Regional Paleocene-Eocene Exhumation of the North American Forearc Basin Margin, South-Central Alaska, Recorded by Apatite Fission-Track Thermochronology

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Abstract

Thirty-six bedrock apatite fission-track (AFT) ages from the margins of the Cook Inlet forearc basin (CIFB), and 9 reconnaissance detrital AFT ages from Cenozoic age strata filling the basin define Paleocene-Eocene cooling of proximal source terranes rimming the CIFB. The timing of this cooling is strikingly similar at the arc-forearc margin along the upper Alaska Peninsula (~56 to 42 Ma) and northwestern upper Cook Inlet (~52 to 40 Ma), and the accretionary complex-forearc margin along northeastern upper Cook Inlet (~55 to 38 Ma) despite the region's different tectonic settings and separation by up to 450 km. The cooling events are coeval with widespread Cenozoic clastic sedimentation throughout the upper Alaska Peninsula and Cook Inlet regions (Copper River, West Foreland, Wishbone, Arkose Ridge, and Chickaloon formations), suggesting that the cooling interval may reflect a regional exhumation event during latest Paleocene to Middle Eocene time that simultaneously involved the intrusive arc and western-most accretionary prism. Preliminary interpretation of detrital AFT and detrital zircon ages suggests Early Oligocene to Early Miocene exhumation of sediment source terranes distal to the CIFB margins. Disparate cooling ages across some fault boundaries (e.g. Bruin Bay and Lake Clark faults) may reflect exhumation of the CIFB margin along those regional-scale structures, but the datasets are either complicated by subsequent structural and thermal overprints, or are too small for robust interpretation. Alternatively, regional Eocene exhumation indicated throughout the forearc region may be related to proposed lithospheric events occurring along the continental margin during Paleocene and Eocene times, such as the subduction of the Kula-Farallon ridge, passing of a related slab window, or changes in obliquity and rate of slab subduction. Conspicuously absent in bedrock samples is evidence for substantial cooling after ~30 Ma recording collision of the Yakutat block with southern Alaska, suggesting relatively low exhumation of the upper CIFB margin in response to Yakutat underplating. However, detrital samples from Middle Miocene and younger Cook Inlet strata exhibit a broadly younging-upsection trend in major age populations from ~25 to 19 Ma, perhaps indicating exhumation related to Yakutat collision or more distal source terranes.

