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Delamination Origin for Columbia River Flood Basalts and Wallowa Mountains Uplift in NE Oregon, USA

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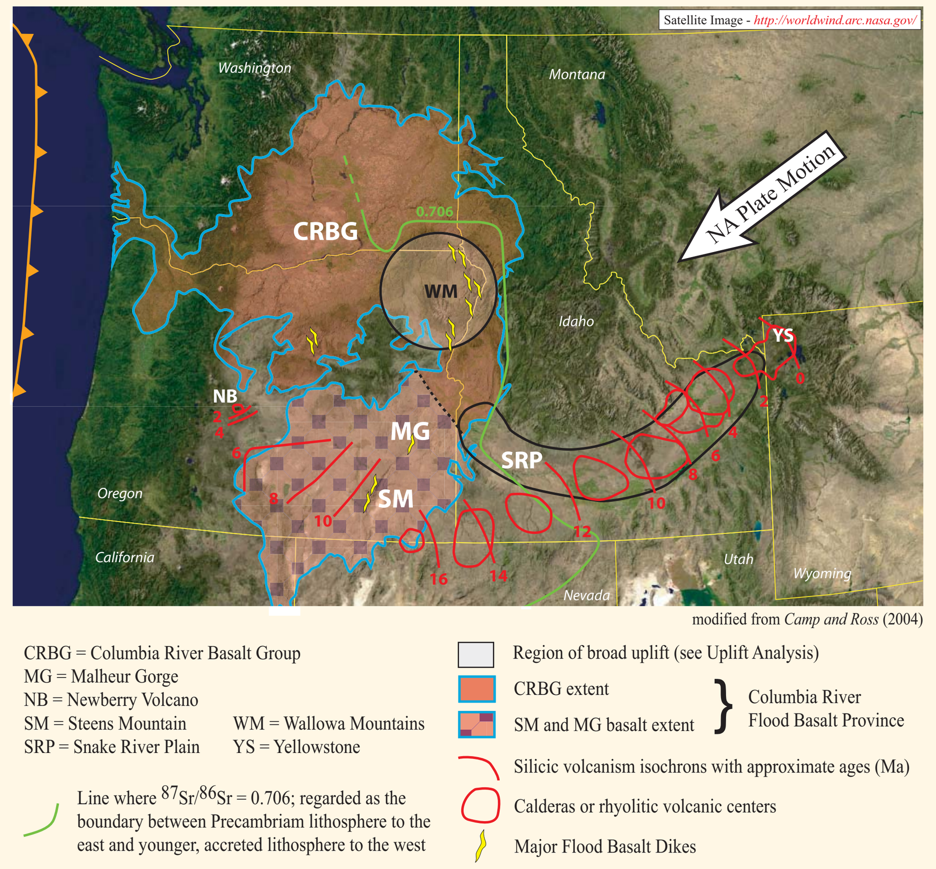
ABSTRACT

The Columbia River Basalts, erupting 17-6 Ma and covering ~175,000 km^2 in the U.S. Pacific Northwest (*Tolan et al.*, 1989), represent the most recent flood basalt event on Earth. The well-mapped, large, continuous areal extent of most early flows allows for detailed flow interface analysis. Significant crustal uplift preceding flood basalt eruption, a feature typically associated with impingement of a rising mantle plume head (*Farnetani and Richards*, 1994), was not present here. Rather, mild pre-eruptive subsidence followed by syn-eruptive and post-eruptive uplift of 300 m, on average, occurred over a broad, 200 km diameter region to the south and west of the dike swarms that produced 90% of these basalts over 1.5 million years, with extreme uplift present in several granite-cored mountains. In addition, from a conventional, fixed deep mantle plume source reference frame for Yellowstone, North American plate motion predicts a hotspot location at 17 Ma that is 400 km south of this area. Though some volcanism (e.g. Steens and Malheur Gorge basalt) was present here at that time, the majority of flood basalt volcanism (e.g. Columbia River Basalts) occurred nearly 400 km away in northeast Oregon, southeast Washington, and western Idaho.

