Resolving the Deformation Style and Slip Behavior of the Castle Mountain Fault, South-Central Alaska

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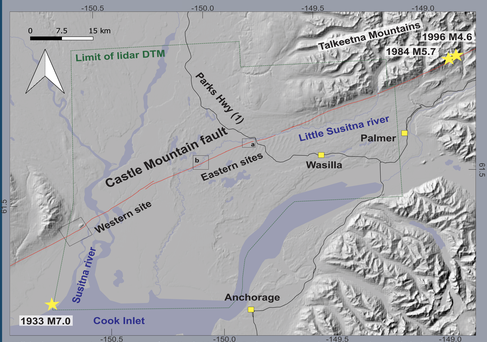
Abstract

Tectonic setting for Alaska and Western Canada Map (Elliott & Freymueller, JGR: 2020) Solid Earth). Red box shows the general fault trace area.

Motivation

- Castle Mountain Fault is a major active fault near Anchorage
- Potential significant seismic hazard
- Conflicting kinematics (strike-slip vs reverse)
  - Willis (2007) Slip rate: ~2.7–3.1 mm/yr right-lateral (based on 36 ± 4 m offset)
  - Elliott & Freymueller (2020) Slip rate: ~2–3 mm/yr right-lateral (from GPS velocities)
  - Haeussler et al. (2002) # of earthquakes: 3 events in last ~2,145 yrs + 1 older (~2,735 yr B.P.)

  Slip rate: 0.07–0.14 mm/yr (right-lateral with possible thrusting)
  - Koehler et al. (2017) Dip-slip motion favored; minimal strike-slip identified
    - # of earthquakes: 2 surface-rupturing events (Pleistocene– Holocene)
    - Slip rate: < 0.3 mm/yr dip-slip (based on long-term bedrock displacement
- Need to constrain slip behavior
- Create a seismic hazard model

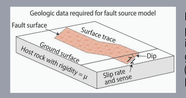


Hillshade map showing the location of the Castle Mountain Fault in the Susitna lowland, south-central Alaska. Map shows the general location of study Site A and B and setting along the fault. DEM obtained from https://dggs.alaska.gov.

Methods

In this study we are constraining the CMF's kinematics using the following methods:

- Creating a detailed geomorphic map along the fault and quantitative analysis of offsets using lidar-derived high-resolution DEM (dggs.https://elevation.alaska.gov/)
- Collect sediment cores to date offset of terraces at Site B
- Collect radiocarbon and Optically Stimulated Luminesence (OSL) for dating of offset landforms
- Collect Electrical Resistivity Tomography (ERT) surveys used to constrain fault geometry
- Explore potential ground shaking caused from an earthquake on the CMF by a deterministic seismic hazard analysis using OpenQuake engine (pagani2014openquake)



Imput data required for an upper plate fault seismic hazard model includes the fault location, fault geometry, slip rate, kinematics (slip direction), and earthquake history.

Future Work

The following methods will be conducted over summer 2026:

- Collect high resolution drone LIDAR at Site A to create ultra high Digital Elevation Model (DEM)
- Map geomorphic features using DEM in GIS to measure fault offsets and identify features related to strike-slip or reverse fault motion at each study site
- Collect and analyze new ERT data to image fault geometry
- Obtain sediment cores and samples at each study site for radiocarbon and OSL dating to date the terraces in order to calculate slip rates
- Excavate a trench to investigate past earthquake events at Site A
- Continue calculating vertical separation along the fault at each study site using MATLAB
- Develop seismic hazard model to evaluate potential ground shaking

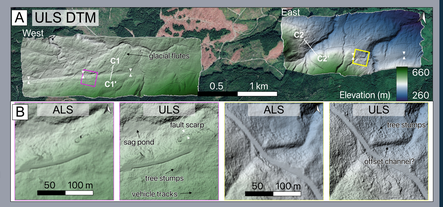


Figure showing the importance of collecting high resolution LIDAR to obtain quality DEM in order to identify critical geomorphic fault related features (A) Hillshaded UAV (drone LIDAR) DTM overlain on satellite photograph. (B) Comparisons between ALS (fixed-wing LIDAR) and ULS DTM hillshades (Salomon, et al. (2024))

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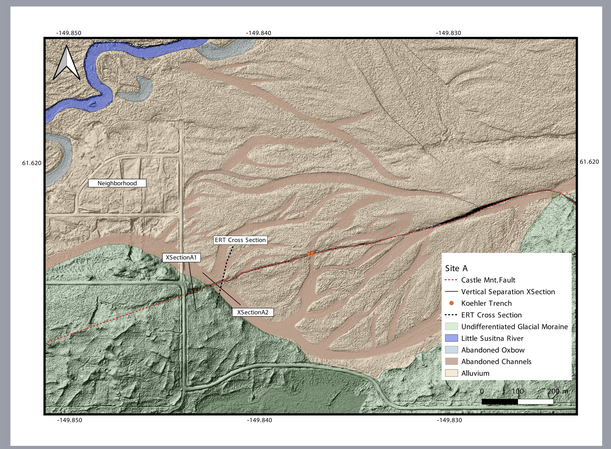
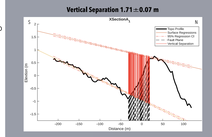
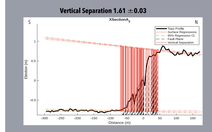
Geomorphic Mapping and Vertical Separation Analysis



