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ALONG-STRIKE VARIATION OF U/PB AND HF ISOTOPE COMPOSITIONS IN THE CHUGACH-PRINCE WILLIAM TERRANE, SOUTHERN ALASKA

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Research Advisor: Cam Davidson

INTRODUCTION

The Chugach-Prince William Terrane (CPW) is a Late Cretaceous to Eocene accretionary complex that spans ~2200 kilometers of the southern coast of Alaska, from Sanak Island in the west to Baranof Island in southeast Alaska (Fig. 1). The flysch of the CPW is composed of turbidites that vary from conglomerate, quartzofeldspathic sandstone, volcanic-lithic sandstone and interbedded mudstone. As one of the most outboard terranes in Alaska, understanding the accretion history of the CPW and its subsequent coast-parallel translation should illuminate key elements of the final assembly of the North American Cordillera.

The long-standing debate concerning the CPW has centered on whether the CPW has experienced significant coast parallel transport since deposition. Cowen (1982, 2003) and Cowen et al. (1997) argue that lithology and paleomagnetism support the hypothesis that the CPW was outboard of the Coast Mountains Batholith (CMB) at 50 Ma. Others (Plafker et al., 1994; Amato and Pavlis, 2010; Kochelek, 2011) support this hypothesis and suggest that the CPW is the missing accretionary complex of the CMB. However, Kusky et al. (1997) and Haeussler et al. (2003), suggest that the CPW was sourced by Alaskan terranes and has experienced only minor coast-parallel translation. This study refocuses the debate by using a large dataset of U/Pb and Hf isotopes from zircons across four field sites to examine the provenance of the CPW. Data from both Phanerozoic and Precambrian zircons from the CPW help to constrain potential proximal and distal sources and suggest that the CPW has a juvenile arc source and a split northern-southern Precambrian signature along strike.

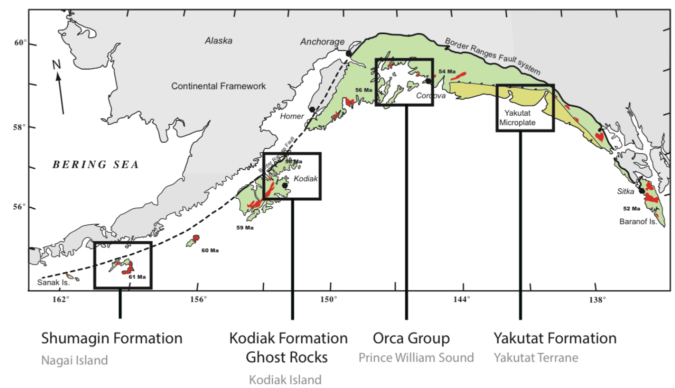

Figure 1. Simplified map of the Chugach-Prince William Terrane (in green), southern Alaska. Samples were collected from four field locations along strike: the Shumagin Formation from Nagai Island; the Kodiak and Ghost Rocks Formations from Kodiak Island; the Orca Group from Prince William Sound; and the Yakutat Formation from the Yakutat terrane.

METHODS

In this study we report 434 integrated U/Pb ages and Hf isotope compositions for zircons from our four field locations spaced widely along almost the entire strike of the CPW: the Shumagin Formation, the Kodiak and Ghost Rocks Formations, the Orca Group, and the Yakutat Formation (Fig. 1). Zircons were separated, mounted, imaged, and sampled for U/Pb and Hf isotope compositions following the methods of Cecil et al. (2011). Isotope data were collected at the LaserChron Center, University of Arizona.