With these simple, well constrained contradictions to the standard plume head hypothesis for hot spot initiation in mind, we deployed the first seismic array focused on imaging the upper mantle in northeast Oregon. Using ~600 teleseismic P-wave arrivals collected over 5 months at the six-station array of broadband, three component seismometers, we find high velocity mantle, +4% Vp relative to IASPEI91, beneath northeast Oregon at 70-150 km depth and interpret this anomaly as the melt-depleted mantle source region for the Columbia River Basalts. Assuming an experimentally based density change for depletion of garnet peridotite, this volume of residuum could provide sufficient isostatic support for the total volume of crustal uplift in the broad region. Yet, when considering the local areas possessing excessive uplift (i.e., the Wallowa, Cuddy, and Elkhorn Mountains) within this broadly uplifted region, it is apparent that a different mechanism for uplift is necessary. Mechanical foundering of the lithosphere would allow for large-scale mantle upwelling and decompression melting to occur prior to uplift (*Elkins-Tanton and Hager*, 2000). Furthermore, the removal of compositionally dense, eclogitic roots to the granitic plutons would decrease density locally, allowing for anomalous areas of uplift. Therefore, we propose that lithospheric delamination provides a better explanation for uplift history and Columbia River flood basalt volcanism than a standard mantle plume.

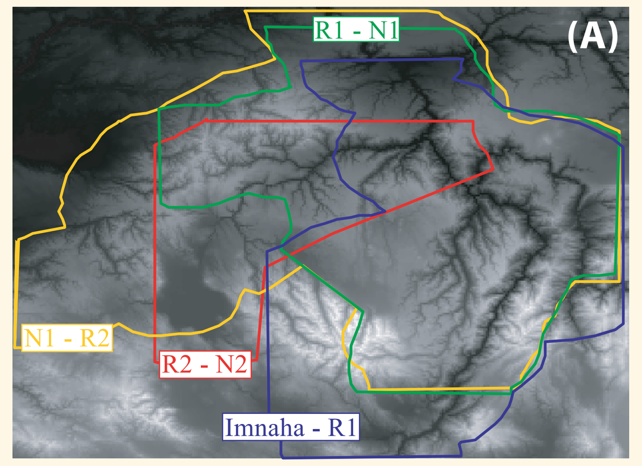
Pacific Northwest Volcanism
17 Ma - Present (*non-Cascadia*)



