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The transition from convergence to translation on the western margin of North America: evolution of the ancestral Denali Fault in southeast Alaska

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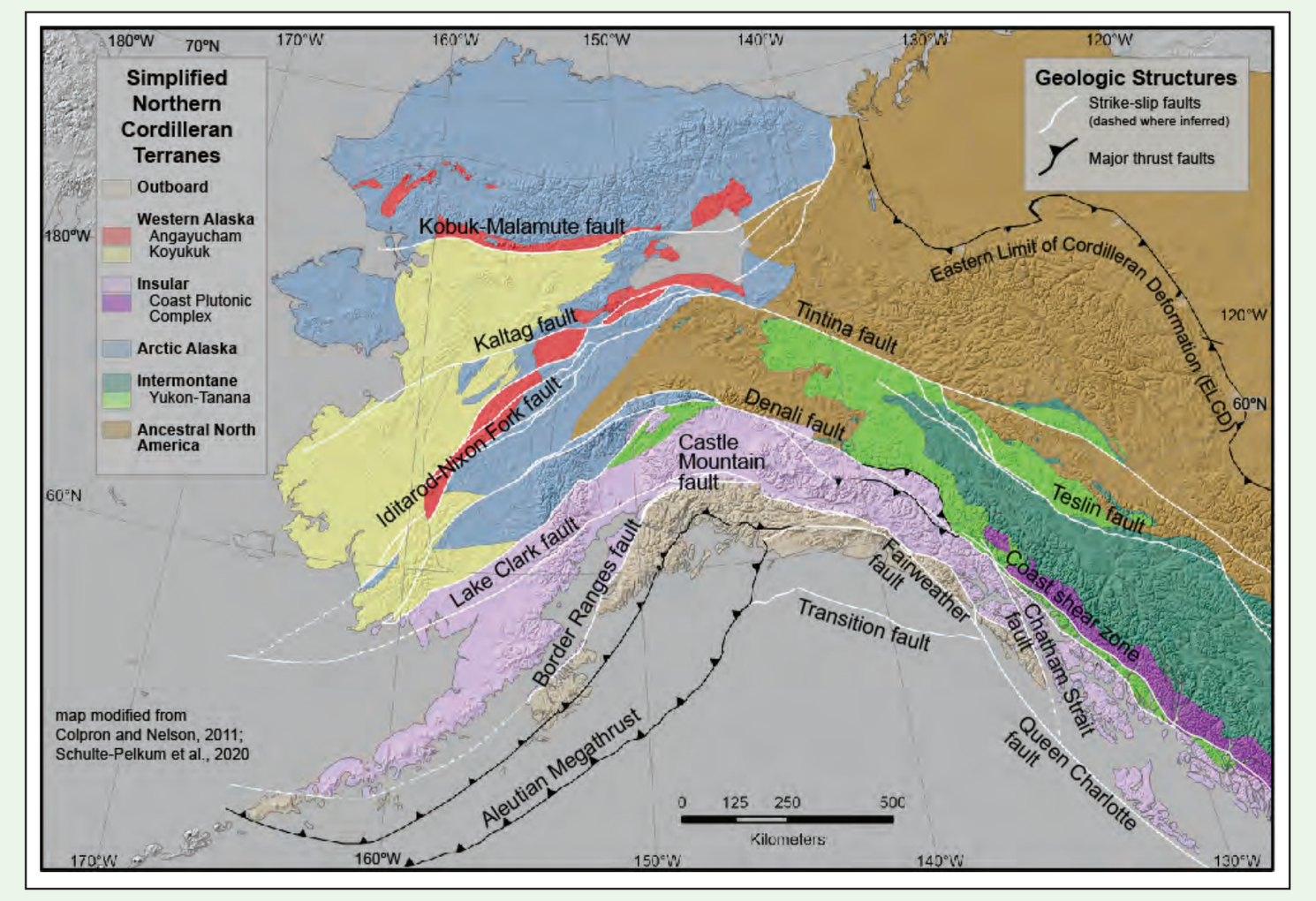
Abstract

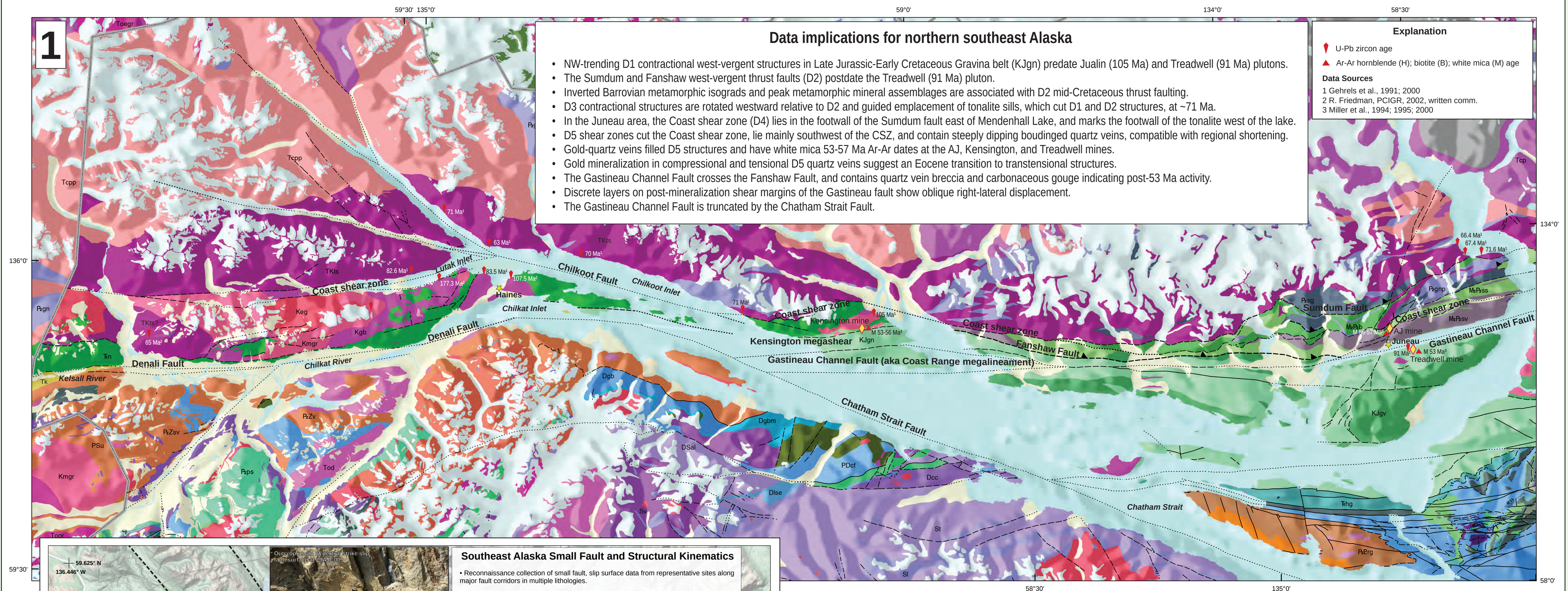
The Denali Fault (DF) is a crustal scale strike-slip fault that extends >2000 km from central interior Alaska to southeast Alaska (SEAK). The DF postdates mid-Cretaceous accretion of oceanic Insular terranes to the North American margin, locally juxtaposes a 10-15 km contrast in Moho depth, and geologic markers indicate >400 km of dextral separation along the fault in east-central Alaska, Yukon, and northwestern British Columbia, mainly since early Eocene time. Models to accommodate post-Eocene separation of >400 km in SEAK vary from a single structure to several interactive dextral faults. We outline the mid-Cretaceous to Tertiary structural history of SEAK, describe the structures that host Tertiary gold mineralization, and consider evidence to constrain tectonic models.




