TECTONIC EVOLUTION OF THE POLYGENETIC INGALLS OPHIOLITE COMPLEX, CENTRAL CASCADES, WASHINGTON: A POSSIBLE RECORD OF JURASSIC FOREARC ACCRETION AND RIFTING?

Paper No. 229-8

MACDONALD, James H., Jr, MILLER, Robert B., and MILLER, Jonathan S.

ABSTRACT

The Ingalls ophiolite complex, Washington Cascades, is dismembered and consists of ultramafic rocks that contain oceanic crust as large-scale fault blocks in a serpentinite mélange. This mélange separates lherzolite in the north from harzburgite and dunite in the south and overprints mylonitic lherzolite. Mineral assemblages in the mylonitic lherzolite suggest T > 900° C and were interpreted to have formed in a fracture zone. Crustal units in the large fault blocks are well preserved and divided into the: Iron Mt. unit; Esmeralda Peaks units; and sedimentary rocks of the Peshastin Fm. The Iron Mt. unit consists of pillow basalt and broken pillow breccia, with minor rhyolite, hyaloclastite, oolitic limestone and chert. A U-Pb zircon age from a rhyolite is *ca.* 192 Ma. Geochemical affinities of this unit are transitional between OIB and E-MORB. Sediments that overlie this unit are Early Jurassic (Pliensbachian). The Esmeralda Peaks unit consists of pillow and massive flows, diabase with minor sheeted dikes, gabbro and rare tonalite and trondhjemite. A U-Pb zircon age from a gabbro is *ca.* 161 Ma. Geochemical affinities of this unit are transitional between island arc tholeiite and N-MORB, and rare boninites exist. Late Jurassic (Oxfordian) sediments conformably overlie this unit and have geochemical affinities indicating a volcanic arc provenance.

It is interpreted that the Iron Mt. unit formed as an off axis seamount *ca.* 192 Ma. This seamount was then accreted onto an Early Jurassic forearc as the oceanic lithosphere it sat on was subducted. Early Jurassic sediments were then deposited on this accreted seamount. Rifting of this forearc began in the Late Jurassic, forming oceanic crust of the Esmeralda Peaks unit. This forearc ophiolite then transitioned into a back-arc basin that included a fracture zone. Late Jurassic sedimentation probably initiated in the forearc and continued in the back-arc. Thus, the Iron Mt. unit and overlying Early Jurassic sediments formed the rifted basement for the Late Jurassic Esmeralda Peaks unit and overlying sediments. This polygenetic ophiolite was then accreted onto the North American margin and translated to the north. It was thrusted over the Cascade Crystalline Core in the Late Cretaceous.

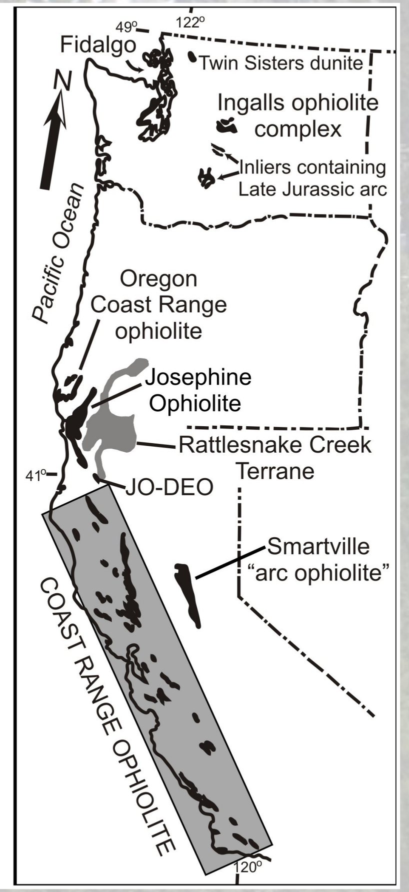


Figure 1

Mid-Late Jurassic ophiolites of the North American Cordilleran. Displaying the: Coast Range; Josephine; and, Ingalls. Modified from Metzger et al. (2002).

