted the ground surface across the Fairweather Fault, while rivers, glaciers, and ocean waves eroded and sculpted the surrounding landscape along the Gulf of Alaska coast in Glacier Bay National Park (fig. 1).

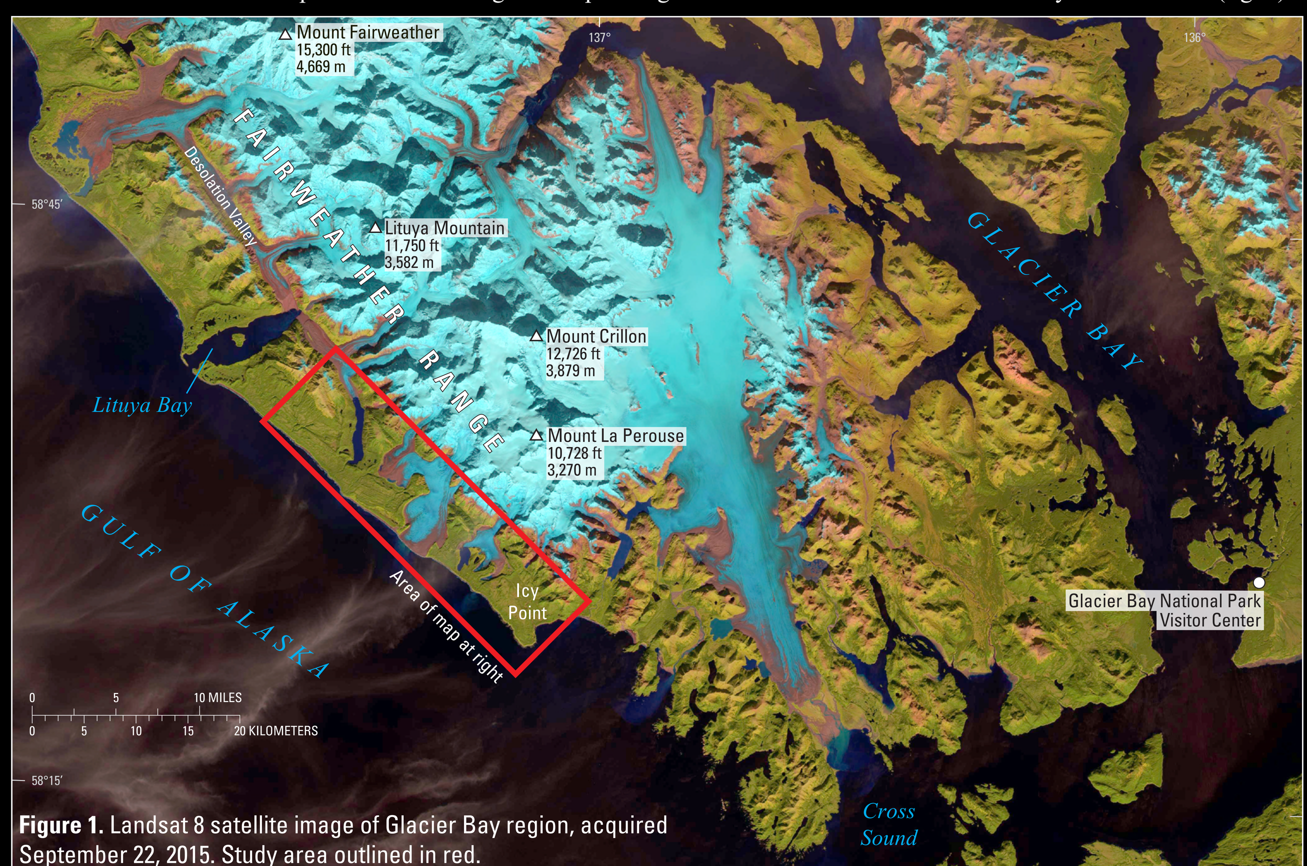


Figure 1. Landsat 8 satellite image of Glacier Bay region, acquired September 22, 2015. Study area outlined in red.