View south down Chilkat inlet, Chatham Strait Fault corridor

Discrete shear structures in Triassic greenstone and rhyolite dikes along the Chilkat River; Denali fault corridor

Mid-Cretaceous accretion of the Insular terranes was accommodated by structures that are represented regionally by rock fabrics assigned to five deformation events. Initial D1 deformation is represented by west-vergent contractional fabrics that are truncated by ca. 90 Ma plutons and contain ca. 89 Ma white mica. Northwest (NW)-trending, moderately to steeply northeast (NE)-dipping D2 structures involve the ca. 90 Ma plutons, have a fabric defined by peak metamorphic minerals, and include faults that place Laurentian-affinity terranes westward over oceanic plate-derived Insular terranes, accommodate contraction within Insular terranes, and involve Cenomanian fossil-bearing Gravina belt strata that were deposited on the continental margin and on Insular terranes. These structures are locally cut by ca. 72-60 Ma plutons of the Coast batholith. D3 structures are oriented as much as 45° counterclockwise from D2 structures, are southwest vergent with moderate to steep NE dips, and guided emplacement of km-scale syndeformational tonalitic sills that intruded accreted continental- and oceanic-affinity terranes diachronously from northwest to southeast in the interval of ca. 80-55 Ma. D1-D3 structures are locally truncated and overprinted by the latest Cretaceous to Eocene Coast shear zone (CSZ), which is 1-6 km wide and extends >800 km from SEAK to coastal British Columbia. The CSZ (D4) dips moderately to steeply NE, contains quartz-filled foliations and shear structures as wide as 20 m, and has moderately NW- or SE-plunging fold hinges and mineral lineations. Its eastern margin is locally characterized by a mylonitic foliation up to several hundred meters thick that deforms the magmatic foliation in hanging wall tonalitic sills as young as 55 Ma in the Coast batholith. CSZ structures cross terrane boundaries and truncate the tonalitic sills. D5 shear zones cut the CSZ, lie mainly southwest of the CSZ, and contain steeply dipping boudinaged quartz veins, compatible with regional shortening. The D5 structures include gold-quartz veins of the Juneau gold belt, which is 160 km long and 5-8 km wide in northern SEAK. The Alaska Juneau (AJ) gold deposit formed in D5 shear zones within the Insular composite terrane. Biotite from ore-bearing diorite yielded Ar-Ar dates of 57-58 Ma and white mica in mineralized structures in the diorite is ca. 56 Ma. Within the Insular composite terrane and roughly 3 km west of the strike of AJ shear structures, the >350 m wide Kensington megashear hosts the Kensington gold deposit, which consists of mesothermal gold-bearing quartz veins that yielded Ar-Ar white mica dates of 53-56 Ma. Gold mineralization formed in tensional and compressional quartz veins, suggesting an Eocene transition to transtensional structures.

