An Inexpensive, Concentrated Field Experience Across the Cordillera

Alison S. Lathrop — Department of Natural Sciences, Lyndon State College, 1001 College Rd., Lyndonville, VT. 05851, alison.lathrop@lsc.vsc.edu

Ballard E. Ebbett — Department of Natural Sciences, Lyndon State College, 1001 College Rd., Lyndonville, VT. 05851

ABSTRACT

We offer a short expedition focused on developing the sense of geologic space and time traditionally acquired during field camp to a wide range of students, including future geoscientists, environmental scientists, K-12 teachers, and anyone planning to communicate geoscience to the public. The expedition and minimal prerequisites fit easily within crowded program requirements. Our methodology is adaptable to most regions, although we chose a transect from the Colorado Plateau to the Sierras because of minimal vegetation, easily distinguishable formations and structures, and the relationship of the geologic history of the region to more obvious plate tectonic events in the Coast Ranges and Sierras of California. This relationship is spectacular and always stirs the imagination of our students. We focus upon enabling students to interpret the landscape wherever they are and to place it within a bigger picture by refining their observational skills at all scales and by requiring intensive practice in inquiry-based critical thinking as they propose and evaluate continually-evolving geological ideas. Active learning promotes facility with maps, images, and current literature and prompts vigorous debate. Extensive pre- and post-trip course-embedded assessments support writing across the curriculum.

INTRODUCTION

We have spent the last decade fine-tuning a field experience incorporating many of the most important benefits of traditional field camp within a short, inexpensive expedition that we believe can be undertaken by almost any institution and adapted to different geologic regions. Our undergraduates participate relatively early in their studies rather than using it as a capstone event, which works well for two reasons. First, this experience requires intensive practice in making, organizing and refining field observations as well as extensive critical thinking to generate hypotheses and conclusions. Practice in all of these endeavors is fundamental preparation for upper-level work regardless of discipline. Second, prerequisites that are limited to our first semester Geology course and a preparatory seminar help students avoid scheduling problems. These limited prerequisites also help us to offer the experience to a wider range of students than those usually directed towards field camps or expeditions. Certainly some of our most skilled and responsive participants have certainly been the future geoscientists we would expect to excel in field studies. Some, however, have been students who plan to bring geoscience to the public as K-12 teachers, park rangers or interpretive naturalists, and a few were just fascinated by geology. Their success underscores our conviction that the essence of field experience is fundamental, not only to the formation of any professional who seeks to communicate the nature of science to the public at large, but for anyone who is drawn to explore the enormity of earth history that scientific inquiry can reveal.

There is no question that field work is a crucial component of undergraduate geoscience education. Many innovative field exercises are available to help get introductory geoscience students out of the lab and into the real world for short periods of time during their regular class hours (e.g., Weiss and Walters, 2004; Noll, 2003). On the other end of the spectrum, the traditional six-to-eight week field camp focused on mapping still exists, although financial and logistical constraints have caused many institutions to limit field camp requirements or offerings (Kirchner, 1997; Evans et al., 1996) and significant pressure continues to threaten these experiences (Drummond, 2001). Some, however, have argued that the field camp experience remains the best, and perhaps the only, forum within which students acquire a true sense of spatial relationships, scale and geologic time through critical thinking informed by disciplined scientific investigation (Flood, T.P., 1996; Kaesler, R.L., 1996). Such understanding is the foundation of any geoscience and is independent of the technology employed during the exercise, although incorporation of cutting-edge high-tech job skills is certainly beneficial (e.g., Manone et al., 2003).

We agree that it is acquisition of the sense of space, scale and time that is indispensable for future geoscientists, but we would add that it is equally important for those who will not pursue geology professionally. In particular, it is crucial for future K-12 teachers. Participation in authentic field-based research can certainly help earth science teachers to understand and incorporate both the scientific method and field-based lessons into their own curricula. Completion of a localized detailed research project, however, rarely brings the teachers face-to-face with the possibilities of space, scale and time that the scientific method in geology can reveal. Today, there is a critical need for teachers who have come to terms with the nature of scientific inquiry that directs us to contemplate human scale in space and time. Such teachers may well offer the only remedy to counteract the fundamental and dangerous lack of public understanding of the scientific process in general, and geology in particular, that contributes substantially to the serious financial and philosophical pressures currently faced by all science education (e.g., Wise, 2001; Parker, 2004).

