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GEOLOGICAL TRAINING OF ASTRONAUTS IN THE TAOS REGION

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INTRODUCTION

The Taos region has a great variety of geological features that can be used for teaching geology to anyone- especially those who are curious about how the world works. It has the additional assets of scenic vistas, a good climate, and good food and accommodations. I had done geological field work early in my career in several areas related to this region: Ojo Caliente Precambrian rocks (1947; remapped onto USGS topographic map, 1960); Capulin Volcano Quadrangle (1954); Chama Basin and Tusas Mountains (1955-1959); and have participated in many geological field trips across the region. I have done extensive field work in the Big Bend region of Texas as well (led an early astronaut training trip there). Big Bend also has a wide variety of good geology that is well exposed (it's a desert!), but the climate is such that it adds a survival element to field work. That is not necessary for this type of learning as the astronauts learn survival techniques on a separate course. Thus I use the Taos region for astronaut geological field trips.

FOR THE MOON

Some History

I became a part of the Apollo geological team of the U.S. Geological Survey when I was appointed to be Principal Investigator for Field Geology for the Apollo 16-17 missions to the Moon (Table 1). My first mission work was with the Apollo 14 mission when we were assembling the report of what the astronauts had done and accomplished on that mission. We analyzed photos, quizzed the astronauts, and took quick looks at the rocks brought back. This resulted in a report that put the rocks into their geological context, so that the sample analysts could take rock samples to their labs for study and have some idea of the geologic setting of the site.

Two teams of astronauts were trained for each lunar mission- one prime, one backup. All our geological field trips were run as if the astronauts were on the Moon and we were in Mission Control in the Science Backroom. The evening before a field exercise, we were briefed by the geologist who had made a photo-interpretation of the area to be traversed (usually the local expert who had mapped the area). He described his interpretation, the stops on the traverse and tasks to be performed at each stop. Because there were two pairs of astronauts to be taught, we had to set up two parallel teams to operate Mission Control, two different radio systems, two vehicles for the astronauts to drive, and two teams of geologists and astronaut 'Capcoms' (Capsule Communicators) to be at 'Mission Control'.

For Apollo 15, the Prime Crew (Dave Scott and Jim Irwin) always worked with the P.I. (Gordon Swann) and his team. I worked with the Backup Crew (Dick Gordon and Harrison "Jack" H. Schmitt). On the radio was the astronaut who would be on the radio in Mission Control (Capcom) during the real mission to the Moon. The Backup capcom for Apollo 15 was Bob Parker (PhD, Astronomy). This was fortunate for me because both Bob and Jack became part of the team for Apollo 17, for which I would be the geology team leader. We were well acquainted with how we worked by the time of Apollo 17!

The geology field trips for the Apollo 15-17 missions, the 'Big Science' missions, were scheduled about a month apart over the year and a half before launch. We went to places that we thought would show geologic features and problems similar to those they

TABLE 1. Apollo Missions to the Moon. Astronauts listed in the following order: Commander, CM Pilot (Command Module Pilot- stayed in lunar orbit), LM Pilot (Lunar Module Pilot- landed on Moon with Commander)

Apollo 8 - launched Dec 21, 1968 - first manned lunar orbital flight. Frank Borman, James A. Lovell, William A. Anders

Apollo 10 - launched May 18, 1969 - first lunar orbital flight of complete spacecraft. Thomas F. Stafford, John W. Young, Eugene A. Cernan

Apollo 11 - launched July 16, 1969- First manned lunar landing. Neil A. Armstrong, Michael Collins, Edwin W. Aldrin, Jr.

Apollo 12 - Launched Nov 14, 1969-second manned lunar landing. Charles Conrad, Jr., Richard F. Gordon, Jr., Alan L. Bean

Apollo 13 - launched April 11, 1970- mission aborted on way to Moon. Astronauts returned safely back to Earth. James A. Lovell, John L. Swigert, Fred W. Haise.

Apollo 14 - launched Jan 31, 1971- first walking mission to a large crater Alan B. Shepard, Stuart A. Roosa, Edger D. Mitchell

Apollo 15 - launched July 26, 1971- first scientific mission with vehicle. David R. Scott, Alfred W. Worden, Jr., James B. Irwin.