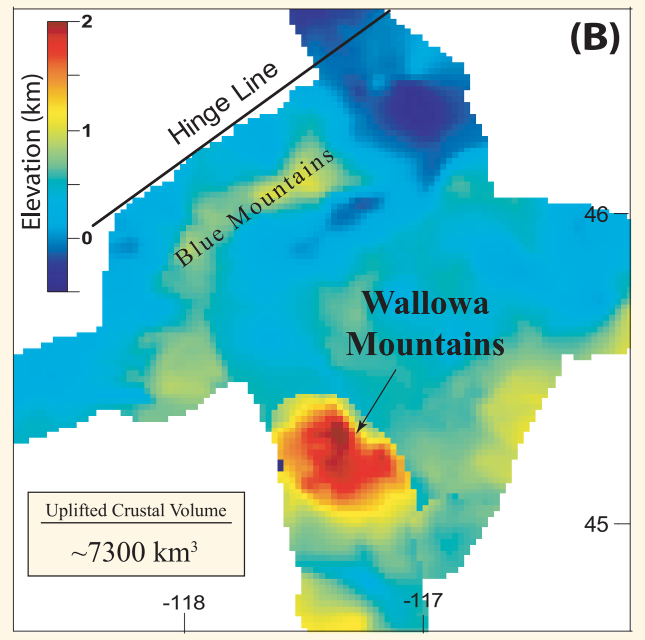
1 Regional Uplift

Flood Basalt Flow Interfaces Provide Datum for a Measure of Deformation

~2 km of Post-Eruptive Uplift Formed the Wallowa Mountains

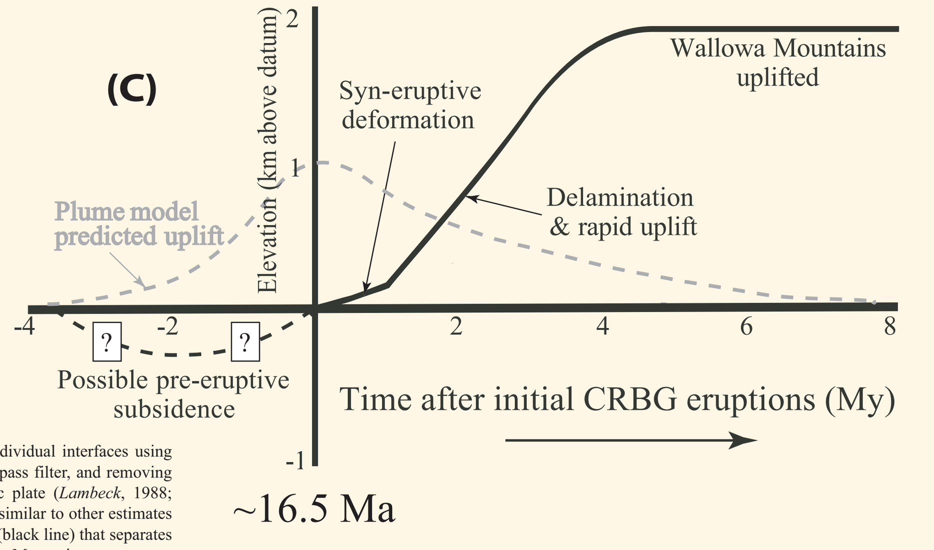


(A) Digital elevation map showing the overlapping distribution of exposed Grande Ronde (R1, N1, R2, and N2) and Imnaha magnetostratigraphic interfaces.

