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Highlights & Breakthroughs contribution for *American Mineralogist* on "Temporal histories of Cordilleran continental arcs: testing models for magmatic episodicity" by Moritz Kirsch et al.

Title: Periodic Activity in Continental Magmatic Arcs

by

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Abstract.

Earth's longest continuous orogenic belts are formed between subducting oceanic plates and over-riding continental plates. The resulting orogenic systems commonly feature continental magmatic arcs and granitic batholith belts. In this issue Kirsch et al. report a comprehensive geochronological and geochemical dataset from the 15,000 km-long American Cordilleras, and demonstrate statistical correlations and periodic magma production that can be related to a complex web of processes both internal and external to the plate subduction factory. This work has far-reaching implications for global mountain building processes.

Keywords: Magmatic arcs, cordilleran orogenic belts, cyclicity

Cordilleran orogenic belts are formed primarily by processes associated with the subduction of oceanic plates beneath the edges of continental plates. On Earth today, the American Cordilleras, spanning one-third the circumference of the globe, represent the

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range of variations seen in older, less coherent cordilleran belts. The Alpine-Himalayan-New Guinean orogenic belt embodies Earth's other great orogenic system, and has formed by both collisional and cordilleran-style processes. Because of the abundance of oceanic lithosphere on this planet, it stands to reason that cordilleran-style orogenesis has been important throughout the portion of geological time during which plate tectonics has operated.

Inasmuch as continental magmatic arcs lie at the hearts of most cordilleran orogenic belts, their long-term (10^7-10^8 yr) behavior must be intimately tied to the diverse processes that collaborate with magmatism to build these great orogenic belts. Thus, changes in magma production through time, as recorded by cordilleran batholiths and volcanic piles, have implications for the broad web of tectonic, magmatic, metamorphic, mantle dynamic, and surface processes operating in cordilleran orogenic systems, as well as potential global climatic effects (McKenzie et al., 2016). For this reason sundry geoscientists, including various types of petrologists, geophysicists, basin analysts, structural geologists, geomorphologists, geochronologists, and even climatologists are paying unprecedented attention to the histories of cordilleran magmatic arcs, which provide one of the most sensitive records of orogenic mode. Perhaps never before has the significance of continental arc magmatism been so widely recognized. The degree to which cordilleran magmatic arcs behave in a cyclical, or periodic, fashion has been the focus of numerous recent studies in arcs throughout the world. Kirsch et al. (this issue) provide one of the most comprehensive and statistically rigorous treatments of this problem to date. They leverage the ever-increasing U-Pb zircon geochronological database from arc bedrocks and detrital samples from adjacent basins to assess the temporal behavior of most of the 15,000 km long American Cordilleran arc (*sensu lato*). By statistically comparing these data with geochemical datasets and plate kinematic models, Kirsch et al. show that the devil is indeed in the details when it comes to analyzing multi-faceted datasets in terms of cordilleran orogenesis.

That cordilleran arcs produce magmatic rocks periodically has been suggested for many decades (e.g., Armstrong, 1988). Kirsch et al. confirm this observation, but also demonstrate that such periodic behavior is variable along strike in the American Cordilleras. Periodic magma production has also been uncovered in the south Asian pre-collisional, cordilleran arcs (especially the 2,500 km long Gangdese arc of southern Tibet; Chung et al., 2005; Wu et al., 2010; Orme et al., 2014). The observation that periodic flare-ups are often associated with geochemical fingerprints of continental material (e.g., Ducea, 2001; also confirmed by Kirsch et al.) provides the critical link between arc magmatism and the host of processes operating inboard of the arc in the upper plate—the so-called Cordilleran Cycle (DeCelles et al., 2009). The upper plate is now considered much more than a passive component of the subduction factory.

Whereas the analysis by Kirsch et al. would appear to set up a dichotomy between models that ascribe importance to upper plate vs. external plate kinematic processes, it should be understood that processes operating in the upper plate must, ultimately, be related to plate kinematics. This was shown by Schellart (2008), among others, as a strong correlation between crustal thickening, on one hand, and orthogonal convergence and trench advance rates, on the other. Without rapid convergence and trench advance, the upper plate does not thicken to produce a cordilleran orogenic belt. The nature of the control, however, is not obvious. Orthogonal plate convergence rate is not strongly

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correlated with magmatic production in either North or South America (Kirsch et al., Figures 3, 4, 5). Nevertheless Kirsch et al. argue that such a potential correlation should not be discarded, and I agree. Many of the processes operating in the Cordilleran Cycle (DeCelles et al., 2009, 2015) must be related to plate convergence rate. For example, rates of shortening in retroarc thrust belts, which probably control the rate at which melt-fertile lower crust and lithosphere are provided to the melt factory at the base of the arc, are logically controlled by plate convergence rate. The nuance here is that other factors, including the kinematic behavior of the orogenic wedge in terms of critical taper concepts (e.g., Dahlen, 1990; Buiter, 2012), strongly controls the rates of shortening and thrust belt propagation. In turn, critical taper in a thrust belt is controlled by rock rheology and strength, fluid pressures, surface processes and erosion, and built-in lithological architecture and composition, among other variables. In other words, thrust belts by themselves do not necessarily respond directly to changes in plate kinematics. Instead, the transfer of stresses from plate-scale to thrust-belt scale is modulated by other processes. Extreme along-strike structural variability of the North American and Andean retroarc thrust belts (e.g., Yonkee and Weil, 2015; McGroder et al., 2015) is testament to this complexity, and scales with the spatial complexity documented by Kirsch et al.

One thing to keep in mind about the Kirsch et al. analysis is that the authors limit their dataset to pre-Cenozoic rocks. Thus, the analysis neglects the history of arc magmatism associated with growth of the Cenozoic Andean orogenic system (e.g., Kay and Coira, 2009), in which ca. 25 Ma magmatic periodicity is evident. It could be argued that the Cenozoic Andes are the best comparison for the Jurassic-Cretaceous North American Cordillera, as these are the time frames during which the corresponding

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orogenic belts experienced their acme of development. In addition, by including pre-late Jurassic data, the analysis in some cases compares arc segments that are fundamentally different (e.g., extensional vs. contractional) and not necessarily associated with what many workers would refer to as a strictly contractional cordilleran orogenic system. Nevertheless there is much food for thought in this analysis, and even, perhaps, a strategy for a new work-flow in studying cordilleran orogenic systems: start with the magmatic history, perhaps even in the detrital record where it may be most reliably preserved (e.g., Kirsch et al., Figure 1, part B), and then proceed to search for potential feedback and feed-forward links in other geological records. One thing seems certain: nothing serious happens in a Cordilleran orogenic belt without affecting other processes. The paper by Kirsch et al. provides an excellent starting point for future work on these fascinating geological domains.

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