We believe that it is the way in which we guide our students' inquiry that makes this short, intense excursion so valuable. The entire experience is focused upon equipping the students to answer the following question:

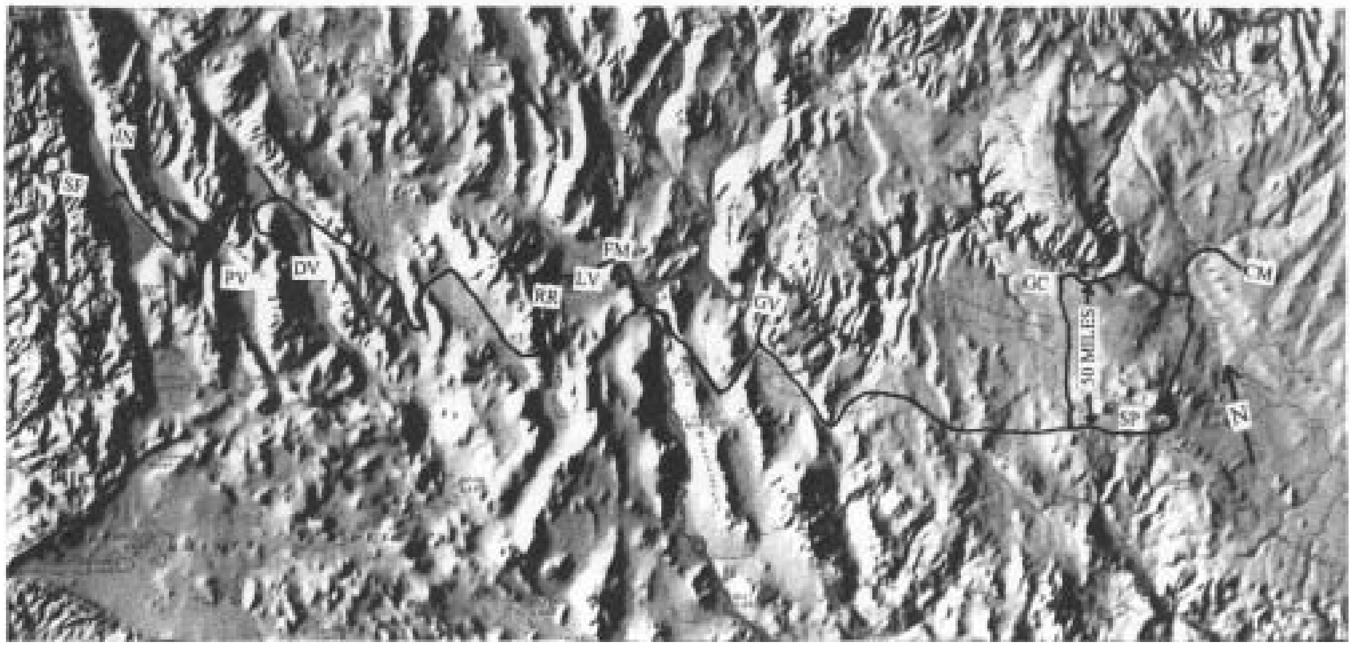

Figure 1. Trip route with locations from east to west: CM, Coal Mine Mesa; SP, San Francisco Peaks; GC, Grand Canyon; GV, Grapevine Mesa; FM, Frenchman Mountain; LV, Las Vegas; RR, Red Rocks Recreation Area; DV, Death Valley; PV, Panamint Valley; IN, Inyo Mountains; SF, Sierran Front. (Base Map from Raven Images, 1992 and USGS)

"What observations have you made that are consistent with…?"