Apollo 16 - launched April 16, 1972- second scientific mission with vehicle. John W. Young, Thomas K. Mattingly, Charles M. Duke, Jr.

Apollo 17 - launched Dec 7, 1972- last scientific mission with vehicle. Eugene A. Cernan, Ronald E. Evans, Harrison H. Schmitt.

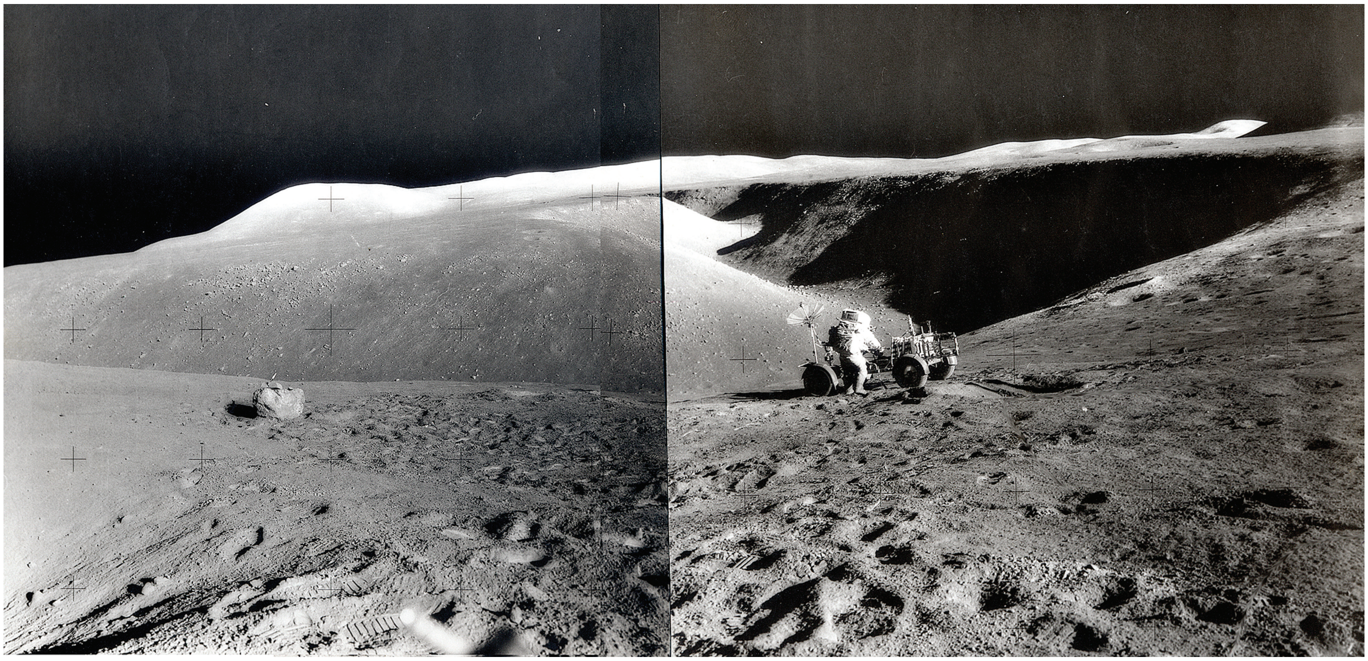

FIGURE 1. AS15-85-11448, 11451. View north along Hadley Rille, Apollo 15 Landing Site. Jim Irwin and Lunar Rover. To view this and other pictures taken during the Apollo missions see <http://images.jsc.nasa.gov/luceneweb/browse.jsp>

would face on the Moon, such as impact craters, volcanic areas, anorthosite bodies, etc. Each traverse was designed to be of similar length to those on the proposed traverses they would cover on the Moon. Our only contact with the crew during the traverse was via the Capcom, the only person to talk to the crew. After radio debriefing, and a break for lunch, the local expert took over. He had been with the crew during the traverse, heard the two way radio conversation as well as seeing what the astronauts actually did. He commented at each stop as to the good and the bad of the conversation and /or sampling technique. “Backroom, they told you this and this, if you had asked this question- look what you would have learned”. “Crew, you told them this and this, that led them on a wild goose chase. You should have said ------!”. From these exchanges, we each learned the language of the others and improved our geological field skills.