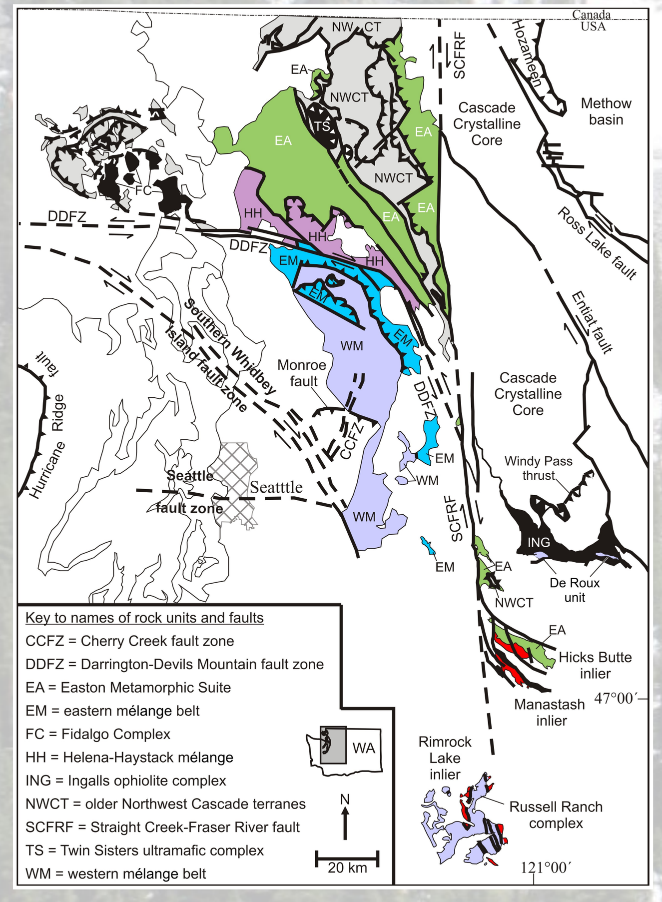


Figure 2

Simplified geologic map displaying pre-Cenozoic tectonic elements of the central and northwest Cascades. Modified from Miller et al. (1993), Tabor (1994), and Brown and Dragovich (2003).

