Eocene Basin Record of Metamorphic Core Complex Exhumation in the Western United States Cordillera

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Hypothesis

The western United States Cordillera contains evidence for multiple phases and styles of extension in the Cenozoic. The onset of Basin and Range extension is well-constrained at 17 Ma (1), but extension along low-angle detachment faults may have initiated as early as 55 Ma. Across Idaho and Montana, Eocene sedimentary rocks record a period of widespread basin formation and filling that has been linked to rapid metamorphic core complex (MCC) exhumation (Deer Lodge and Bitterroot) and episodic collapse of structural culminations (Salmon and Muddy Creek) (2,3,4) (Fig. 1). **The problem** is that existing chronometry does not constrain the earliest phase of extension or the relationship between deformation and basin evolution, which are key to deciphering the distribution of extensional styles and drivers for MCC formation. **I hypothesize** that there will be a decrease in lag time between coarse-grained fluvial and organic-rich lacustrine lithofacies in collapse basins, representing the change from paleo-valley filling to the onset of extension, but that MCC exhumation will result in short lag times in early coarse-grained lithofacies (Fig. 2).

Research Plan

Previous work dating MCC exhumation, primarily using bedrock thermochronology, resulted in a range of exhumation ages (52-40 Ma) and rates of extension (4,5), but no studies have determined how MCC exhumation and basin formation are related. The Muddy Creek and Salmon basins have been studied using stratigraphy, structural analysis, and stable isotope geochemistry (3,6,7). Both basins are thought to have been a part of a Cretaceous paleovalley that filled with volcanic rocks prior to a major phase of extension along low-angle detachments (3,7). The stratigraphic shift from ignimbrites and tuffaceous fluvial sandstone and conglomerate to organic-rich lacustrine mudstone may represent the transition from valley fill to extension and basin ponding.

To test my hypothesis, I will conduct a detailed stratigraphic, geochronologic, and thermochronologic investigation of syntectonic basin strata associated with the Anaconda MCC and the surrounding Muddy Creek and Salmon basins (Fig. 1). I will measure decimeter scale-stratigraphic sections and paleocurrent indicators to determine depositional environments, basin architecture, and (combined with detrital U-Pb ages) sediment provenance. I will use sanidine $^{40}Ar/^{39}Ar$ dating of interbedded tuffs to obtain depositional age control. Using detrital zircon (U-Th)/(He-Pb) double dating, I will obtain crystallization and cooling ages of targeted age clusters (8) in order to calculate lag times (t_L=t_c-t_d): an individual grain's travel time from cooling (t_c) to deposition (t_d) (8,9). Different basin subsidence mechanisms will create distinct relationships between lag time, cooling age, and depositional age (Fig. 2) (8,9). I will compare these variables to determine the timing of initial MCC exhumation, how changes in basin architecture correlate to unroofing, and the early differences between extensional styles.

Table 1 shows an expected timeline for field work, sample prep, and analysis. Detrital zircon (U-Pb) analyses are in progress at the University of Texas, Austin (Fig. 3). I am leveraging published $^{40}Ar/^{39}Ar$ ages of Lowland Creek volcanics (10) and separating sanidine from collected samples to run at the University of Wisconsin. Receiving this grant will provide funding for detrital zircon (U-Th)/He analysis on U-Pb-dated grains, which are critical in order to calculate sediment lag times, make precise provenance determinations, and determine the connection between MCC exhumation and basin formation (Fig. 3).

Scientific and Societal Significance

The collapse of the North American Cordillera is a continental scale tectonic process that is critical to our understanding of how extension is accommodated in the lithosphere. The northwest trending line of MCCs extending from Mexico to Canada is characterized by three regions with varying exhumation ages (Eocene-Miocene) and magnitudes of extension (> 10 km): the Northern Belt, Central Belt, and Southern Belt (11). These MCCs are thought to represent the location of the thickest crust in the Sevier Hinterland pre-extension and are a type locality for understanding MCC dynamics in a continental setting (11). Exhumation in the Northern Belt, which includes the Anaconda and Bitterroot MCCs, and basin subsidence may have coincided in time with a change of tectonic driving force from compression to extension, but a change in plate boundary conditions is not an adequate explanation for high-magnitude extension here, as is often cited for MCCs in the Central Belt (1,8,11). The removal of the Farallon slab following Laramide compressional deformation is proposed to have occurred as early as ca. 55 Ma, initiating voluminous magmatism in the Challis, Absaroka, and possibly Lowland Creek volcanic provinces (12,13). Improved temporal resolution on MCC exhumation and basin subsidence can help us determine if shallow slab removal and/or delamination was coeval with extension, or if volcanism associated with this renewed magmatism was necessary to thermally weaken the lithosphere, triggering extensional subsidence (13).