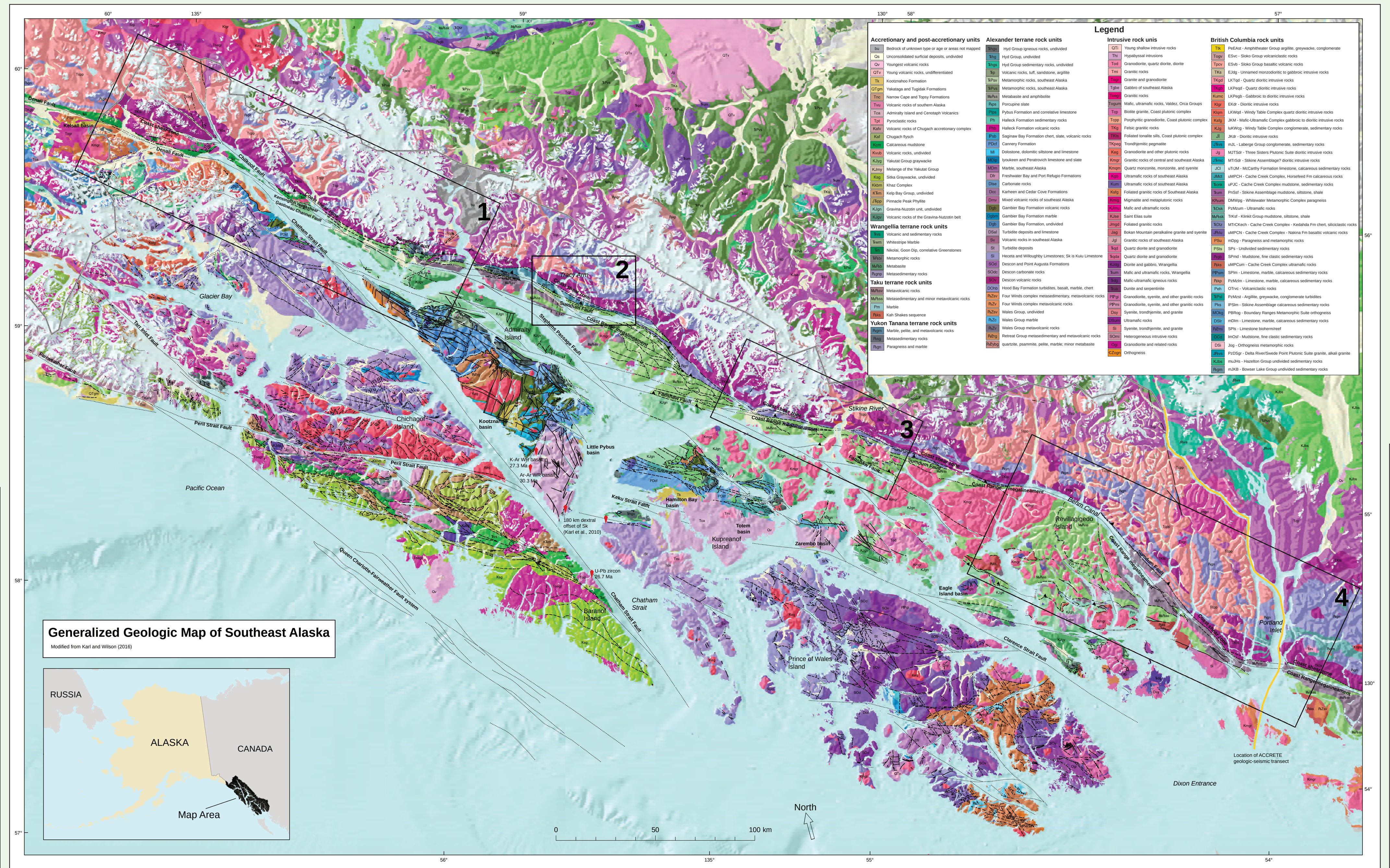


Data implications for northern southeast Alaska

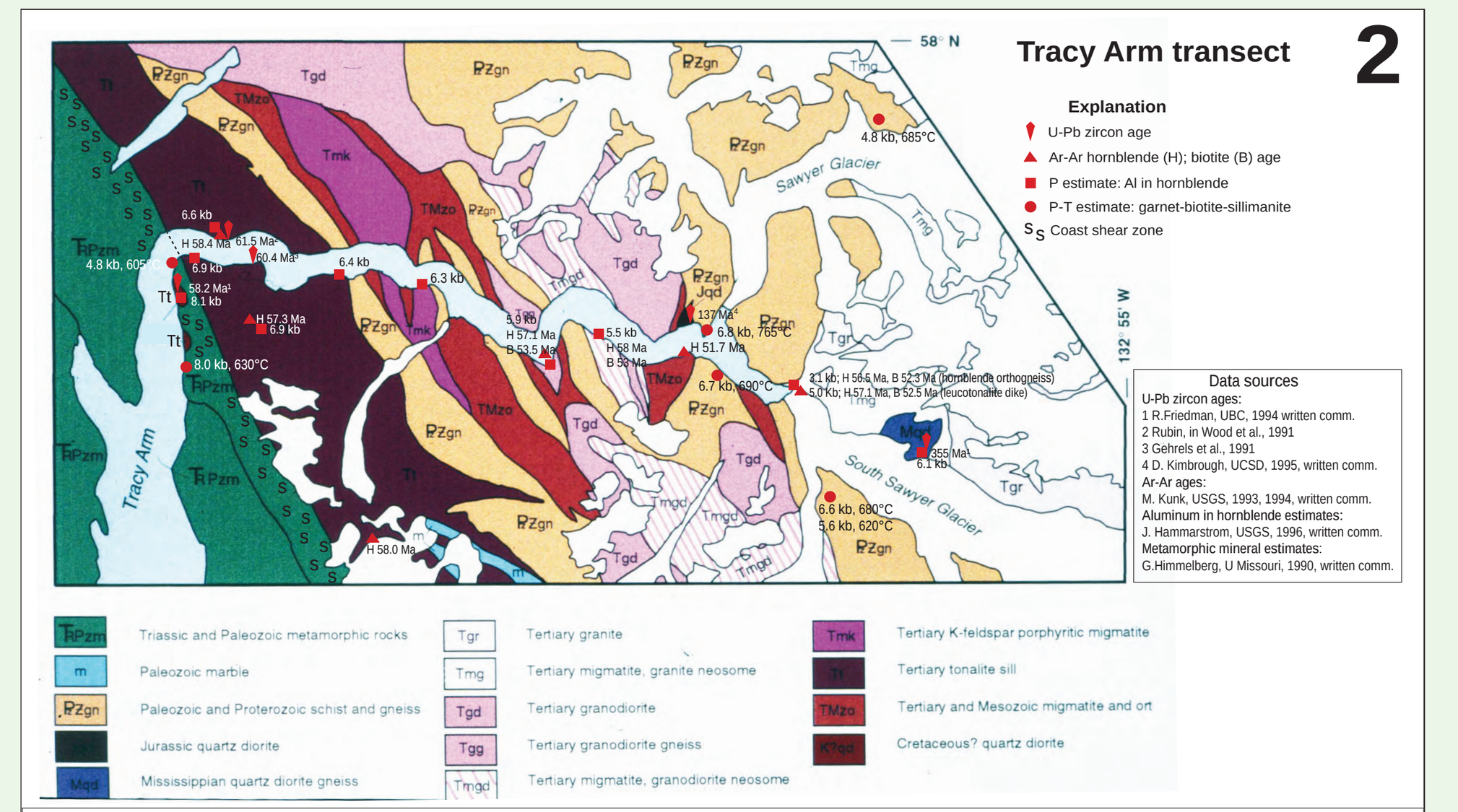
- NW-trending D1 contractional west-vergent structures in Late Jurassic-Early Cretaceous Gravina belt (KJgn) predate Jualin (105 Ma) and Treadwell (91 Ma) plutons.
- The Sumdum and Fanshaw west-vergent thrust faults (D2) postdate the Treadwell (91 Ma) pluton.
- Inverted Barrovian metamorphic isograds and peak metamorphic mineral assemblages are associated with D2 mid-Cretaceous thrust faulting.
- D3 contractional structures are rotated westward relative to D2 and guided emplacement of tonalite sills, which cut D1 and D2 structures, at ~71 Ma.
- In the Juneau area, the Coast shear zone (D4) lies in the footwall of the Sumdum fault east of Mendenhall Lake, and marks the footwall of the tonalite west of the lake.
- D5 shear zones cut the Coast shear zone, lie mainly southwest of the CSZ, and contain steeply dipping boudinged quartz veins, compatible with regional shortening.
- Gold-quartz veins filled D5 structures and have white mica 53-57 Ma Ar-Ar dates at the AJ, Kensington, and Treadwell mines.
- Gold mineralization in compressional and tensional D5 quartz veins suggest an Eocene transition to transtensional structures.
- The Gastineau Channel Fault crosses the Fanshaw Fault, and contains quartz vein breccia and carbonaceous gouge indicating post-53 Ma activity.
- Discrete layers on post-mineralization shear margins of the Gastineau fault show oblique right-lateral displacement.
- The Gastineau Channel Fault is truncated by the Chatham Strait Fault.

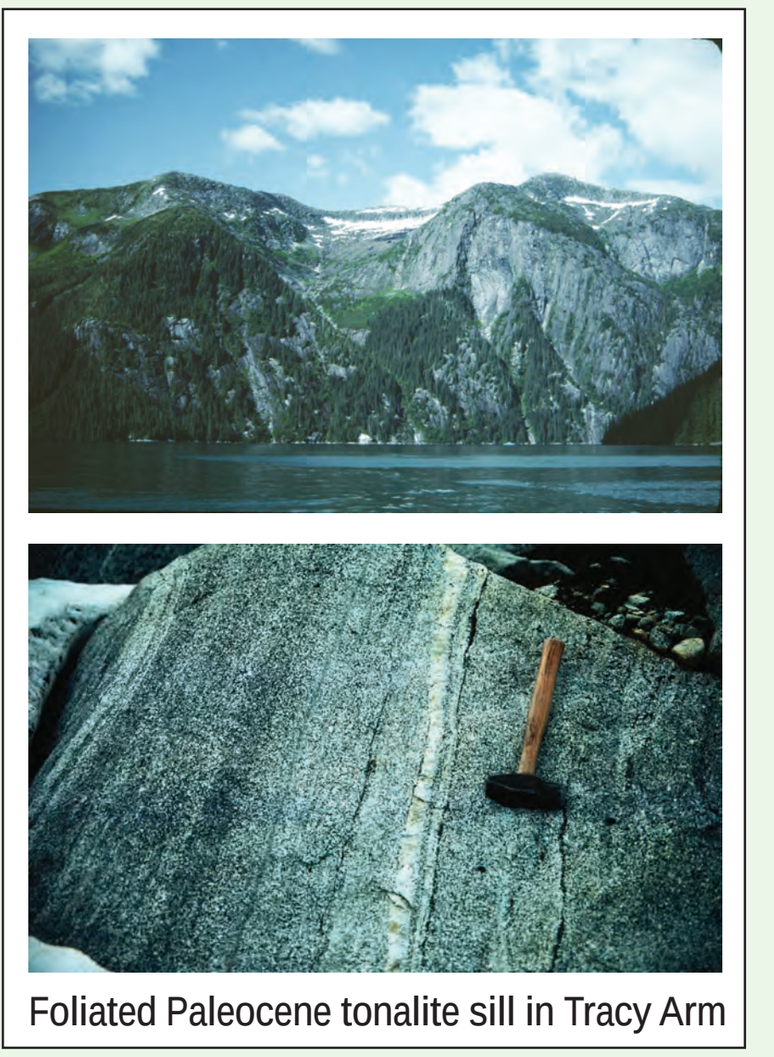
Explanation
U-Pb zircon age
Ar-Ar hornblende (H); biotite (B); white mica (M) age