To better understand the processes that shape the landscape, in September 2015 scientists surveyed ice-free parts of the Fairweather Fault between Lituya Bay and Icy Point using an airborne laser mapping technique called light detection and ranging, or lidar. Acquisition of lidar data involved scanning the landscape with a laser system mounted to a helicopter. The system emits laser pulses that are subsequently reflected off the ground surface and vegetation as light. Post-survey processing selects only the lidar points that reflect off the ground surface beneath the forest canopy. The resulting "bare Earth" lidar data shown on this poster include, on average, 1.4 to 2.3 laser measurements per square meter. Four digital terrain models (DTMs) with 1 meter per pixel (m/pixel) resolution derived from the lidar data are shown in color in figure 2. The lidar DTMs resolve landscape features in greater detail than the regional 5-meter Alaska DTM (gray base map). These new high-resolution maps will help scientists assess seismic hazards posed by the Fairweather Fault and will contribute to studies of glacial advance and retreat, long-term mountain building in the Fairweather Range, and relative sea-level change along the Gulf of Alaska coast. Shown here, four enlarged views of the lidar data highlight how landscape features can be modified by the interaction of earthquakes, glaciers, wind, and water.

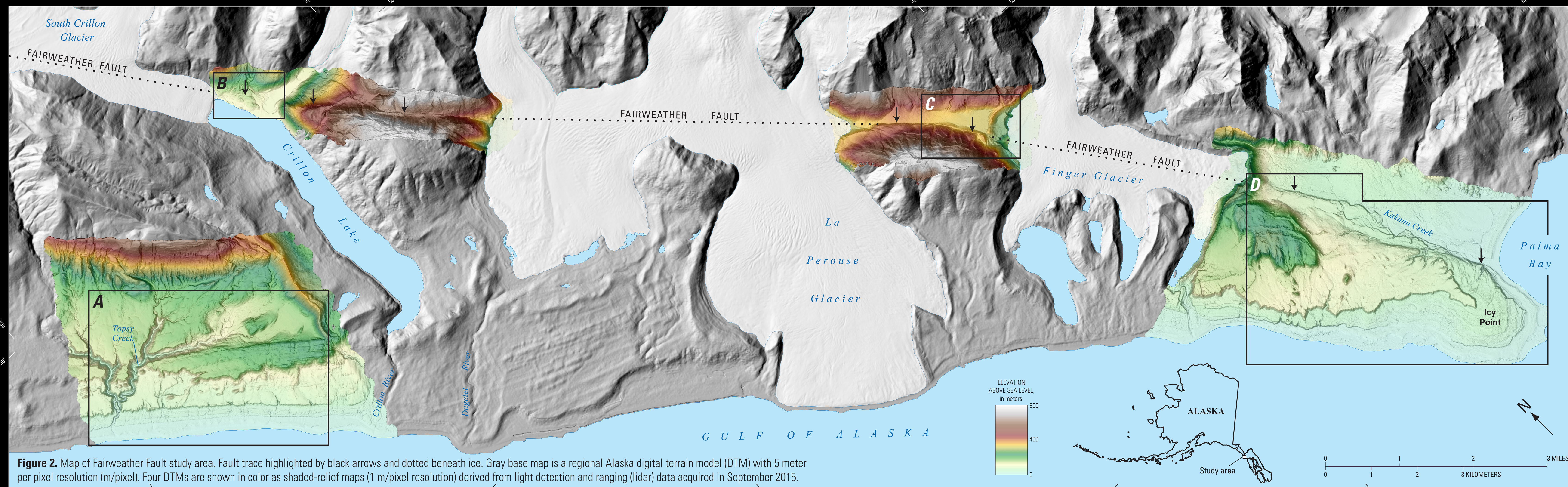
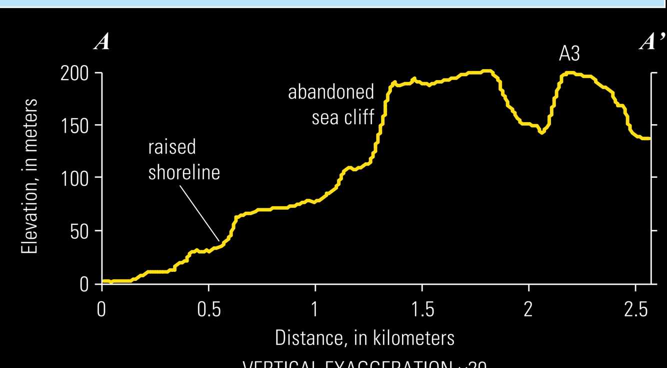


Figure 2. Map of Fairweather Fault study area. Fault trace highlighted by black arrows and dotted beneath ice. Gray base map is a regional Alaska digital terrain model (DTM) with 5 meter per pixel resolution (m/pixel). Four DTMs are shown in color as shaded-relief maps (1 m/pixel resolution) derived from light detection and ranging (lidar) data acquired in September 2015.

