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Petrology of the Basalt of Summit Creek: A [Slab] Window into Pacific Northwest Tectonics During the Eocene

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Abstract

Passage of Eocene slab windows beneath the Pacific Northwest is documented by plate motion reconstructions as well as the on-land geologic record. The earliest known record of this process is the 55-44 Ma Basalt of Summit Creek (BSC), a steeply dipping 1600 m section of subaerial lavas exposed southeast of Mount Rainier. These tholeiitic basalts erupted in an arc setting (as evidenced by underlying tuffs) but display a mix of MORB and OIB traits (0.1 – 1.2 wt. % K_2O, Y/Nb = 1.1-5, concave spidergram profiles) and have isotopic signatures of a depleted mantle source ($^{207}Pb/^{204}Pb < 15.56$; εNd = +5.8 to +7.8). In chemical and isotopic composition BSC lavas overlap with the voluminous Crescent Formation basalts on the Olympic Peninsula, which are of similar age but located ~100 km farther west. A few BSC samples display arc traits (e.g., HFSE depletions); we suggest these may record interaction between ascending asthenospheric mantle / melts and a mantle wedge previously modified by subduction processes.

Compositional diversity among BSC lavas (Mg# 66-30) appears to reflect both fractional crystallization and source heterogeneity. Modeling with MELTS (Ghiroso and Sack, 1995) indicates that differentiation dominated by removal of clinopyroxene and plagioclase took place at mid crustal depths (P = 5 kbar) and that the parent magma had <0.2 wt. % water. However, this process cannot account for all incompatible element data, which appear to require multiple parent magmas.

Field Setting of Basalt of Summit Creek

- ~1600 m thick section of steeply dipping (~66°) subaerial Eocene (55-45 Ma) basalt flows (Figure 1).
- Located SE of Mt. Rainier (Figure 2).
- Unconformably overlies pre-Tertiary basement rocks (Figure 2).
- Overlies and interbedded with arc tuffs and magmas (Figure 3).
- Contains plagioclase, clinopyroxene and iron oxides.

Figure 1

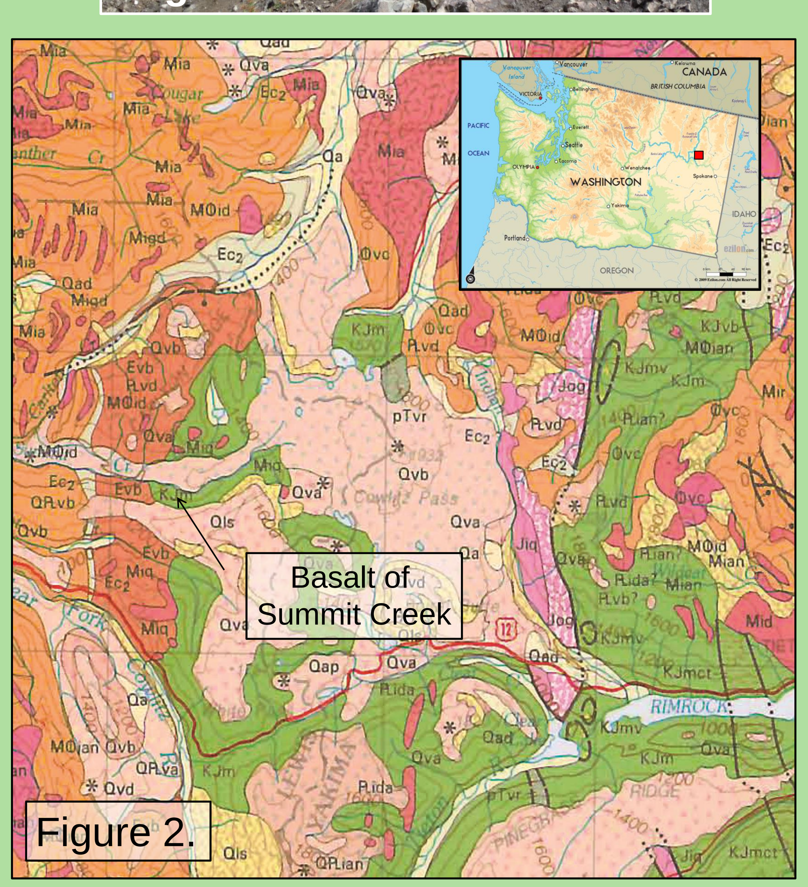

Figure 2.