Data Sources



Generalized Geologic Map of Southeast Alaska

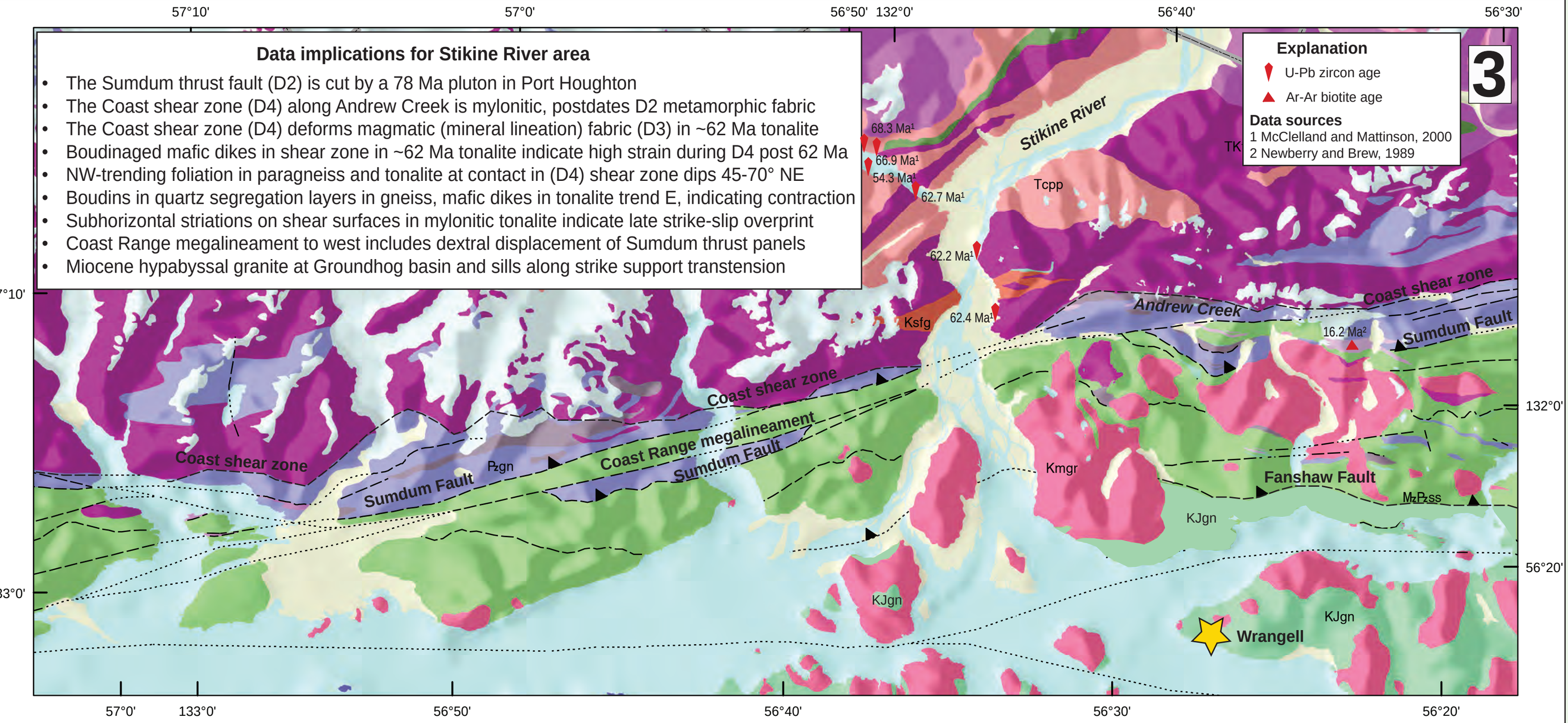



Foliated Paleocene tonalite sill in Tracy Arm


Mylonitic tonalite-paragneiss contact in Coast shear zone, and tonalite boudin within underlying paragneiss unit along Andrew Creek corridor south of the Stikine River. Boudin axis plunges east in moderately NE-dipping fabric.

Data implications for the Tracy Arm 35 km transect

- The tonalite sill cooled from zircon blocking temperatures of ~900°C at ~60.5 Ma to biotite cooling temperatures of ~300°C at ~53 Ma
- Aluminum in dated hornblende indicates the Coast plutonic complex was uplifted as a block without tilting ~57 Ma
- The Coast shear zone defines the west margin of the tonalite sill, and sheared lenses of correlative tonalite are found within the CSZ
- The Coast shear zone contains ductile structures that are overprinted by brittle structures suggesting rapid uplift