Astronaut trips into northern New Mexico

Geological training of astronauts depends heavily on finding and using terrestrial analogues. The Rio Grande Gorge near Taos is a 1:1 scale model of Hadley Rille at the Apollo 15 landing site. The volcanic hills next to the gorge made good analogues for the Apollo 16 landing site. Thus this area became one of the prime NASA training areas. Apollo 15 was the first to use the Taos area for a field trip. Leon (‘Lee’) Silver, one of the Geology Co-investigators for the Apollo Missions, suggested the Rio Grande Gorge as an analog to the Hadley Rille (Figs. 1, 2) that the Apollo 15 crew was going to land near and traverse along its rim. Lee and I went there in the dead of winter (!) to check the feasibility of doing it and found enough dirt road access to make it work so on we went. March 11-12, 1971 the astronaut teams did two days of traverses along the rim of the Gorge (weather was cold! But, no rain or snow!). Because there was no way to cross the rille (or the Gorge), the crew practiced with 500mm telephoto lens on their Hasselblad cameras to take panoramas along the far face

FIGURE 2. AS15-84-11287. Telephoto view of the boulder field in rille floor (see Figure 1 for location- it is just above the TV antenna on the Lunar Rover). Note angular sides on the large boulders (columnar joints!)

FIGURE 3. S-71-23472. Dave Scott (right) and Jim Irwin, Apollo 15 crew driving the battery-powered "Grover", the simplified version of the Lunar Rover used in the geological field training trips. All the equipment was mounted in the correct locations but nothing was workable – e.g., TV antenna, TV camera, sample bag holders (kept behind the crew). Rio Grande Gorge in middle distance.

and repeat again when they had moved to the next station along the rim (Figs. 3, 4). These photos gave us a stereo base to study the rocks exposed along the far wall and to interpret stratigraphy (Fig. 5).

They described and photographed the walls of the gorge in proportions ("the top quarter is composed of 4 flows; the next quarter has three, the lower half is covered by landslide material") rather than in feet or meters (Figs. 6, 7). Photogrammetrists then converted the pieces into meters of cliff section.

Apollo 16 used this region for a field trip on Sept. 9-10, 1971, but with a different emphasis. Their landing site had two different morphologic types: hills of "Descartes Formation" and smooth plains of "Cayley Formation". The volcanic hills west of the Gorge were used as Descartes Formation and the smooth plains

FIGURE 4. S-71-23475. Dave Scott (right) and Jim Irwin preparing to sample along the rim of the Rio Grande Gorge. The backpack and harness held all equipment in the identical positions to those on their space suits, so that they would automatically know where everything was when in the real suit.

FIGURE 5. S-71-23461. Harrison (Jack) H. Schmitt (with camera) and Dick Gordon, Apollo 15 Backup crew along rim of the Rio Grande Gorge. The 500mm lens on the camera was to take panoramas of the far wall for stereo study back on earth. The canyon in view (road climbing far wall is the old Taos Junction road) is the same size as Hadley Rille on the Moon.

surrounding them were used for the Cayley. The Gorge was used for description of the walls to mimic the walls of the mile-diameter North Ray Crater that they would be investigating on the Moon.

Apollo 17 did not come here because Jack Schmitt had already been here on a training trip. Thus ended the Apollo era trips to New Mexico.

FOR THE EARTH

Post-Apollo Trips

Skylab and the Apollo-Soyuz astronauts had earth observations as part of their training but field trips were not included-time was too short.

FIGURE 6. USGS Photo (unnumbered). View of far wall of Rio Grande Gorge taken by Apollo 15 crew member using the 500-mm telephoto lens showing basalt stratigraphy and interbedded soft layers.