Petrologic Diversity

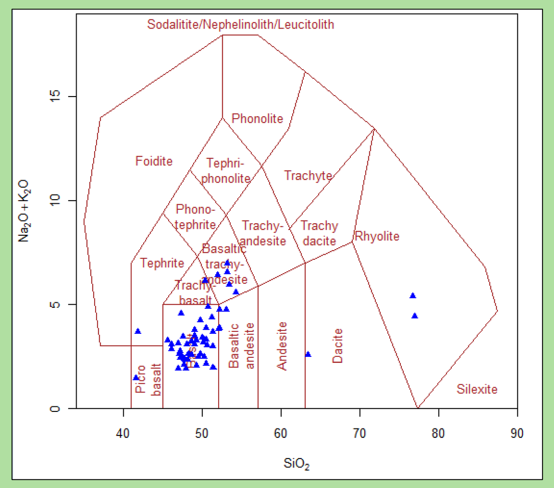

Figure 4

- BSC lavas are mainly basalt with minor basaltic andesite and rhyolite (Figure 4).
- Mg # 66-30

Fractional Crystallization

- MELTS (Ghiorso and Sack, 1995) was used to model fractional crystallization
- Results indicate that BSC evolved via removal of clinopyroxene, plagioclase and minor phases at mid-crustal depths (P=5 kbar) from a parent magma with ≤0.2 wt. % water (Figures 5 a-f)
- However, fractional crystallization alone cannot explain large variations (>100% at a given Mg#) that is present in CaO , Na_2O and other elements.