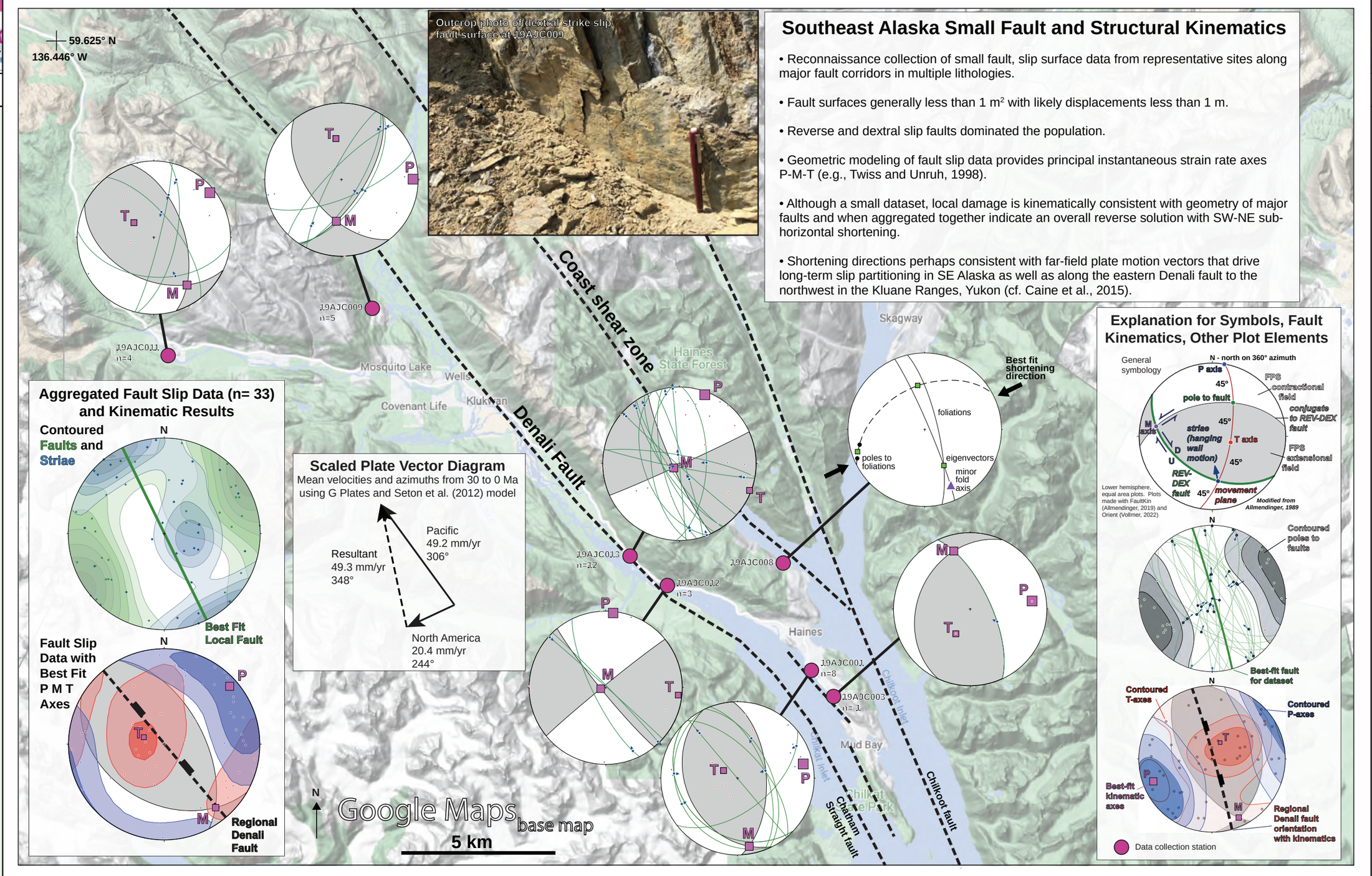


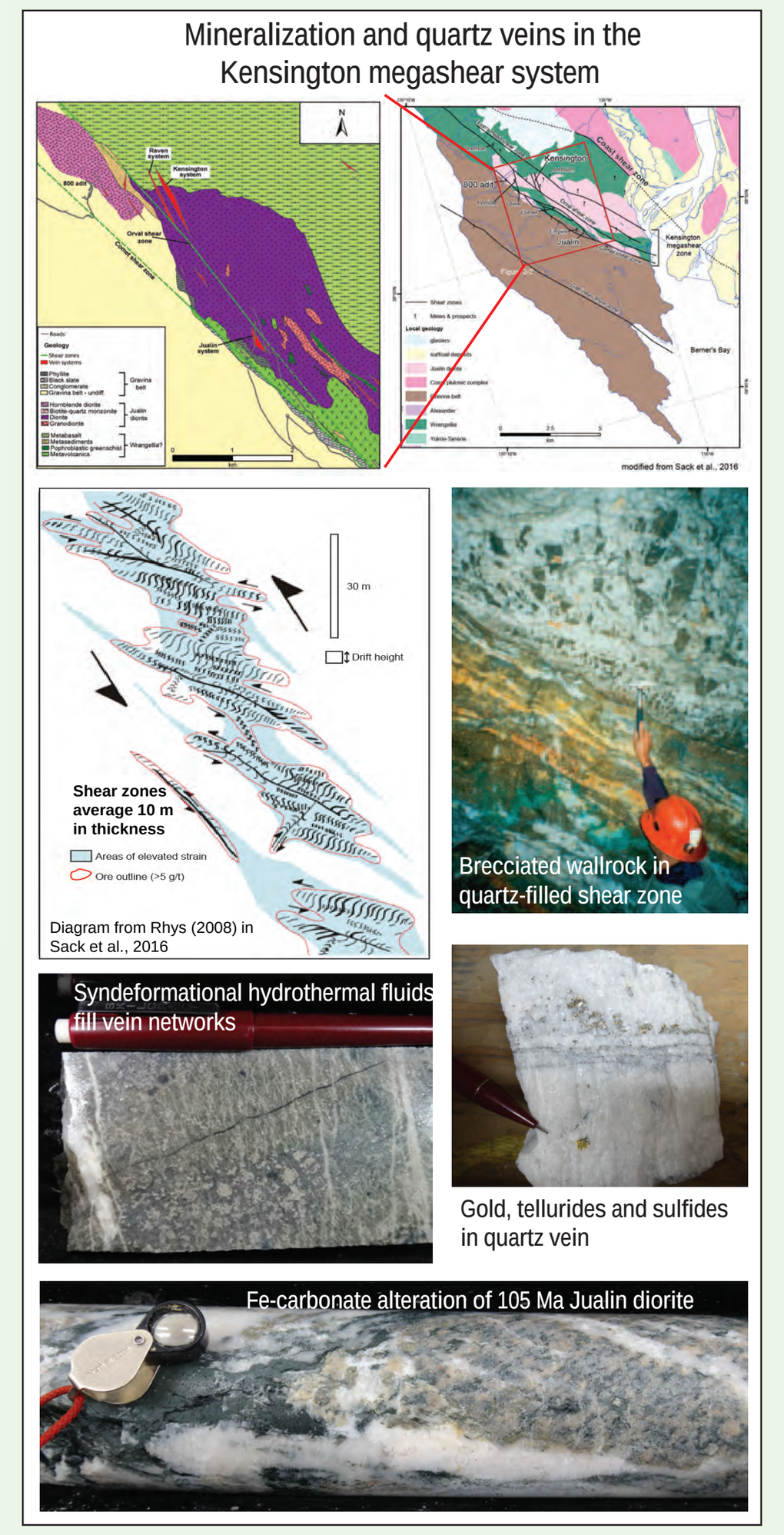
Data implications for Stikine River area

- The Sumdum thrust fault (D2) is cut by a 78 Ma pluton in Port Houghton
- The Coast shear zone (D4) along Andrew Creek is mylonitic, postdates D2 metamorphic fabric
- The Coast shear zone (D4) deforms magmatic (mineral lineation) fabric (D3) in ~62 Ma tonalite
- Boudinaged mafic dikes in shear zone in ~62 Ma tonalite indicate high strain during D4 post 62 Ma
- NW-trending foliation in paragneiss and tonalite at contact in (D4) shear zone dips 45-70° NE
- Boudins in quartz segregation layers in gneiss, mafic dikes in tonalite trend E, indicating contraction
- Subhorizontal striations on shear surfaces in mylonitic tonalite indicate late strike-slip overprint
- Coast Range megalineament to west includes dextral displacement of Sumdum thrust panels
- Miocene hypabyssal granite at Groundhog basin and sills along strike support transtension


Transition from mylonitic tonalite to foliated tonalite ~1 m above the contact with paragneiss at Andrew Creek.


Looking northwest along the Coast shear zone on Andrew Creek toward the Stikine River. Photos show the mylonitic contact between an overlying Paleocene tonalite sill and underlying Paleozoic paragneiss. Rock types in the paragneiss include quartzite, marble, meta-siliciclastic rocks and pelite, with lesser metafelsite and metabasite layers. The paragneiss is correlated with the Yukon Tanana terrane.




Mineralization and quartz veins in the Kensington megashear system

Gastineau Channel Fault-Coast Range Megalineament

In Gastineau Channel, a steep to vertical NW-trending ductile-brittle fault zone containing quartz vein breccia and gouge postdates mineralized gold-quartz veins, indicating post-53 Ma activity. This fault is a segment of the regional Coast Range Megalineament (CRML), which extends from Chatham Strait southeastward to coastal British Columbia. This regional fault crosses and locally overprints D1-D5 structures and includes structures indicating reverse-dextral motion. This transition from dominantly contractional to wrench-dominated transpressional deformation is inferred to correlate with a shift in oceanic plate trajectories relative to North America at 55-52 Ma during D5. Previous workers have suggested that the Gastineau Channel fault and CRML represent an ancestral DF. Our work suggests the CRML evolved in response this early Eocene change in relative plate motions, which is corroborated by recent work on the DF in central Alaska and Yukon that indicates >400 km of dextral separation was initiated around this time.

The Chatham Strait Fault Offsets and History

Constraints:
- 180 km offset of Silurian limestone across fault – robust largest offset
- 110 km offset of Admiralty volcanics and Sisters volcanics – not robust but plausible

Timing of offset:
- The Admiralty – Sisters offset and truncation of the 26 Ma Gut Bay granite on Baranof Island implies most motion was Oligocene or younger
- There's no evidence of Holocene offset in multibeam bathymetry or in high-resolution seismic data

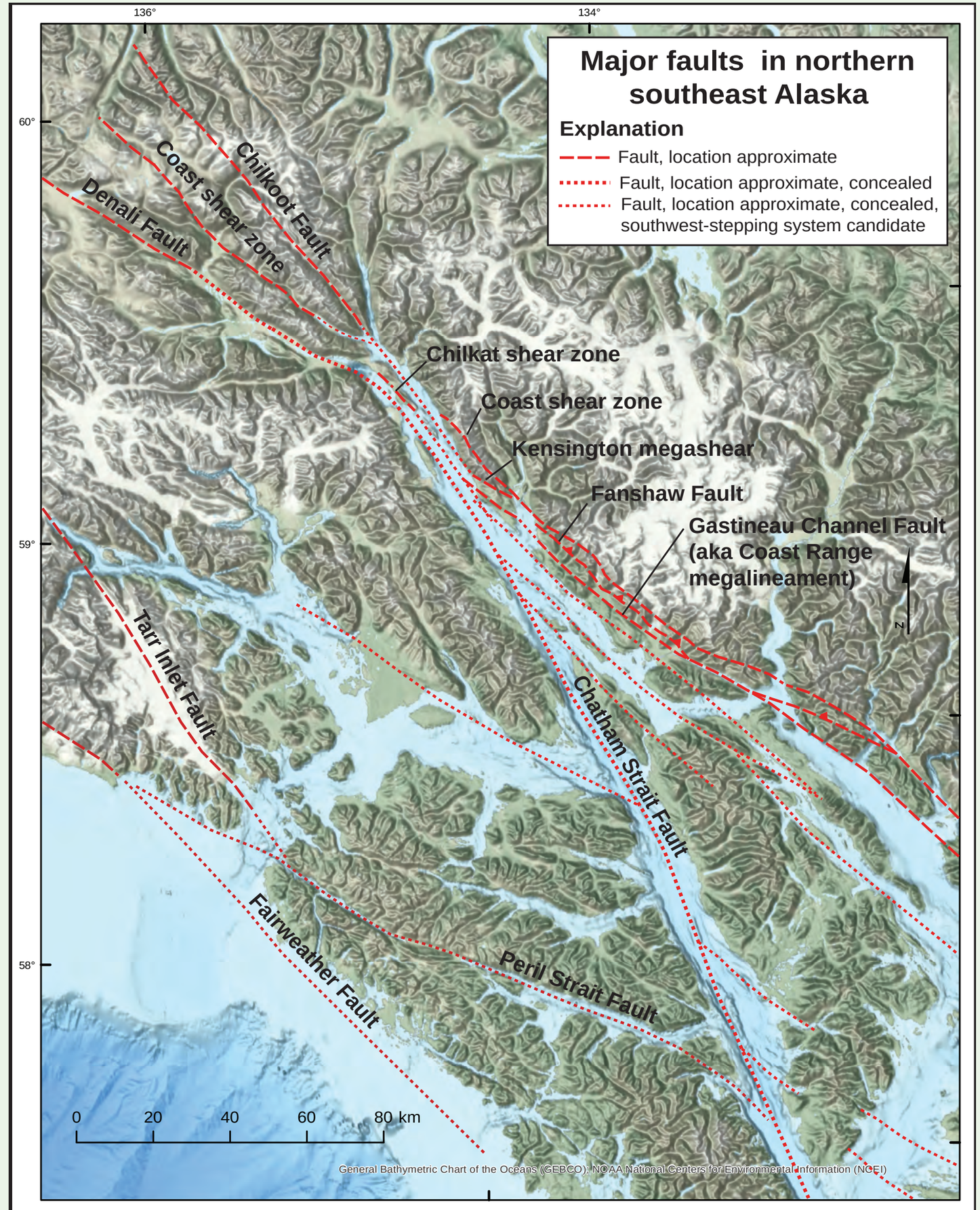
Chatham Strait – Eastern Denali fault connection and the 'Chilkat bend' in the fault system