Here, this phrase precedes proposed geologic histories, ideas about landscape evolution, and fundamental tenets of Plate Tectonic Theory. Contrary to a common field trip practice, we do not introduce any location we visit by telling the students what the geologic community thinks has happened there. Instead, keeping our "insider information" to ourselves, we guide them towards the most useful observations for informing their own critical thinking as they construct viable explanations for what they see. In most cases, we then prompt them for further ideas that are consistent with their observations, thus reinforcing the use of the scientific method through creation of multiple hypotheses, most of which they themselves will reject after further observations (Chamberlin, 1965, reprinted from 1890). Soon the students are attempting to determine their own lines of inquiry, which we actively encourage while ensuring that the trip progresses according to plan. Students find that this method requires them to be active learners. Passive learning is impossible because they must continually generate, refine and expand explanations (with our guidance), and the cumulative nature of this effort makes it immediately apparent that no one can afford to fall behind by opting not to participate. For example, at the beginning of the trip students identify specific formations at the outcrop, associate them with depositional environments, and arrange them chronologically for their initial proposed histories. We move fast, and students cannot develop their continually evolving stories if they have not kept their first observations and conclusions fresh in their minds. Our discussion at outcrops and panoramas during the trip reminds the students to winnow the flood of possible observations to those most helpful in addressing the immediate issues: What kinds of rocks do we see? How are they arranged relative to each other? What do some of the structures in these rocks suggest has happened to them since they were formed? How does what we are seeing now relate to what we have seen before? Based on what we see here, what might we expect to see over there? Because of this approach, students recognize the fundamental nature of good observation and careful interpretation early in the trip and they are motivated to practice those skills effectively to ensure their success.

Prerequisites

Students are prepared for this field experience once they have learned to ask, "what happened here?" automatically wherever they are, and have acquired enough basic geologic knowledge to begin to answer that question. We have found that our first semester geology course and a seminar designed to acquaint students with the geology along the trip transect and introduce them to geologic issues specific to the region provide enough content and experience in landscape interpretation and construction of geologic histories for students to succeed. These limited prerequisites also make it possible for non-majors to participate because most programs at our institution leave very little room for electives.

Students find this limited preparation sufficient primarily because our first-semester geology course follows an entirely-field-based, inquiry-driven model free of traditional chapter-based, segmented content organization. Students taught this way not only acquire the necessary content, but are prepared and confident enough to use it to decipher the geology along our transect for themselves. Specifically, students begin to observe, critically analyze and construct written geologic histories for the local landscape from the very first day of class, based on fieldwork supported by an extensive library of samples and images from classic locations worldwide. In our experience, students taught this way are more successful in upper-level work requiring extensive critical thinking than their traditionally-taught colleagues (even at other institutions, according to students who transferred away in search of a geology major but maintained contact with us), and after just two terms have more than enough experience to recognize and begin to interpret the rocks and structures they encounter along our transect.

TRIP DESIGN

We chose a transect from the southwestern Colorado Plateau to the eastern Sierran Margin near the latitude of Las Vegas (Figure 1) for many reasons. First, this area is relatively free of vegetation and contains formations and structures that are recognizable and distinguishable at a distance, thus allowing beginners to make valuable observations from distant panoramas after a close-up introduction to the stratigraphy. Second, the effects of plate tectonics are visible here in a spectacular and apparent way, such that novices can work plate tectonic-scale events into their own conclusions and histories based on their own observations rather than quoting textbook theory. For example, during the Fall seminar we emphasize plate movements that are directly relevant to what the students will see on the trip by first studying magnetic stripes on the Pacific sea floor and their relationship through time with the North American Pacific margin. Then during the trip the students correlate what they know happened to the sea floor with what they observe has happened inland. Because the story is the key, our itinerary is very carefully chosen by limiting geo-spectacular sites to those that best enhance student understanding of that story. By pondering their own observations of an extraordinary part of the world, students eventually come to terms with both scale and contiguity of time and place (Hume, 1854). Finally, this is a spectacular region that is utterly different from the landscape that most of our students call home. Merely being there stretches their sensibilities in many ways, from the need to carefully monitor sun exposure even in early April to assimilating the fact that the 11,000-foot relief between Badwater on the Death Valley floor and Telescope Peak in the Panamint Range a mere 15 horizontal miles away looks no greater than the familiar 3000- 4000 feet of relief in New Hampshire's Presidential Range.

