
INSIGHTS ON CENOZOIC LANDSCAPE DEVELOPMENT AND MESOPROTEROZOIC CRUSTAL EVOLUTION FROM THE WET MOUNTAINS, COLORADO

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INTRODUCTION

The Wet Mountains of south central Colorado present opportunities for important new research focused on Cenozoic landscape evolution and on Precambrian crustal evolution. The Eocene erosion surface is widely exposed and locally overlain by volcanic deposits (Scott & Taylor, 1986), providing a datum for investigation of post-Eocene landscape features. Precambrian gneisses and granitoids make up the bedrock in the range, with abundant outcrop and good access. Little investigated until the 1990s (Noblett, 1997, 1998), the Precambrian basement rocks in the Wet Mountains expose an oblique crustal profile containing a superb record of Paleoproterozoic and Mesoproterozoic events.

In Colorado, questions of late Tertiary and Quaternary landscape evolution and climate have been addressed at Florissant, where a rich fossil and isotopic record is preserved in lacustrine sediments (e.g. Chase & Gregory, 1994). New insights are coming from modelling of erosion and isostatic response (Leonard, in press) due to incision along transects such as the Arkansas River corridor, and from cooling histories determined from apatite fission-track thermochronology (Pazzaglia & Kelley, 1998).

In the Precambrian realm, the “anorogenic controversy” has focused attention on the Mesoproterozoic history of North America. Current research strives to resolve conflicting interpretations of Mesoproterozoic tectonics from geochemistry and petrology of granitoids (cf. Anderson & Cullers, 1999) versus those based on structural geology and mapping (Kirby et al. 1995; Marcoline et al. 1999; Siddoway et al. 2000). New $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology for timing of mineral growth during dynamic metamorphism (Shaw et al. 1999) supports hypotheses for Mesoproterozoic plutonism in a dynamic setting and suggests the need to distinguish two discrete tectonothermal events, one pre-1.42 Ga, and one post-1.39 Ga.

The Colorado Keck project of 2001 supported two research projects addressing questions of Cenozoic landscape evolution and seven projects focused on Precambrian metamorphism and plutonism.

STUDENT PROJECTS

Cenozoic Landscape Evolution in the northern Wet Mountains

The Arkansas River transects the northern Wet Mountains, flowing within a deep gorge through rugged landscape formed upon resistant-weathering Precambrian bedrock (Fig. 2). Other major rivers of southern Colorado, such as the Gunnison River, have

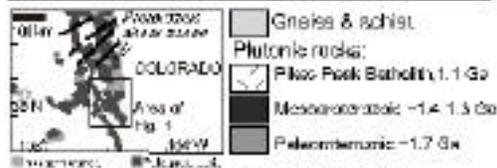
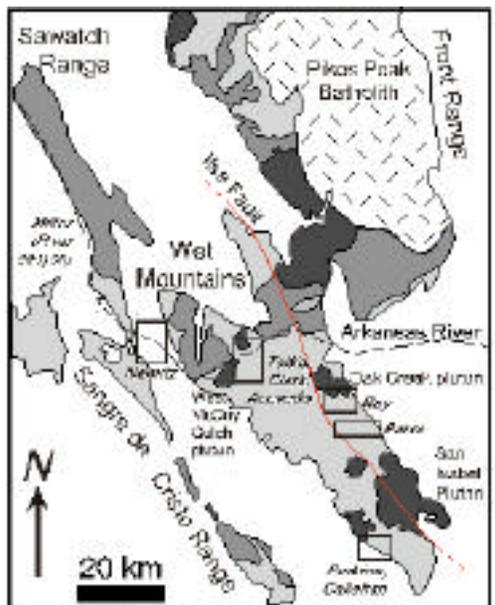


Figure 1: Map of the Wet Mountains and Proterozoic rocks of south-central Colorado. Locations for student projects are framed by boxes. Small map of Colorado highlights Proterozoic rocks and major stream courses of Colorado.

carved deep canyons due to dramatic rates of downcutting since Pleistocene time (e.g. Cole 2001). To investigate the Quaternary incision history of the Arkansas River, **Zachary Miller** of Pomona College used differential GPS to survey the succession of terraces along a 108 km reach of the Arkansas River. Digital elevation models provide a regional topographic base and data for quantitative aspects of the work, such as terrace height and gradient calculations. Eric Leonard of Colorado College provided input on this project.