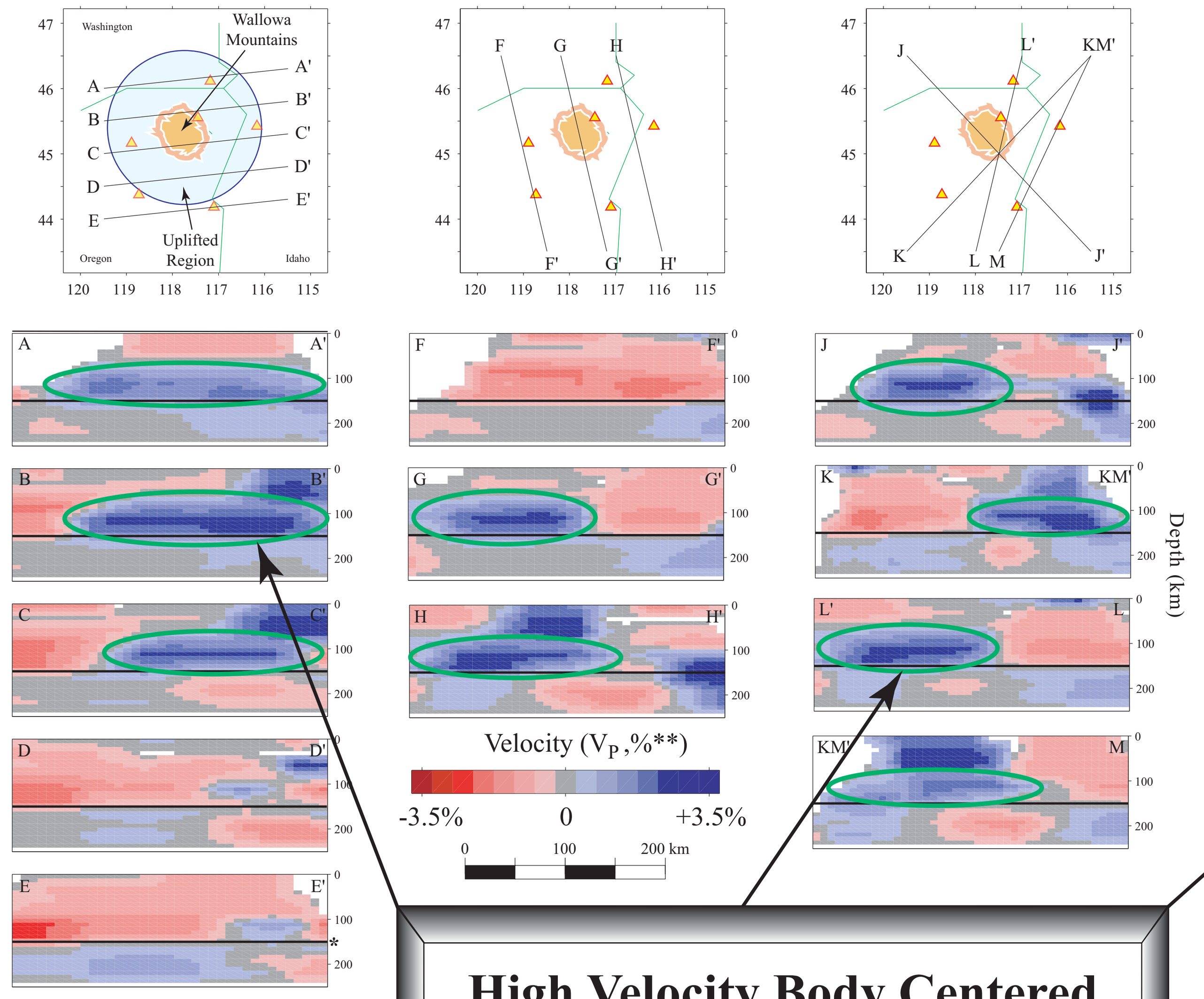


(B) Composite surface for GR uplift. This surface was made by vertically shifting the individual interfaces using published flow thicknesses (*Camp*, 1981), smoothing the resulting surface with a mild low-pass filter, and removing the effects of erosional unloading by deconvolving the point load response of an elastic plate (*Lambeck*, 1988; *Anderson*, 1994), assuming total coverage by the GR lavas and an elastic thickness of 5 km, similar to other estimates from this area (*Lowry and Smith*, 1995). The absolute elevation is referenced to a hinge line (black line) that separates the uplifted Blue Mountains from the down-dropped Pasco Basin immediately NW of the Blue Mountains.

(C) Schematic plot of the Wallowa Mountains uplift history (dark line) and a hypothetical area affected by a thermal plume (grey line). Wallowa Mountain uplift history is controlled at three times. Pre-eruptive subsidence, inferred from ponding of early Imnaha lava flows in basins, is interpreted as the initiation of delamination. We calculated ~300 m of syn-eruptive uplift in this area over the 1 m.y. duration of Grande Ronde eruption. This is followed by rapid uplift of the Wallowa Mountains 3-4 m.y. after initial Imnaha eruption, evidenced by the development of structures bounding the Wallowa Mountains14, and current topographic relief of the composite surface shown in (b). Note that the hypothetical uplift curve for a thermal plume can vary significantly in magnitude, we have chosen a representative amount of uplift predicted from CRBG magmatism.

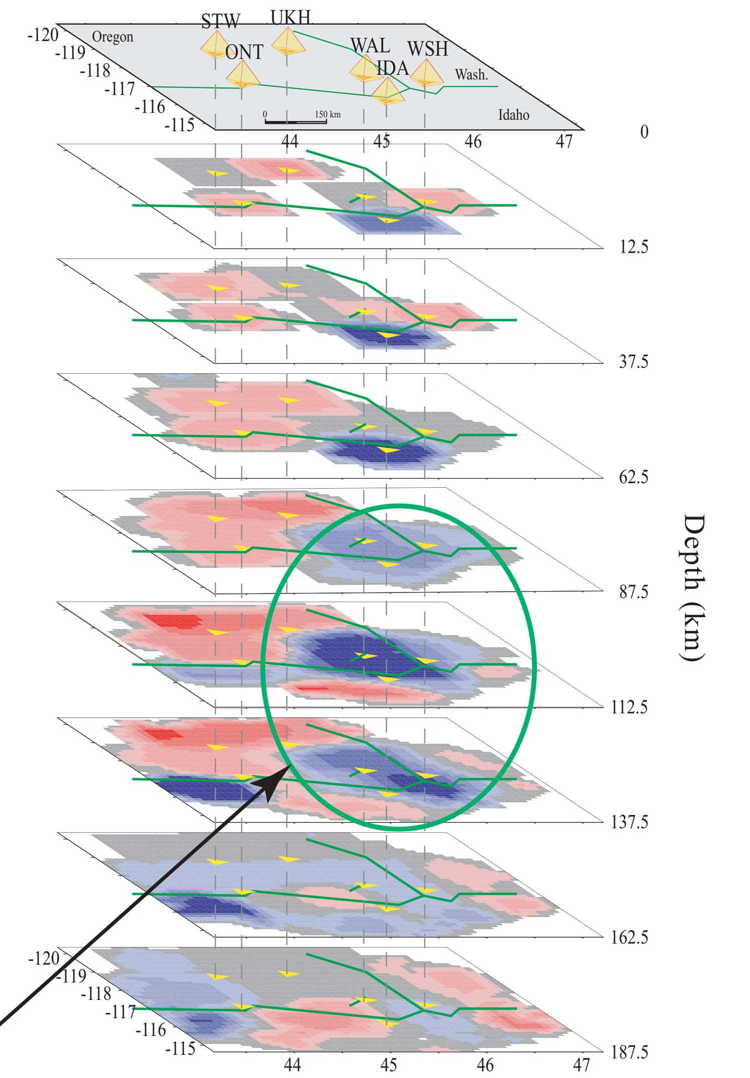


2 Upper Mantle Seismic Structure



* Black line in cross-sections is the squeezing depth. No significant structure is required below 175 km
** Relative to IASP91