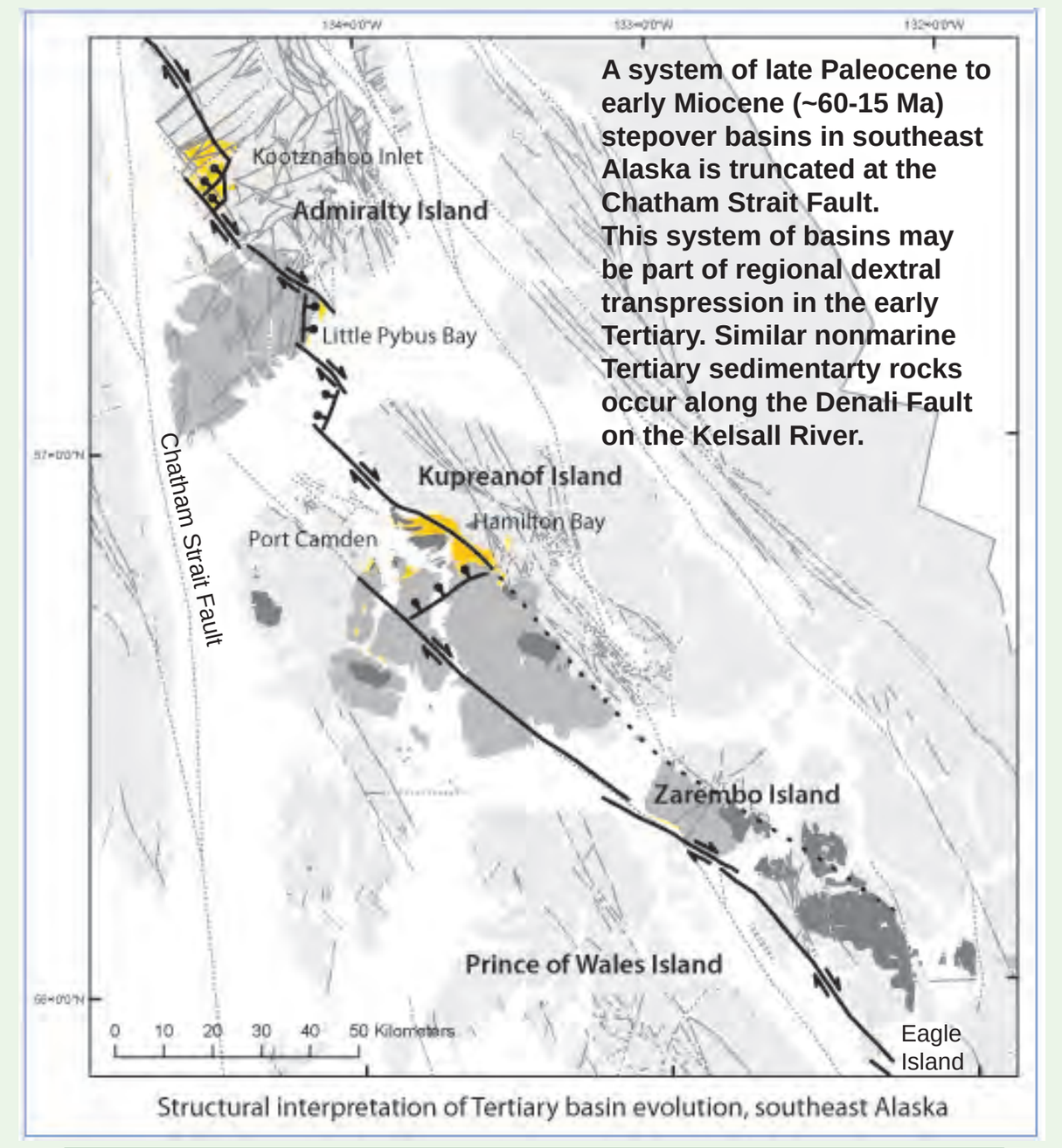
A 15° to 23° bend marks the intersection of the Chilkat River and Chilkat Inlet
An offset of 180 km on the CSF implies at least that much went through the bend
There are no scarps along the eastern Denali fault to the SE of Kluane Lake – indicating this bend is pre-Holocene
The SW side of the Chilkat bend should be a restraining bend
- There is no evidence of exhumation of deeper crustal rocks
- There is no high topography inside the bend
- Perhaps the bend is a late-stage kink of a previously straighter fault?
- Future thermochronology work could test ideas on the orogen and timing of the bend.

Why did the Chatham Strait fault form?

If the fault formed in perhaps late Oligocene time and most offset was complete by late Miocene or Pliocene time, this is similar to the timing of the initiation of the Yakutat microplate collision and the timing of movement of the modern Queen Charlotte – Fairweather fault system.
- This implies CSF activity is related to the Yakutat collision
- Thus, the ancestral Denali Fault is unrelated and predates the CSF

Why did activity on the CSF cease? There is no evidence the CSF is active
- The central Denali and Totschunda faults are active, as well as the NW half of the eastern Denali fault
- This suggests that as the Connector-Totschunda fault connection with the Fairweather fault system was established (Richter and Matson, 1972), then there was a more straightforward path to propagate strain into central interior Alaska, and the CSF, perhaps an early Connector analogue, died.





Structural interpretation of Tertiary basin evolution, southeast Alaska

Paleocene-Miocene transtensional wrench basins

Southwest of the CRML, a network of steep dextral faults is overlain by alkaline felsic to mafic volcanic rocks dated at 30 to 25 Ma. A series of transtensional step-over basins that contain Late Paleocene to Miocene fossils, extending from the Kelsall River in northwestern British Columbia to Eagle Island in southern SEAK, are also overlain by these volcanic rocks. These basins, 30-25 Ma volcanic rocks, 26 Ma granite, and the Gastineau Channel-CRML are truncated by the north-trending Chatham Strait Fault (CSF), on which Paleozoic stratigraphic markers indicate ca. 180 km of total dextral separation that likely occurred since 26 Ma.

