Impact of varied slab age and thermal structure on enrichment processes and melting regimes in sub-arc mantle: Example from the Cascadia subduction system.

Nathan L. Green[1], A. Krishna Sinha[2]

[1]Dept. Geological Sciences, University of Alabama, Tuscaloosa, AL 35487
(ngreen@wgs.geo.ua.edu)
[2]Dept. Geological Sciences, Virginia Tech, Blacksburg, VA 24061

Correctly identifying actual fluxes of slab components and how flux and slab chemical inventories are influenced by various physical and kinematic parameters is crucial in attempting mass balance of elements at subduction zones and hence in calculating the flux of continental material recycled into the mantle. The Cascadia subduction system shares tectonic and geochemical relationships with many other convergent margins, but represents an end-member 'hot' subduction environment. The subducting slab has a steep thermal gradient along the slab-mantle wedge interface (Hyndman and Wang, 1993; Oleskevich et al., 1999) and is subject to strong dehydration and depletion of fluid-mobile elements as a result of metamorphism operating primarily within the fore-arc region (Peacock and Hyndman, 1999; Peacock and Wang, 1999).

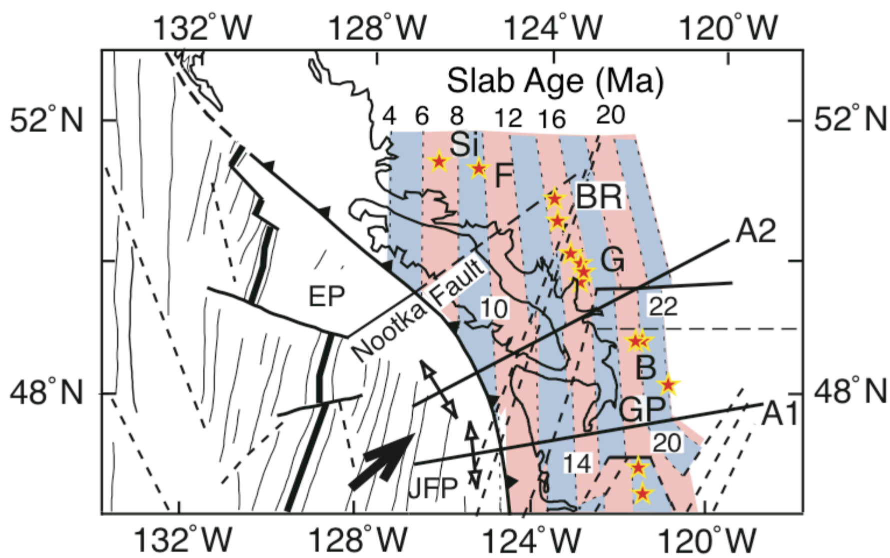

Fig. 1: Tectonic elements of northern Cascadia subduction complex. Isochrons on subducted plate (shaded bars) indicate estimated slab ages beneath convergent margin based on Wilson (1988) reconstruction, modified for slab dip). Also shown: pseudofaults (dashed lines); transform faults (thick lines); oceanic magnetic lineations (thin lines); structural arches in subducted plate (A1 and A2). Volcanic complexes (stars): Silverthrone, Si; Franklin Glacier; Bridge River, BR; Garibaldi, G; Baker, B; Glacier Peak, GP. Arrow indicates Juan de Fuca plate motion relative to North America.

The 15-km-wide Late Cenozoic Garibaldi volcanic belt (GVB) of the northern Cascadia Subduction System is intimately associated with aseismic subduction of extremely young and presumably 'hot' Juan de Fuca plate beneath northwestern Washington and southwestern British Columbia. Magnetic anomalies in the convergent Juan de Fuca plate are oblique to the Cascadia margin, and decrease in age from about 10 Ma along the northern Washington coast to about 5 Ma off Vancouver Island. As a result, the inferred age of subducted oceanic crust decreases from ca. 22 m.y. below Glacier Peak in Washington to about 14 m.y. beneath the northernmost Mosaic (Meager Mountain) and Salal Glacier-Bridge River eruptive centers in British Columbia (Fig. 1) This age difference is consistent with a northward change in the thermal structure of the subducted oceanic crust along the convergent margin (temperature increase up to approximately 75°C at 4 km depth; Green and Harry, 1999). Such variation in thermal state and associated metamorphic conditions in the subducted plate can be expected to influence strongly the nature and extent of associated volcanism.