Although we find our transect an ideal location for this experience, we suggest that it can be offered elsewhere, depending upon the resources and experience of the instructor(s). The inquiry-based approach to fieldwork can be applied anywhere and should always yield the significant benefits described above, regardless of setting. We include a scaled-down version as the centerpiece of our second-semester Geology course by beginning with a weekend trip across Vermont from the serpentinite belt westward to the carbonate platform. Students generate a geologic history of northern New England based primarily on their observations from that trip, then spend the balance of the term comparing stages in the geologic evolution of Vermont to present-day Indonesia. Instructors considering similar trips will find it most helpful to be guided by a specific geological "story" they wish their students to discover, rather than planning a tour of classic locations.

THE "ROAD LOG:" A TEN-DAY GUIDED INQUIRY

We narrate the itinerary from a perspective that reflects how students discover evidence for that history along the way, so we can demonstrate specifically how we point our students towards observations that best help them to grasp scale and contiguity in time and space during such a short excursion. A list of references that we found most useful, inspiring, and occasionally indispensable as we prepared both this trip and this approach to field study appears at the end of this paper.

We head first towards the Colorado Plateau, where the students will consider the breadth and depth of the relatively undeformed Paleozoic and Mesozoic sequences and Precambrian basement, learn to recognize them from a distance, and observe that recent basaltic volcanism has pierced the Plateau, originating from beneath the continental crust. As we head southeast toward the Plateau from Las Vegas, we introduce a class of observations that will help the students considerably as we travel from one region to another: How does the shape of the land reflect its geologic history? For example, we note the vast extent of alluvial fans filling long north-south trending valleys just to the west of the Plateau, how those alluvial fans have literally buried the foothills of the volcanic and Precambrian crystalline ranges bounding some of the valleys, how those ranges are shaped differently than the Grand Wash Cliffs exposing the flat-lying Paleozoic section of the Plateau, and especially, how long it could take to build those valley-filling fans, one flash flood at a time. Some fans are deeply incised by streams while others are not. What could account for the difference? In places we can confirm that late Cenozoic volcanics directly overlie the Precambrian crystalline basement, although the significance of that observation is not yet apparent. After our long climb from the dusty valleys and ranges we observe the flat expanse of the surface of the Colorado Plateau south of the Grand Canyon, weathering grey in gentle swales and thereby recalling the grey, flat-lying Paleozoic Kaibab Formation visible in road cuts just before we topped out on the Plateau. Students soon learn to recognize recent basalt flows beneath the sparse vegetation, occasionally visible in road cuts and eventually familiar as gentle and oddly flat-topped heights, shedding black boulders. Volcanoes of different ages loom into view, ranging from the Pliocene and Quaternary snow-capped San Francisco Peaks to unvegetated black Holocene cinder cones just beginning to rust. It soon becomes a game to distinguish flat-topped Mesozoic erosional remnants from cinder cones as we approach the South Rim of the Canyon, although what primarily occupies the students is their first real view of the vastness, the sheer enormity of the landscape unfolding before them as they gaze across the Painted Desert towards Navajo Mountain.

We spend time investigating the rocks in detail at locations selected to familiarize the students with the basic stratigraphy and geologic history of the Plateau. An afternoon is devoted to climbing a Holocene cinder cone, because a) none of our students has ever been on a volcano before, and b) we can verify that this is basaltic volcanism and that the basalt contains xenoliths that are consistent with a mantle origin. The students suggest that the basaltic magma had to come all the way up through the Plateau from beneath the continental crust (because they have heard that basalt originates as a partial melt of the mantle, and the xenoliths help), and the cinder cone must be a pretty recent feature because it's unconsolidated and it's still here, and it's on top of everything else. From the crater rim, we can see the lava flows that originated from this vent and how the age of the flows correlates with the amount of vegetative cover. Eventually, this site will be used by the students as evidence for what is beneath the basement/sedimentary sequence exposed in the Canyon, and in what order geologic events probably happened, but for now, their questions show that they are absorbed with their immediate surroundings. This illustrates one of the most frustrating but rewarding aspects of this approach: acquiring the discipline required to keep both the Big Picture and the local events in mind at once. We turn eastward into the Navajo and Hopi reservations to examine the Mesozoic Navajo Sandstone closely enough to acknowledge crossbedding on a huge scale and frosted, clean white grains that crumble away with minimal encouragement; the students recognize a terrestrial eolian deposit. Farther southeast and stratigraphically higher at Coal Mine Mesa, we examine a coal shale amid shallow marine deposits, and there is always a coastal New Englander along who recognizes an oyster bed among the well-preserved fossils. The students are beginning to see changes in environment, to consider the implications of alternating marine and terrestrial deposits, to understand a fragment of the progression of time in this place. Just southeast of the Canyon we examine a series of matrix- and clast-supported conglomerates containing pebbles of basement in what appears to be a stream deposit. Where could those pebbles have come from? No basement in sight from here... How then (and when?) must this landscape have been different, when "basement" was a high place from which pebbles could be shed? At the Grand Canyon we hike from rim to river and back, allowing for careful examination of the Paleozoic stratigraphy. We focus on lithology, sedimentary structures and fossils, and we note disconformities. We touch the Great Unconformity and recognize the basement which, as schists, gneisses and intrusive igneous rocks, is familiar territory at last for students from northern New England! While in and near the Canyon, we observe monoclines that disrupt what seemed from a distance to be uncomplicated and undisturbed horizontal layers. These monoclines seem to be rooted in reverse faults that, in the Late Precambrian, appear to have been active normal faults. These surprises serve as a prelude to what we will see much further on.