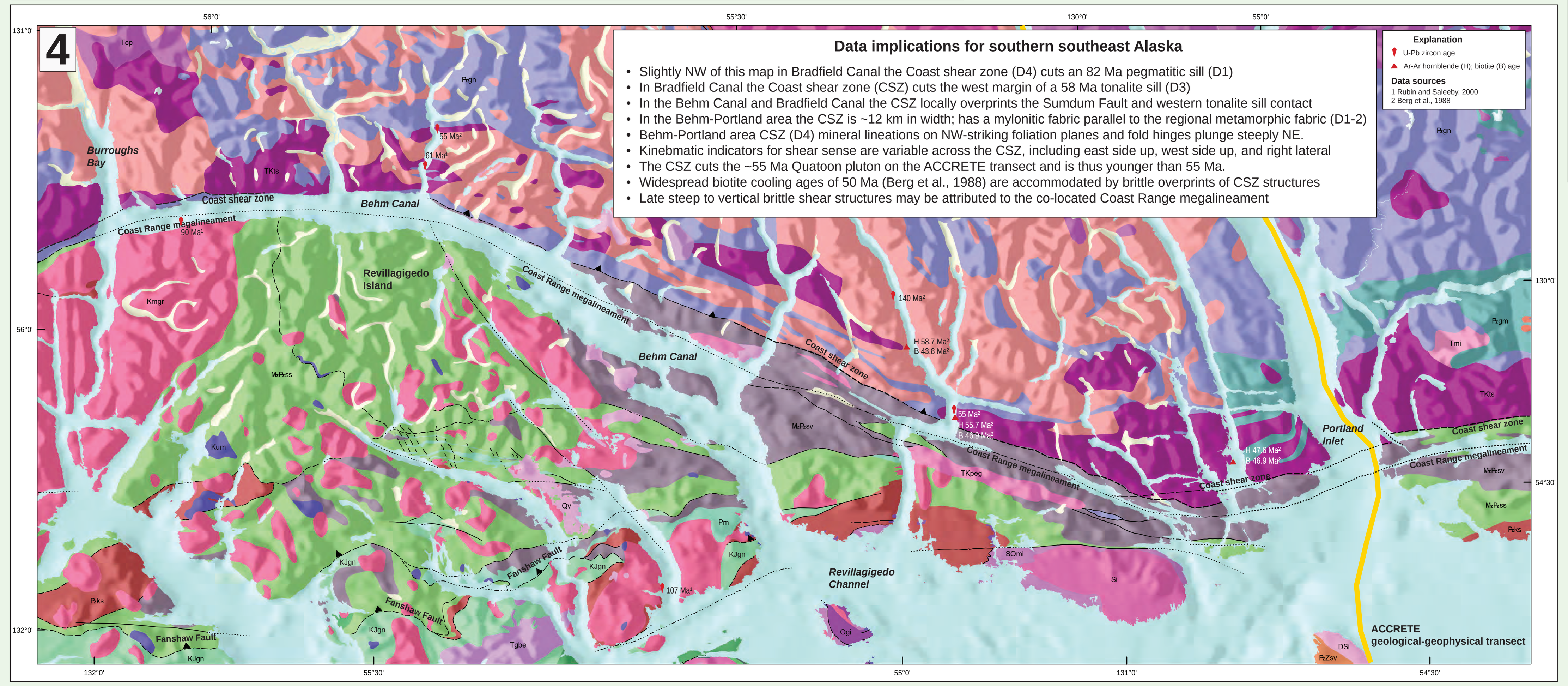

Oligocene coal bed and conglomerate, Admiralty Island

Conglomerate channel in sandstone, Eagle Island

Basalt flow on fluvial conglomerate, Eagle Island

Eocene-Oligocene dextral-transtensional fault network

In northwestern SEAK, merging of the trace of the Denali Fault (DF) in the Chilkat River with the trace of the Chatham Strait Fault (CSF) in Chilkat Inlet is supported by well-defined linear bathymetric structures in Chatham Strait. This segment of the DF shows little seismicity; the CSF is not currently active, and seismicity is lacking east of the CSF. Oligocene initiation of the CSF corresponds to transfer of dextral translation from the CRML and coeval dextral faults in SEAK to the CSF-DF. Less than 35 km separates the CRML from the DF on the CSF, which is significantly less than the 180 km of separation on the CSF, requiring additional Eocene to Oligocene dextral translational faults that may be part of an ancestral DF system in SEAK. If 400 km of separation occurred on the DF, then the ca. 180 km offset on the CSF leaves as much as 220 km of unaccounted-for separation to be accommodated on an ancestral DF in SEAK prior to or coeval with CSF activity. The missing slip may be accommodated on the network of dextral faults mapped southwest of the CRML during the ca. 25 m.y. time interval between initiation of activity on the CRML and initiation of the CSF. The combined evidence suggests that the ancestral DF in SEAK, prior to truncation by the CSF in the Oligocene, consisted of an array of dextral strike-slip and transtensional faults.