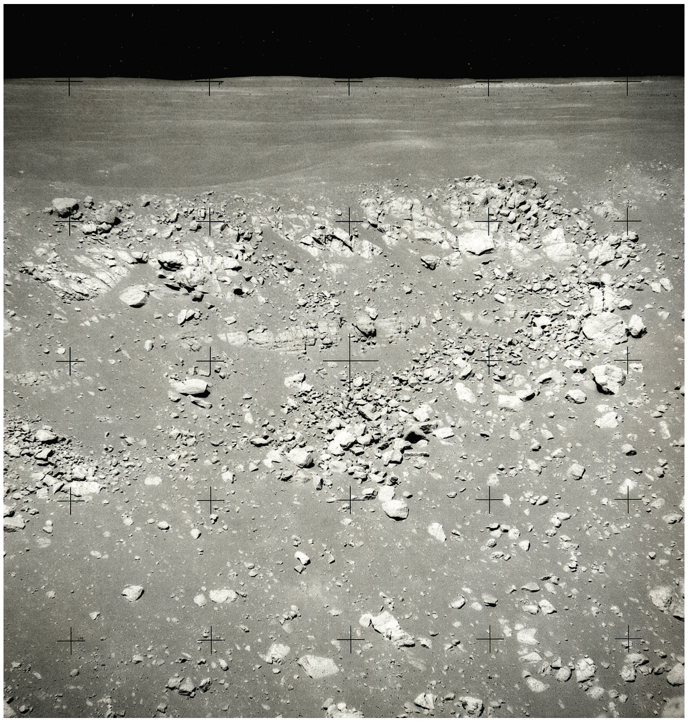

FIGURE 7. AS15-89-12157. Far wall of Hadley Rille showing stratigraphy. Taken by Dave Scott with a 500-mm telephoto lens.

The Space Shuttle was conceived and took several (too many) years to be designed and built. In the meantime, Sally Ride (PhD, Physics), one of the astronauts waiting to fly on the Shuttle was assigned the task of determining what science could be done from the window of the Shuttle. Obviously geology was one subject, with oceanography and meteorology being the other major topics. She would fly with another astronaut (different each time) to Austin and we would spend the day talking geology, looking at maps, etc. Out of those discussions developed a series of lectures (to be given at Johnson Space Center) and a geological field trip to northern New Mexico (she was a member of that first trip; Fig. 8). Earth-orbiting missions require a wider knowledge of geology. Thus, all of northern New Mexico becomes the geological training ground. Virtually all of the Shuttle (and Space Station) astronauts have been on a four-day field trip to visit the variety of great geology exposed in this region. In addition to the geologic days, in 1999, and last August, the group spent another day performing gravity traverses across Taos and vicinity to assist in delineation of buried faults that would affect the distribution of groundwater.

More History

In the years after Apollo and before Shuttle, my students and I had done considerable field work along the Rio Grande Gorge (mapping the stratigraphy shown on the walls), along the Embudo fault, and studying the deformation of the Taos Plateau. My wife and I had published a tourist guidebook (Muehlberger and Muehlberger, 1982), which described the human history and geology along the roads from Santa Fe to Chama to Taos and back to Santa Fe. It became the guidebook for the astronaut field trips that I have led beginning with the first class of Shuttle astronauts. The trip has evolved through the years (starting in 1979) to what is outlined below.

Space Shuttle Astronaut Geology Field Trip

From the Albuquerque airport, where I join them, we travel to the Placitas area where we talk of grabens, their filling, and later draining; of the Great Unconformity seen on the flanks of the Sandia Mountains, the sea shells in the Pennsylvanian rocks now high above us - except for cobbles brought down by flood waters from the mountain; and a row of little volcanoes on the other side of the valley. (I take them one van load at a time so that they can ask questions and I can comment at any time). Then on to Santa Fe and Taos (our home for the trip) with stops in the lower Rio Grande Gorge to look at basalt boulders, the first stream-gauging station in the United States, Precambrian metasediments and the Embudo fault (Fig. 9).