Of the 434 zircons analyzed for Hf isotopes, 230 are Precambrian and 204 are Phanerozoic. We specifically targeted Precambrian zircons for Hf analysis from a much larger detrital zircon U/Pb dataset (n>2000, Davidson and Garver, this volume), but this study

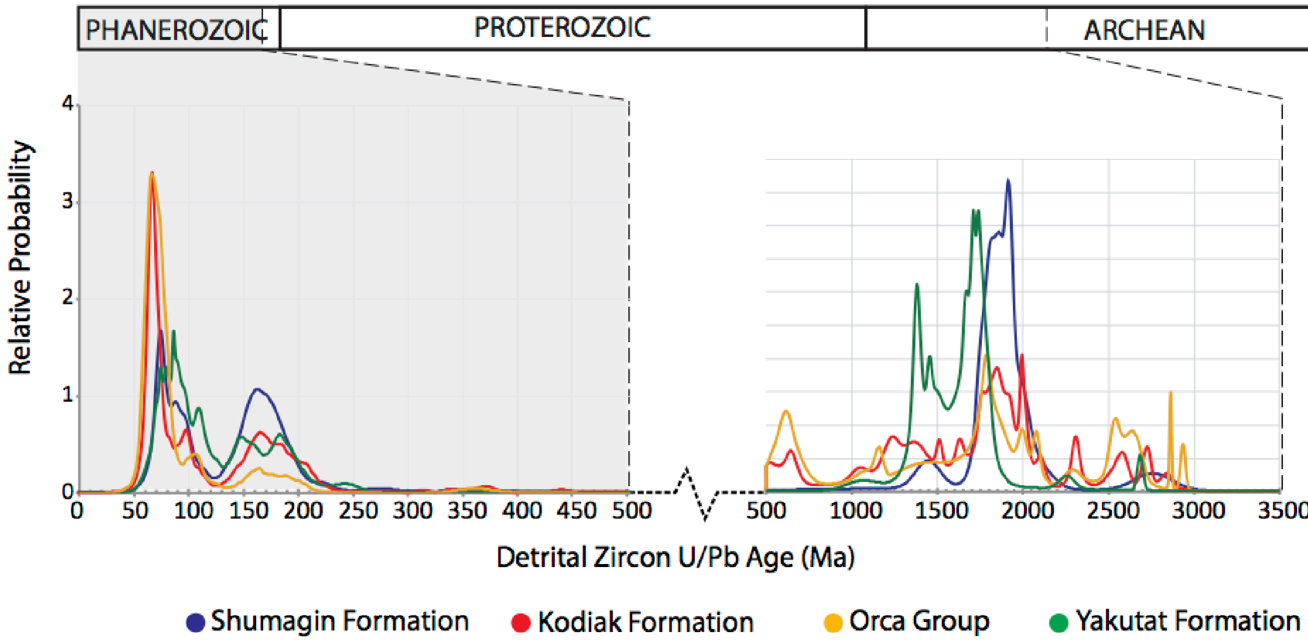

Figure 2. A U/Pb age probability plot for all zircons of max depositional age between 63 Ma and 75 Ma from the CPW, plotted by field location. The Phanerozoic time scale is expanded relative to the Precambrian time scale. Included are 2599 Phanerozoic grains and 213 Precambrian grains.

also includes Hf isotope compositions from major Phanerozoic populations present in each sample and field location in the CPW.

RESULTS

Figure 2 shows a probability plot for U/Pb ages of zircons from the CPW. Zircon ages range from 34 Ma to 2935 Ma. Figure 3 shows an $\varepsilon_{Hf}(t)$ plot of the 337 grains of Late Cretaceous to Early Paleocene max depositional age analyzed for Hf isotopes. These grains range in $\varepsilon_{Hf}(t)$ values from +17.3 to -31.2. This plot includes 213 Precambrian grains and 124 Phanerozoic grains. We do not include grains from sample sites of Late Paleocene or Eocene max depositional age so that we can compare variations along strike for approximately coeval samples. We present our findings as two subsets: Phanerozoic grains, which comprise 90-99% of zircons in the samples from the Chugach-Prince William Terrane, and Precambrian grains.