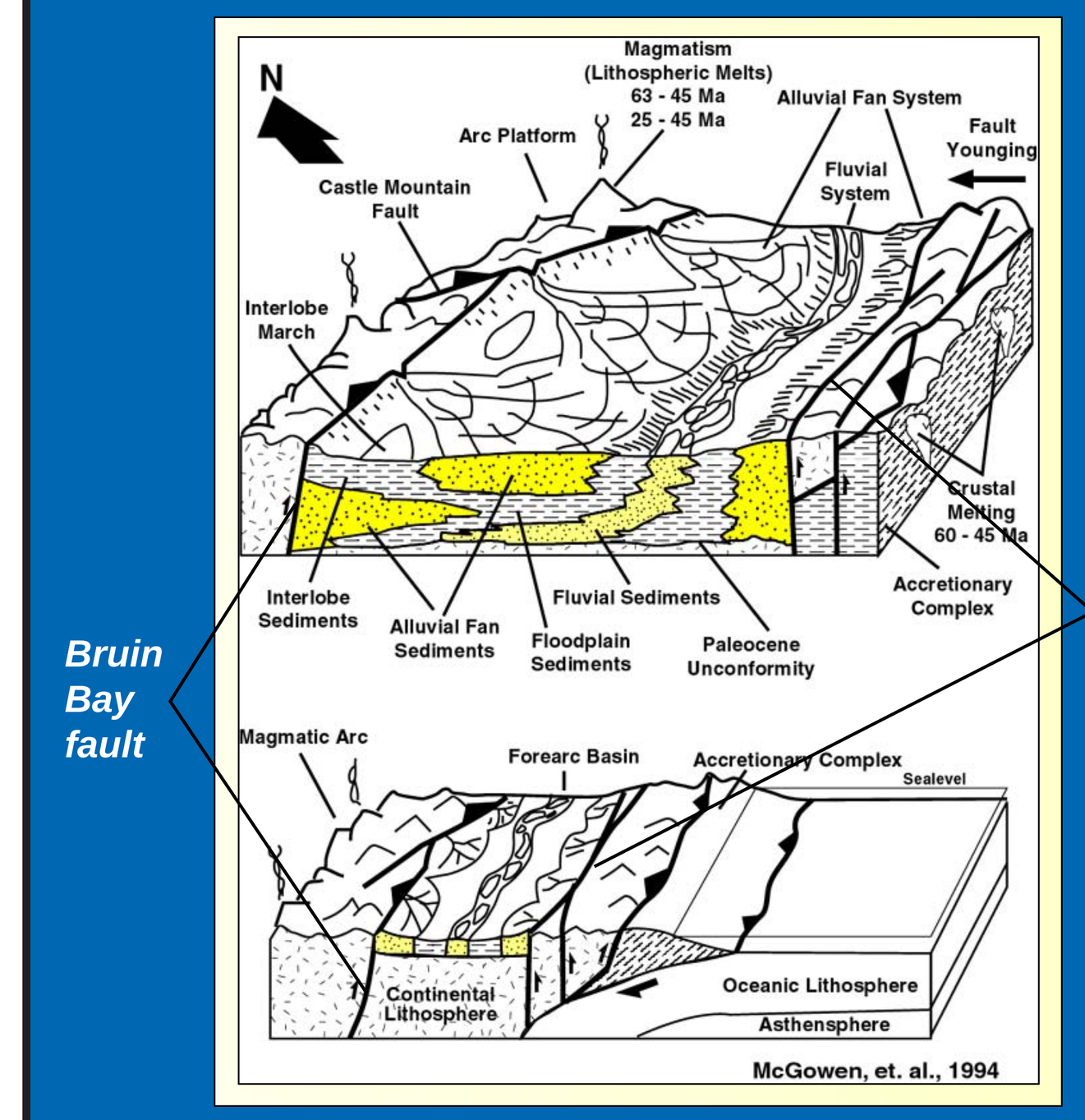


Figure 1
Schematic representation of the modern Alaska forearc basin (McGowen, et. al., 1994) showing the relationship of basin-controlling structures to forearc deposition and plate convergence

