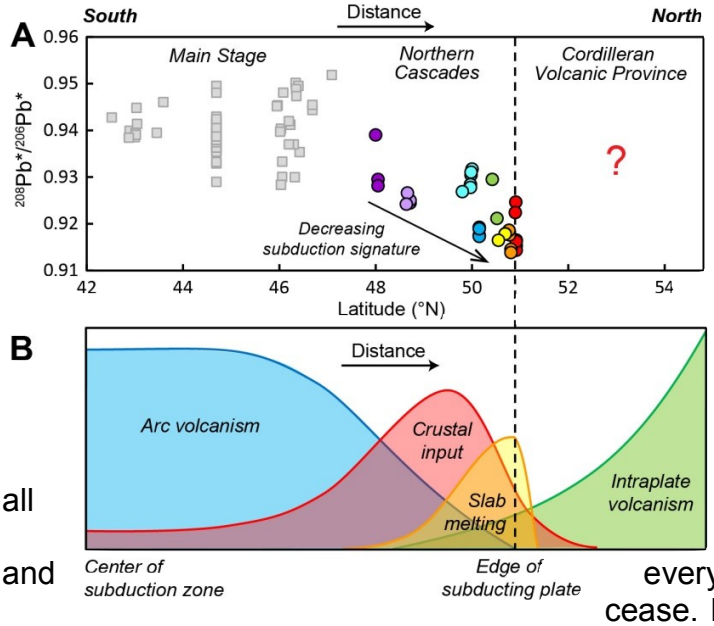
1- Characterization of magmatism at the termination of an arc: A case study of the Northern Cascades, British Columbia, Canada

Post-Doctoral Project: Dr. Emily Mullen (LMV-UBC)

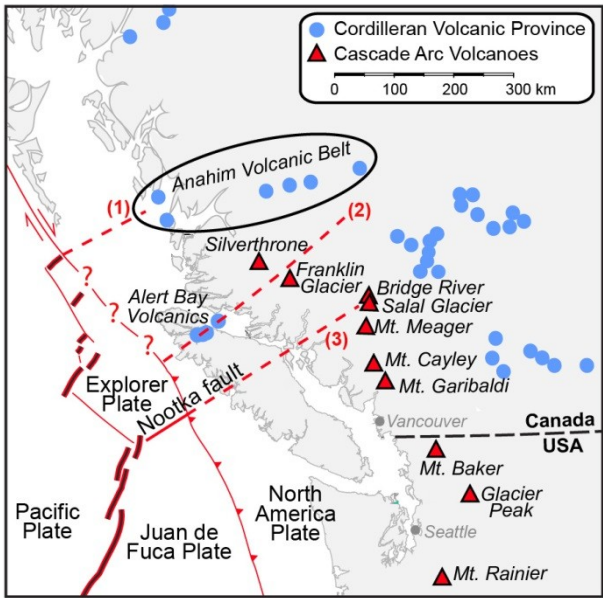
Introduction to the Problem



Subduction zones are the most geologically active areas on Earth and they present some of the most complex questions faced by Earth scientists. After many decades of study, consensus has been reached on a model for magma generation in volcanic arcs, the chains of volcanoes above subduction zones. However, no study has addressed how arcs terminate from a magmatic perspective. This question has temporal and spatial connotations: all of Earth's subduction zones terminate at each end of the trench, and every subduction zone will eventually cease. New patterns are emerging from new data from the northern end of the Cascade Arc (**Fig. 1a**). Northern Cascade magmas analyzed thus far (Mullen and Weis, 2013; Mullen et al., in prep) have distinctly different compositions from Main Stage Cascade Arc magmas. However, insufficient data currently exist to determine whether the Northern Cascade patterns provide a viable global model for arc termination, or why these magmas differ from the Main Stage.