Major-element, trace-element, and Sr isotopic abundances have been determined for Garibaldi belt basaltic lavas erupted along the volcanic arc (Fig. 2). All GVB basaltic suites exhibit somewhat similar ranges in moderately incompatible and compatible element

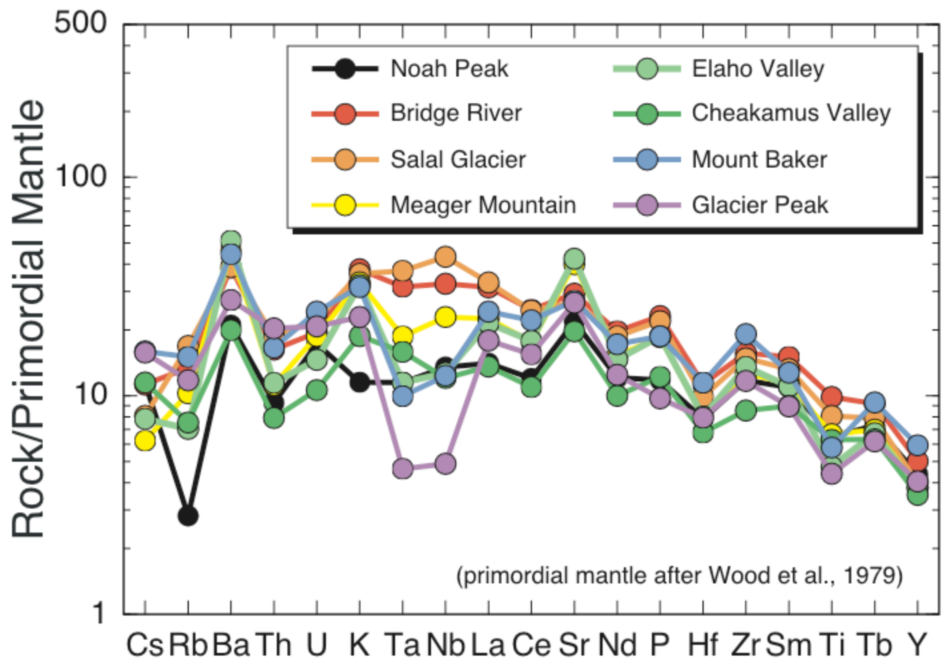

Figure 2. Primordial mantle normalized trace-element patterns of average Garibaldi belt basalts. Note (1) the reduced Nb-Ta anomalies exhibited by lavas in northern (Bridge River and Salal Glacier suites) relative to southern GVB suites (Mount Baker and Glacier Peak) and (2) depletions in Rb, Th and U relative to Ba and K shown by most GVB lavas.

abundances, suggesting that mantle sources in the northern Cascadia system possessed similar degrees of pre-subduction heterogeneity. The primitive and near-primitive basalts (most with Mg# [100Mg/(Mg + Fe)] > 60 and Ni content > 120 ppm), however, exhibit significant arc-parallel variations in major-element, trace-element, and Sr isotopic abundances that correlate with inferred age of underlying subducted oceanic crust (Fig. 3). Minimum Sr-isotopic ratios show a general decrease from 0.70351 to 0.70317 northward along the arc; more elevated values (>0.70382) may reflect limited interaction with Cretaceous basement rocks. The Sr isotopic compositions, unsupported by lava Rb contents, show positive correlations with Cs/Rb, La/Nb, Ba/La, Ba/Nb, Ba/Ta, B/La, B/Zr, Sr/Nd, and Sr/P, and negative correlations with high field strength elements (HFSE: Nb, and Ta), FeO and other transition metals (Co and Zn), Cr/Ni, Sm/Yb, Ta/Yb, Hf/Yb, K/Ba, K/Sr, and La/Yb. The along-strike variations in concentrations of

