Introduction to: The Rocky Mountain Region — An Evolving Lithosphere: Tectonics, Geochemistry, and Geophysics

Karl E. Karlstrom

Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico

G. Randy Keller

Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas

The Rocky Mountains are the eastern, high elevation portion of the continental-scale Cordilleran mountain chain that extends along the western portion of the North American continent. This wide zone records the complex tectonics associated with a series of Mesozoic to Recent additions to and modifications of the continent. This volume focuses on the southern Rocky Mountain region, the area that extends from southern Wyoming, across the Colorado Rockies, to meld with the region dominated by the Rio Grande rift and Colorado Plateau. These various physiographic domains share a common tectonic heritage as a region that was uplifted from near sea level in the late Cretaceous, underwent regional uplift, compressive deformation, and lithospheric modification at appreciable distance from the western margin of the North American plate during the 70–45 Ma Laramide orogeny, then underwent a complex series of magmatic modification events, localized lithospheric extension, and late Cenozoic denudation and incision. The result is the high elevation and topographically rugged western U.S. orogenic plateau shown in Plate 1.

There has been strong scientific interest in the region of the Southern Rocky Mountains for over a century, but our knowledge of the deep lithospheric structure of the region has been improved greatly by a series of seismic experiments that began in the mid 1990s. New insights have been provided by seismic data that were acquired by a combination of earthquake and natural source recording efforts; such as the Deep Probe experiment (Henstock et al., 2001; Gorman et al., 2002), Rocky Mountain Front experiment (Sheehan et al., 1995), and CD-ROM experiment (Dueker et al., 2001; Karlstrom and the CD-ROM Working Group, 2002). Previous work on the geologic evolution of this region has been extensive and includes recent summaries related to the CD-ROM experiment (Karlstrom, 1998; 1999).

This volume provides a synthesis and integration of geological and geophysical results of the CD-ROM (Continental Dynamics of the Rocky Mountains) collaborative investigation. This effort has involved more than 22 investigators at 14 institutions and 21 graduate students. After an initial workshop in 1995, CD-ROM was funded from 1997 to 2002 by the Continental Dynamics Program of the National Science Foundation, with supplemental funding from the Deutsche Forschungsgemeinschaft. The experiment was designed as a fully interdisciplinary series of coordinated geologic and geophysical studies to understand the tectonic evolution of the lithosphere of the southern Rocky Mountain region. As described in the papers in this volume, the overall project produced a seismic refraction line from Wyoming to New Mexico (Plates 1 and 2), geologic studies of shear zones and Laramide structures, xenolith studies, and teleseismic and reflections lines across key tectonic boundaries within the longer transect, including the Cheyenne belt and Jemez lineament.

The southern Rocky Mountain region is one of the best places in the world to study continental evolution because this region preserves a unique record of the assembly, stabilization, maturation, and early stages of disassembly of a continent. The core of North America is underlain by high velocity (old, cold) lithosphere (blue in Plate 2) whereas many areas
Plate 1. Digital topography in the western United States (from Simpson and Anders, 1992). The overall high plateau in the western United States records buoyant mantle. Subtle differences in Rocky Mountain topography appear to correspond to Precambrian lithospheric blocks, suggesting that different columns are responding differently (magmatically and isostatically) to present mantle reorganization. The CD-ROM transect crosses different Precambrian provinces and obliquely crosses the Rocky Mountains: $CB =$ Cheyenne belt; $CMB =$ Colorado Mineral belt; $JEML =$ Jemez lineament.
Plate 2. Composite image of the upper mantle seismic structure at 100 km depth beneath the greater North America region. Blue is high velocity mantle and red is low velocity mantle. The continental scale image is from the S-wave modeling of Grand (1997), with overlay of data from regional arrays (Humphreys and Dueker, 1994). Black lines are Precambrian provinces, showing some correspondence between crustal provinces and mantle velocity domains in the Rocky Mountain region: SPR = Snake River Plain; SGL = Saint George lineament; AA = Aspen anomaly; JEML = Jemez lineament. Location of CD-ROM transect is shown.
INTRODUCTION

along the Pacific plate margin are underlain by low velocity (young, hot) mantle (red in Plate 2). This is one of the largest transitions in mantle velocity structure on Earth, some 14% variation in shear wave velocity from the core of the continent to the active plate margin. As shown in Plate 2, this same scale of velocity variation takes place over the shorter, 10-km, length scale of tectonic/magmatic provinces such as the Snake River Plain (SRP), St George lineament (SGL), Aspen anomaly (AA), and Jemez lineament (JEML). Part of the goal of the CD-ROM experiment was to investigate the origin of these velocity anomalies.