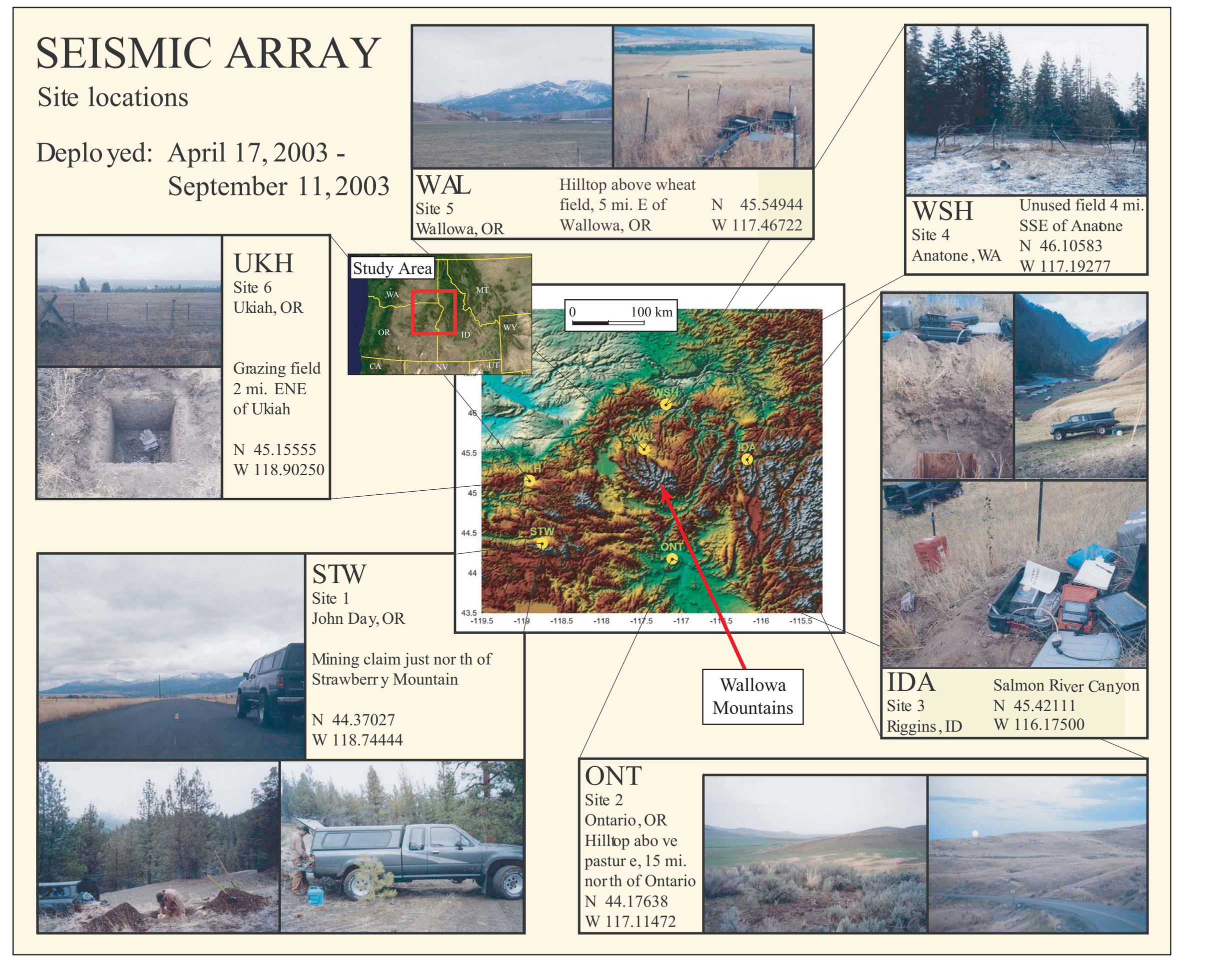
High Velocity Body Centered Beneath Wallowa Mountains
(delineated by green ovals)