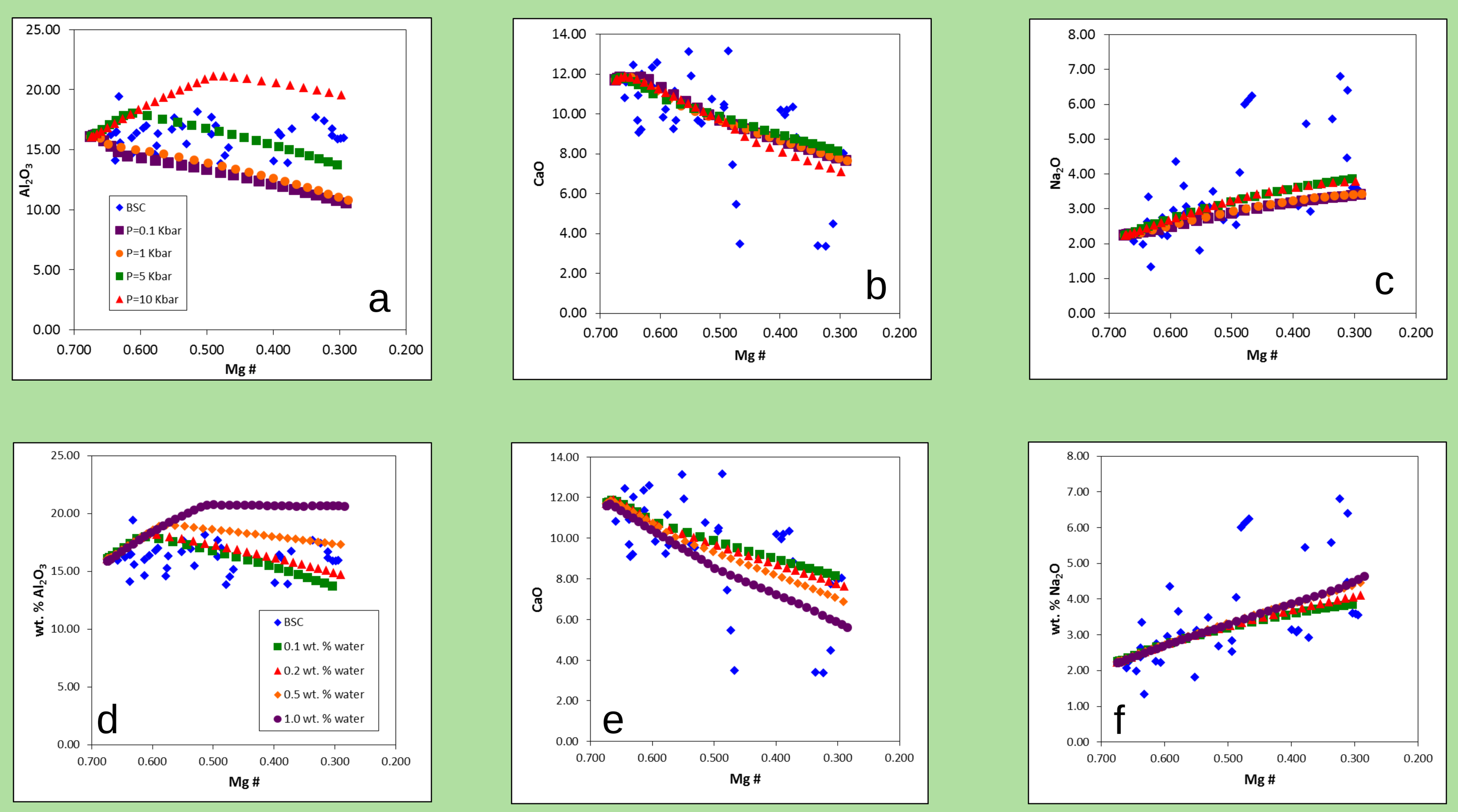

Figure 5

- MELTS data was also used to calculate fractional crystallization vectors for highly incompatible trace elements (D=0)
- These elements remain almost entirely in the melt, so they are extremely sensitive to fractional crystallization
- Results demonstrate that fractional crystallization is at least partly responsible for trace element diversity (Figure 6).
- As with major elements, fractional crystallization cannot account for >100% variation at a given Mg # that is seen in Th, U and other elements.
- For Sr there seem to be two patterns, one of which cannot be explained by fractional crystallization.

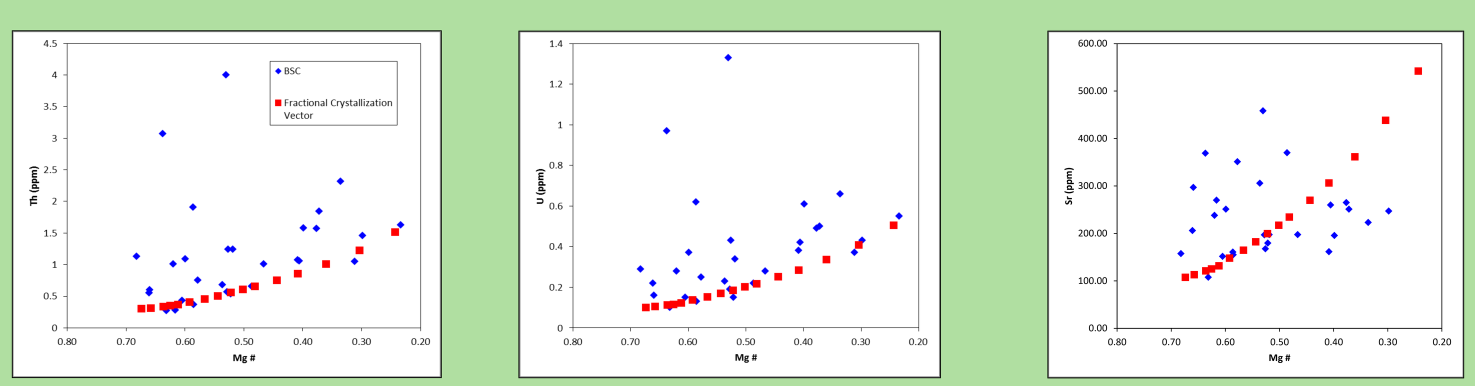

Figure 6

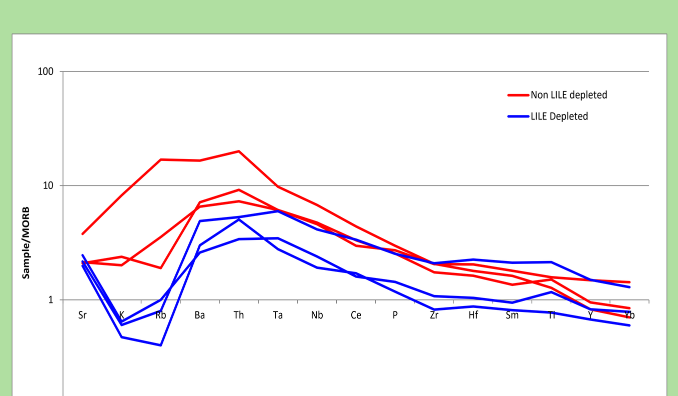

Figure 7

Source heterogeneity:

- Trace element concentrations indicates that BSC is mostly OIB.
- Spidergram patterns appear to define two groups: one series has a LILE depletion in K and Rb, the other does not and is slightly more enriched (Fig 7).
- This may be a sign of source heterogeneity.