COOK INLET MARGIN BEDROCK THERMO/GEOCHRONOLOGY

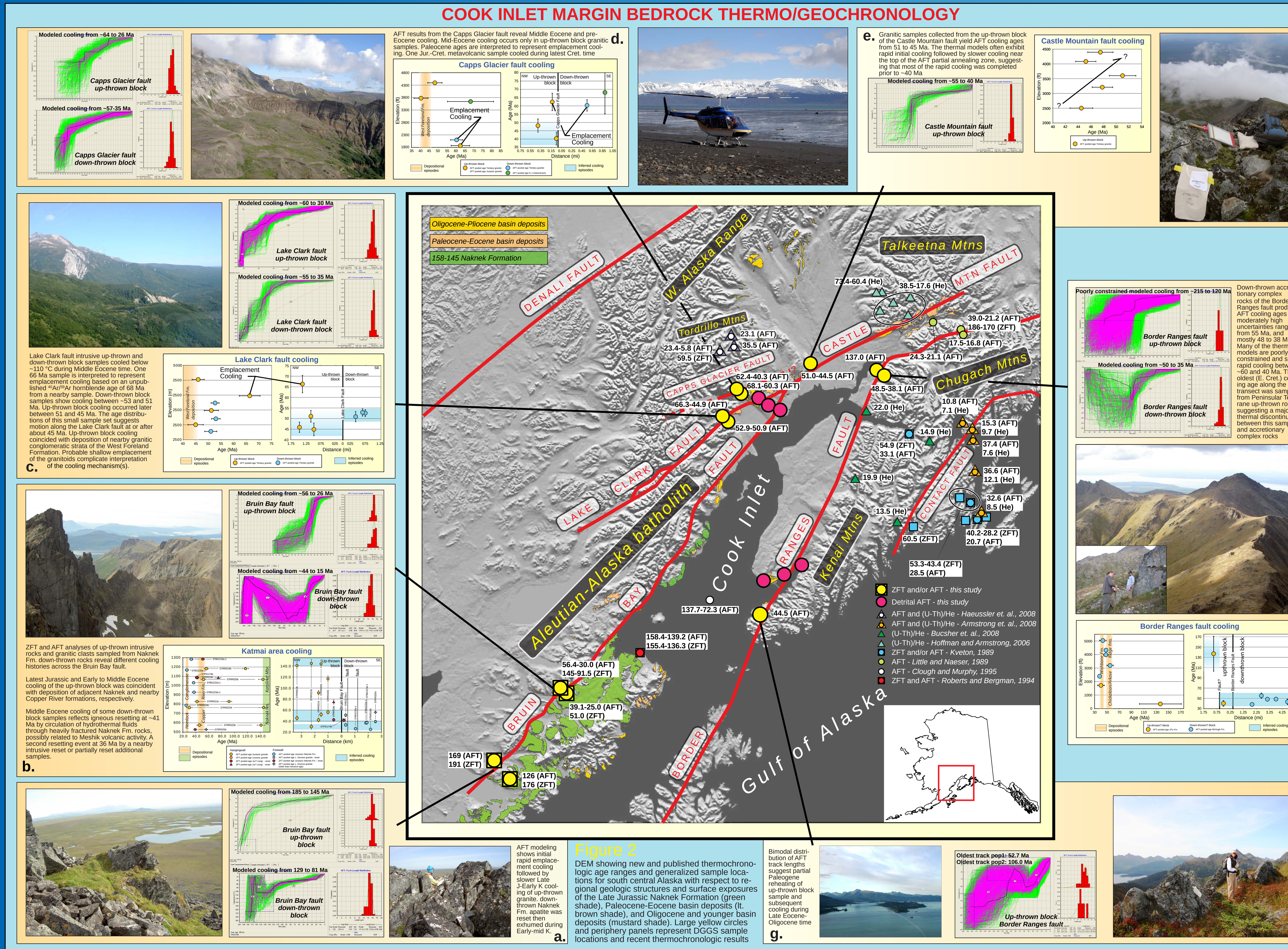


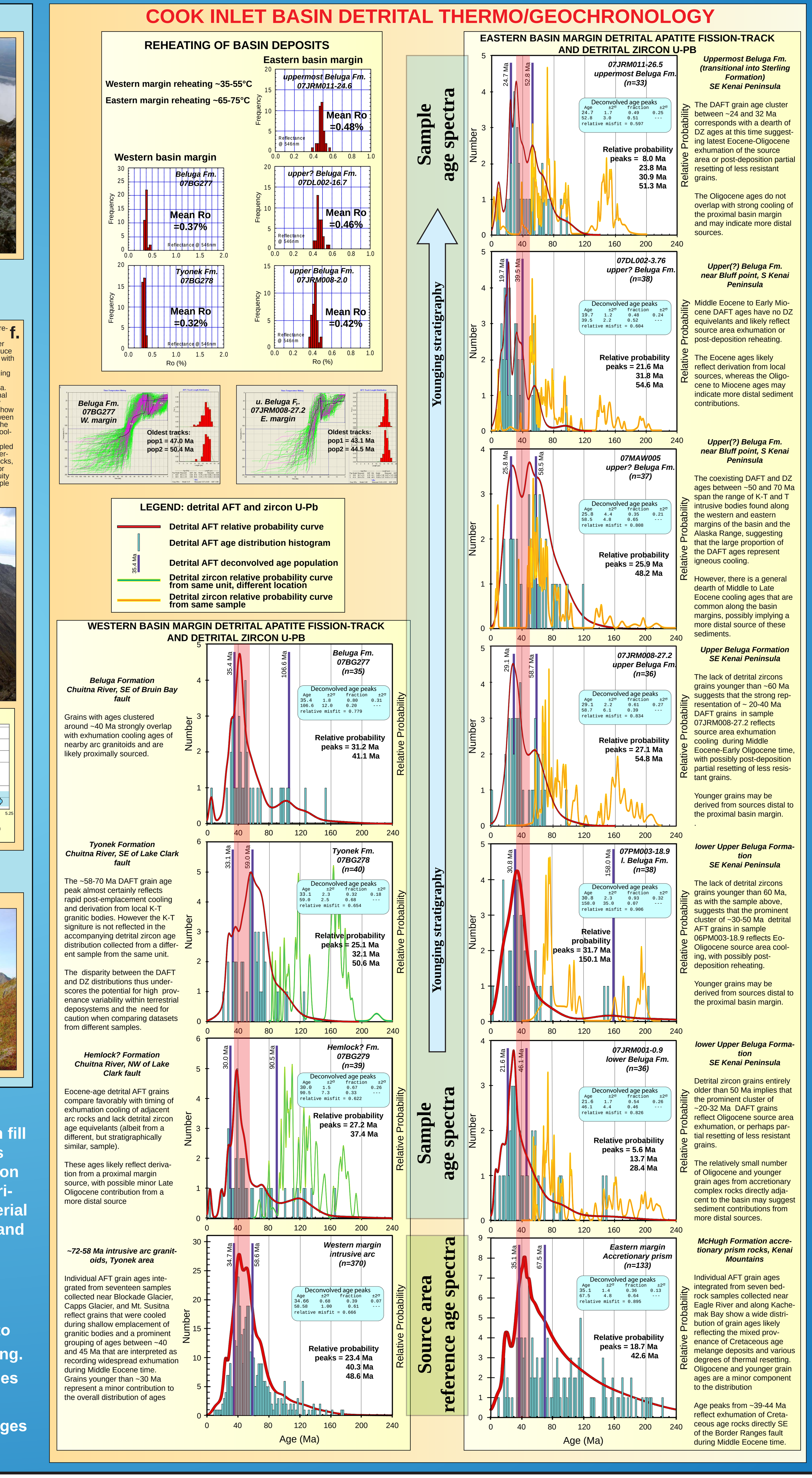
Figure 2
DEM showing new and published thermochronologic age ranges and generalized sample locations for south central Alaska with respect to regional geologic structures and surface exposures of the Late Jurassic Naknek Formation (green shade), Paleocene-Eocene basin deposits (lt. brown shade), and Oligocene and younger basin deposits (mustard shade). Large yellow circles and periphery panels represent DGGS sample locations and recent thermochronologic results

Bedrock cooling

Thirty-six bedrock AFT cooling ages were derived from Middle Jurassic, Cretaceous-Tertiary, and early Tertiary intrusive arc rocks, and Permian-Triassic and Late Cretaceous metasedimentary Peninsular terrane and accretionary complex rocks from the perimeter of the CIFB. Sampling was carried out across regional basin-bounding faults along the northwestern and southeastern basin margins to illucidate the timing, kinematics, and significance of structural controls on basin development.

- Cooling ages range from 137 ±34 (Peninsular terrane) to 25.0 ±1.6 Ma (Aleutian-Alaska Tertiary arc).
- Interpretation of cooling ages is complicated by partial to complete resetting, and presumed emplacement of sampled igneous bodies near the top of the AFT partial annealing zone in some locations.
- Cooling ages not related to intrusive cooling or reheating range between 56 and 38 Ma and occur basin-wide.
- Cooling ages do not vary significantly with structural position or tectonic setting, suggesting a regional control on cooling

COOK INLET BASIN DETRITAL THERMO/GEOCHRONOLOGY



Detrital AFT thermochronology

Nine reconnaissance detrital AFT cooling ages from Early Oligocene? to Late Middle Miocene basin fill deposits were collected on the northwestern and southeastern margins of the CIFB. Detrital zircons were analyzed from six of the samples, whereas the remaining three are compared with detrital zircon results from different samples collected from the same stratigraphic unit to differentiate between primary igneous cooling and exhumation cooling. Vitrinite reflectance analyses of carbonaceous material often collected from within meters of the AFT samples help to quantify peak reburial temperatures and assess potential AFT resetting.