The next day begins at the High Bridge over the Rio Grande Gorge to start the discussion of canyon formation, controls on shape, and a comparison with the Grand Canyon (not too different in age, but very different in shape and size). Then we move north to the Dunn's Bridge crossing of the Rio Grande to explore why the canyon is different in shape, evidence for faulting during deposition of the exposed rocks, and to visit a lava tube and a hot spring. I also expose them to rock sampling in the gravels in the sedimentary section of the canyon ("You have just landed on Mars! But you have an abort situation. You have five minutes to sample the area. Go!") They are not given any insights as to how to sample such a hodgepodge of rocks, but invariably they sample and bring back one of each color. Then I ask questions, such as

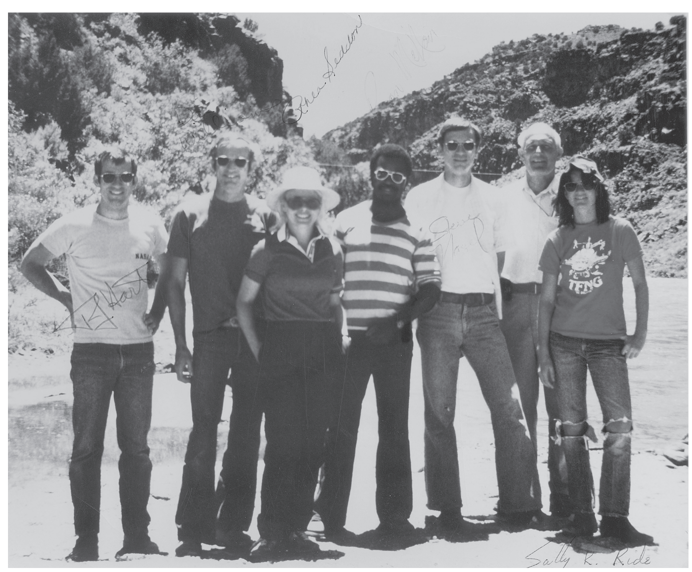

FIGURE 8. First group of Shuttle astronauts to go on the northern New Mexico geology field trip, summer 1980. Rio Grande at Dunn Bridge. From left to right: T. J. Hart; Don Williams; Rhea Seddon; Ron McNair; Steve Nagel: Bill Muehlberger (instructor); Sally Ride.

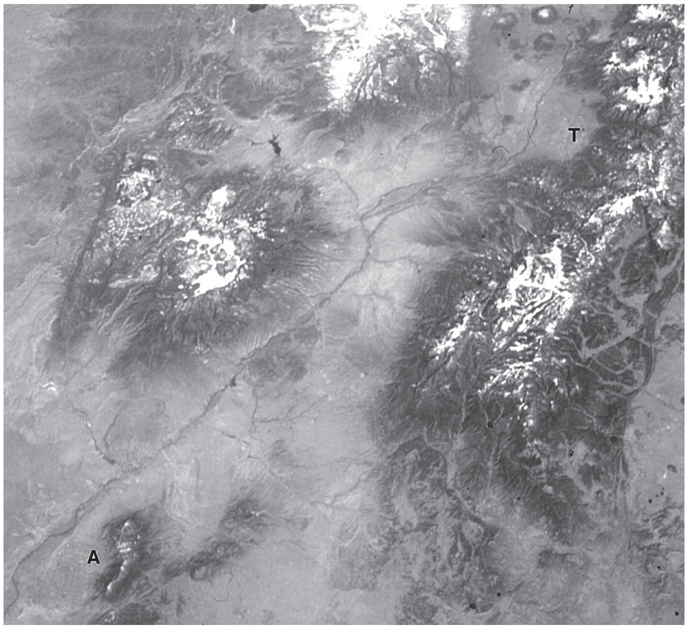

FIGURE 9. NM 23-714-553. New Mexico field-training region viewed from the Russian Space Station *Mir*: Taos (T) is at the foot of Sangre de Cristo range. The Jemez Mts. volcanic complex is left of center. Albuquerque (A) and the adjacent Sandia Mountains are at lower left. Taos is 217km/135mi from Albuquerque. (NASA photo, Johnson Space Center, Earth Science & Image Analysis Lab). For this photo and 550K others taken of Earth from manned spacecraft see: <http://eol.jsc.nasa.gov>.

"what was the most common rock type"; "why didn't you grab a sample of the soil?". Then we use hand lenses to look at the crystals and work out the igneous rock classification among the rocks (rhyolite, andesite, basalt, and their intrusive equivalents granite, diorite, and gabbro; all are present in the variety of igneous, metamorphic and sedimentary rocks in this gravel).