Phanerozoic zircons

A total of 2599 Phanerozoic detrital zircons with depositional age between 63 Ma and 75 Ma were analyzed for their U/Pb age. The Phanerozoic contains two major age populations: a Jurassic population and a Late Cretaceous to Eocene population, and are consistent along the entire strike of the Chugach-Prince Willian Terrane. Slight variation in peak location of the Late Cretaceous to Eocene population reflects differences in max depositional age rather than source regions. The only significant difference along strike is in the Yakutat Formation, which has a bimodal distribution within the Jurassic population.

Hf isotope compositions of Phanerozoic grains show a strong positive $\varepsilon_{Hf}(t)$ signature for both the Jurassic and Late Cretaceous to Paleocene populations with some important exceptions along strike. The Shumagin Formation has the strongest positive signature with $\varepsilon_{Hf}(t)$ ranging from -3.2 to +11.7, and where most grains plot almost exclusively above CHUR (Fig. 4). The $\varepsilon_{Hf}(t)$ of Phanerozoic grains in the Kodiak and Ghost Rocks Formations range from -17.5 to +11.7. In the Orca Group, this range is -6.9 to +9.4. The Yakutat

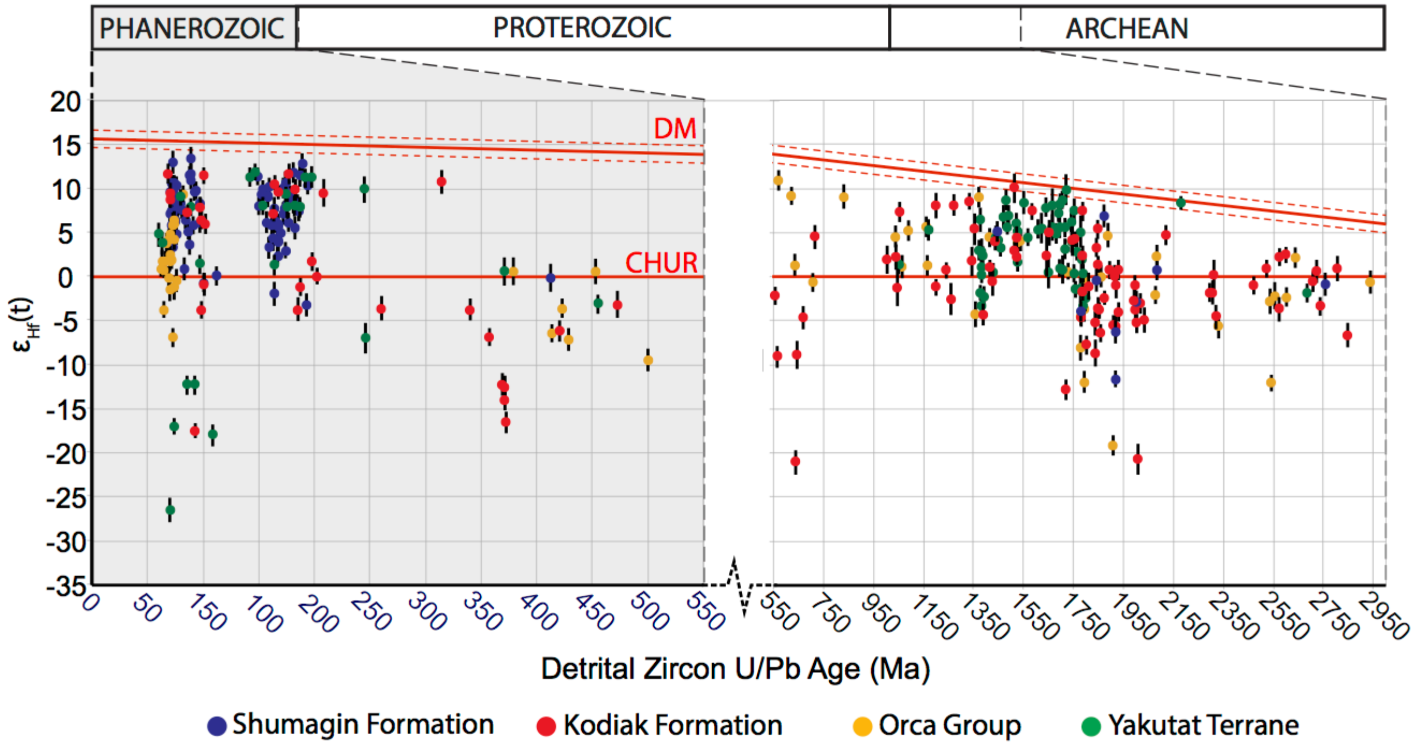

Figure 3. $\varepsilon_{Hf}(t)$ vs. U/Pb age for 337 zircons in the CPW, plotted by field location. The Phanerozoic time scale is expanded relative to the Precambrian time scale. These data indicate that Phanerozoic grains tend to have a positive $\varepsilon_{Hf}(t)$ while Precambrian grains have generally positive $\varepsilon_{Hf}(t)$ from 550 Ma to 1700 Ma and generally negative $\varepsilon_{Hf}(t)$ for grains older than 1700 Ma. DM = Depleted Mantle (Vervoort and Blichert-Toft, 1999). CHUR = Chondrite (Bouvier et al., 2008).

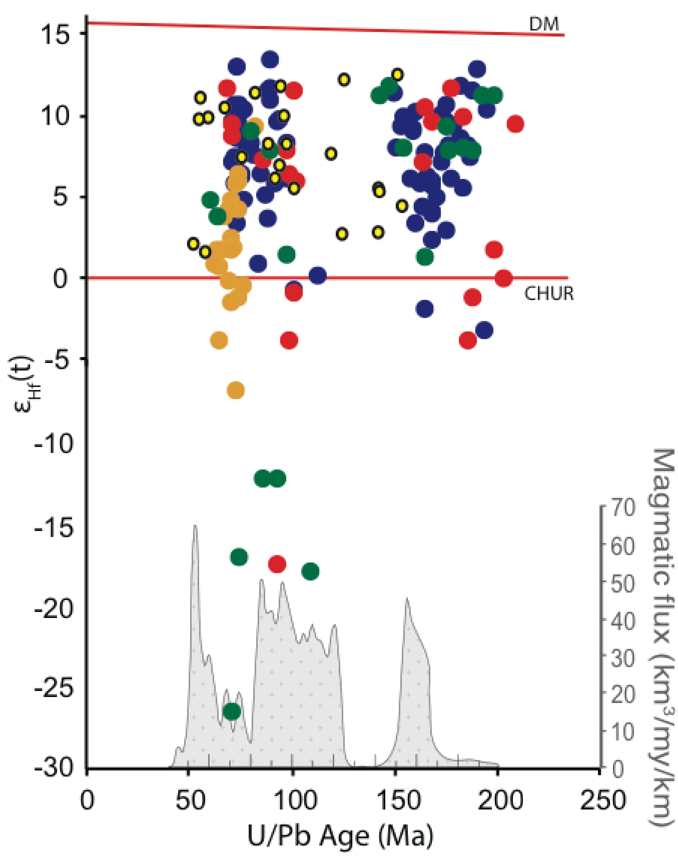

Figure 4. $\varepsilon_{Hf}(t)$ vs. U/Pb age of Mesozoic zircons from this study as well as data from Cecil et al. (2011). Symbols the same as shown in Figures 2&3 with small yellow filled circles from Cecil et al. (2011). The magmatic flux of the Coast Mountains Batholith from Gehrels et al. (2009) is shown for reference. DM = Depleted Mantle (Vervoort and Blichert-Toft, 1999). CHUR = Chondrite (Bouvier et al., 2008).

Formation, which contains an $\varepsilon_{Hf}(t)$ range of -26.5 to +11.9, contains the most negative $\varepsilon_{Hf}(t)$ value in our entire dataset.