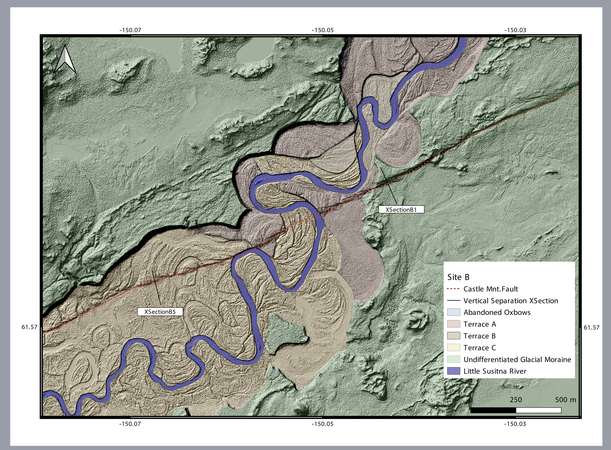
Site A of the CMF offsetting alluvial deposits and glacial sediments. ERT profile cross-sections are shown along the dashed black line that cut across the scarp and abandoned stream channel. Observations suggest on 1 earthquake event happened. The vertical separation figures show the scarp height relatively the same at XSection A1 and XSection A2. Koehler (2017) trench site locations excavated.

Horizontal red lines represent the range of possible slopes for the upper and lower surfaces across the scarp. Vertical red lines show the projected vertical separation between these surfaces, illustrating the range of possible displacement values.

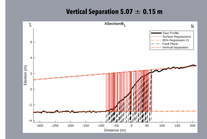


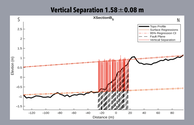


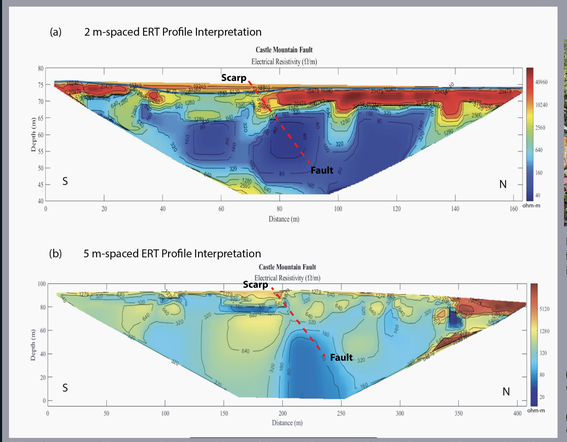
We used MATLAB to apply best-fit lines to the hanging wall and footwall and projected to the fault plane, rather than relying on interpretive point selection. A Monte Carlo simulation varies key inputs such as surface slopes, fault dip, and fault position to account for uncertainty in the calculation. The result is a statistical estimate of vertical separation and in relation to slip components with quantified uncertainty, rather than a single fixed value (Regalla, C. [2016-2024]. ScarpOffsetAnalysis_v1.0 (MATLAB script). In the vertical seperation charts above the vertical axis has arbitary elevations and are not meters above sea level.



Site B located along the Little Susitna River where the scarp cuts through glacial moraine and river terraces along the CMF strike. XSection B1 has much larger scarp height cutting across older glacial moraine. XSection B5 shows a smalller scarp cutting accross younger aged river terraces. The change in scarp height is shown in the vertical separation figures. Observing the vertical separation and terrace landforms suggest 1 or more earthquake events occured.





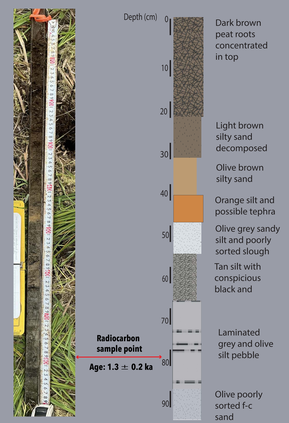


ERT profiles proccessed by Jens Munk. (a) ERT probes spaced 2 m apart along 160 m. (b) ERT probes spaced 5 m apart along 400 m.

ERT probes placed along a profile perpendicular to the fault trace to image subsurface resistivity contrasts and identify the location and geometry of the fault zone.

(a) ERT profile taken along a 160 m long cross section with probes spaced 2 m apart.

(b) ERT profile taken along a 400 m long cross section with probes spaced 5 m apart.



Soil profile taken during the summer of 2025 south of the scarp in the abandoned stream channel near the ERT profile at Site A.

Rob Witter and Rich Koehler collecting soil core sample in an abandoned channel near the scarp at Site A

Radiocarbon Sample from Site A

- Small tree cone sample collected from peat layer (79 cm depth)
- Located in offset abandoned channel
- Radiocarbon age: 1.3 ± 0.2 ka
- Indicates channel active ~1300 years ago
- Suggests recent earthquake activity at Site A

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