Next we go north to the BLM Wild and Scenic River road to see the interesting variety of canyon shapes, the cross section of a cinder cone buried by the youngest flows, the headward growth of the Gorge above its junction with Red River, and to identify the volcanic sources for flows exposed in the canyon walls (see road log, this guidebook). The use of stereo photos is introduced using volcanic areas - Glass Flow, Mauna Loa, Kilauea, etc. From there we take the Enchanted Circle loop into the Sangre de Cristo Mountains (Bauer et al, 1991; excellent road logs), past the Questa molybdenum mine, Red River (the change from river-cut to glacier-cut canyons), study intrusive versions of some of the volcanic rocks seen along the Rio Grande, Eagle Nest, Angel Fire, Pennsylvanian marine fossils at 8,000 feet above sea level, and back to Taos.

The next day is a long loop west across the graben, north along the eastern edge of the Colorado Plateau, east across the Tusas Mountains and back to Taos. We cross the Rio Grande on the old Taos Junction road (where it climbs out of the Gorge is the one-to-one scale model of the Apollo 15 Hadley Rille), pass ancient pueblo ruins north of Ojo Caliente, study the Abiquiu/Santa Fe Formation lithic differences, and ancient hot spring deposits. Continue to El Rito (where the valley is east-tilted: a large scale version of the many tilted drainages on the Taos Plateau), to Abiquiu. Stops at the western edge of the graben to study Permian-Triassic exposures and on to Echo Amphitheater (a gorgeous place to discuss formation of dunes, how they move, patterns they make and end with photos taken from the Shuttle of dune fields elsewhere in the world to ask 'which way is the wind blowing?'). Then on north past the spectacular road cuts in Jurassic-Cretaceous river deposits ending with a Cretaceous (Dakota) beach sand. Chama is lunch and a detour up the road to Cumbres Pass (before the pass are spectacular exposures of the unconformity between west-tilted Mesozoic rocks of the Chama-San Juan Basin and the overlying post-Laramide Tertiary clastic and volcanic section that is tilted eastward toward the Rio Grande graben). From there we go east on U.S. 64 over the Tusas Mountains for spectacular views west, then into the Hopewell mining district. Then on to viewing faults that control the drainage, a roadcut in a huge river channel deposit and back onto the Taos Plateau for profile views of the variety of volcanoes on the plateau, and back to Taos.

The fourth day of the field trip is involved again with the Embudo fault but it is primarily a traverse across the Jemez caldera, and on to the airport to fly home at the end of the day. The road cut along highway NM-68 at the southern edge of the Taos Plateau exposes the reverse-faulted segment of the currently active branch of the Embudo fault. This is also an excellent view across the Taos Plateau to review and summarize what has been covered over the past few days. The Jemez traverse makes stops on the ignimbrite outflow units before climbing the Pajarito fault scarp (fastest moving fault in the Rio Grande rift: about 300 feet in 1.1 Ma!) into the Valle Grande with its pumice beds and obsidian flow. Then on to Battleship Rock, Soda Dam hot springs, and back into the graben again in sand dune facies of the Santa Fe Formation. From there we continue on to the airport and home.

In 1999 we were actively involved in developing a field-training program in preparation for human exploration of Mars. One of the experiments that had been conducted on the Moon was a gravity survey. Thus, in that year the class had the benefit of an additional day of geophysical surveying arranged by Pat Dickerson, co-leader on the previous class trip, in collaboration with Paul Bauer of the New Mexico Bureau of Geology and Mineral Resources. Paul and colleagues had been conducting a detailed groundwater study of the Taos valley and intended to do geophysical work. The astronauts became the work force to survey station locations, record gravity measurements, and transfer the data to the field base. The astronauts were delighted with the project – they had made a valuable contribution to scientific understanding of the region. We were able to do additional gravity traverses in the Taos area with the latest class of astronauts this August, 2004. See companion paper by Dickerson for details of the technique and results.

Future geological and geophysical training, whenever that might occur, will build upon this experience and address varied scientific objectives, as candidate sites for lunar and martian exploration are selected. For example, an exercise in sampling and analyzing spring waters, as well as ancient and modern spring deposits, has been developed (see Dickerson article) toward seeking water and possible biota on Mars. Regarding this initial geophysical exploration simulation, we hope that we have contributed to building an exploration culture within and beyond NASA and to preparing explorers for the task.