After having devoted the first third of the trip to investigating the Plateau stratigraphy, we head westward to see what has happened to it elsewhere. We pause at the northern edge of Grapevine Mesa, just west of the emergence of the Colorado into Lake Meade through the Grand Wash Cliffs. The students construct cross-sections of the scene before them where the eastern-most tilted blocks of Basin and Range are visible beside the now-familiar horizontal Paleozoic stratigraphy in the Grand Wash Cliffs. They see the tilted layers and, thanks to distance views supported by geologic maps, can recognize the Paleozoic sequence in the tilted blocks; it is up to them to propose subsurface structures and hypothesize to explain the separation, the tilt, and when those events might have happened. Next, the students examine the Pliocene closed-basin lake sediments on which they stand 1500' above the Colorado and consider the implications of their perch: If this was a closed basin, where was the Colorado River five or six million years ago? And what does that say about the age of the Canyon itself? Before leaving the area, we examine some of the debris flows associated with the closed basin sediments and discover rapakivi granite clasts. Geologic maps reveal that the only known source for this unusual rock is in the Precambrian crystalline basement exposed in the adjacent southern Virgin Mountains. Forty miles west of Grapevine Mesa, we pass the equally-tilted Paleozoic sequence at Frenchman Mountain northeast of Las Vegas and revisit the Great Unconformity separating Precambrian basement from Cambrian beachfront at van-level (why do all that hiking in the Canyon??). We also find a debris flow bearing rapakivi clasts unconformably overlying the tilted Paleozoic and Mesozoic sequence at Frenchman Mountain. What are those clasts doing here, all the way across Lake Meade and 40 miles away from their only known source?

Our next stop is Wilson Cliffs and Red Rocks Recreation area just west of Las Vegas, where the red and white Mesozoic Aztec Sandstone so beloved of climbers reminds us of the Navajo Sandstone. However, no one is really sure why the fossiliferous grey Paleozoic rocks should be above these Mesozoic rocks. This puzzle, along with other structural observations, introduces the Keystone and Wilson Cliffs Thrusts, easternmost of the great thrusts we will see. By this time, student questions indicate that their grasp of fundamental structural relationships in the Basin and Range is improving dramatically. However, they now know enough to observe that the picture is not completely tidy: Why do outcrops of Aztec appear offset from one another, particularly in the Calico Hills section to the northeast? Why did the ranges visible from Frenchman Mountain appear to curve systematically towards the northeast? Why were there horizontal slickenlines clearly exposed on the eastern side of Hoover Dam? And how did those rapakivi clasts reach Frenchman Mountain?