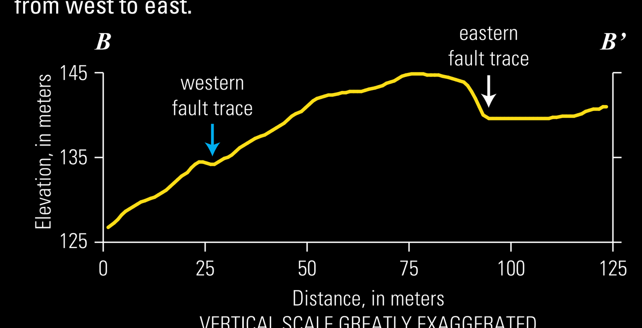
A. Marine terraces near Topsy Creek. On the Gulf of Alaska coastline south of Lituya Bay, the lidar data reveal stepped topography that includes a flight of at least five marine terraces that have emerged above sea level (profile A–A′). Over the past 40,000 years or so, tectonic uplift along the Fairweather Fault, in combination with glacial rebound, caused the coast to rise faster than sea level. This uplift raised marine terraces to elevations greater than 160 meters above sea level (A1).

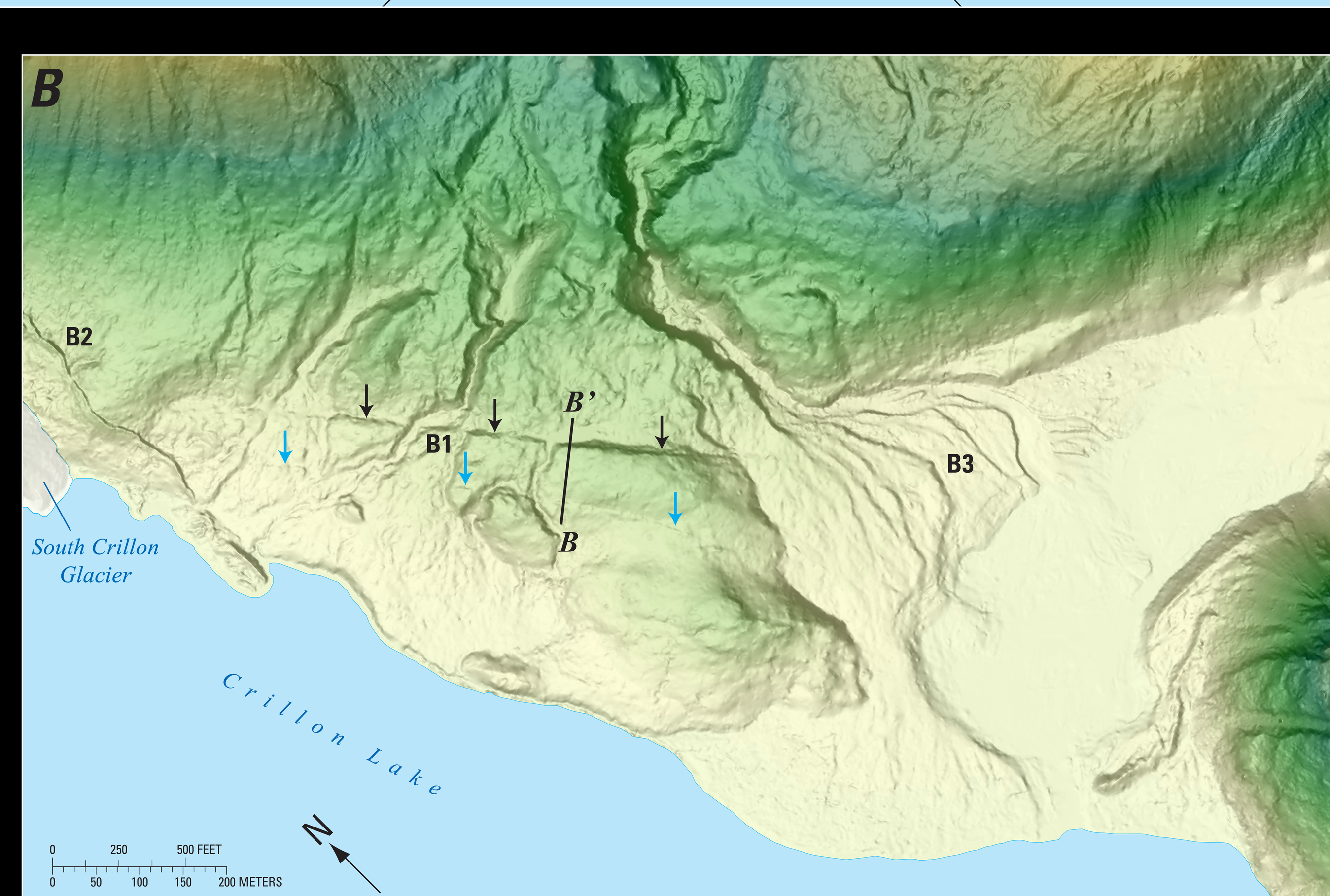


The relative ages of the terraces can be deduced from the different amounts of stream channel incision along Topsy Creek. In the map above, the Topsy Creek channel cuts down more than 90 meters into the highest terrace (A1), which is substantially more than the 20 meters of incision