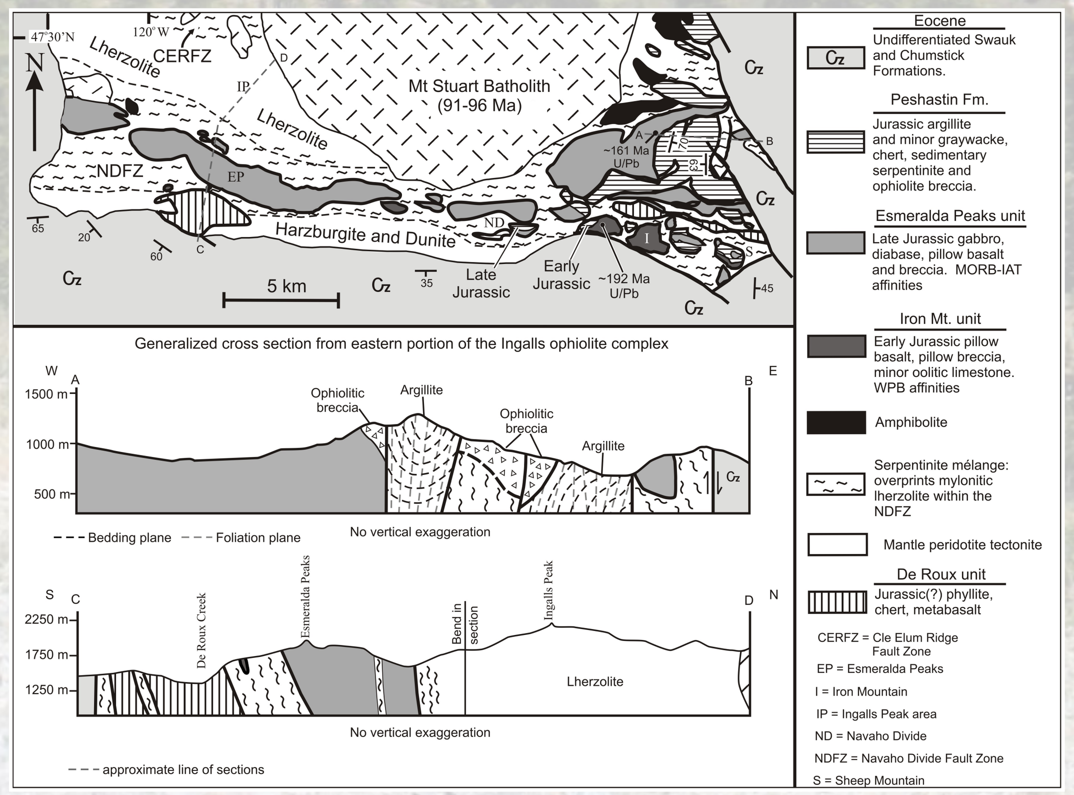


Figure 3

Generalized geologic map of the Ingalls ophiolite complex. Generalized cross section is through the eastern portion of the complex. Modified from Miller (1985), Miller et al. (1993) and MacDonald et al. (2008a). East-west cross section was drafted by A. N. Mlinarevic and is used with permission.

- 3 mantle types
- *ca.* 192 Ma Iron Mt. unit
- *ca.* 161 Ma Esmeralda Peaks unit
- Early and Late Jurassic sediments

STATEMENT OF PROBLEM

- In the southeastern portion of the Ingalls ophiolite complex (Fig. 3), the Sheep Mountain and Kings Creek areas, there is an unusual occurrence where Early Jurassic ophiolitic basement, the Iron Mt. unit, appears to conformably sit under Early Jurassic argillite (Fig. 4 & 5). This Early Jurassic argillite transitions to Late Jurassic argillite (based on radiolarian fossils in chert; Fig. 4 & 5). Finally, Late Jurassic ophiolitic rocks, the Esmeralda Peaks unit, sits conformably on top of the Late Jurassic argillite (Fig. 4 & 5).
- What tectonic setting could have resulted in the unusual occurrences of lithologies in the Sheep Mountain and King Creek areas of the Ingalls ophiolite complex (Fig. 4 & 5)?