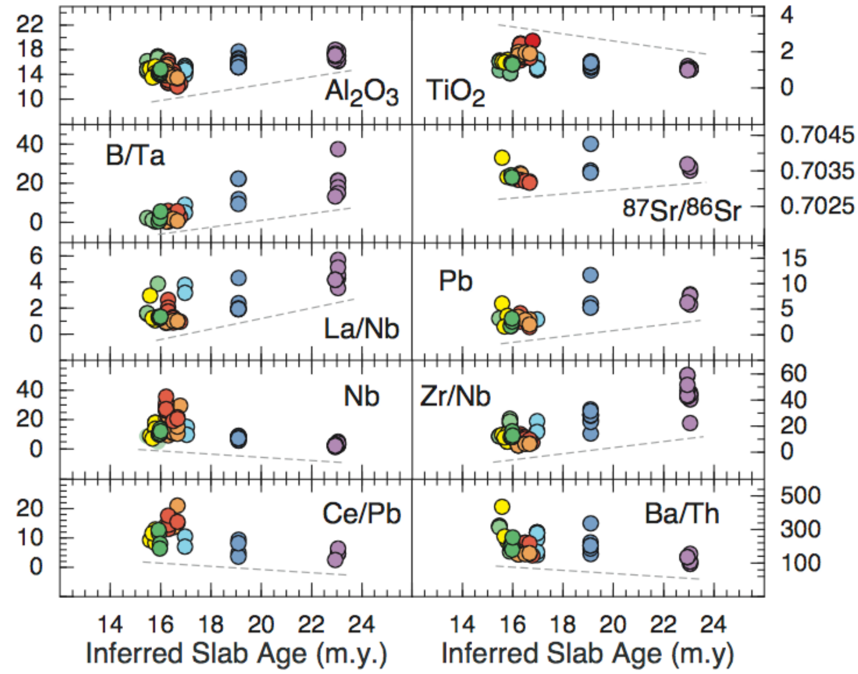

Figure 3. Geochemical variations in Garibaldi belt basalts plotted against inferred slab ages immediately below the volcanic front (arc) inferred from the isochrons in Figure 1. Symbols as in Figure 2.

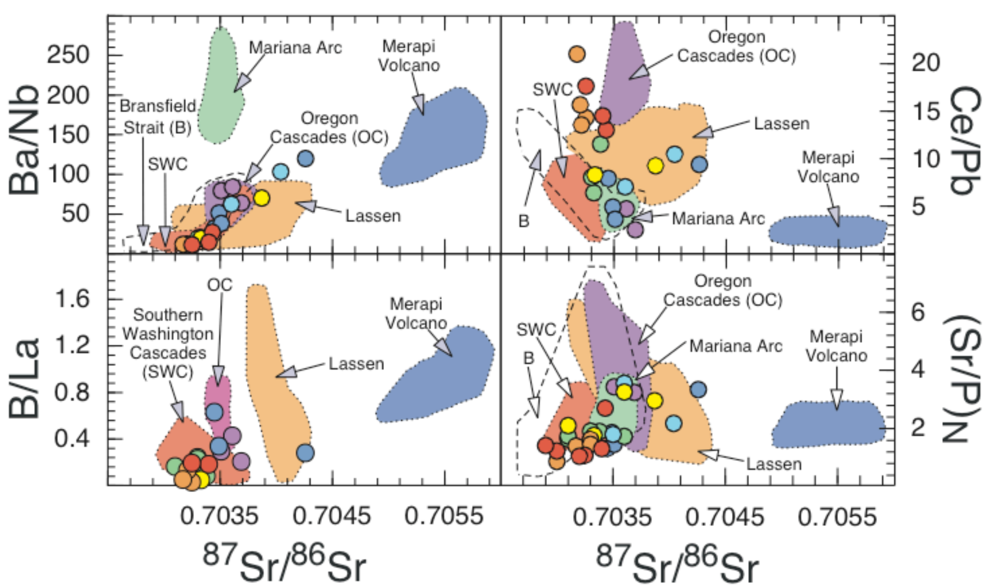

Figure 4. Ba/Nb, Ce/Pb, B/La, and $(Sr/P)_N$ plotted against $^{87}Sr/^{86}Sr$ compositions. Symbols as in Figure 2. Note that southernmost Glacier Peak and Mount Baker lavas tend to have lowest Ce/Pb and highest $^{87}Sr/^{86}Sr$, Ba/Nd, B/La and $(Sr/P)_N$ values of GVB basaltic lavas.

fluid-mobile and immobile elements are suggested to reflect arc-parallel variations in both (1) the nature and extent of slab-derived fluxes and (2) varied degrees of partial melting within metasomatized basalt source regions in the Cascadia mantle wedge. Experimental phase equilibria and geochemical variations suggest that an observed along-strike northward transition from high-alumina olivine tholeiite to alkali basalt and basanite compositions is consistent with magma generation involving lower degrees of melting at higher temperatures and pressures beneath northern eruptive centers. Intrasuite variations of Nb, Ta, Ti, Nb/Ta, Y/Ho and Zr/Hf imply that melting processes responsible for individual GVB eruptive suites involved varied phase assemblages and or different mineral/melt distribution coefficients.