evident on a lower terrace (A2). Based on these differences in incision, the higher terraces must be older than the lower terraces if incision rates are constant. Combining these observations with other geologic evidence, scientists have determined the highest terrace formed tens of thousands of years ago, whereas the lowest terrace formed just a few hundred years ago.

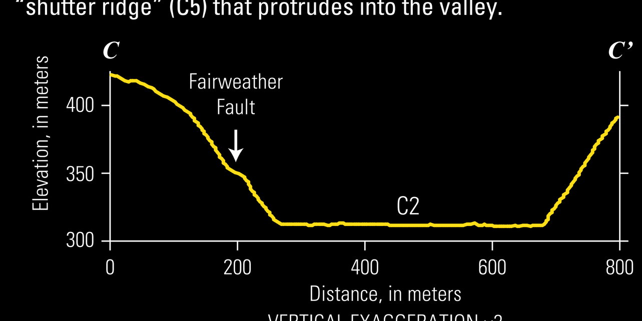
Cross-cutting relations between terraces and glacial landforms provide clues about the history of glacial advance and retreat. For example, the long axis of a roche moutonnée (A3), a glacier-sculpted bedrock knob, parallels the direction of ice flow. The striated gentle east-facing slope points upstream. Additionally, subdued irregular ridges mark recessional moraines (A4), indicating that glaciers advanced and retreated after the terraces formed.