The formation of the Salmon and Muddy Creek basins is proposed to have occurred along low-angle detachment faults at Sevier structural culminations (2,3). While these detachment faults have similar geometries to those related to the exhumation of MCCs, the high gravitational potential energy of that culmination did not result in the formation of an MCC. The factors controlling this uneven distribution and magnitude of extension in the lithosphere are not well understood. This study will provide insights into the relationship between deformation and basin formation, constraining the role MCC exhumation plays in basin subsidence and ponding. Deciphering extensional styles and drivers of MCC formation are crucial to our understanding of the mechanical processes contributing to collapsing lithosphere, the role that MCCs play in the differentiation of crust, and the evolution of orogenic belts through geologic time (11).

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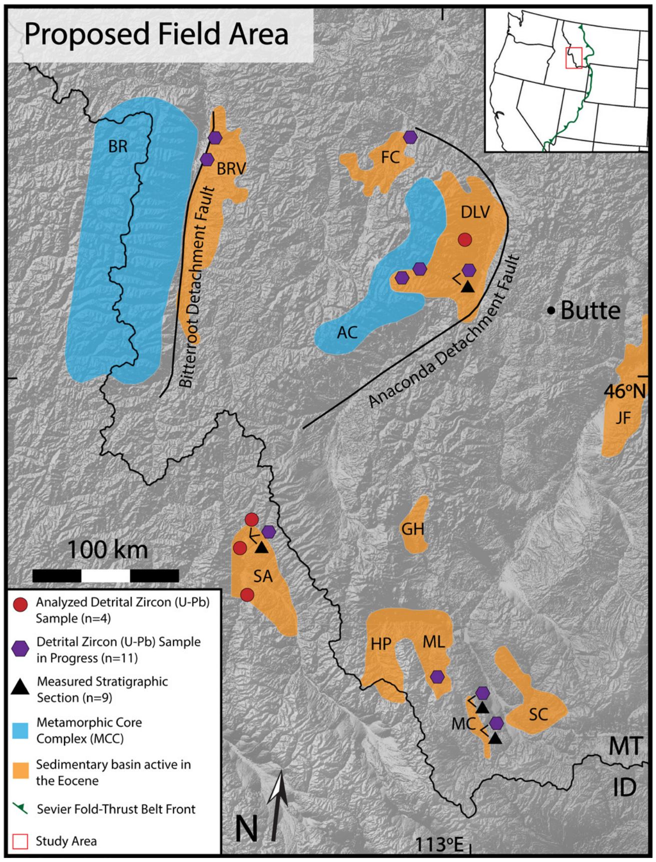

Figure 1: Proposed field area with sample and measured stratigraphic section localities, basins active in the Eocene, and metamoprhic core complexes (MCC). Bitterroot MCC (BR), Anaconda MCC (AC), Bitterroot Valley (BRV), Flint Creek (FC), Deer Lodge Valley (DLV), Salmon (SA), Horse Prairie (HP), Medicine Lodge (ML), Muddy Creek (MC), Sage Creek (SC), Jefferson (JF), Grasshopper (GH). Basin locations from (Constenius, 1996).