This study will be the first to characterize how the "death" of an arc is expressed through compos-itional, temporal, and spatial variations in the magmatic record. The Cascade Arc provides an ideal natural laboratory for investigating processes at the ends of arcs because it is a subduction zone on the verge of its demise. About 4 million years ago, the northern part of the subducting Juan de Fuca plate detached along the Nootka Fault to form the separate Explorer microplate (**Fig. 2**). The tectonic regime changes across the Nootka Fault from subduction to strike-slip motion on the Queen Charlotte Fault. Although subduction of the Explorer microplate has essentially ceased, active volcanism continues in this region. Where and how to define the northern termination of the arc in this tectonically complex region is controversial (**Fig. 2**). The most northerly volcano considered part of the Cascade Arc (Silverthrone) lies just north of the Brooks Peninsula fault zone, proposed to mark the northern edge of the microplate. Volcanism is also abundant in the Cordilleran Volcanic Province that extends 1500+ km north of the plate edge, but the extent to which these magmas are influenced by subduction is unclear.

The overarching question addressed by this study is: What is the magmatic fingerprint of the "death" of an arc, and how does it differ from arc "life"? This study will (1) establish types of eruptive products in the Northern Cascades and how they have changed during the ~40 million year lifetime of the arc; (2) use petrologic and geochemical modeling to determine the roles of



mantle, subducting slab and crust in generating these magmas; and (3) determine how and why Northern Cascades and Main Stage magmas differ.

Description of the Project

The Northern Cascade Arc and Cordilleran Volcanic Province are understudied regions with little information on eruptive products. Therefore it is not currently possible to determine patterns defined by magmas at the termination of the arc. This study will acquire new geochemical and geochronologic data for magmas from these regions.

Strategically located volcanic centers with the longest magmatic records will be targeted for study and include Franklin Glacier, Silverthrone, Mt. Meager, Anahim Volcanic Belt, and Alert Bay (**Fig. 2**). Mafic through silicic rocks will be analyzed from each volcanic center. Samples from representative crustal basement units will also be analyzed to provide a framework in which to quantify crustal inputs. Collaboration with the research groups of Profs. **Dominique Weis** and **Kelly Russell** at UBC and Prof. **Glyn Williams-Jones** at SFU will provide access to samples already collected. The first set of samples to be analyzed will be selected from the UBC-SFU collections and additional samples will be obtained by joint field excursions.

Samples will be analyzed for (1) age dates, (2) major elements, (3) trace elements, and (4) isotope ratios of strontium, neodymium, hafnium, lead and osmium. Age dating requires two techniques, U-Pb geochronology on silicic rocks and $^{40}Ar/^{39}Ar$ on mafic rocks. These data will facilitate a full assessment of how mantle sources, subducting plate contributions, and crustal interactions have changed through time.

Achieving the goals of this study will require a team of investigators with a unique combination of expertise and state-of-the-art analytical facilities that are provided by LMV and UBC. Trace elements, $^{40}Ar/^{39}Ar$ age dates, and strontium, neodymium, hafnium and lead isotope ratios will be measured in collaboration with Prof. **D. Weis** at UBC in the Pacific Centre for Isotopic and Geochemical Research. Major elements, osmium isotope ratios, and LA-ICP-MS U-Pb zircon analysis will be carried out at LMV with Drs. **Francois Nauret** and **Jean-Louis Paquette**. Identification of magmas that contain melts of the subducting slab will be carried out with Prof. **Herve Martin** at LMV, a leading authority on slab melts.

Expected Results

This study will quantify the spatial and temporal fingerprint for the termination of an arc (**Fig. 1b**). Papers submitted for publication will describe and explain:

- The types and relative ages of eruptive products that occur at the ends of arcs,
- The differences between eruptive end-products and Main Stage arc magmas,

- Which processes in the mantle, subducting plate and crust become dominant and which wane as an arc approaches its terminal state, and
- The “lag time” between the end of subduction and the end of arc magmatism.

The Cascadian model will be applied to volcanic arcs on a global scale to determine if common patterns of magmatism exist at the terminations of arcs. Knowledge of the ages and compositions of eruptive products at the ends of arcs is also critical for moving towards understanding how eruptive styles and volumes differ at the termination of arcs.

References

Audet, P., Bostock, M. G., Mercier, J.-P., and Cassidy, J. F. (2008) Morphology of the Explorer–Juan de Fuca slab edge in northern Cascadia: Imaging plate capture at a ridge-trench-transform triple junction. Geology 36, 895–898.

