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From Mineral Grain to Mountain Range: X-ray Microanalysis, Geochronology, and Himalayan Geology

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The Himalayan mountain range, created by the collision of India with Asia which began ~50 million years ago, is an ideal laboratory for understanding the response of continental lithosphere to plate tectonic forces. Metasedimentary rocks that once made up the leading edge of India today form the summits of Himalayan peaks. The range is presently characterized by high rates of seismicity and deformation, and widespread exposure of post-collisional high-grade metamorphic and igneous rocks implies long-term, large-scale vertical transport. The distribution of rock types within the range has, for over one hundred years, inspired theories of crustal metamorphism that have been exported to explain aspects of other mountain belts. Over the past 25 years, a number of geodynamic models have been proposed that make quantitative predictions regarding the petrologic and tectonic evolution of the Himalaya [see review by 1].

However, it is only recently that we have been able to test these models by directly determining the timing of metamorphism using both electron and ion microprobes. Th-Pb dating of small (~10-15 μm-sized) monazite grains in rocks obtained adjacent the crustal-scale fault that largely created the highest mountain range on this planet yield remarkably young ages (Fig. 1). Monazite [Ce,La,Th)PO_4] is easily found in rock thin sections as one of the brightest phases in backscattered electron (BSE) imaging due to its radioactive constituents. The mineral is resilient to radiation damage, excludes Pb during crystallization while remaining relatively impervious to radiogenically-derived Pb loss at high crustal temperatures [2]. The mineral can recrystallize during certain geologic events, recording information about complexly metamorphosed regions [e.g., 3]. Monazite is routinely dated using an ion or electron microprobe in thin section. Dating the mineral in rock context is ideal because the chemistry and the textural relationships of mineral grains are preserved and analyses of small grains (~10μm) and zones within larger grains are feasible. The compositions of garnets and matrix minerals can be used to gain the peak pressure-temperature conditions experienced by the rock (Fig. 2), and when combined with the ages of monazite, can yield important insight into the conditions of metamorphism. X-ray element maps of monazite along with the garnet hosts can provide important data about when the mineral's crystallization history, potential radiation damage, and chemical relationship with other minerals. As is often the case, understanding the largest scale features requires knowledge of the microscale; the signal with which to explain the processes involved when two continents collide is preserved within crystals only 10 μm's in size.

References

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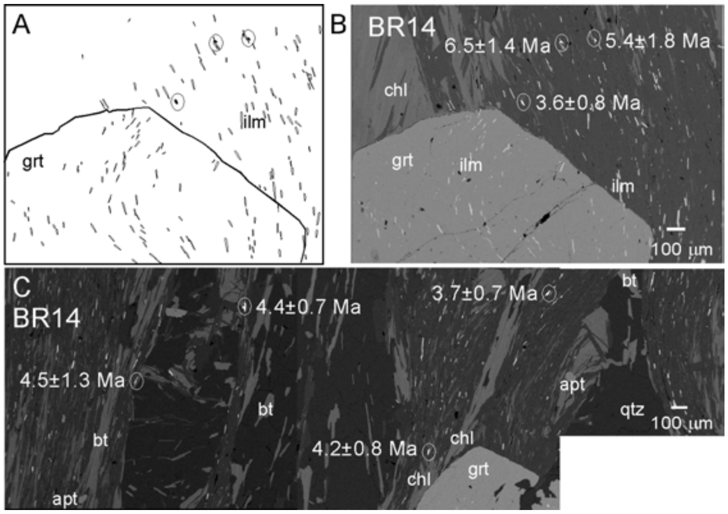

FIG. 1. (A) Cartoon of a Himalayan rock collected from the Main Central Thrust shear zone in NW India with euhedral garnet ([(Mn,Ca,Mg,Fe)Si_3O_8], ilmenite, and monazite (circled). (B) Backscattered electron image of the same region; monazite ages are ±1σ. (C) BSE image of other monazites dated in this same rock. Abbreviations: "apt", apatite, "ilm", ilmenite. The ages average 4.5±1.1 Ma with a Mean Square Weighted Deviation of 0.8, consistent with a single population.

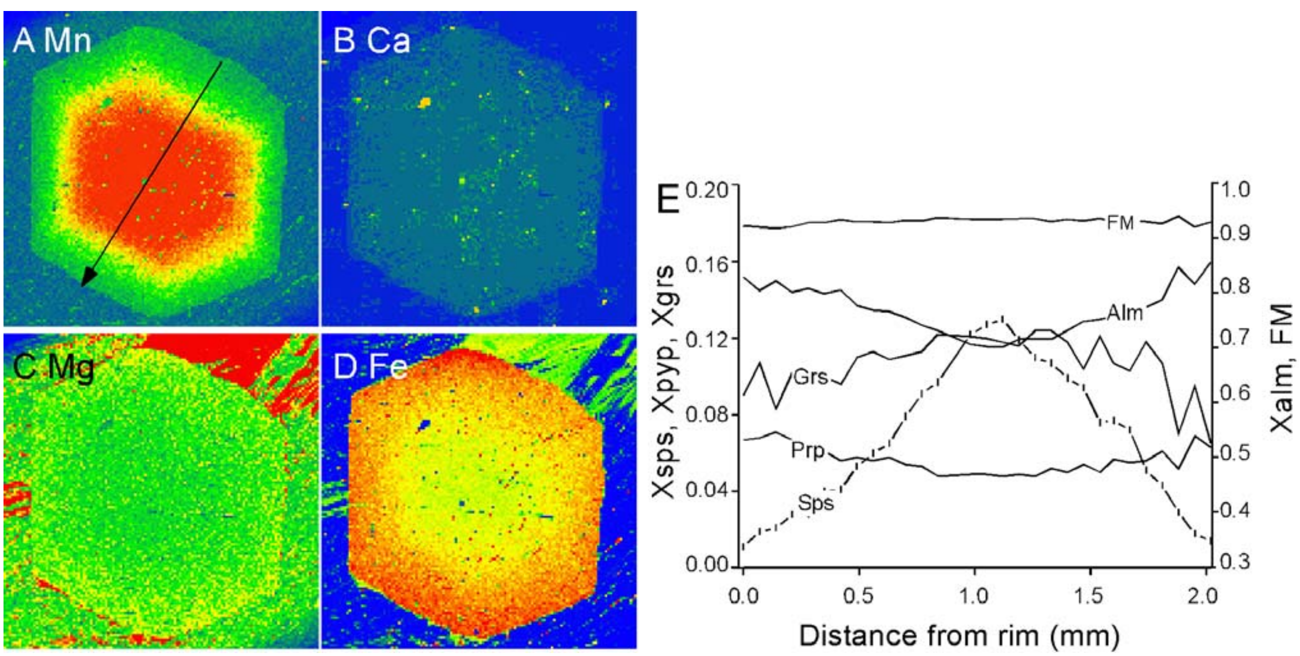

FIG. 2. X-ray element maps of (A) Mn, (B) Ca, (C) Mg, and (D) Fe of the Himalayan garnet in Fig. 1. Red=higher concentration, blue=lower concentration. (E) Compositional traverse across the garnet along the arrow in (A). The traverse is in Sps (spessartine or Mn content), Pyp (Mg or pyrope content), Grs (Ca or grossular content), Alm (Fe or iron content), and FM (Fe/Fe+Mg). The tick marks on the Sps profile indicate where compositions were obtained. The profile indicates that the garnet grew during a single metamorphic event and did not experience significant diffusion. Pairing the garnet composition with matrix mineral compositions in thermobarometric calculations indicate the rock achieved peak conditions of 540±25°C and P= 700±180 MPa.