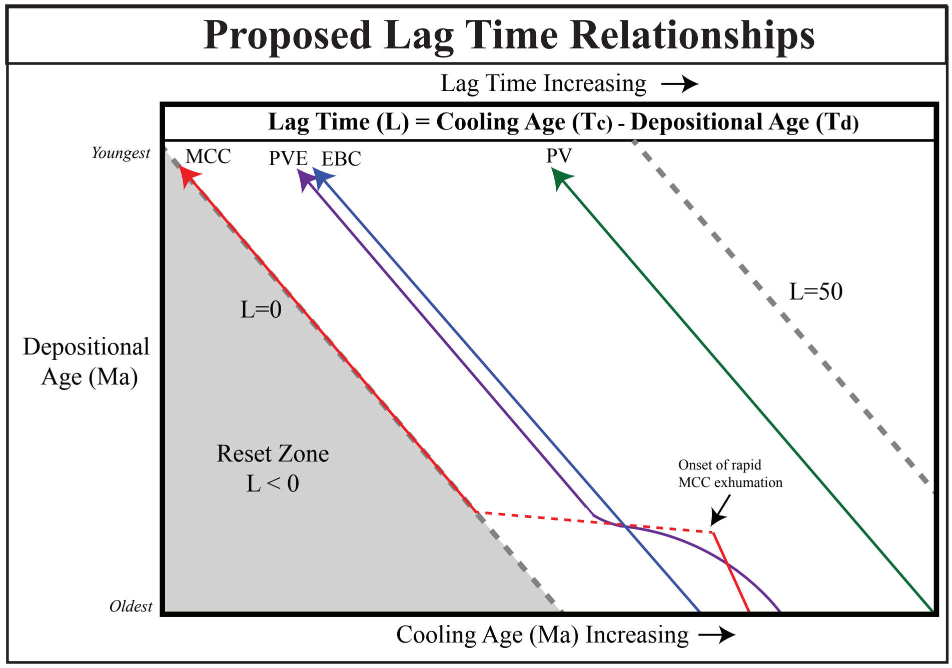

Figure 2: Expected trends in lag time based on basin forming mechanisms. Cooling age is detrital zircon (U-Th)/He age of youngest, non-volcanic population. Metamorphic Core Complex (MCC), Paleovalley to Extensional Basin (PVE), Extensional basin with constatant subsidence rate (EBC), Paleovalley filling (PV). Dashed gray lines represent lines of equal lag time.

Table 1: Detailed Expected Timeline

Spring 2021	Send additional detrital zircon (U-Pb) samples to the University of Texas, Austin. Start synthetizing (U-Pb) data and choose populations for (U-Th)/He analyses. Separate sanidines from Lowland Creek Tuff beds for $^{40}Ar/^{39}Ar$ age control; send for radiation through WiscAr at the University of Wisconsin in six months.
Summer 2021	Conduct five weeks of field work, collecting additional samples and measuring detailed stratigraphic sections in the Deer Lodge Valley and other Eocene Basins (Fig. 1). Continue processing detrital zircon samples for additional analyses.
Fall 2021	Travel to Connecticut in October for 3 weeks for initial (U-Th)/He analyses, focusing on detrital zircon populations that represent the bottom and top of each section. Start processing newly collected samples from field season. Present initial data at 2021 GSA Annual conference.
Winter 2021/2022	Model (U-Th)/He results. Continue processing newly collected samples. Send second round of (U-Th)/He samples to University of Connecticut after analysis of first round of samples.
Rest of 2022	Write up manuscript to publish stratigraphy. Model second round of (U-Th)/He data.

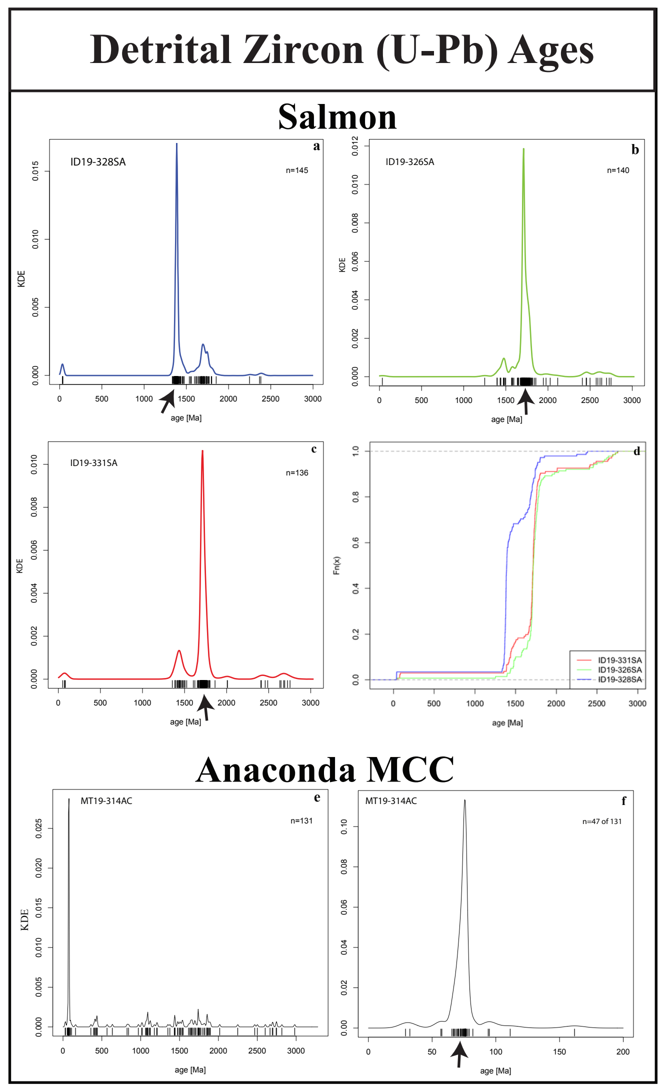

Figure 3: Inital detrital zircon (U-Pb) analyses. a-c) Kernel density estimates (KDE) of three samples from the Salmon Basin in stratigraphic order d) Cumulative density estimate (CDE) of all three Salmon Basin samples. e-f) KDEs of the Anaconda MCC syntectonic conglomerate. Black arrows indicate targeted age populations for (U-Th)/He analyses.