Precambrian zircons

A total of 213 Precambrian detrital zircons were analyzed for Hf isotopes. Zircons from the Shumagin Formation, Kodiak and Ghost Rocks Formations, and the Orca Group have U/Pb age distributions with major populations at 1810-1870 and 2520-2680 Ma and have $\varepsilon_{Hf}(t)$ from +13.9 to −21.1 . These values contrast with the age distribution from Yakutat with modes at 1380-1450 and 1710-1740 Ma, and $\varepsilon_{Hf}(t)$ from +11.7 to −3.4. Mesoproterozoic and late Paleoproterozoic (<1750 Ma) zircons from the Yakutat Formation, Kodiak and Ghost Rocks Formations, and the Orca Group have $\varepsilon_{Hf}(t) > -5$ and all zircons between 1420 and 1750 Ma have positive $\varepsilon_{Hf}(t)$ values. These positive values suggest a relatively juvenile source area for the origin of these zircons.

DISCUSSION

Phanerozoic source: The Coast Mountains Batholith

The Coast Mountains Batholith (CMB) is a belt of Jurassic to Paleocene plutons that intruded into western British Columbia and Southeast Alaska between the Stikine Terrane to the east and the Alexander and Wrangelia terranes to the west (Wheeler and McFeely, 1991; Gehrels et al., 2009). The CMB is one of the best-studied plutonic belts in the Cordillera because of its central role in the debate of the final assembly of the Cordillera, and it is the only potential Phanerozoic source terrane for the Chugach-Prince William Terrane for which there are published Hf isotope data (Cecil et al., 2011).

Farmer et al. (1993) used Nd, Sr, and Pb isotopic data to propose that the Coast Mountains Batholith is the source for the Chugach-Prince William Terrane, and argued that the unroofing of the CMB could have provided the enormous volumes of sediment found in the CPW. If the Chugach-Prince William Terrane experienced significant coast-parallel translation, the Coast Mountains Batholith is very likely involved in its provenance.

Along the entire strike of the Chugach-Prince William Terrane, the Phanerozoic U/Pb age populations are consistent with pluton crystallization ages for the Coast Mountains Batholith. Gehrels et al. (2009) attempted to model pulses of magmatism in the CMB by using the extent of present-day exposure of dated plutons over the entire CMB. While only a rough estimate of exposure extent during deposition of the CPW, this magmatic flux diagram suggests that the CMB has both a Jurassic and Late Cretaceous to Eocene magmatic maximum. The Hf data from a transect sampled by Cecil et al. (2011) is plotted with the Gehrels et al. (2009) magmatic flux diagram in Figure 4. These data all plot with positive $\varepsilon_{Hf}(t)$, which suggests that the Coast Mountains Batholith has a strongly juvenile source.

Also shown in Figure 4 are the Phanerozoic $\varepsilon_{Hf}(t)$ data from this study. In the Shumagin Formation, all but two zircons plot with a positive $\varepsilon_{Hf}(t)$. The Kodiak and Ghost Rocks Formation and the Orca Group also have a strong juvenile signature, but some grains plot well below CHUR, which indicates an evolved source. The Yakutat Formation plots positively except for a cluster of extremely evolved grains ($\varepsilon_{Hf}(t)$=-26.5). These data support the conclusions of Farmer et al. (1993) that the young arc populations of the CPW have both juvenile and evolved signatures. While the presence of these evolved signatures does not rule out the Coast Mountains Batholith as the major source terrane for the CPW, we can make the testable prediction that a comprehensive survey of Hf isotope compositions in plutons of the Coast Mountains Batholith should find plutons that contain evolved $\varepsilon_{Hf}(t)$ signatures.