Tectonic Setting

- BSC are oceanic tholeiites (Figures 8 and 9).
- They have a combination of OIB and MORB affinities: Y/Nb=7.2-16.3 (Figure 10), varying amounts of enrichment relative to MORB (Figure 5), and are enriched relative to modern Juan de Fuca MORB in terms of Pb isotopes (Figure 11).

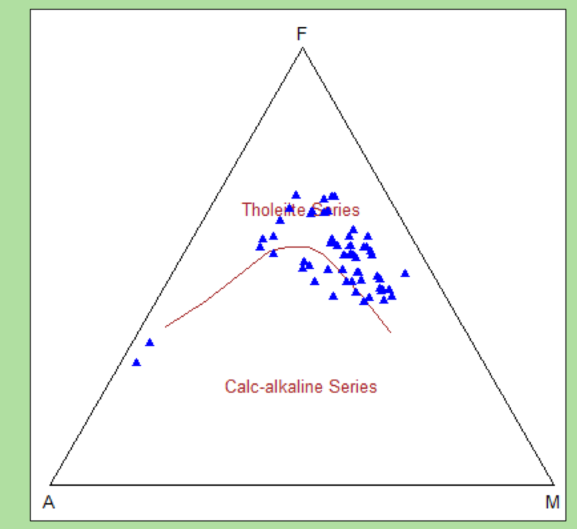

Figure 8

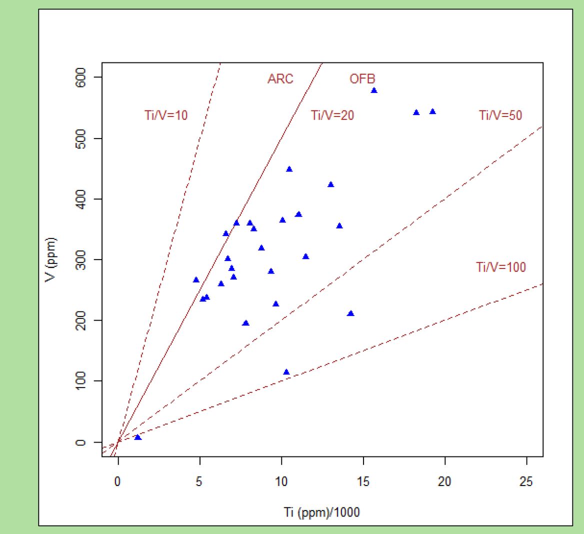

Figure 9

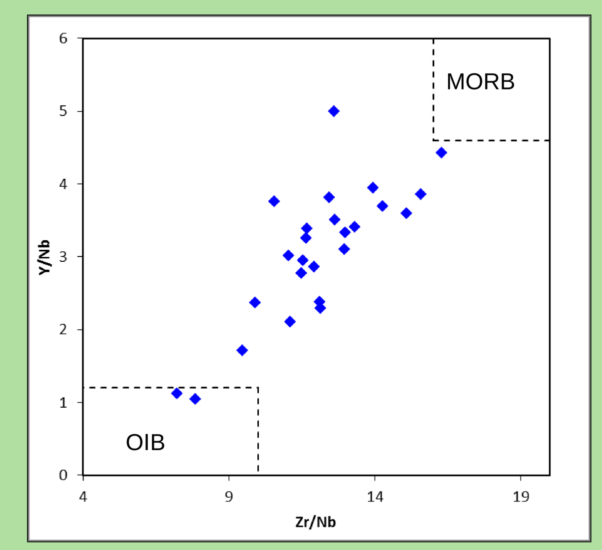

Figure 10

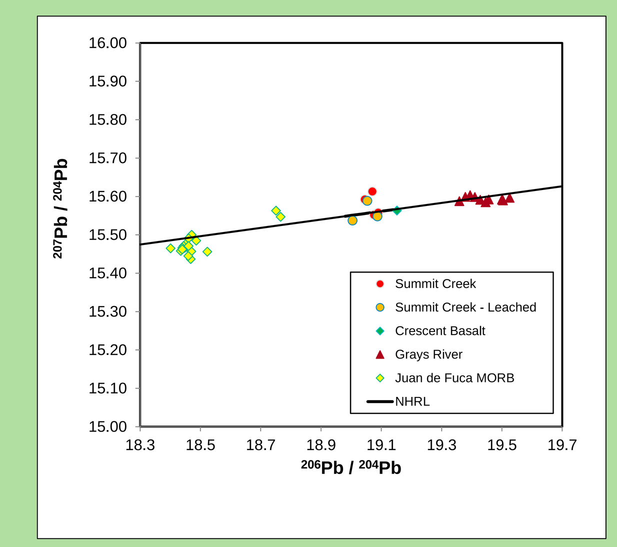

Figure 11

Arc –Slab Window Transition

- Arc-related tuff beneath the BSC indicates emplacement in a subduction zone setting.
- Additional exposures of arc rocks at Bear Creek; together these may represent the southern continuation of the North Cascades arc (Miller et. al., 2009; Tepper and McKinley, 2011).
- Lavas at the base of BSC have more pronounced OIB affinities (Figures 10,12).
- Lavas higher in the section magmas display a mix of of OIB and MORB traits (Figures 7, 10).
- A slab window provides an mechanism for asthenosphere derived magmas to reach the surface without acquiring are traits.