Geochemical variations exhibited by Garibaldi belt lavas place constraints on the nature of slab inputs (melt versus fluid) to originally depleted mantle sources. Sediment normalized Th/Rb values for GVB basalts are greater than unity and compatible with sediment melting processes. The strongest sediment signatures, however, characterize lavas erupted above the southernmost (coolest) part of the subduction system. Elevated B, Ba, K, Pb and $(Sr/P)_N$ in GVB lavas, together with variations in Ba/Nb-Th/Nb (Fig. 5), may indicate the subduction component was dominantly a hydrous fluid derived through sediment dehydration. Along-strike changes in the nature and magnitude of the slab signature in GVB basalts are compatible with increasingly reduced (slab and/or mantle wedge) magma production in the northern Cascadia Subduction system, as the subducted lithosphere becomes younger, hotter, and possibly drier.

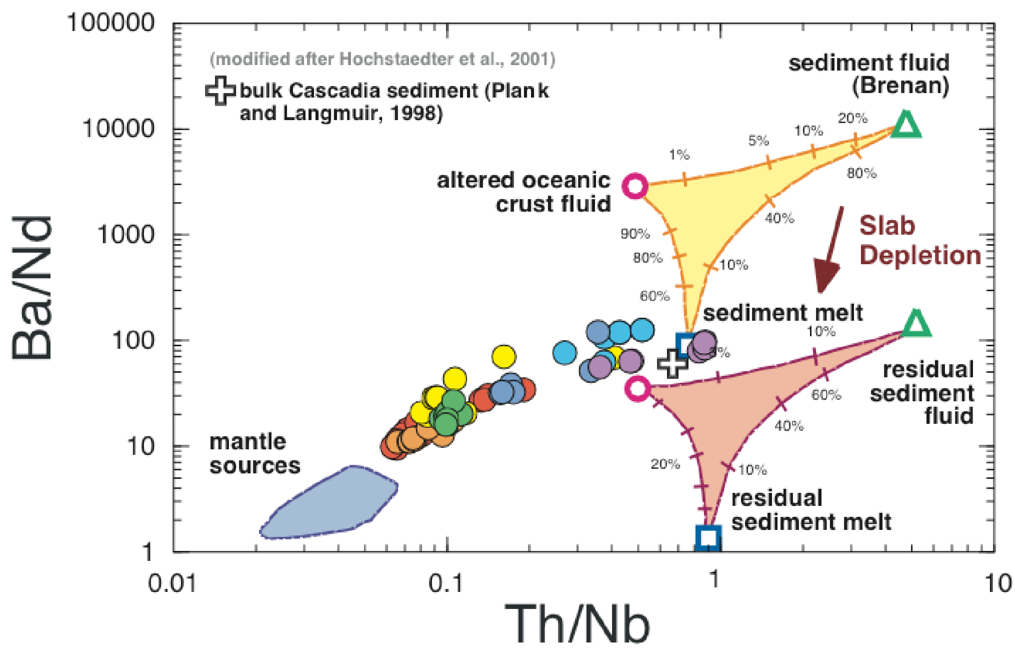

Figure 5. Th/Nb versus Ba/Nb diagram shows a data trend for GVB basalts that may be fit to a family of mass balance mixing lines between mantle compositions and either a sediment melt or residual sediment fluids from a variably depleted slab component.

References

Green and Harry, 1999, Earth and Planetary Science Letters 171: 367-381.
Hochstaedter et al., 2001, Geochemistry, Geophysics, Geosystems 2: 2000GC000105
Hyndman and Wang, 1993, Journal of Geophysical Research, 98, 2039-2060
Oleskevich et al., 1999 Journal of Geophysical Research, 104, 14965-14991.
Peacock and Hyndman, 1999, Geophysical Research Letters, 26, 2517-2520.
Peacock and Wang, 1999, Science, 286, 937-939.
Wood et al., 1979, Contributions to Mineralogy and Petrology 70: 319-339.