In the vicinity of Howard, Colorado, the Arkansas River flows through a landscape with more subdued topography and less dramatic relief, coinciding with poorly lithified clastic sediments and volcanic rocks of Tertiary age. The depocenter has been termed the "Howard paleovalley" by Epis & Chapin (1975), with earliest strata considered to have been deposited in a NE-flowing channel upon the Eocene erosion surface. The oldest strata were potentially derived from the San Juan volcanic field; however, younger conglomerates appear to have a proximal

source in the Sangre de Cristo Range. On their east side, the Sangre de Cristo Mountains form the sheer western margin of the Howard valley; on the west, the sharp eastern limit of the northern Rio Grande Rift (Fig. 2). To **Eric Nemitz** of Carleton College, this suggests the possibility that Howard sediments record the transition from a low-relief, integrated drainage system in the middle Tertiary Period to the dramatically segmented, modern landscape of intermontane basins, with the Howard Valley as a peripheral basin flanking the Rio Grande Rift. Through field sedimentologic studies and mapping, Eric discovered ash beds in the Howard sediments that offer important new age control on sedimentation at Howard. Bill McIntosh is completing the $^{40}\text{Ar}/^{39}\text{Ar}$ tephrochronology at New Mexico Tech University. He and Chuck Chapin participated in field studies last summer.

Record of Mesoproterozoic Events in the Wet Mountains

The Mesoproterozoic plutonic belt of North America is currently of considerable research interest because of the growing consensus that magmatism was associated with convergent plate boundary processes (e.g. Nyman et al. 1994) rather than passive rifting (Anderson & Cullers, 1999) and the emerging evidence for two pulses of tectonism, one at > 1.4 Ga, and a second, circa 1.38-1.35 Ga (Williams et al. 2001). The Wet Mts have received little study so far; however, a solid starting position is provided by the geochronology and geochemistry of Mesoproterozoic plutons reported by Bickford et al. (1989) and Cullers et al. (1992, 1993). The three plutons in the Wet Mts include the Oak Creek and West McCoy Gulch plutons in the north, and the San Isabel pluton in the southern Wet Mountains. Research sponsored by the Keck Consortium in 1996-98 (Noblett, 1997, 1998) involved reconnaissance mapping of 125 km² in the northern Wet Mts and addressed questions of metamorphic protoliths and igneous petrogenesis of host rocks surrounding the plutons. Within this genetic framework, it is now possible to investigate the deformational and metamorphic history of