Anomaly is Melt-Depleted Region of CRBG Residuum

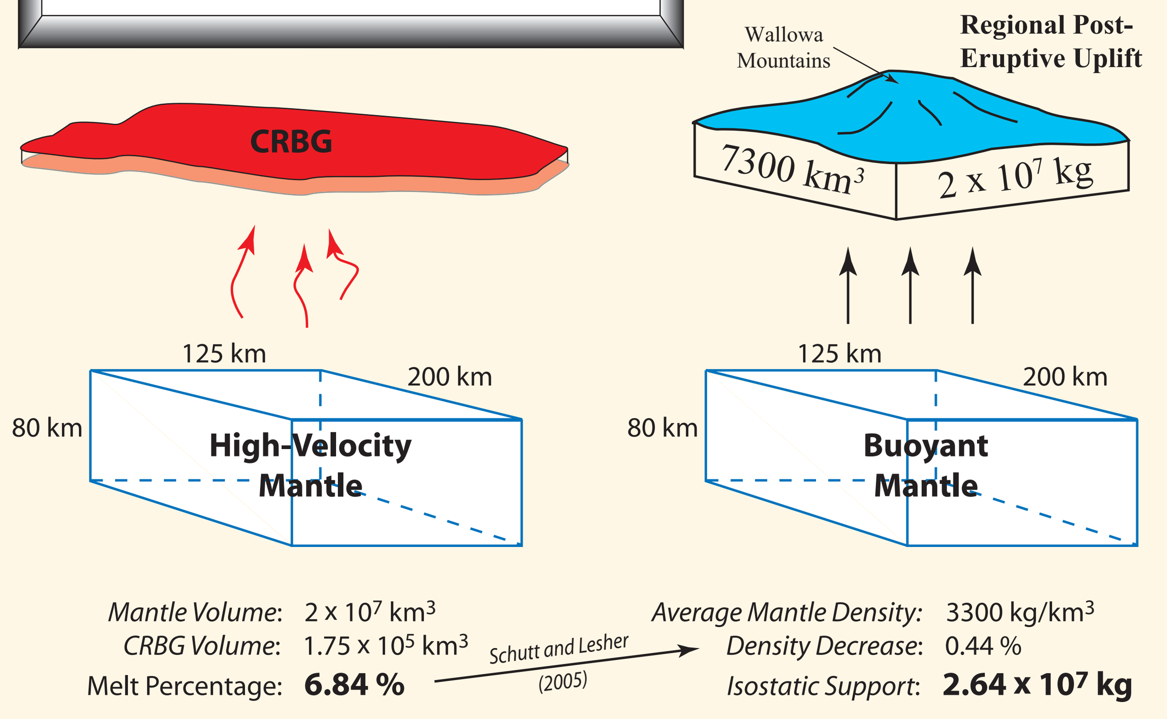
SEISMIC ARRAY
Site locations

Deployed: April 17, 2003 - September 11, 2003

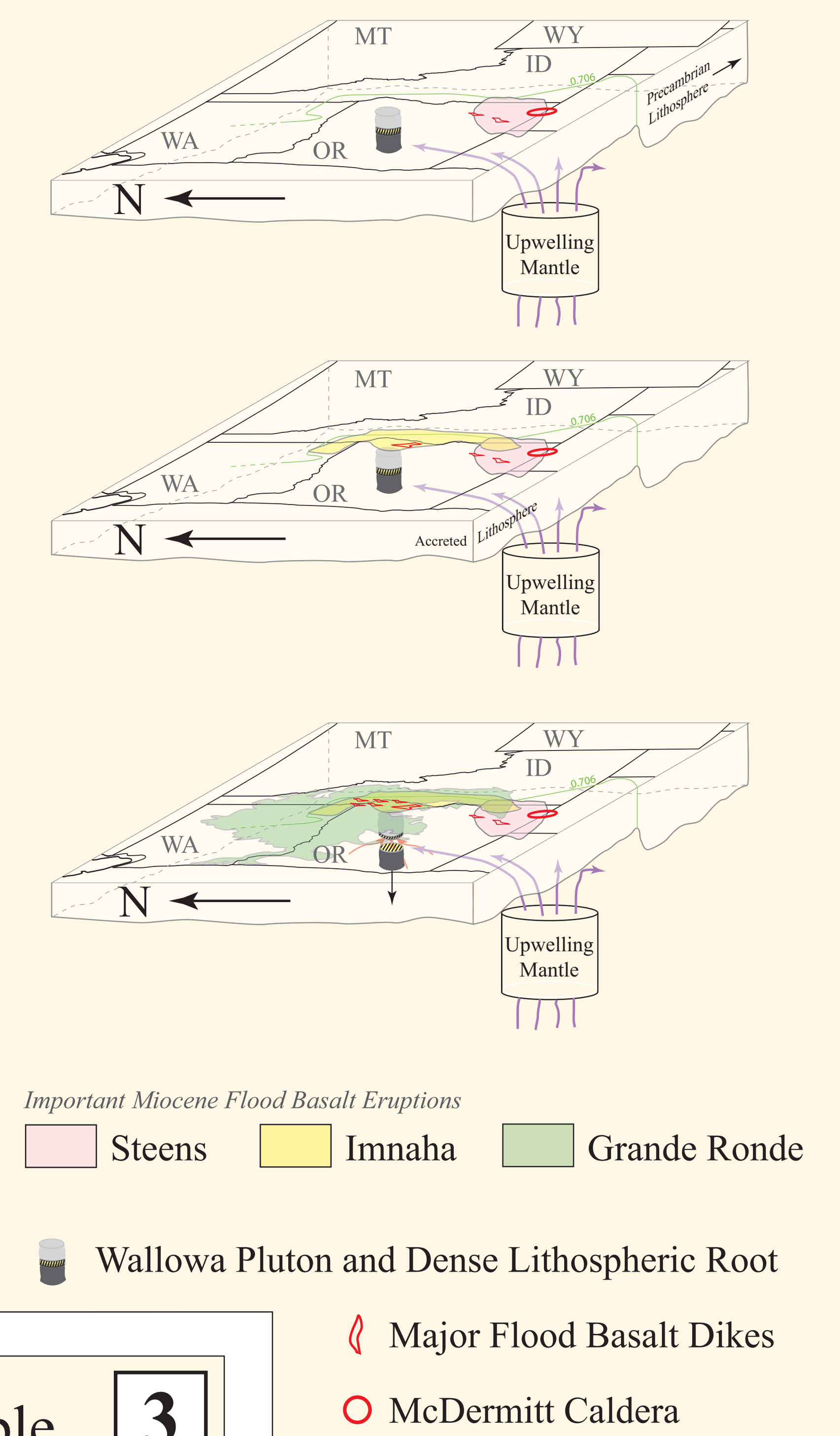


Buoyant Residuum Can Support Regional Uplift

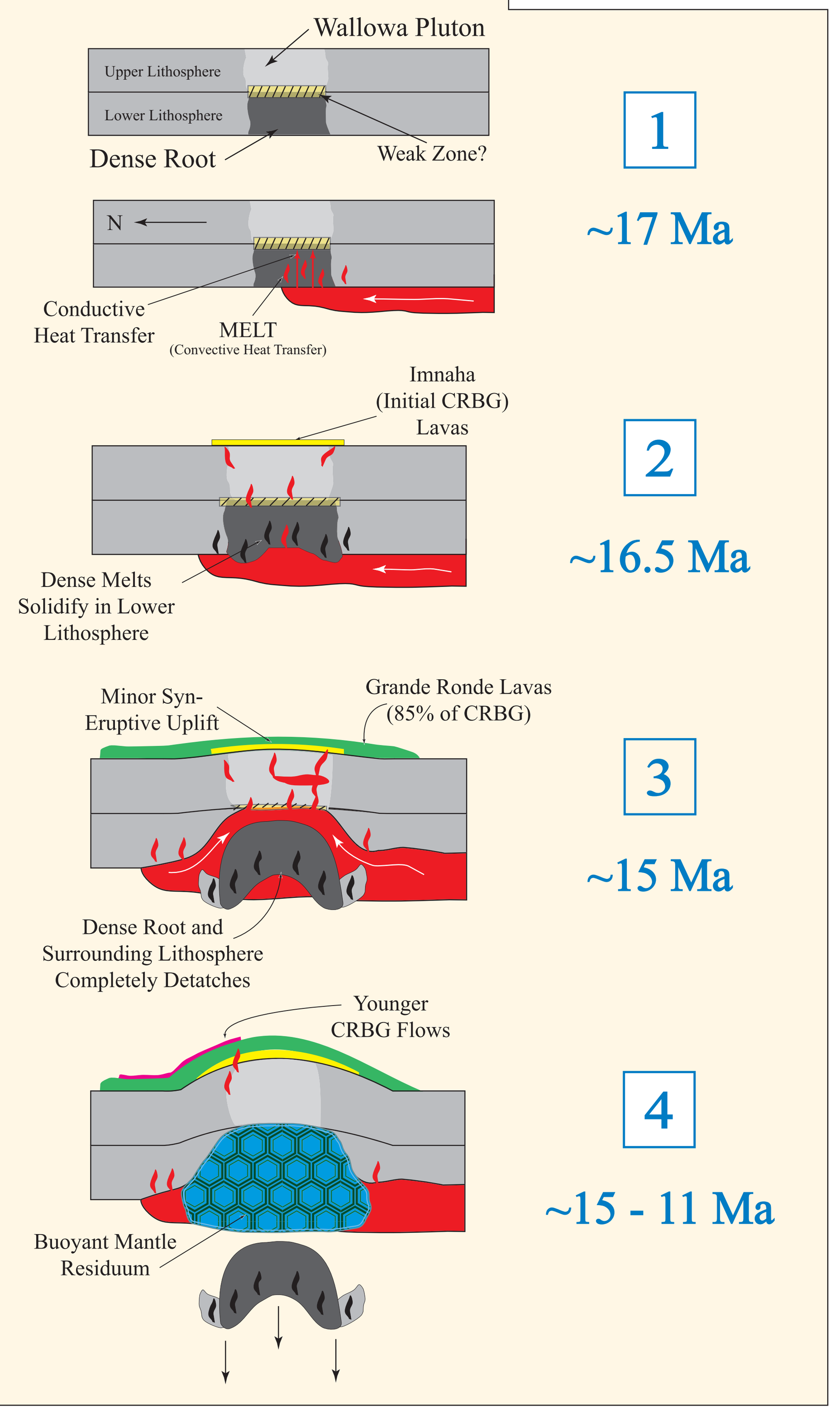
3 Remarkable Coincidence?



4 Proposed Model for CRBG Volcanism and Regional Uplift



- **Hot, upwelling mantle** (possibly a plume head) reaches the lithosphere in SE Oregon producing SM basalts and McDermitt Caldera
- Anomalous mantle **spreads north**, possibly as a migrating finger (e.g., *Camp and Ross*, 2004) and most likely guided by the adjacent, thicker Precambrian lithosphere
- **Destabilization** of the lower lithosphere, caused by heating and injection of dense melt, leads to **initial CRBG eruptions**