We continue westward to Death Valley. Along the way we continue to keep track of the Paleozoic sequence which has changed character somewhat (an example of sedimentary facies changes), thickened considerably (as could be expected in the deeper portions of a sedimentary basin), and repeats in range after range, blocks relentlessly tilted towards the east (which demonstrates extraordinary crustal extension). We note more thrust faults in the tilted blocks, always verging east. Which came first, the thrusts or the breaking and tilting of blocks? One of our most important stops is Aguerreberry Point high in the Panamint Range on the western side of Death Valley. From this height the students compare the vast coalesced alluvial fans visible beneath us on the western side of the Valley with the small, separate, and perfect fans on the eastern side of the Valley beneath abrupt steep cliffs of the Black Mountains. What could explain such a difference? The students observe the pattern of vegetation defining the Furnace Creek fan where our campground is located and the tremendous springs above the fan, harnessed now but still producing enough water to run free in brooks, nourish date palms and make the swimming pool at the Furnace Creek Ranch seem marginally less absurd. Where does the water come from? Turning to look north, they see the Paleozoic sedimentary section in its entirety dipping as always to the east, but now it is 30,000 feet thick instead of 4000, Late Proterozoic as well as Paleozoic, and lacking the disconformities present in the Grand Canyon. It is suddenly clear that the sequence of rocks before us collected far out in a depositional basin where sediments rarely stop gathering, and the Paleozoic section in the Grand Canyon, so incomprehensibly immense a few days ago, can be considered "just" the thin remnants deposited on the edges of that basin, a place sometimes collecting marine sediments and sometimes high and dry as sea level fluctuated. This realization provides a context for the missing Paleozoic section west of the Colorado Plateau noted on the first day. We can also see the vividly-striped volcanics of Artist's Drive and Zabriskie Point. How old are they and where did they come from? How does the tilt of the volcanic layers fit within the evolution of these basins and ranges? Back down on the valley floor, we observe fault scarplets in unconsolidated fan gravels. The conclusion that faulting must be actively happening now is startling for our students whose home experience has kept such obvious geologic disruption in the comfortably distant past. The scarplets occur at the foot of the steep face of the Black Mountains, which in places is composed of basement crystalline rocks rather than the familiar basin sequence. Could ductile shear zones that we see in canyons incising that basement be surfaces along which thrusting occurred during the Mesozoic? Could those same surfaces then host normal faulting beginning in the Late Cenozoic that actually continues today, causing scarplets in the alluvial fans at their feet? Why do we find the Proterozoic Noonday Dolomite below the Precambrian crystalline basement in canyons incising the basement? Could the normal and thrust faults actually penetrate the crystalline basement (consistent with the cross-sections we drew at Grapevine Mesa far to the east) instead of sliding along it? And where has the 30,000 feet of basin sequence gone?? The students can no longer ignore the structural untidiness before them. Simple thrust- and normal faulting cannot explain the landscape, especially when they observe oblique slickenlines in mylonites and a right-laterally-offset cinder cone in southern Death Valley, and remember the curving ranges at Frenchman Mountain, horizontal slickenlines at Hoover Dam, and the puzzling rapakivi clasts. Strike-slip faulting will have to be worked in as a major factor in the structural evolution of this province.

Finally, we approach the Sierras. We pause at Father Crowley's Outlook to view yet another thrust fault disrupting the basin sedimentary sequence displayed across the eastern wall of the Panamint Valley, and to note something new: the Hunter Mountain Pluton, eastern outpost of the Sierran granites. Cenozoic volcanics that appear offset across the valley reinforce the presence of strike-slip faulting throughout the region. If time permits we visit the talc deposits near Darwin to register that we are surrounded by metamorphic rocks now, and even more granite. Could there be a connection? Then we have reached the end of our trip, flat up against the granite wall of the Sierran Front beneath Mt. Whitney. Students whose eyes have learned to register western scale still rebel at the 11,000 feet of relief before them. They certainly recognize alluvial fans by now, yet they have seen nothing like the abundance of huge granite boulders scattered about the surface of these Sierran fans, hinting at huge meltwater floods pouring out of the steep drainages above. Moraines and cirques are visible. Strike-slip faulting is alarmingly immediate here too, at the century-old, 10-foot high right-lateral oblique-slip fault scarp at Lone Pine. If the snow line permits, we drive up the Whitney Portal Road and climb from about 9,000 to 11,000 feet, cresting one ridge only to see ten more above, exploring tarns in thickets of redwoods, and reveling in more granite in one place than anyone thought possible. How does all this Mesozoic granite fit into the story? We remember volcanics exposed in the adjacent Alabama Hills and look for volcanic xenoliths in the granite nearby, both of which support the idea that the Sierras are the remains of an extensive Mesozoic volcanic arc. From the heights we see Telescope Peak above Death Valley to the east and know that beyond it is Charleston Peak above Wilson Cliffs, then the Grand Wash Cliffs, the Grand Canyon, Coal Mine Mesa, and everything we have seen in between, all revealing parts of one vast story in space and time. Then we are finally sliding home on the remnants of winter snows, enjoying our last campfire, and rising to dawn light on the Sierras. It is only four hours by superhighway from Lone Pine beneath Mt. Whitney to Las Vegas and our flight back to New England.