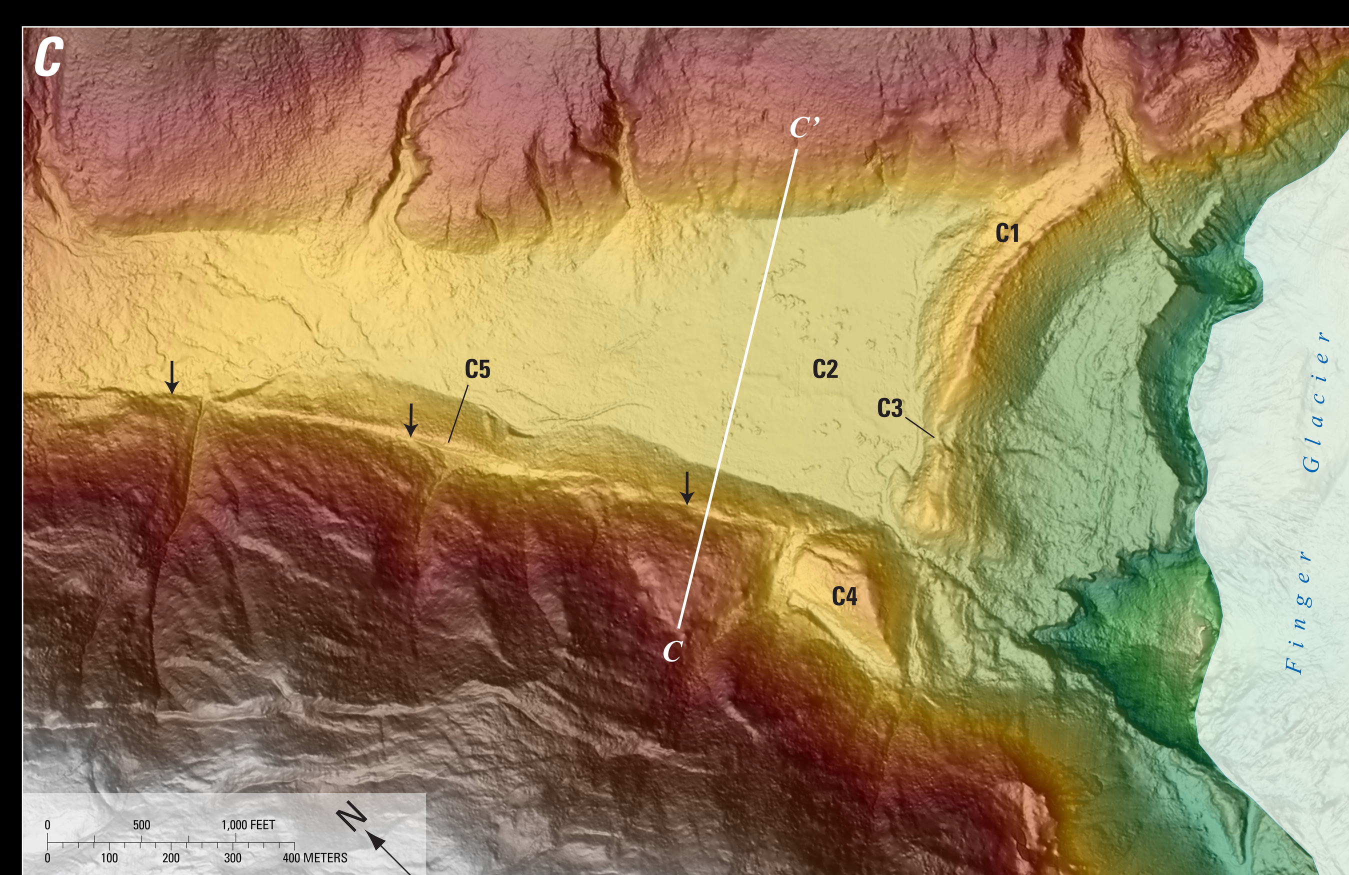
B. Stream channels offset by faulting. Along the northern shore of Crillon Lake, the Fairweather Fault displaces both glacial and stream channel deposits along two uphill-facing fault escarpments, or scarps (profile B–B′). The more prominent eastern fault trace (black arrows) forms an 8-meter-high scarp, along which 6.6 meters of horizontal and 1.1 meters of vertical displacement were documented during surveys following the 1958 earthquake. The more subtle western fault trace (blue arrows) had not been identified prior to the 2015 lidar survey. Rupture along both fault traces in 1958 created linear discontinuities in the forest marked by toppled and tilted trees. Stream channels are deflected 66 to 128 meters across both scarps in a right-lateral, strike-slip sense (B1). Neither scarp deforms the lateral moraine (B2) of South Crillon Glacier, indicating that ice advanced to the position of the moraine and subsequently retreated to its present position after the 1958 earthquake. Uplift of the west side of the fault in 1958 caused aggradation of stream sediment on a broad alluvial fan, which now buries both scarps to the southeast (B3). Since 1958, periodic flooding and channel migration have cut a flight of at least six stream terraces that step down to the modern channel from west to east.