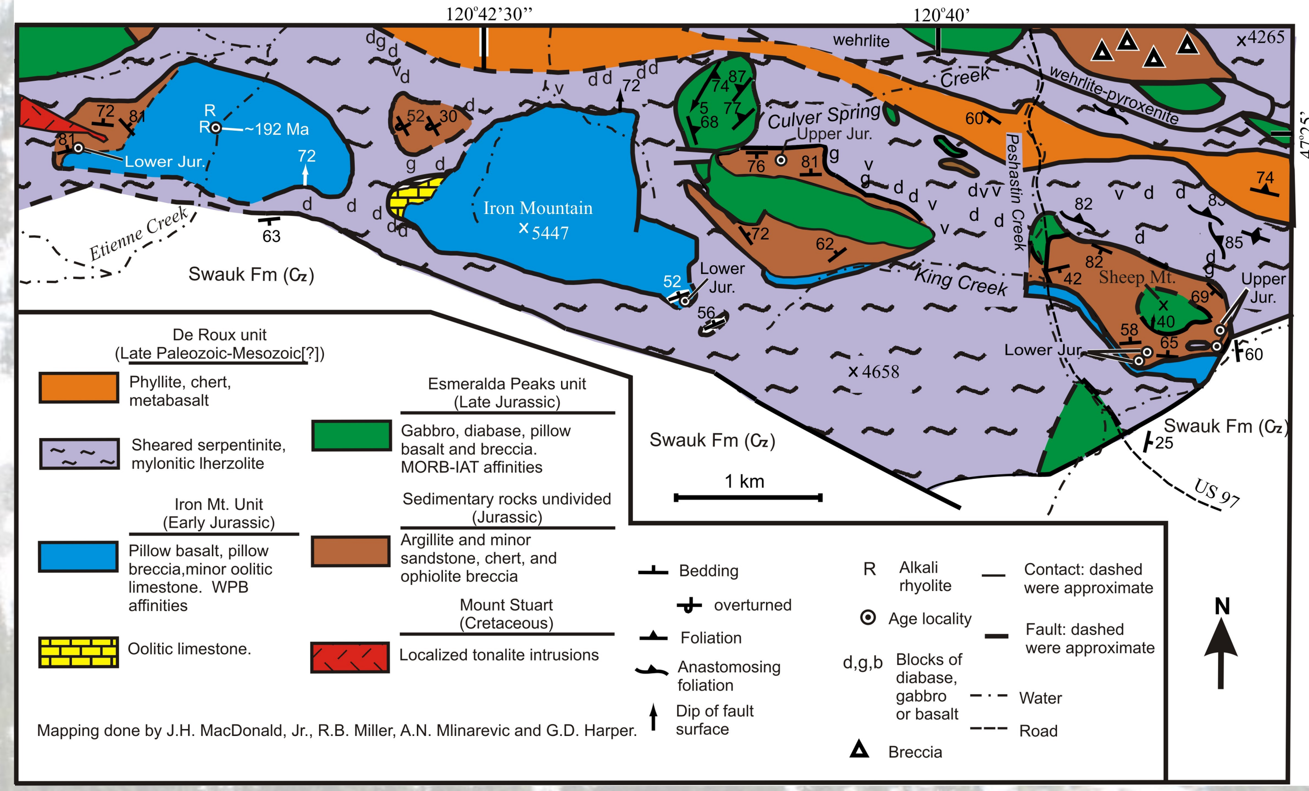


Figure 4

Generalized geologic map of the southeastern portion of the Ingalls ophiolite complex. Note the Sheep Mt. and King Creek area geology. Figure modified from MacDonald et al. (2008b)

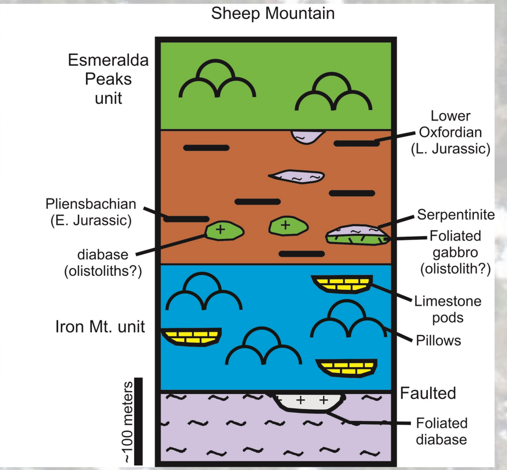
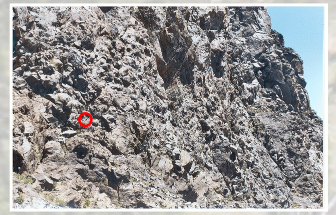


Figure 5

Generalized geologic column of Sheep Mountain. Figure modified from MacDonald et al. (2008b)

Figure 6

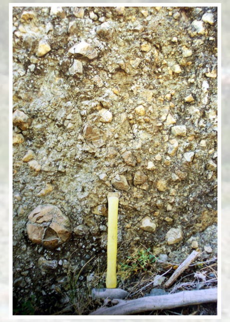
Iron Mountain unit geology



Pillow lava. Massive flows also common.

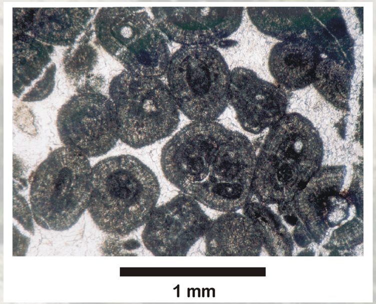
Intra-pillow limestone is common in pillows. Vesicles also common.

Massive bedded limestone sits conformably on basalt.



Broken pillow breccia is commonly bedded between flows.

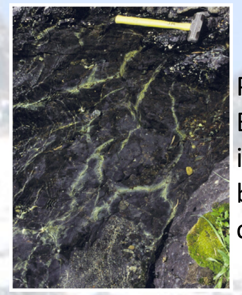
Hyaloclastites are also bedded between flows.