Precambrian zircons: A split Northern-Southern Laurentian signature

Of the Laurentian Precambrian terranes, northern terranes tend to be Archean to Paleoproterozoic, while those to the south tend to be Mesoproterozoic to Neoproterozoic (Whitmeyer and Karlstrom, 2007). U/Pb age populations from the Chugach-Prince William Terrane suggest that the Shumagin Formation, Kodiak and Ghost Rocks Formations, and Orca Group all have a strong Northern Laurentian signature (Davidson and Garver, this volume). However, the Yakutat Formation has a U/Pb age signature that matches reasonably well with Southern Laurentia, specifically the Yavapai-Mazatzal crustal provinces. The Yavapai-Mazatzal is the largest of the southern Laurentian terranes. It is comprised of accreted terranes, orgogenic belts, and anorogenic granites that span nearly the width of North America with ages from 1350 Ma to 1760 Ma (Whitmeyer and Karlstrom, 2007). Major crustal boundaries mapped using Nd-Sm isotope compositions show that the Yavapai-Mazatzal is juvenile crust and has a mantle separation age of 1700-2000 Ma (Bennett and DePaolo, 1987; Goodge and Vervoort, 2006). The age range and juvenile nature of the Yavapai-Mazatzal make it identifiable in the context of North American sediment source regions.

The Precambrian grains from the Chugach-Prince William Terrane can be subdivided based on their $\varepsilon_{Hf}(t)$. Grains older than 1700 Ma tend to have a negative $\varepsilon_{Hf}(t)$ value, which is consistent with a Northern Laurentia signal. Precambrian grains younger than 1700 Ma have a mostly juvenile signature (Fig. 3). Every grain with a U/Pb age between 1436 Ma and 1716 Ma has a positive $\varepsilon_{Hf}(t)$ value, which is consistent with the 1350-1760 Ma age range of the Yavapai Mazatzal. We calculate an approximate mantle separation age of 1550-2100 Ma for this juvenile window (Fig. 3), which fits well with proposed Yavapai-Mazatzal mantle separation ages (Bennett and DePaolo, 1987). Unlike the Shumagin Formation, Kodiak and Ghost Rocks Formations, and the Orca Group, all of which have broad Precambrian age distributions, Precambrain grains from the Yakutat Formation almost exclusively plot in the Yavapai-Mazatzal juvenile window, with less juvenile grains just outside that window.

While Precambrian zircons in the Yakutat Formation may have ultimately come from the Yavapai-Mazatzal Terrane, their path to deposition within the Chugach-Prince William Terrane may include at least one burial and exhumation cycle. Raman spectroscopy of Precambrian zircons reveals that zircons from the Yakutat Formation are crystalline, while zircons from the Kodiak Formation are metamict. This suggests that the source region for the Precambrain grains in the Yakutat Formation experienced burial and metamorphism and was exhumed sometime in the Phanerozoic, most likely in the Mesozoic (Kaminski and Suarez, 2013). There are several schists in the Cordillera that could potentially have a Yavapai-Mazatzal signature, including the California and Orocopia schists.

CONCLUSION

New U/Pb and Hf isotope data from the Chugach-Prince William Terrane shed new light on the multi-decade debate concerning its provenance. This study has two main findings: 1) The Coast Mountains Batholith is a reasonable source region for the bulk of sediments from the CPW, although the Hf isotope data from the Coast Mountains Batholith are limited (n=29). Future Hf isotope data collected from the Coast Mountains Batholith should provided evidence of evolved crustal contamination of the Cretaceous and Paleocene plutons. 2) Analysis of Hf isotopes in Precambrian grains strengthens the case that the Chugach-Prince William Terrane varies along strike from a primarily Northern Laurentian signal in the west to a primarily Southern Laurentian signal in the east. Isotopic analysis of schists in the western Cordillera could provide further constraints to the latitude of deposition of the Chugach-Prince William Terrane.

REFERENCES

Amato, J. M., and Pavlis, T. L., 2010, Detrital zircon ages from the Chugach Terrane, Southern Alaska, reveal multiple episodes of accretion and erosion in a subduction complex: Geology (Boulder), v. 38, no. 5, p. 459-462.