C. Moraine offset by faulting. Along the northern flank of Finger Glacier a large lateral moraine (C1) marks the greatest advance of ice at this location since the last glacial maximum, 16,000 to 14,000 years ago. When it was active, the moraine blocked the valley and impounded water, causing a lake to form north of the moraine (C2). The former lake is marked by the generally flat topography on the north side of the moraine (profile C–C′). The lake subsequently drained through a low saddle (C3), cutting a stream channel on the moraine's south side. This channel was abandoned when displacement on the Fairweather Fault breached the moraine to the south. Here, the moraine's crest, which trends nearly perpendicular to the fault, is offset horizontally by 115 meters (C4) and indicates right-lateral, strike-slip faulting. The lidar map depicts a single fault trace coincident with an uphill-facing scarp along the western margin of the valley (see arrows on map to right and profile below). Right-lateral, strike-slip motion also has moved alluvial fan sediment from the north to the south, creating a feature called a "shutter ridge" (C5) that protrudes into the valley.

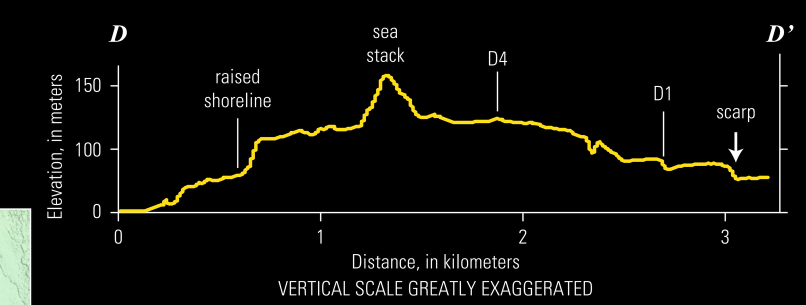


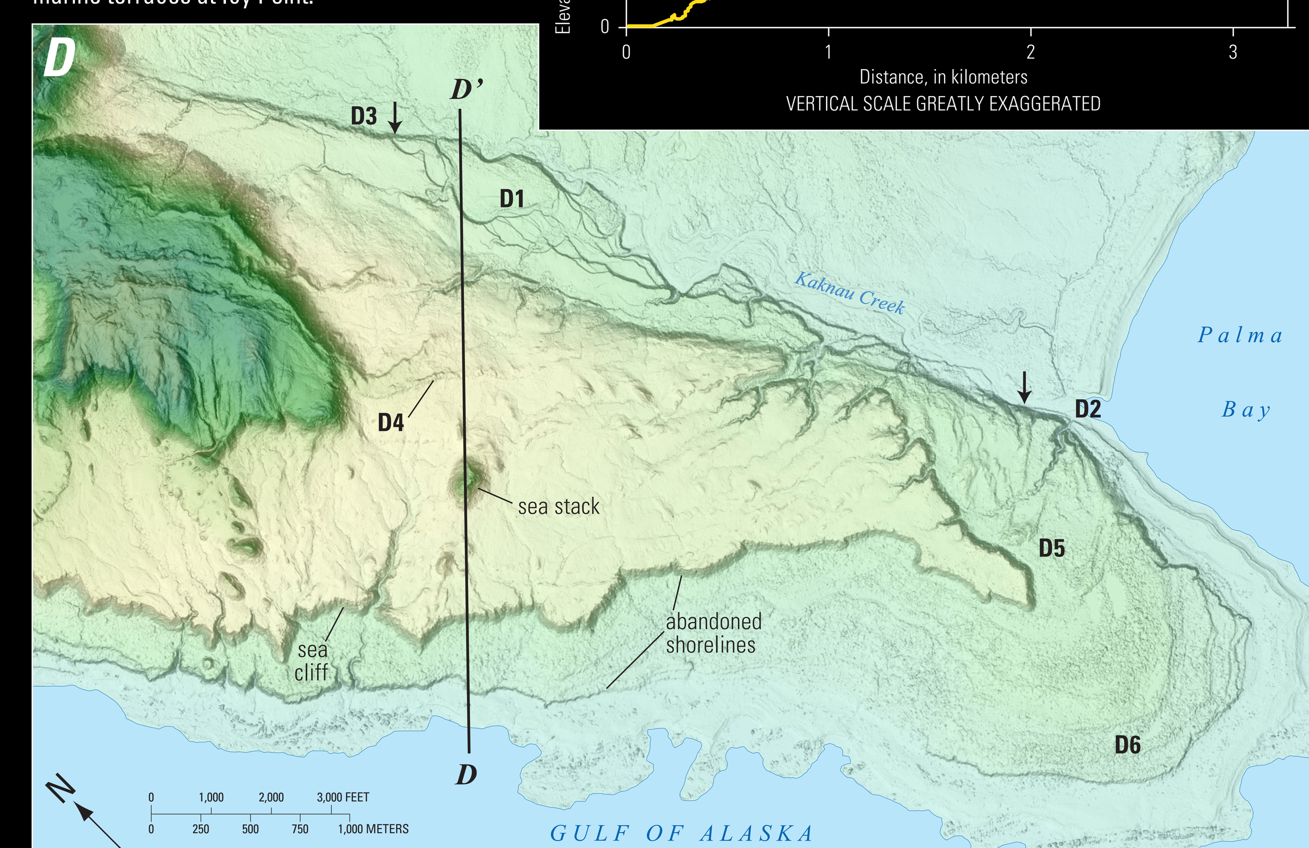


D. Terraces of Icy Point. The terraces of Icy Point bevel a peninsula that separates the Gulf of Alaska from Palma Bay and reveal a history of uplift on the southwest side of the Fairweather Fault (profile D–D′). The absence of terraces east of the fault implies that uplift west of the fault during past earthquakes raised the marine and stream terraces at Icy Point. Alternative explanations, like glacial rebound, produce broader uplift that affects both sides of the fault.

On the inland side of the peninsula, a flight of at least five stream terraces flanks the west bank of Kaknau Creek (D1), but none exist east of the creek. After the 1958 earthquake, scientists observed stream channels near the mouth of Kaknau Creek (D2) offset by 2.5 to 4 meters across the Fairweather Fault. Stream-channel erosion modified scarps that mark the fault trace (arrows), which steps to the right between Palma Bay and a conspicuous 25-meter tall, east-facing fault scarp (D3).