- Most detrital zircon grain ages predate Tertiary cooling ages, implying that Cenozoic cooling recorded in CIFB strata are largely the product of exhumation of sediment source areas
- Cenozoic strata on both margins of the CIFB have experienced peak reheating temperatures up to ~80°C, resulting in minor partial resetting and apparent younging of grains less resistant to annealing.
- Early Oligocene? to late Middle Miocene western margin strata exhibit mostly Eocene cooling ages derived predominantly from the proximal basin margin.
- Late Middle Miocene eastern margin strata yield a mix of Eocene to late Early Miocene cooling ages likely derived from local and distal sources.

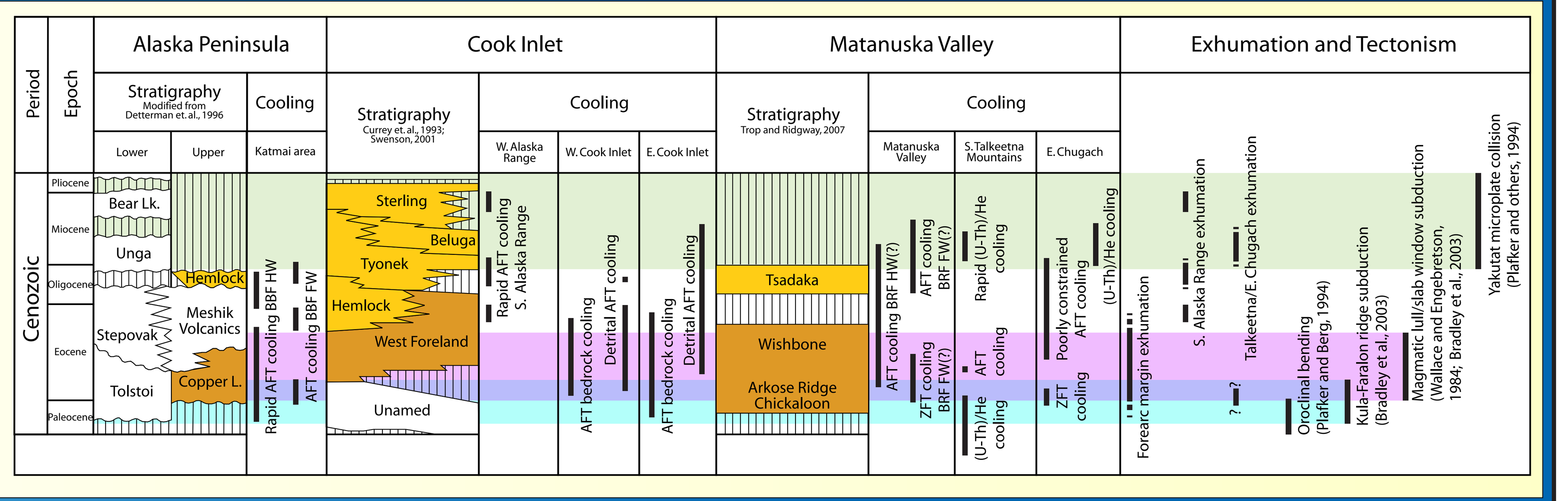


Figure 4
Stratigraphic column of the Alaska Peninsula and Cook Inlet regions highlighting units containing significant conglomeratic facies of granitic and volcanic composition presented with respect to major tectonic events and available cooling information from this and other studies.