In the Southern Rocky Mountains, many excellent exposures of Precambrian rocks provide the ground truth needed to study how the old structures (in this case Archean and Proterozoic lithospheric provinces and sutures) are influencing younger lithospheric restructuring in response to Cenozoic sublithospheric processes. In addition, the region is an excellent field laboratory because different tectonic provinces record different aspects of the total history that involves rapid lithosphere accretion (1.8–1.6 Ga), long-term stability (1.6–1.4 Ga and 1.3–0.53 Ga), crustal “overturn” (1.4 Ga), intracontinental deformation (Ancestral Rockies orogeny, Laramide orogeny), and early stages of extension (Rio Grande rift). The large amount of new data in the Southern Rocky Mountain region presented in this volume provide an opportunity to constrain and unravel aspects of Proterozoic, Laramide, and Neogene tectonism and their interactions, and the processes that have shaped the region during the past 2.0 Ga.

Continents are the long-term record keepers of plate interactions before 200 Ma. However, accumulated modification often obscures the record of older events. The southwestern U.S. is unique in that juvenile Proterozoic lithosphere was accreted as belts of volcanic arcs that were added to the south margin of an Archean cratonic core. These Precambrian provinces are also shown in Plate 2. These belts were then truncated in the Phanerozoic at a high angle so as to create a N-NW trending continental margin oblique to the NE-trending Precambrian accretionary structures (Plate 2). The result was the creation of a wide region where all stages of structural reactivation and continental modification are preserved. The Rocky Mountain deep interior of the Cordilleran orogen reveals two remarkable features: (1) much of the Precambrian assembly of the continent is still well preserved and well exposed over a large region; and (2) Cenozoic orogenesis is in a stage where the recently modified Precambrian continent strongly expresses both the older and the newer structures. Many of the papers in this volume address the hypothesis that the older lithospheric structures influenced younger tectonic and magmatic activity.

The scale of the investigations in the CD-ROM experiment is commensurate with the scale of the important constructional and reconstructional processes that affected the region, and the papers in this volume cover the large horizontal and vertical lengths and the billion-year time scales involved. At the same time, these papers feature the high level of resolution afforded by modern seismic and analytical techniques. An important overarching goal of this volume is a better understanding of processes of formation, stabilization, and reactivation and modification of continental lithosphere. The growth of continental crust from the amalgamation of island arcs is conceptually simple and often invoked. However, the processes involved in transforming accreted arcs to stable continental lithosphere with a thick lithospheric mantle are still not well understood. One result that emerges from the papers in this volume is a much better understanding of how dominantly oceanic tectonic elements (island arcs, back-arc basins, sea mounts, accretionary prisms) became amalgamated into “continental lithosphere”. Accretion was followed by a series of underplating events that added to the mafic lower crust. Numerous magmatic differentiation events have been important in the evolution and stabilization of the continental crust and upper mantle, and the original mechanical and compositional anisotropies of the lithosphere have repeatedly influenced the tectonic and magmatic response of the continent to events around its margins.

The Laramide orogeny is an emphasis of several papers in this volume, and it probably represents the best-documented example of basement-involved foreland deformation on Earth. This impressive and enigmatic intracontinental restructuring and reactivation event was superimposed at high angles to the pre-existing lithospheric architecture. The mechanisms controlling basement-involved foreland deformation, including the role of basement structural anisotropy and lithosphere-asthenosphere interactions, remain subjects of great interest, as does the puzzle of how plate tectonic processes, both west of and underneath the Rockies, connect with the complex pattern of shortening in the upper crust. Several papers in this volume also address the geomorphology, thermochronology, and modeling studies of post-Laramide tectonism that gave rise to today’s spectacular topography.

This volume is organized into five sections. The first nine papers present new data on the tectonics, structure geology, and regional geophysics for the area. A series of three papers deal with geochemistry, geochronology and xenolith studies. The CD-ROM project featured a 900 km long seismic refraction profile and two > 200 km long seismic reflection profiles. After an overview of controlled seismic techniques and previous studies, there are six papers that present and interpret the new CD-ROM data, and two papers that present results from older, but newly released, seismic reflection profiles. Passive source seismic studies have been featured by a series of experiments in the Southern Rocky Mountain region and seven papers present analyses of these data. The final two papers synthesize our pres-
ent understanding of the evolution of the continental lithosphere in the Rocky Mountain region.

REFERENCES