Photomicrograph of oolitic limestone from Iron Mountain unit

Figure 7

Esmeralda Peaks unit geology



Pillow flows. Broken and isolated pillow breccia are also common.

Sheeted diabase dikes. Massive diabase is more common.

Isotropic gabbro with mafic and pegmatitic gabbro dikes.

Figure 8

Peshastin Formation

Peshastin Formation consists predominantly of argillites with lesser chert, volcaniclastic sandstone, and breccia.

Chert yields both Early and Late Jurassic age radiolarians.

AGE OF UNITS

IRON MOUNTAIN UNIT:

- MacDonald et al. (2008a) reported a multi-fraction TIMS U-Pb zircon age from an Iron Mountain unit rhyolite as 192 ± 0.3 Ma (2σ; MSWD = 3.3) (Fig. 3 & 4).
- MacDonald et al. (2008a) reported intra-pillow chert that contained Early Jurassic age (Pliensbachian) radiolarian fossils (Fig. 3 & 4).

ESMERALDA PEAKS UNIT:

- Miller et al. (2003) reported a multi-fraction TIMS U-Pb zircon date from a hornblende pegmatite gabbro of the Esmeralda Peaks unit as 161 ± 1 Ma (2σ weighted mean $^{206}Pb/^{238}U$ age of three nearly concordant fractions) (Fig. 3).

PESHASTIN FORMATION:

- MacDonald et al. (2008b) reported Early Jurassic (Pliensbachian) radiolarian fossil ages from Peshastin Fm. chert that sits above the Iron Mt. unit (Fig. 3 & 4).
- Miller et al. (1993) and MacDonald et al. (2008a) reported Late Jurassic (Oxfordian) radiolarian fossil ages from Peshastin Fm. chert that sits above the Esmeralda Peaks unit (Fig. 3 & 4).
- Miller et al. (2003) reported U-Pb ages of detrital zircons found within a Peshastin Fm. sandstone to have a bimodal age distribution of 153 Ma and *ca.* 227 Ma.

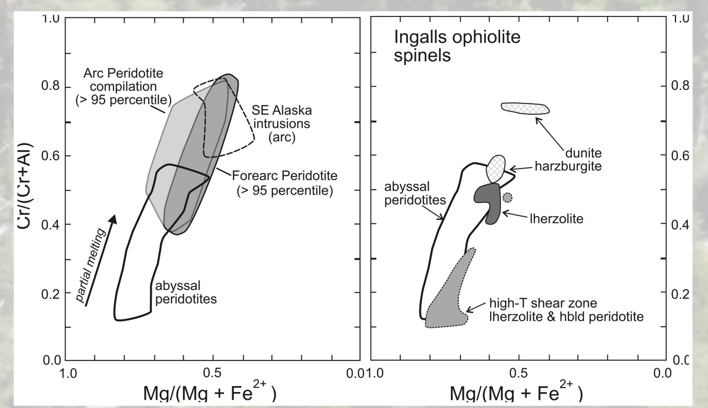


Figure 9

Cr-spinel geochemistry from the Ingalls mantle units. Data from Miller & Mogk (1987). Fields in "A" from Dick & Bullen (1984) and Ari et al. (2011).

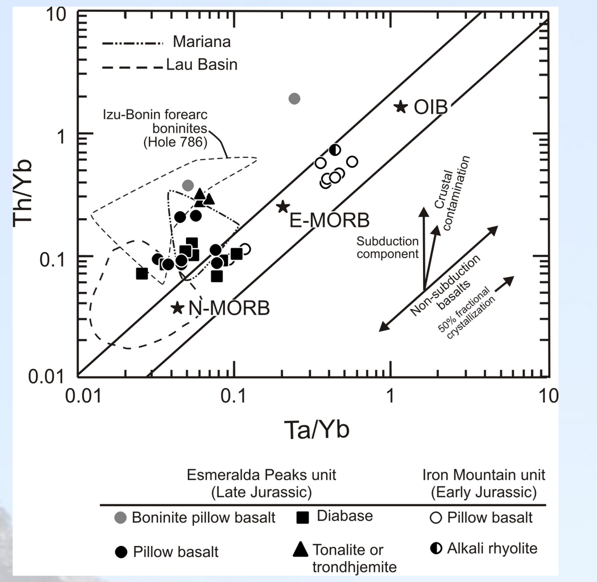


Figure 10

Th/Yb-Ta/Yb diagram from Pearce (1982) for Ingalls ophiolite complex samples. Symbols are also used in Figures 11 and 12. Modified from MacDonald et al. (2008a).