Ancient cliffs, abandoned shorelines, and bedrock sea stacks define as many as seven marine terraces on the coastal side of the peninsula, but similar features are absent east of the fault along the Palma Bay shoreline. Since the oldest marine terraces emerged from the sea, glacial advance and retreat has modified the terrace surfaces and left behind recessional moraines (D4). Coastal deposits, including sand dunes (D5) and shore-parallel beach ridges (D6), elevated above the active beach adorn the youngest marine terraces at Icy Point.





Data Sources

U.S. Geological Survey, 2016, 5 meter Alaska Digital Elevation Models (DEMs)—USGS National Map 3DEP Downloadable Data Collection, accessed April 3, 2017 at http://nationalmap.gov/3DEP/.

U.S. Geological Survey, 2015, LandsatLook Images, Landsat 8 satellite image of Glacier Bay National Park acquired September 22, 2015, accessed April 3, 2017 at http://landsat.usgs.gov//LandsatLookImages.php.

Witter, R.C., LeWinter, A., Glennie, C., Hauser, D., Bender, A.M. and Finnegan, D., 2017, Digital elevation models of Glacier Bay National Park, between Lituya Bay and Icy Point, Alaska, derived from airborne lidar data acquired in September 2015: U.S. Geological Survey data release, https://doi.org/10.5066/F7W094D4.

Additional Reading

Mann, D.H., and Ugolini, F.C., 1985, Holocene glacial history of the Lituya District, southeast Alaska: Canadian Journal of Earth Sciences, v. 22, p. 913–928.

Miller, D.J., 1960, Giant waves in Lituya Bay, Alaska: U.S. Geological Survey, Professional Paper 354–C, p. 51–86.

Plafker, G., Hudson, T., Bruns, T., and Rubin, M., 1978, Late Quaternary offsets along the Fairweather fault and crustal plate interactions in southern Alaska: Canadian Journal of Earth Science, v. 15, p. 805–816.

Tocher, D., 1960, The Alaska earthquake of July 10, 1958—Movement on the Fairweather fault and field investigation of southern epicentral region: Bulletin of the Seismological Society of America, v. 50, p. 267–292.

ISSN 2332-354X (online)
https://doi.org/10.3133/gip177