Introduction to special issues, Part II: Nature of tectonic boundaries in lithosphere of the Rocky Mountains

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This is the second of two issues of Rocky Mountain Geology that addresses the structure and evolution of continental lithosphere in a transect through the Rocky Mountains from Wyoming to New Mexico. Contributions are mainly from participants in the CDROM (Continental Dynamics - Rocky Mountain) project, recently funded by the Continental Dynamics Program of the National Science Foundation (Karlstrom, 1998). The overall theme for papers in both issues involves the present geometry and long-term evolution of tectonic boundaries within the 1000 km-wide Paleoproterozoic crust of the southwestern United States (Fig. 1). In this region, as in many other orogens, a first-order geodynamic problem is to understand where ancient accretionary structures are located and how they become reactivated in subsequent tectonic events. We would like to know which components of present lithospheric structure were “inherited” from the time of lithosphere formation. The first issue (RMG, v. 33, no. 2, 1998) contains papers that discuss the concept of inheritance, the present geophysical structure of the region, and the Archean-Proterozoic boundary (Cheyenne belt) in Wyoming. The Cheyenne belt is one of the most profound lithospheric structural boundaries exposed anywhere and is well documented at crustal and mantle levels (Fig. 1).

This second issue contains papers that are, for the most part, focused on the nature and evolution of the Proterozoic province boundaries in Colorado and New Mexico. These papers highlight the importance and difficulties of understanding tectonic boundaries. As was first noted in Arizona (Karlstrom and Bowring, 1988), and confirmed by geologic studies in other parts of the Rocky Mountains, the Proterozoic crust is divided into blocks, commonly bounded by shear zones, that exhibit differences in tectonic history relative to other blocks. The possibility exists that some of these blocks represent different accreted terranes that were sutured together to form the Proterozoic juvenile lithosphere. However, tectonic boundaries have long histories and commonly are reactivated. Thus it is necessary to work back through various reactivation events to evaluate the possible importance of each boundary in terms of the original accretionary structure of the orogen versus later intracratonic tectonism. This is an inherent difficulty of terrane analysis in all orogens. The identification of blocks or terranes is only a start; we also need to evaluate fully the three-dimensional nature and evolution of their boundaries.

The first two papers of this issue summarize nearly a decade of work on the Park Range of northern Colorado by Foster and his graduate students at the University of Iowa. This mountain range contains a possible boundary between the Green Mountain block to the north, a 1780–1760-Ma volcanic sequence that was the first Proterozoic block accreted to the Archean Wyoming province, and the 1750–1720-Ma Yavapai (Colorado) province to the south, a possible back-arc assemblage. The nature of the boundary or boundaries is still open. However, candidates for a major accretionary boundary are the zone between the Fanvell and Lester mountains, which exhibit different P-T histories, and the Fish Creek-Soda Creek shear zone. The latter also was active as a transpressional zone during emplacement of the 1.4-Ga Mount Ethel pluton, and thus has a polyphase movement history.

The paper by Shaw and Karlstrom summarizes present knowledge of the long-proposed boundary between the Yavapai (Colorado) and Mazatzal provinces in southern Colorado (Fig. 1). The hypothesis presented is that sutures between terranes at middle-crustal levels may have been folded and imbricated several times. Such low-angle boundaries are expressed on a geologic map as a wide zone of transition for which different types of studies might locate the boundary in different places. This is realistic given the 100 km-scale of colliding arcs, for example in the Indonesian region, and the concept whereby widely distributed deformation might be expected.
Figure 1. Location of Precambrian province boundaries in the Southwest and present mantle structure (from Fig. 2). Black represents Cenozoic volcanism along the Jemez and St. George lineaments; line pattern designates the Rio Grande rift. Numbers show locations of study areas in this issue: (1) Park Range (Foster et al.; Barinek et al.); (2) Yavapai-Mazatzal boundary of southern Colorado (Shaw and Karlstrom); (3) Tusas Mountains (Williams et al.); (4) Rincon Range (Read et al.); (5) Manzano Mountains (Marcoline et al.); (6) southwestern New Mexico (Chang et al.); line pattern is the Rio Grande rift (Keller and Baldridge). Reflection experiments across the Cheyenne belt and Jemez lineament (solid red lines), a regional refraction experiment (dashed red line), and a co-located passive seismic experiment are planned for summer 1999 as part of the CDROM project (see text).

in juvenile crust that is hot, thin, and weak (Royden, 1996).