- Gravitational pull of mechanically connected lower lithosphere counteracts positive thermal buoyancy resulting in **negligible uplift** at this time.
- **Delamination** of the lower lithosphere allows extensive upwelling of hot, fertile asthenosphere to shallow depths.
- This produces the **voluminous Grande Ronde basalts**.
- Release of the lower lithosphere facilitates **mild syn-eruptive uplift** in northeast Oregon.
- As the mantle melts to produce the GR and the delaminated lithosphere continues to sink, **buoyant residuum forms** within the lithosphere and asthenosphere.
- **Significant post-eruptive uplift** occurs and is focused in regions with granitic plutons (especially the Wallowa). Broad regional uplift is also produced, and the flow interfaces that we observe today are deformed.



Acknowledgements
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Conclusions

- Lithospheric delamination is likely the principle cause of mid-Miocene uplift and flood basalt volcanism in northeast Oregon
- A rising mantle plume head is not required to produce the large volume of flood basalts in this region, but may play a secondary role.

Future Work

Although this study incorporates exciting new seismic data and uplift analysis, there remain several other possibilities for corroboration or disproval of our proposed model:

- Geochemical mixing models that account for the addition of plutonic root material into the melt system
- Geodynamical modeling of the migration velocity and subsequent thermal potential of a plume at distances up to 500 km from impingement
- High resolution seismic imaging at greater depth to locate the delaminated lithosphere which may still be coherent

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