Madsen, J. K., Thorkelson, D. J., Friedman, R. M., and Marshall, D. D. (2006) Cenozoic to Recent plate configurations in the Pacific Basin: Ridge subduction and slab window magmatism in western North America. Geosphere 2(1), 11–34.

Mullen, E. K., and Weis, D. (2013) Sr-Nd-Hf-Pb isotope and trace element evidence for the origin of alkalic basalts in the Garibaldi Belt, northern Cascade arc. Geochem. Geophys. Geosyst. 14, doi:10.1002/ggge.20191.

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Timeline

	2014		2015		2016			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Collect and prepare samples	■			■				
Field trips	■			■				
Sample analysis: UBC		■	■	■	■	■	■	
Sample analysis: LMV		■	■	■	■	■	■	
GSA Conference, Vancouver	■							
AGU Conference		■				■		
Goldschmidt Conference				■				■
Write and submit papers		■	■	■	■	■	■	■

2- Presentation of the labs in which the candidate will work:

The Laboratoire Magmas et Volcans comprises a Thermo Neptune Plus MC-ICP-MS and Thermo Triton TIMS for isotopic analysis, a Thermo Element XR HR-ICP-MS and Agilent 7500s Q-ICP-MS coupled to a Resonetics Resolution M50 Excimer 193nm laser for U-Pb geochronology, and a Jobin Yvin Optima+ ICP-AES for major element analysis. A JEOL electron microprobe is available for mineral analysis by EDS and cathodoluminescence. Mineral separation facilities include a Wilfley table, Frantz magnetic separator, heavy liquids, and binocular microscopes. Chemical separations are conducted in cleanrooms with Class 100 laminar flow hoods.

Personnel taking part in the project will include: Emily Mullen: Postdoctoral Researcher, Jean-Louis Paquette: Directeur de Recherche, Hervé Martin: Professeur, François Nauret: Maitre de Conférence, Jean-Luc Piro: ICP-MS and laser Ingénieur, Delphine Auclair: TIMS Ingénieur, A. Mouhcine Gannoun: MC-ICP-MS Ingénieur, Mahmed Benbakkar: ICP-AES Ingénieur, Claire Fonquernie: Mineral separation Technicienne, and Jean-Marc Hénot: SEM Technicien.

The Pacific Centre for Isotopic and Geochemical Research at the University of British Columbia is a state-of-the-art geochemical analysis facility equipped with 10 instruments including a Nu Attom HR-ICP-MS, Thermo Element2 HR-ICP-MS, and Agilent 7700 Q-ICP-MS for trace element analysis, a Micromass 5400 for Ar-Ar dating, and a Thermo Triton TIMS and three Nu Plasma MC-ICP-MS's for high-precision Sr-Nd-Hf-Pb isotope analyses. Also available are a Resonetics M50 laser system for in-situ trace element analysis. Sample preparation is conducted in three class 1000 clean laboratories equipped with class 100 laminar flow hoods.

Personnel participating in the project will include: Emily Mullen: Postdoctoral Researcher, Dominique Weis: Professor and Tier 1 Canada Research Chair, Bruno Kieffer: Research Scientist, Kathy Gordon: MC-ICP-MS Technician, Liyan Xing: MC-ICP-MS Technician, and Janet Gabites: Ar-Ar Technician.

Presentation of advisors for the candidate:

Dominique Weis, Professor, UBC: director of the Pacific Centre for Isotopic and Geochemical Research. She holds a Tier 1 Canada Research Chair in Geochemistry. She was the organizer of the 2008 Goldschmidt conference in Vancouver and has over 150 publications on geochemistry, from large igneous provinces to the environment. Recent awards are: American Geophysical Union Fellow and Daly Lecturer, Geochemical Society Fellow, and Distinguished Lecturer of the European Consortium for Ocean Research Drilling.

Jean-Louis Paquette, Directeur de Recherche, Laboratoire Magmas et Volcans: leading specialist in U-Pb geochronology by CA-ID-TIMS and laser ablation ICP-MS with ~100 publications on geochronology. He is the leader of the LMV "Laser" group and member of the "Origin, Evolution and Chronology of Magmas" group.