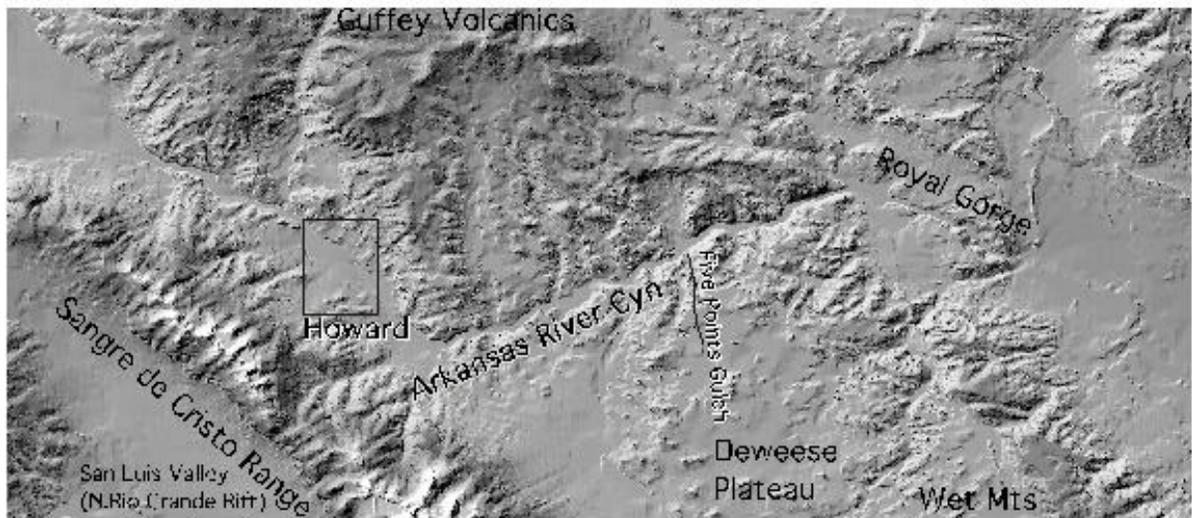


Figure 2. Digital elevation model showing elements of the Cenozoic landscape of the northern Wet Mountains. Howard study area is indicated with box, site of E. Demic study. Z. Miller surveyed portions of the Arkansas River upstream of Royal Gorge. The location of Five Points Gulch is shown, an area studied by C. Tellio, T. Clark, and G. Acevedo.

the little-studied amphibolite-grade gneisses hosting the plutonic rocks.

In July 2001, **George Perkins** of Colorado College and **Owen Callahan** of Hampshire College formed a heroic pair who accepted the challenge of a distant and little-known field site in the southernmost Wet Mountains. The remaining five students address research problems revealed by mapping during previous Keck field research projects.

Candice Tellio of Mesa State College and **Jimmy Ray** of the University of Texas—El Paso investigated shear zones discovered in the gneisses hosting the Oak Creek pluton and West McCoy Gulch pluton (Siddoway et al., 2000) in the northern Wet Mountains.

Gabriel Acevedo of U.T. El Paso and **Elizabeth Clark** of Carleton College focused on the metamorphic petrology of paragneisses and aluminous schists, and **Julie Parra** of California State Polytechnic University presents a detailed study of syntectonic granitic sills emplaced within migmatite gneisses.

Jimmy Ray took on the extreme terrain south of the Oak Creek pluton (Fig. 1), in order to study the Newlin Creek shear zone. Jimmy's mapping reveals two dynamic fabrics and lineation trends, where a single fabric had been recognized before. Mapping predominantly in gneissic granitoids, Jimmy nonetheless discovered screens of calcsilicate gneisses, amphibolite, and garnet-sillimanite

rocks that contain suitable assemblages for thermobarometry. Relict granulite assemblages from Paleoproterozoic orogeny are locally preserved. Quantitative strain analysis on oriented samples from the Oak Creek pluton reveal dynamic fabrics produced by solid state deformation in the margin of the pluton, suggesting that the pluton intruded during regional deformation at ~1.4 Ga.

Candice Tellio's project involved detailed structural mapping in sillimanite-rich quartzofeldspathic gneisses of the Five Points Gulch shear zone, adjacent to the West McCoy Gulch pluton. Candice mapped a 6 km transect along the Arkansas River, plus small areas in fairly inaccessible terrain south and north of the river. She discovered low strain zones in which early deformational fabrics are preserved; in some domains, primary bedding even exists as compositional layering defined by aluminosilicate porphyroblasts! Thus, Candice proposes a new interpretation of the progressive deformation history for gneisses within a penetrative deformation zone associated with the West McCoy Gulch pluton.

An unusual texture defined by quartz-sillimanite "pods" characterizes some of the aluminous gneisses of the Five Points zone. Somewhat common in Precambrian gneisses of southern Colorado and New Mexico (e.g. Pedrick, et al. 1993), there has been no agreement about the metamorphic reactions

responsible for pod formation (cf. Foster, 1982). **Gabe Acevedo** took on the task of careful petrographic analysis of pod rocks in thin section, with quantitative mineral analysis for thermobarometry, and found textural evidence that the quartz-sillimanite-muscovite aggregates in the Five Points area formed through continuous reactions involving muscovite, under amphibolite facies conditions. The influence of plutonism in creating an optimal T-fluid environment for nucleation of the pods remains to be explored. [Director's note: Gabe's field study was cut short by an injury, after a single (long!) day of work. In light of all that Gabe accomplished (Acevedo, this volume) with one day's worth of samples, it's daunting to imagine what he might have achieved from the full field season!]