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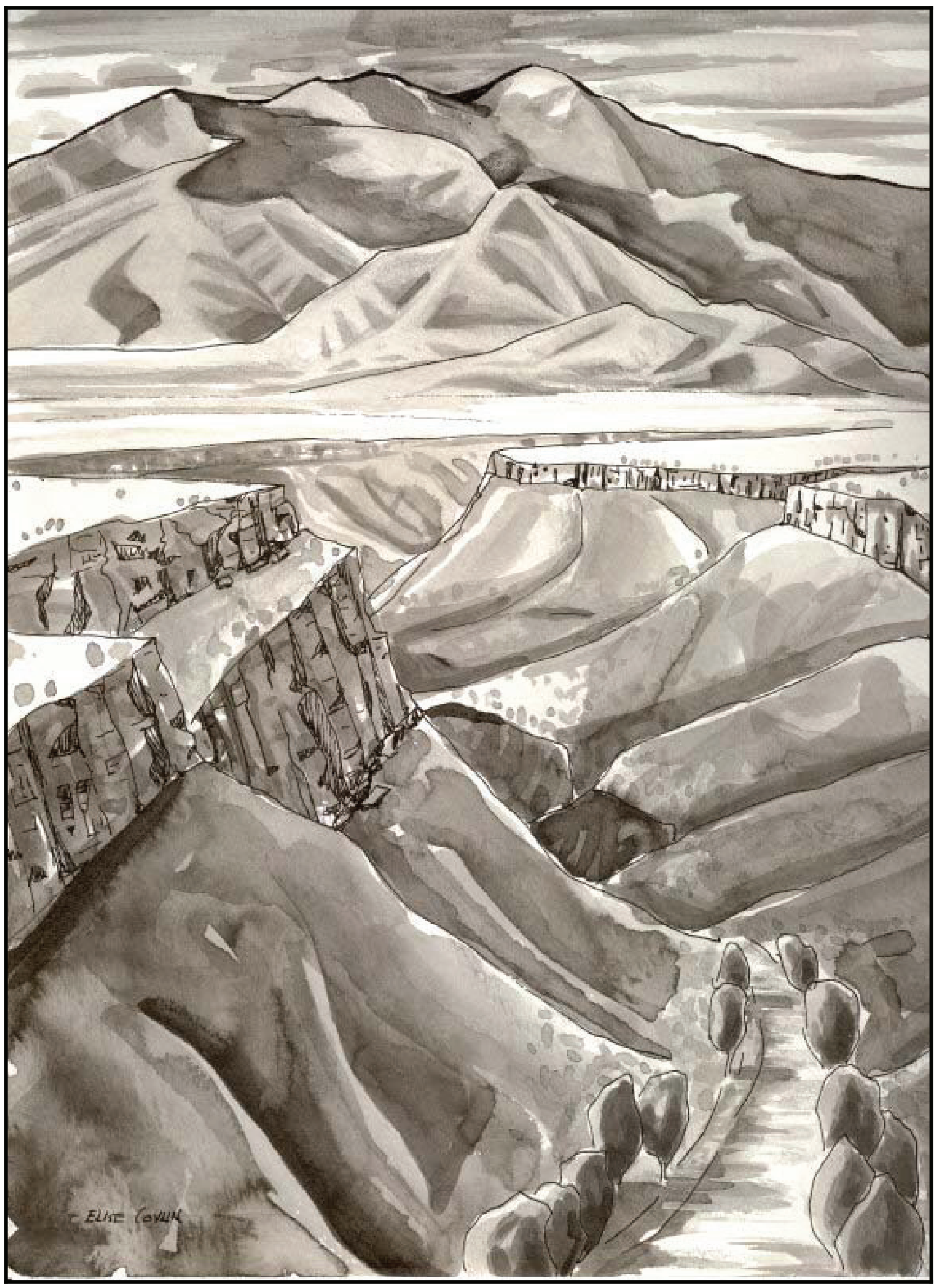

The Gorge *by Elise Covlin* *Courtesy Brian and Julie Brister*