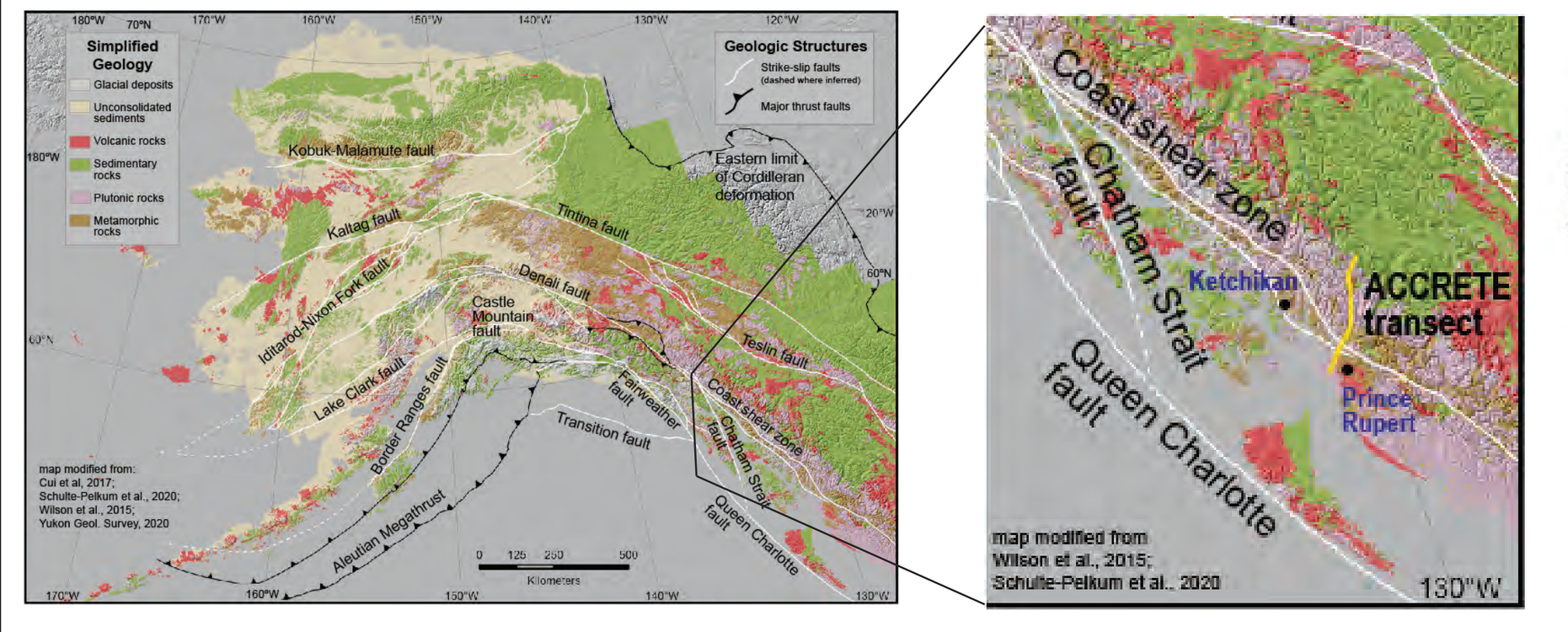


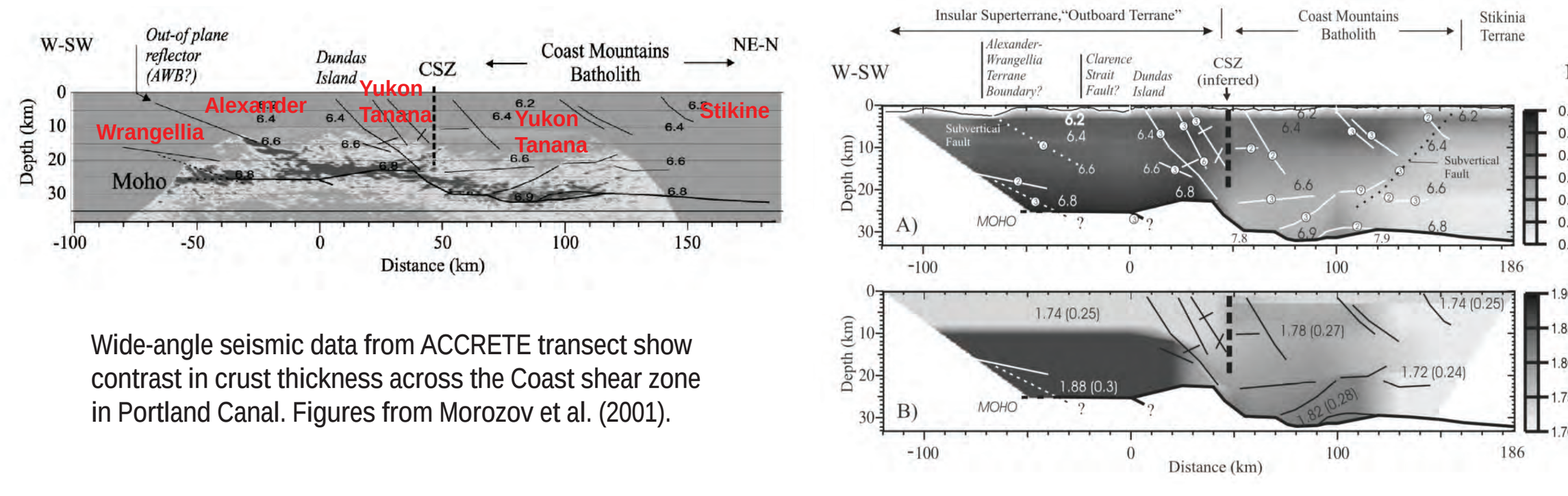
Data implications for southern southeast Alaska

- Slightly NW of this map in Bradfield Canal the Coast shear zone (D4) cuts an 82 Ma pegmatitic sill (D1)
- In Bradfield Canal the Coast shear zone (CSZ) cuts the west margin of a 58 Ma tonalite sill (D3)
- In the Behm Canal and Bradfield Canal the CSZ locally overprints the Sumdum Fault and western tonalite sill contact
- In the Behm-Portland area the CSZ is ~12 km in width; has a mylonitic fabric parallel to the regional metamorphic fabric (D1-2)
- Behm-Portland area CSZ (D4) mineral lineations on NW-striking foliation planes and fold hinges plunge steeply NE.
- Kinebmatic indicators for shear sense are variable across the CSZ, including east side up, west side up, and right lateral
- The CSZ cuts the ~55 Ma Quatoon pluton on the ACCRETE transect and is thus younger than 55 Ma.
- Widespread biotite cooling ages of 50 Ma (Berg et al., 1988) are accommodated by brittle overprints of CSZ structures
- Late steep to vertical brittle shear structures may be attributed to the co-located Coast Range megalineament

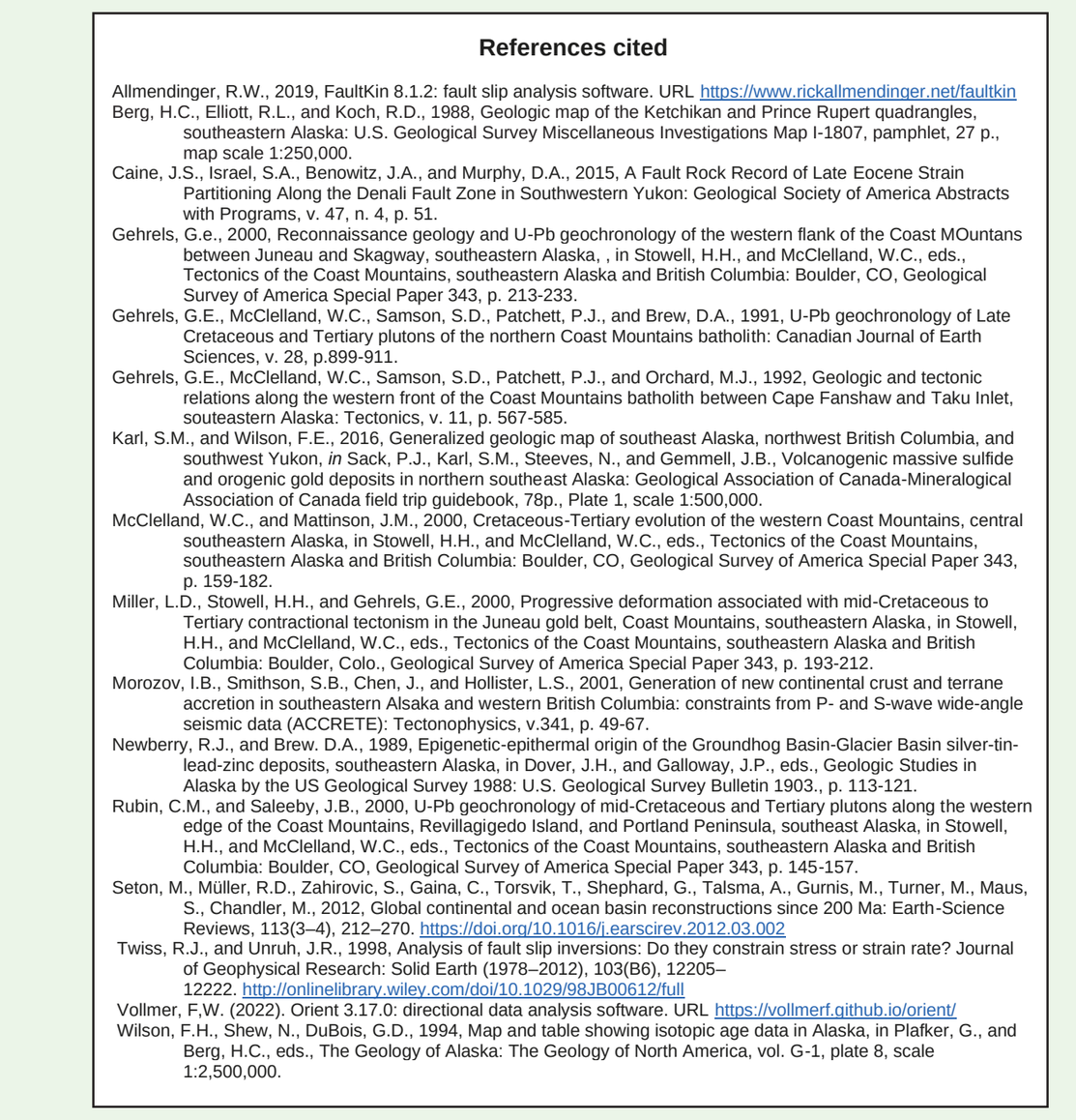
Explanation
U-Pb zircon age
Ar-Ar hornblende (H); biotite (B) age

Data sources
1 Rubin and Saleeby, 2000
2 Berg et al., 1988





Wide-angle seismic data from ACCRETE transect show contrast in crust thickness across the Coast shear zone in Portland Canal. Figures from Morozov et al. (2001).



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