One of the important occurrences of the mineral Cordierite in Colorado is in the Five Points Gulch/Echo Park area along the Arkansas River (Fig.2). **Liz Clark** focused her attention on stages of the regional deformation history recorded in relict fabrics preserved as mineral inclusions within large cordierite poikiloblasts in East Gulch. Stereonet analysis of "internal" and external fabrics revealed important correlations and differences with cordierite schists of Five Points Gulch (Wilson et al., 1998). Liz proposes that a continuation of the Five Points Gulch shear zone can be found in East Gulch, north of the Arkansas River.

In addition to the large, discrete plutons of Mesoproterozoic age, voluminous granitoids exist in the Wet Mountains as extensive sheets and layers concordant with regional foliation. Detailed mapping of these granitoid bodies is needed, to document crosscutting relationships, fabric development, and textures for kinematic interpretation. **Julie Parra** mapped an exceptional transect in a Mesoproterozoic sill complex along North Hardscrabble Creek and undertook detailed descriptive analysis, to assess the style and degree of deformation of concordant sheets of granite and their host gneisses.

Owen Callahan and **George Perkins** agreed that it was crucial to obtain some knowledge

of the gneisses hosting the San Isabel pluton. The youngest known Mesoproterozoic pluton, the San Isabel intrusion (1.365 Ga) was emplaced at the deepest crustal level, according to Al-in-hornblende geobarometry (Cullers et al., 1993). As they investigated the heterogeneous gneisses of the southwesternmost Wet Mountains, George and Owen focused on structural mapping and collected oriented samples for geometrical and kinematic analysis of regional fabrics. In the field, they identified lithologic units and examined crosscutting relationships to determine a relative chronology. In the lab, George took on the task of detailed thin section study for metamorphic petrology, finding that dynamic mineral assemblages in amphibolites offer exceptional textures for estimation of metamorphic temperatures. Owen focused on quartzofeldspathic gneisses and pursued an opportunity for U-Th-Pb monazite dating made possible by collaboration with Mike Williams of the University of Massachusetts.

CONCLUSIONS

Findings from the Colorado Keck project represent important progress in understanding the geological history of Colorado, with contributions in two disparate time intervals. The Wet Mountains offer superb geological relationships that record Proterozoic orogenic events and evolution of part of the continental crust of North America. As well, they are a promising area in which to explore questions of Mesozoic tectonics (the Laramide Orogeny and Tertiary volcanism) and Cenozoic landscape development. Findings of the accomplished team of 9 students in the Colorado Keck project are presented in the following nine abstracts (this volume).

ACKNOWLEDGMENTS

During the field work in July, many guest participants enriched the research program, spending time in the field with students, presenting evening seminars, brainstorming about geological questions over breakfast, and assisting with sampling efforts in the field. Sponsors who visited the project to assist their students are Jonathan Nourse (Cal Poly Pomona), Rick Livacarri (Mesa State), Shelby

Boardman and Bill Dinklage (Carleton College). Proterozoic researchers include Karl Karlstrom and Micah Jessop (U. New Mexico); Mike Williams and Joe Kopera (U. Massachusetts); Jim Connelly and Jamey Jones (U. Texas—Austin). Visitors devoted to the Mesozoic and Cenozoic history of the area were Eric Leonard (Colorado College), Eric Erslev (Colorado State U.), Mary Hubbard (Kansas State U.), Steve Chapin, Bill McIntosh, and Chuck Chapin (New Mexico Tech). We gratefully acknowledge that the research was supported by the Keck Consortium for Undergraduate Research and NSF Earth Sciences grant 0101314 to Siddoway.

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