COURSE-EMBEDDED ASSESSMENT TOOLS

Assessments for this field experience have always centered on the students' ability to respond in writing to questions asking them to cite their observations in support of a particular conclusion that can take the form of a regional history, a plate-tectonic scenario, or the solution to a structural conundrum. We always require that the students be able to coordinate ages and types of rocks so that they can recognize regional environments through time. For example, we stress the chronological connection between rocks indicating an active volcanic arc, the volcanic products of that arc appearing elsewhere along our transect, and how those rocks may have been affected by subsequent events.

Here is an example of question, student response and assessment from the Grand Canyon segment:

Question: Describe evidence supporting the following conclusions: Over 15,000 feet of mostly Middle Proterozoic and Late Proterozoic shallow marine sediments (SM) and continental sediments deposited far from mountains including stream channel, floodplain and lake sediments (SF) were deposited on early Proterozoic metamorphic and plutonic "Basement." Mafic igneous activity occurred in Late Middle Proterozoic and normal faulting occurred in the Late Proterozoic.

Student Response: Over 15,000 feet of mostly SM and SF Middle Proterozoic and Late Proterozoic sediments is evident at Grand View and Desert View. Specific evidence that the strata are SM is the fossils of algae found in the Bass Limestone Formation. The sandstone of the Shinumo is also further evidence of a shallow marine environment. The Hakatai red shale with stream and floodplain deposits is evidence for the SF. Evidence for these sediments being deposited on Early Proterozoic metamorphic and plutonic "Basement" is seen from Grand View where the Bass is lying unconformably on top of the visible metamorphic and plutonic Early Proterozoic rocks. The mafic igneous activity is evident from the mafic sill within the Bass Formation. The fact that this mafic sill is in the Bass which is Late Middle Proterozoic supports the dating of this activity. It is also evident that normal faulting occurred during the Late Proterozoic at Grand View. Here we see the normal faults in the rock formation east of the Colorado River. The Tapeats that overlies these is Cambrian in age. From this we can determine that the faulting is Precambrian, specifically Late Proterozoic because it involves the Middle Proterozoic strata.

Assessment: This student was encouraged to provide more details about how sedimentary features in specific formations reflect the SM and SF environments. She was also reminded to be more careful about hurried and therefore incomplete explanations. For example, it is not clear from her answer that isotopic dates for the mafic rocks had been given to her and her statement about the age of the mafic sill crosscutting the Bass was a structural observation in support of those dates, not a misuse of crosscutting relationships. This answer is characteristic in that most students find it very difficult to keep track of all the information that they have, and frequently offer incomplete answers because they do not proofread thoughtfully. Many students do take advantage of the opportunity to rewrite their responses. Also, most students process either large-scale structural observations (as this student did) or relatively small-scale sedimentary features better, and that one of the most difficult aspects of the whole experience is fitting both into the same Big Picture.

Questions are discussed and answers revised during several post-trip meetings that help the students sort out a still-overwhelming set of experiences. During the trip we help the students refine their note-taking strategies and encourage them to collaborate in gathering information. However, the final essays in response to the questions are individual products and are graded as such. Our rubrics for grading depend indirectly on the students' ability to craft essays, as we must be able to discern the geological point being made clearly in order to assess it. Thus our final product supports our institutional emphasis upon writing across the curriculum.

STUDENT ASSESSMENT

Student response to this experience has been overwhelmingly positive since its inception. The trip is always fully- or over-subscribed, and we must maintain waiting lists at least a year in advance to assure students a place. Formal student evaluations are equally positive, describing "mind-blowing" experiences and fascination with both subject and approach. The only suggestions for change have come from the very few students (<2% overall) who were unprepared for the relentless intensity of the trip, or who felt that they were receiving too little academic credit for the amount of work required. In response, we devote more effort to making sure students know what they are getting into by signing on. However, the best response to this potential problem comes from students themselves for whom this trip has become a legendary rite of passage and who eagerly give up their Spring break (thereby risking falling behind in other courses) to go along.