- Less common lavas with hybrid arc/MORB (HSFE depletion) traits (Figure 13) occur throughout the section suggesting minor interaction of rising asthenospheric mantle with arc-modified mantle wedge.
- Plate reconstructions are consistent with passage of the Kula-Farallon slab window beneath summit creek during this time (Figure 14).

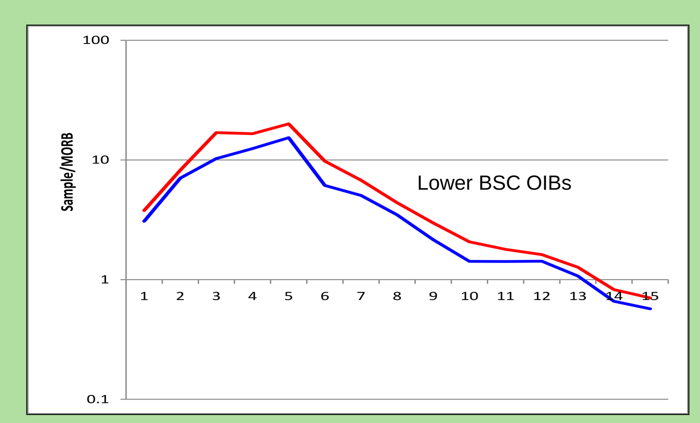

Figure 12

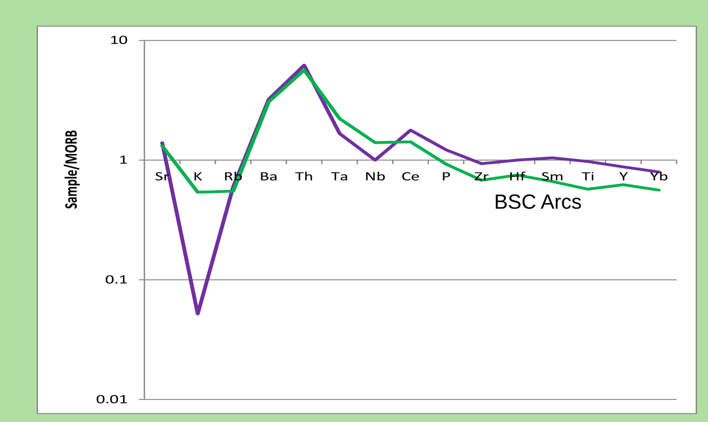

Figure 13

Figure 3

Comparison to the Crescent Basalts

- The Crescent Basalts are exposed ~100 km to the west of the Summit Creek area and consist of voluminous tholeiitic lavas with a mix of MORB/OIB affinities.
- Ages of Crescent Basalts overlap with those of BSC.
- BSC are very similar to the Crescent Basalts in terms of major and trace element chemistry (Figure 14); as well as Epsilon Nd and Sr^{87}/Sr^{86} (Figure 15).
- Crescent Basalts are thought to have erupted in rift basins that opened in response to oblique subduction of the Kula-Farallon spreading ridge, inboard of the trench this process would have been manifested as a slab window.