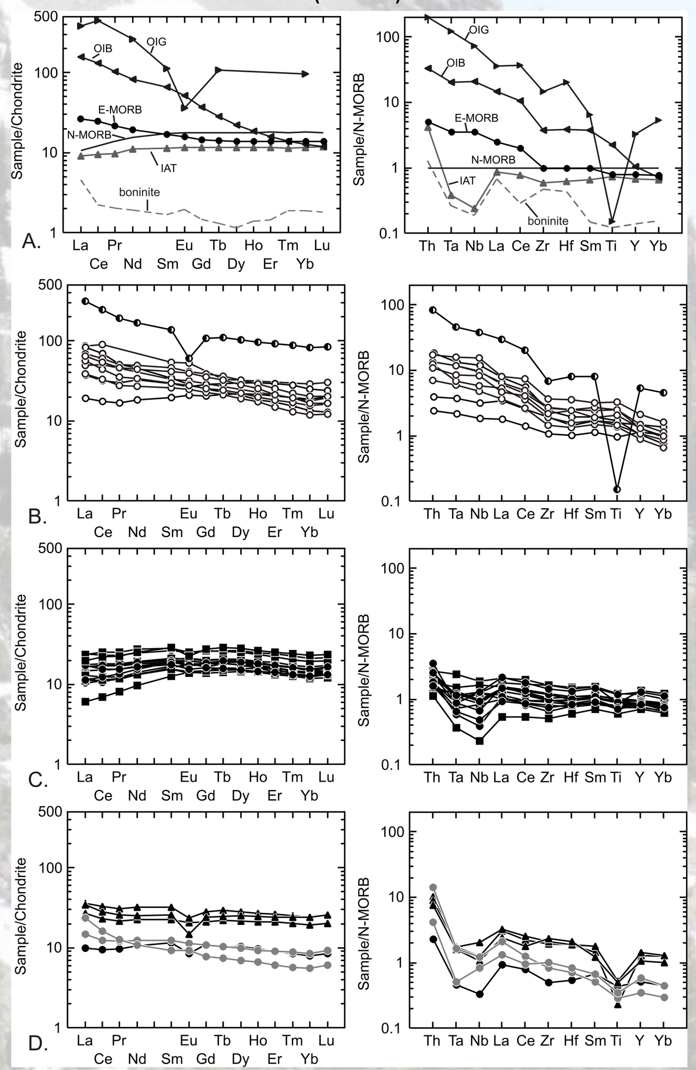


Figure 11

Chondrite- & N-MORB-normalized diagrams for Ingalls ophiolite complex samples. Normalization values from McDonough & Sun (1995).

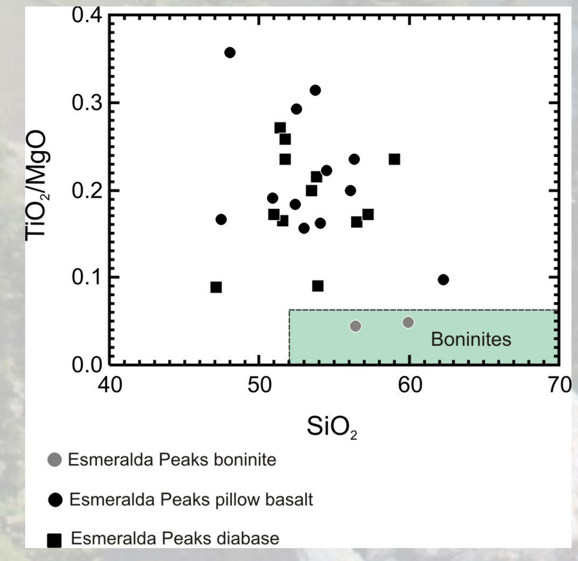


Figure 12

Major element classification of boninites from the Esmeralda Peaks unit. Values from Le Maître (2002).