We find that students who participate in this field experience acquire a demonstrably improved understanding and appreciation of the nature and practice of science. Their ability to make useful field observations, critically assess data, and form and evaluate multiple hypotheses noticeably improves their performance in upper-level science classes. Some of our students who have become teachers have said that this approach specifically fueled their own curiosity and helped them to figure out how to maintain and pass on that curiosity about geology in the classroom in order to inspire their own students. Others have claimed that this experience motivated them to focus their studies as nothing had before.

We have administered surveys to recent participants in an attempt to assess the degree to which students feel that they have achieved learning objectives in this experience. Students report that they are "confident that I can choose useful observations from amongst a flood of possible observations in order to help evaluate a particular geologic hypothesis." and had "improved abilities to correlate geologic features in time and space over large geographic areas," "had learned how to use the shape of the landscape while speculating about subsurface geology," or "had improved [my] grasp of the scale of landscapes and the scale at which geologic processes can occur." (Approximately 90% agree, 10% strongly agree with these statements.) While we appreciate this confirmation from our students, we remain convinced that course-embedded assessments are the most appropriate tool for evaluating the degree to which students have achieved course goals.

All formal assessments aside, we have never encountered a student whose world view was not profoundly affected by this experience. Participants realize that the apparent randomness of the earth's surface turns out to be a vast piece of architecture that is constantly being torn down and rebuilt on a scale at the very edge of human comprehension. While learning this, they experience firsthand how science deals with something a lot bigger and a lot older than they are. This invaluable lesson is most tangible, perhaps, in the field.

LOGISTICS

Student enrollment is restricted to 11. This allows three faculty plus students to fit in no more than two vehicles, thus minimizing caravan hassles, gas costs and park entrance fees, and permitting the use of walkie-talkies for lectures on-the-road. Our trip takes place during the spring semester because summer courses can be problematic for our students, most of whom have families and/or jobs precluding lengthy summer absence. We use the later of our two week-long spring semester breaks and add a few days beyond the break to complete the twelve-day trip (Two travel days bracket ten days in the field. There are no days off.) for which the students earn 2 credits of upper-level geology. Traveling during the first week of April minimizes snow at the higher elevations we visit, the temperatures in Death Valley, and tourist populations and camping facility loading in the National Parks. We fly to and from Las Vegas, which gives us nearly unlimited flexibility in flight times, cheap flights, and abundant vehicle rental facilities as well as a central location to begin and end our loop trip. We camp in National Park sites, National Forest developed campgrounds, or on BLM lands (undeveloped for camping, so no fee is required). We often travel before summer fees are in effect, so National Forest campgrounds are open but without facilities and therefore free, and some National Park fees are lower. After many experiments, we have settled on group food for suppers, organized and cooked in camp by the trip food boss (determined beforehand) and willing assistants. Individual provisions for lunch on the go and no-cook breakfasts speed morning departures, allowing us to be on the road and in the field from 8 AM until after dark. We limit grocery stops to two or three spaced visits to superstores for individual provisioning and group food purchases. National Park visits provide access to shower facilities, and the occasional restaurant meal eases camp chores. Total participant cost for the twelve-day trip is approximately $700 (in 2004), including roundtrip airfare between New Hampshire and Las Vegas, common costs such as van rental, gasoline, camping fees, park entrance fees and incidentals such as cooking propane and ice, and the purchase of food, both common and individual (a portion of the $700 is returned to each student at departure for buying individual food on the road). Most students bring, or have access to, extra cash for souvenirs or incidental costs. The $700 is labeled a lab fee, so it is eligible for most students' financial aid. Although the trip is a two-credit course, tuition is not usually extra because most students enrolled in it remain within the full-time window of 12-18 credits at our institution, within which tuition does not vary.

ACKNOWLEDGEMENTS

We thank our colleague Ramon Geremia for invaluable logistical help during the trip and for reminding the students that there is also a human history in this area. We thank all of the students who have traveled with us, and particularly Kimberly Caljouw who permitted us to quote her assignments.

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