The papers by Williams et al., Read et al., and Marcoline et al. also discuss tectonic boundaries, but they go farther than others in documenting the impressive extent of ca. 1.4-Ga regional deformation and metamorphism that reactivated the crust in northern New Mexico. All of these papers highlight the continuing problem in understanding the nature and relative intensity of 1.65-Ga versus 1.4-Ga events in New Mexico, and each has a slightly different conclusion for its subject area. From new U-Pb dating of metamorphic minerals and structural studies, Williams et al. suggest that most or all of the amphibolite-grade metamorphic minerals in the Tusas and Picuris mountains formed between 1.47-1.42 Ga. Macroscopic geometries probably formed earlier (1.65 Ga), but they were softened and variably reactivated at 1.4 Ga. Read et al. reach a similar conclusion for the Rincon Range with respect to the 1.4-Ga event. They suggest, however, that 1.68-Ga tectonism was the peak event because of the spatial coincidence among a 1.68-Ga pluton, transposed subhorizontal foliation, and the highest grade of metamorphism. Marcoline et al., working in the Manzano Mountains, are in closer agreement with Williams et al. in suggesting from 40Ar/39Ar dates and micropetrical analyses...
that the peak event occurred at 1.4 Ga. Regardless of uncertainties in timing, collectively these papers provide a hypothetical image of the middle crust that involves interactions of steep and shallow foliation domains and heterogeneous metamorphic and deformational fabrics. Deeper crustal levels may show a dominance of subhorizontal foliation as shear zones (and "sutures"?) that follow "ramps" and "flats" to deeper crustal levels. The currently exposed crustal sections may represent a critical transition between 1.7-1.65-Ga upper crust and refabricated 1.4-Ga lower-crustal signatures.

Notwithstanding the possible importance of inherited Proterozoic structures, the structures that give the Rocky Mountain region its present tectonic expression formed during contractional deformation and uplift in the Late Cretaceous–early Tertiary Laramide orogeny, followed by extensional deformation in the late Tertiary. Thus, any attempt to understand lithospheric structure should combine studies of both Precambrian and Phanerozoic events. The paper by Chang et al. shows the type of reprocessing of industry seismic lines that accompanies our CDROM project. These data show impressive subhorizontal reflectors in basement rocks. They also reinforce the importance of combined geologic, seismic, and gravity studies to decipher the crustal images that emerge from seismic experiments. These reflectors are interpreted to represent Laramide low-angle, basement-involved thrusts.

Figure 2. Mantle velocity structure at 100-km depth (modified from Humphreys and Dueker, 1994; Grand, 1994). Western U.S. mantle is currently being restructured from below. West of the Cordilleran hingeline, mantle is low velocity, hot, with a few percent partial melt, and Cenozoic in age (yellow and red-brown colors). East of the Colorado–Kansas border, the mantle is high velocity, cold, and Proterozoic in age. Blue represents high-velocity mantle. In the Rocky Mountain region, fingers of hot, young mantle are penetrating Proterozoic lithosphere along older, northeast-striking boundaries.
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Keller and Baldridge provide a review of the tectonic evolution of the Rio Grande rift and the most recent tectonic events to have shaped Rocky Mountain lithosphere.

The nature of tectonism in the mantle during the Paleoproterozoic assembly process, during the Mesoproterozoic, and in the Phanerozoic remains uncertain. To what extent did accreted Paleoproterozoic lithospheric fragments carry their own mantle lithospheres? Figure 2 shows that northeast-trending fingers of hot mantle extend into the Rocky Mountain region along the Snake River plain, St. George lineament, and Jemez lineament, and that there is a major velocity contrast from Archean to Proterozoic lithosphere across the Cheyenne belt in southern Wyoming. This suggests that, in spite of Laramide and Cenozoic mantle reorganization, mantle-velocity provinces may be controlled by Paleoproterozoic crustal provinces. Similarly, isotopic data from xenoliths and young basalts (Livaccari and Perry, 1993) may suggest that crustal provinces have been linked since the time of accretion to mantle provinces of similar age. In an alternative model, crustal fragments were detached from mantle roots as orogenic float during assembly, just as present-day Timor was added to the flank of Australia within the last million years (e.g., Genrich et al., 1996). Perhaps the mantle lithosphere carries no memory of the accretion process but instead reflects younger tectonism.

To further test these alternative hypotheses, seismic lines will be run by our CDROM project in summer of 1999. This activity will include an integrated set of reflection, refraction, and passive teleseismic geophysical studies concentrating on the Cheyenne belt and Jemez lineament. We will, however, also attempt to construct a regional lithospheric cross section from Wyoming to New Mexico. Can the crustal shear zones and province boundaries shown in Figure 1 be imaged through the lower crust and into the upper mantle? Based on geologic studies such as those reported in this issue, we would expect the boundaries to be complex and the upper-crustal province boundaries to have been displaced relative to their respective mantle sutures. Combined geologic and geophysical expertise will continue to be essential to unravel the complex history of tectonism recorded by present lithospheric structure.

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