DISCUSSION

- The Iron Mountain unit consists primarily of highly vesicular pillow flows and shallow water limestone (Fig. 6).
- The geochemistry of the Iron Mountain unit is indicative of deep mantle melting as a result of decompression (Fig. 10 & 11) that is transitional to E-MORB. This is consistent with an oceanic islands that erupted in proximity to a divergent plate boundary.
- The lithologies, age, and transitional OIB-E-MORB affinities suggest the Iron Mountain unit originated as an Early Jurassic seamount that was in proximity to a divergent plate boundary (Fig. 13).
- The Esmeralda Peaks unit consists primarily of pillow flows, massive diabase, and gabbro (Fig. 7). Sheeted dikes and "plagiogranite" are rare.
- The geochemistry of the Esmeralda Peaks unit is indicative of shallow mantle melting as a result of decompression melting that was "contaminated" by arc metasomatism above a downgoing plate (Fig. 10 & 11).
- The Esmeralda Peaks unit contains rare boninites and other "primitive" arc flows (Fig. 10, 11, & 12).
- The lithologies, age, and geochemistry suggest the Esmeralda Peaks unit originated in a forearc setting that transitioned into a back-arc basin (Fig. 13).
- Accretion of the Iron Mountain unit into a forearc, followed by forearc rifting to establish the Esmeralda Peaks unit, could had resulted in the age relationships observed in the Peshastin Fm., Sheep Mountain and King Creek areas (Fig. 3, 4, 5, 8, & 13).
- The Cr-spinel geochemistry of the southern harzburgite and dunite supports high degrees of partial melting in a forearc setting (Fig. 9); however, the relationship between the mantle and crustal units in the Ingalls is not understood (Fig. 3).
- The juxtaposition of different mantle types across the Navaho Divide fault zone (Fig. 3), and Mineral assemblages in the mylonitic lherzolite suggest T > 900° C, lead Miller & Mogk (1987) to suggest that the Ingalls was cut by a possibly Late Jurassic fracture zone.