Conclusions

Thirty-six bedrock AFT, and 9 detrital AFT samples widely collected from source terranes to the Cook Inlet forearc basin and Cook Inlet strata help define a regional episode of cooling along the North American plate margin in south central Alaska during latest Paleocene to Middle Eocene times. The cooling episode from ~56 to 38 Ma is coeval with widespread deposition of proximal arc-derived detritus discontinuously cropping out from the upper Alaska Peninsula northwestward ~450 km to the Matanuska Valley (Figures 2 and 4). Ongoing detailed stratigraphic studies by the Alaska Division of Geological and Geophysical Surveys strongly support proximal margin sources for Middle Eocene West Foreland Formation strata southeast of the Tordrillo Mountains, including new U-Pb zircon ages of granitic clasts that are similar to U-Pb ages from nearby granitoids, linking basin margin exhumation to CIFB deposition during Middle Eocene cooling. A similar relationship has been reported between sediment source areas in the Talkeetna Mountains and late Paleocene to Middle Eocene basin fill in the Matanuska Valley (Bleick et. al., 2009; Trop et. al., 2003).

Proximal margin source terranes continue to be a major contributor of detritus into the basin until at least Late Miocene time based on detrital AFT and zircon U-Pb results from Tyonek and Beluga formation strata exposed along the northwestern and southeastern margins of the basin. A middle to late Oligocene detrital cooling signal observed in many of the sedimentary samples can only be partially explained by thermal resetting of less resistant apatite grains and likely indicates sediments that are being sourced from more distal, unidentified regions. A broadly younging-upward of detrital cooling ages in samples from the southeastern side of the basin indicate sediment contributions sourced from rocks cooled during late Miocene time. Possible candidates include axial sources in the Matanuska Valley to the northeast and Tordrillo Mountains to the northwest. Additional analyses are required to make more robust interpretations of detrital cooling trends observed in the Cook Inlet basin fill and their potential sources.

Approximately 56-38 Ma unroofing does not appear to be dependent on deformation focused along major basin-bounding faults, suggesting a more regional-scale cause for the widespread exhumation observed throughout the Cook Inlet region. Potential mechanisms for accelerated exhumation along the Alaska continental margin during this time interval include surface uplift of the overriding continental lithosphere by subducting young, buoyant oceanic lithosphere during Kula-Farallon ridge subduction (~58-52 Ma in this region, Bradley et. al., 2000) and/or associated passing of a slab window (Thorkelson and Taylor, 1989) from ~55-40 Ma (Wallace and Engebretson, 1984), or changes in subduction rate and obliquity of the subducting oceanic lithosphere at ~50 Ma (Engebretson, et al., 1985). An intriguing, unexplored potential mechanism for accelerated exhumation is the effect the Paleocene-Eocene thermal maximum (PETM) had on denudation rates along the continental margin starting at ~55 Ma.