Bennett, V. C., and DePaolo, D. J., 1987, Proterozoic crustal history of the Western United States as determined by neodymium isotopic mapping; with Suppl. Data 87-30: Geological Society of America Bulletin, v. 99, no. 5, p. 674-685.

Cecil, M. R., Gehrels, G., Ducea, M. N., and Patchett, P. J., 2011, U-Pb-Hf characterization of the central Coast Mountains batholith: Implications for petrogenesis and crustal architecture: Lithosphere, v. 3, no. 4, p. 247-260.

Cowan, D. S., Brandon, M. T., and Garver, J. I., 1997, Geologic tests of hypotheses for large coastwise displacements-a critique illustrated by the Baja British Columbia controversy: American Journal of Science, v. 297, no. 2, p. 117-173.

Cowan, D. S., 1982, Geological evidence for post-40 m.y. B.P. large-scale northwestward displacement of part of southeastern Alaska: Geology (Boulder), v. 10, no. 6, p. 309-313.

Cowan, D. S., 2003, Revisiting the Baranof-Leech River hypothesis for early Tertiary coastwise transport of the Chugach-Prince William Terrane: Earth and Planetary Science Letters, v. 213, no. 3-4, p. 463-475.

Farmer, G. L., Ayuso, R., and Plafker, G., 1993, A Coast Mountains provenance for the Valdez and Orca groups, Southern Alaska, based on Nd, Sr, and Pb isotopic evidence: Earth and Planetary Science Letters, v. 116, no. 1-4, p. 9-21.

Gehrels, G. E., Rusmore, M., Woodsworth, G. J., Crawford, M., Andronicos, C., Hollister, L., Patchett, J., Ducea, M., Butler, R., Klepeis, K., Davidson, C., Friedman, R., Haggart, J. W., Mahoney, B., Crawford, W., Pearson, D., and Girardi, J., 2009, U-Th-Pb geochronology of the Coast Mountains Batholith in north-coastal British Columbia; constraints on age and tectonic evolution: Geological Society of America Bulletin, v. 121, no. 9-10, p. 1341-1361.

Goodge, J. W., and Vervoort, J. D., 2006, Origin of Mesoproterozoic A-type granites in Laurentia; Hf isotope evidence: Earth and Planetary Science Letters, v. 243, no. 3-4, p. 711-731.

Haeussler, P. J., Bradley, D. C., Wells, R. E., and Miller, M. L., 2003, Life and death of the Resurrection plate: Evidence for its existence and subduction in the northeastern Pacific in Paleocene-Eocene time: Bulletin of the Geological Society of America, v. 115, no. 7, p. 867-880.

Kaminski, K., and Suarez, K., 2013, Determining radiation damage through Raman spectroscopy analysis of detrital zircon grains in the Chugach-Prince William terrane, Alaska; 23nd Steinmetz Symposium, Union College, Schenectady NY.

Kochelek, E. J., Amato, J. M., Pavlis, T. L., and Clift, P. D., 2011, Flysch deposition and preservation of coherent bedding in an accretionary complex: Detrital zircon ages from the Upper Cretaceous Valdez Group, Chugach terrane, Alaska: Lithosphere, v. 3, no. 4, p. 265-274.

Kusky, T. M., Bradley, D. C., and Haeussler, P. J., 1997, Progressive deformation of the Chugach accretionary complex, Alaska, during a Paleogene ridge-trench encounter: Journal of Structural Geology, v. 19, no. 2, p. 139-157.

Plafker, G., Moore, J. C., and Winkler, G. R., 1994, Geology of the Southern Alaska margin, Boulder, CO, United States (USA), Geological Society of America, Boulder, CO, The geology of Alaska.

Wheeler, J.O., and McFeely, P., 1991, Tectonic Assemblage Map of the Canadian Cordillera: Geological Survey of Canada Map 1712A, scale 1:2,000,000.

Whitmeyer, S. J., and Karlstrom, K. E., 2007, Tectonic model for the Proterozoic growth of North America: Geosphere, v. 3, no. 4, p. 220-259.