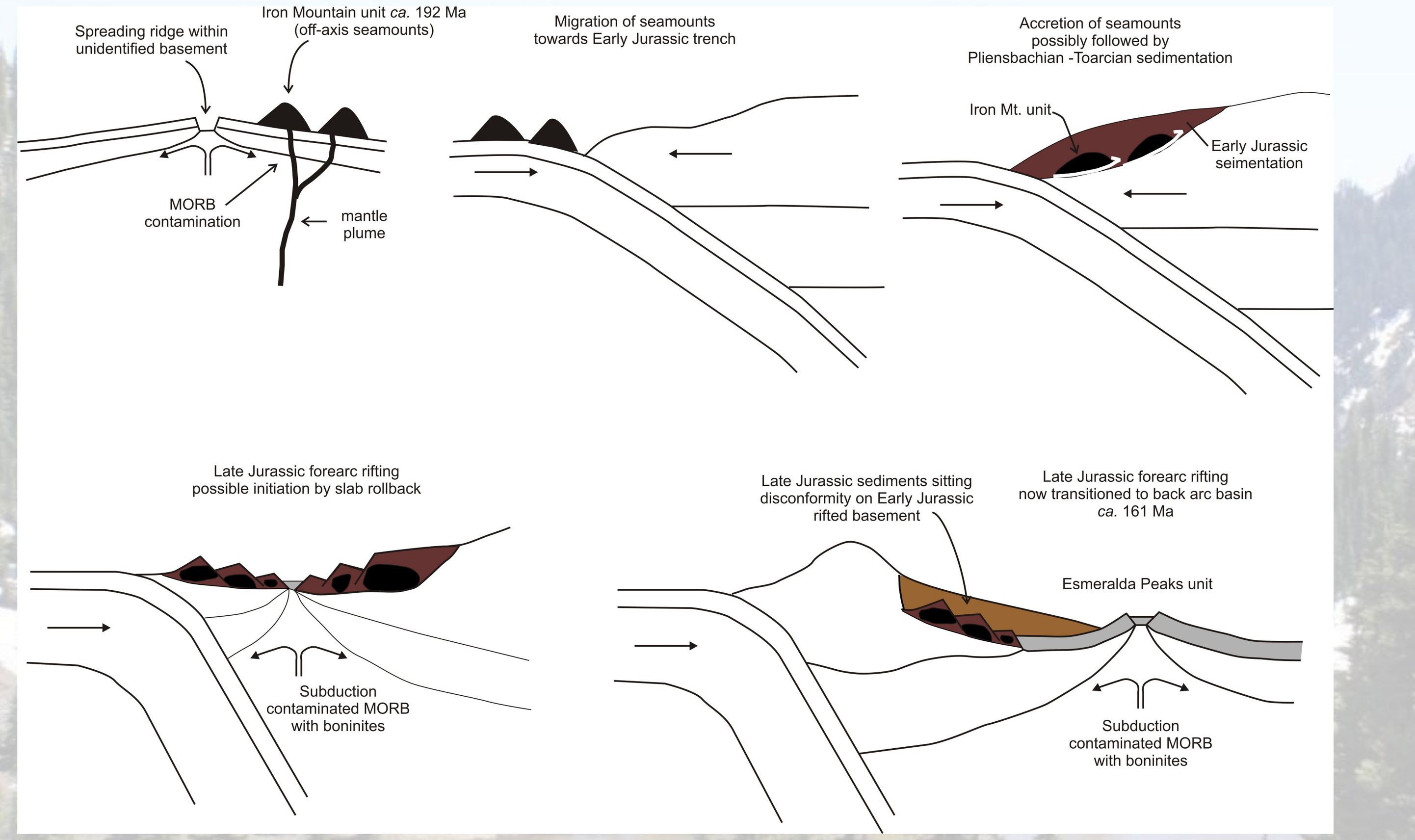


Figure 13

Tectonic cartoon for the possible evolution n of the Ingalls ophiolite units.

SELECTED REFERENCES

MacDonald, J.H., Jr., Harper, G.D., Miller, R.B., Miller, J.S., Mlinarevic, A.N., and Schultz, C.E., 2008a, The Ingalls ophiolite complex, central Cascades, Washington: Geochemistry, tectonic setting, and regional correlations, in Wright, J.E., and Shervais, J.W., eds., Ophiolites, Arcs, and Batholiths: A Tribute to Cliff Hopson: Geological Society of America Special Paper 438, p. 133–159.

MacDonald, J.H., Jr., Harper, G.D., Miller, R.B., Miller, J.S., Mlinarevic, A.N., and Miller, B.V., 2008b, Geochemistry and geology of the Iron Mountain unit, Ingalls ophiolite complex, Washington: Evidence for the polygenetic nature of the Ingalls complex, in Wright, J.E., and Shervais, J.W., eds., Ophiolites, Arcs, and Batholiths: A Tribute to Cliff Hopson: Geological Society of America Special Paper 438, p. 161–173.

Miller, J.S., Miller, R.B., Wooden, J.L., and Harper, G.D., 2003, Geochronologic links between the Ingalls ophiolite, north Cascades, Washington, and the Josephine ophiolite, Klamath Mts., Oregon and California: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 113.

Miller, R.B., 1985, The ophiolitic Ingalls Complex, north-central Cascade Mountains, Washington: Geological Society of America Bulletin, v. 96, p. 27–42.

Miller, R.B., and Mogk, D.W., 1987, Ultramafic rocks of a fracture-zone ophiolite, north Cascades, Washington: Tectonophysics, v. 142, p. 261–289.

Miller, R.B., Mattinson, J.M., Goetsch Funk, S.A., Hopson, C.A., and Treat, C.L., 1993, Tectonic evolution of Mesozoic rocks in the southern and central Washington Cascades, in Dunne, G.C., and McDougall, K.A., eds., Mesozoic Paleogeography of the Western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists, Field Trip Guidebook, part II, v. 71, p. 81–98.