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References

Armstrong, P.A., Haeussler, P., Sendziak, K. and Arkle, J., 2008, The western Chugach core: Locus of subduction-related exhumation?: *In Garver, J.I., and Montario, M.J. (eds.), Proceedings from the 11th International Conference on thermochronometry, Anchorage Alaska, Sept. 2008*
Bleick, H.A., Till, A.B., Bradley, D.C., O'Sullivan, P.O., Trop, J.M., Wooden, J.L., Bradley, D.B., Taylor, T.A., Friedman, S.B., and Hults, C.P., 2009, Early Tertiary exhumation of the flank of a forearc basin, southwest Talkeetna Mountains, Alaska, Geological Society of America Abstracts with Programs, Vol. 41, No. 7, p. 303
Bradley, D.C., Parrish, R., Clendenen, W., Lux, D., Layer, P., Heizler, M., and Donely, D.T., 2000, New geochronological evidence for the timing of early Tertiary ridge subduction in southern Alaska: U.S. Geological Survey Professional Paper 1651, p. 5-21
Bradley, D.C., Kusky, T.M., Haeussler, P.J., Goldfarb, R.J., Miller, M.L., Dumoulin, J.A., Nelson, S.W., and Karl, S.M., 2003, Geologic signiture of early Tertiary ridge subduction in alaska, in Sisson, V.B., Roeske, S.M., and Pavlis, T. L., eds.,*Geology of a transpressional orogen developed during ridge-trench interaction along the North Pacific margin,* Geological Society of America Special Paper 371, p. 19-49.
Currey and others, 1993, Internal ARCO Report
Buscher, J.T., Berger, A.L., Spotila, J.A., 2008, Exhumation in the Chugach-Kenai mountain belt above the Aleutian subduction zone, southern Alaska: *in Active Tectonics and Seismic Potential of Alaska, Geophys. Monogr. Ser., edited by J.T. Freymueller, P.J. Haeussler, R. Wesson, and G. Ekstrom, Geophysical Monograph 179, AGU, Washington, D.C.*
Detterman, R.L., Case, J.E., Miller, J.W., Wilson, F.H., and Yount, M.E., 1996, Stratigraphic framework of the Alaska Peninsula: U.S. Geological Survey Bulletin 1969-A, 74 p.
Engebretson, D.C., Cox, A., and Gordon, R.G., 1985, Relative motions between oceanic and continental plates in the Pacific basin: Boulder, Colorado, Geological Society of America Special Paper 206, 59p.
Haeussler, P.J., O'Sullivan, P., Berger, A.L., and Spotila, J.A., 2008, Neogene exhumation of the Tordrillo Mountains, Alaska, and correlations with Denali (Mt. McKinley): *in Active Tectonics and Seismic Potential of Alaska, Geophys. Monogr. Ser., edited by J.T. Freymueller, P.J. Haeussler, R. Wesson, and G. Ekstrom, Geophysical Monograph 179, AGU, Washington, D.C.*
Hoffman M.; Armstrong P. A., 2006, Miocene exhumation of the southern Talkeetna Mountains, south central Alaska, based on apatite (U-Th)/He thermochronology. GSA Abstracts with Programs, 38, No. 5.
Kveton, K.J., 1989, Structure, thermochronology, provenance, and tectonic history of the Orca Group in southwestern Prince William Sound, Alaska, Ph.D. thesis, Univ. of Washington, Seattle, Wash., 227 pp.
Little T. A.; Naeser C. W., 1989, Tertiary tectonics of the Border Ranges fault system, Chugach Mountains, Alaska: deformation and uplift in a forearc setting. Journal of Geophysical Research, 94, 4333-4359.
Riehle, J.R., and Detterman, R.L., 1993, Quaternary geologic map of the Mount Katmai Quadrangle and adjacent parts of the Naknek and Afognak quadrangles, Alaska, 1 sheet.
McGowen, J.H., and Doherty, D.J., 1994, Internal ARCO Report
Plafker, G., and Berg, H.C., 1994a, The Geology of Alaska: Geological Society of America, The Geology of North America, v. G-1.
Plafker, G., Moore, J.C., and Winkler, G.R., 1994b, Geology of the southern Alaska margin in Plafker, G., and Berg, H.C., eds., The Geology of Alaska: Geological Society of America, The Geology of North America, v. G-1.
Roberts , Chuck, Coastal Science Laboratories , Bergman, Steven, and Geochron Laboratories, Inc., 1994, Data resulting from the U.S. Minerals Management Service 1993 geologic field program in Lower Cook Inlet, Alalska: Alaska Division of Geological & Geophysical Surveys Geologic Materials Center Data Report 233, 183 p.
Swenson, R., 2001, Introduction to Tertiary tectonics and sedimentation in the Cook Inlet basin, in Dallegge, T.A., comp., 2003, 2001 *Guide to the Petroleum Geology and Shallow Gas Potential of the Kenai Peninsula, Alaska: A Field Trip Guidebook*: Alaska Div. of Geol. & Geophys. Surveys Miscellaneous Publication 128, 89 p., 1 disk.
Thorkelson, D.J., and Taylor, R.P., 1989, Cordilleran slab windows, Geology, v.17, p.833-836
Trop, J.M., Ridgway, K.D., and Spell, T.L., 2003, Sedimentary record of transpressional tectonics and ridge subduction
Wallace, W.K., and Engebretson, D.C., 1984, Relationships between plate motions and Late Cretaceous to Paleogene magmatism in southwestern Alaska, Tectonics, v.3, p.295-315