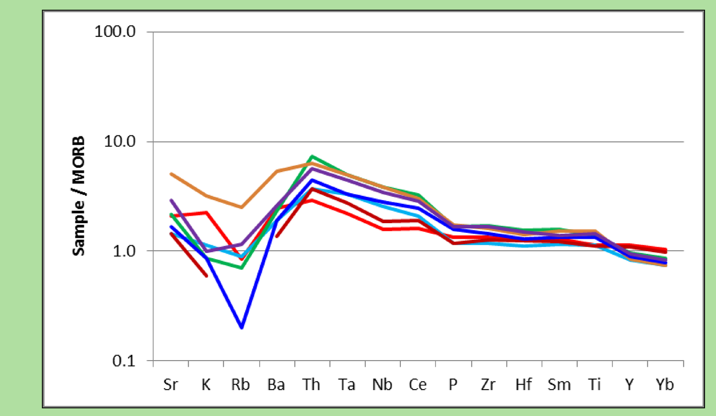

Figure 15

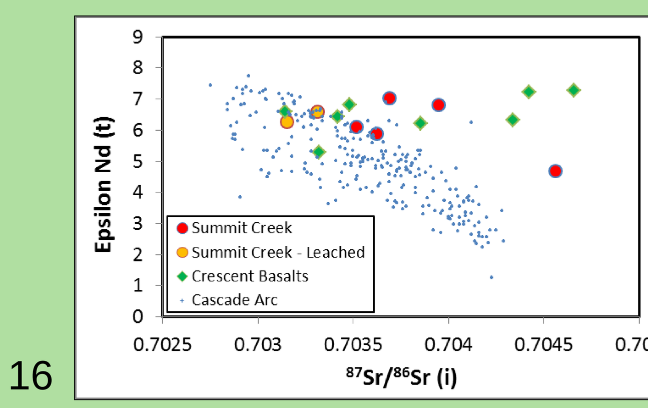

Figure 16

Conclusions

- BSC are mainly basalt with OIT and EMORB features, indicating that BSC had a asthenospheric source..
- Mechanisms for diversity include fractional crystallization and source heterogeneity.
- BSC are broadly similar to the Crescent Basalt.
- Petrologic and plate reconstruction data (Figure 17) suggest that the BSC formed in a slab window setting.

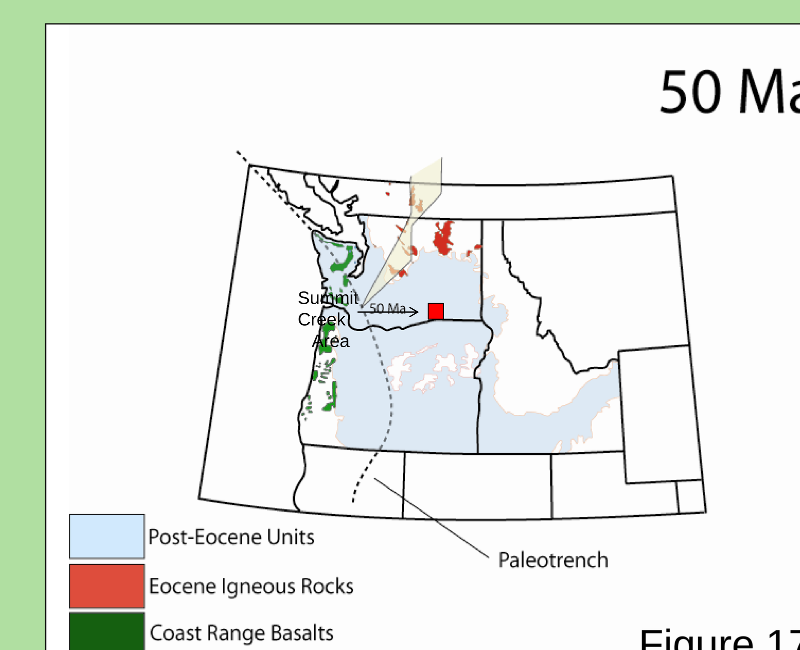

Figure 17

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Acknowledgements

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