GeoScape: AN INSTRUCTIONAL ROCK GARDEN FOR INQUIRY-BASED COOPERATIVE LEARNING EXERCISES IN INTRODUCTORY GEOLOGY COURSES

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ABSTRACT

GeoScape is a landscape design, consisting of colored gravel, strategically placed flagstone and boulders, and two vertical features that simulates the geology of some fictitious region (a combination of geologic features in Utah, Arizona and Nevada). The design incorporates many topographic and geologic concepts that introductory geology students are expected to understand. GeoScape is an educational tool employing "hands-on", inquiry-based, and cooperative learning techniques to help students develop problem solving and critical thinking skills by applying their geologic knowledge to a simulated field situation. Students are charged with the task of producing topographic and geologic maps and a report on the geologic evolution of the area to help solve problems in resource exploration and geologic hazards. GeoScape illustrates three-dimensional geologic structures on a smaller scale to help students visualize concepts such as bedding tilt, plunging folds, unconformities, and stratigraphic principles. GeoScape can also be used to provide at least a simulated geologic field experience to disabled students or students taking evening classes who otherwise would be unable to participate in a traditional field exercise. GeoScape is relatively easy to build and could be constructed in a variety of areas where geologic exposures are scarce or field excursion resources are limited.

Key Words: Field Trips, Field Study, Areal Geology - Maps, Charts, Photographs, General Summer Field Courses, Structural Geology, Geology, Education – Undergraduate, Education - Geoscience

INTRODUCTION

Introductory geology students seem to find the interpretation of geologic maps particularly frustrating to grasp (Kali and Orion, 1996; Kali et al., 1997; Orion, et al., 1997). The ability to visualize the three dimensions represented on a two-dimensional geologic map is not easy for most students, yet it is fundamental for geologic thinking (Chadwick, 1978). Traditionally, geology instructors have endeavored to "bring the field to the classroom" in the form of slides, films, and photos. Although these media clearly promote the understanding of geological concepts, they are still fundamentally two-dimensional. Kali and Orion (1996) found that students needed two types of visualization skills to solve geologic problems, the ability to perceive spatial configurations and the ability to mentally penetrate the image of a structure.

Many geology students benefit from the observation of geologic structures in the field (Manner, 1995). Although we are fortunate to live in Arizona where many structural relationships are visible within a hundred miles of our campuses, we too are subject to the difficulties outlined by Malone (1999). It is not always logistically or economically feasible, especially in commuter-oriented community colleges, to transport students to these geologically magnificent field areas. In addition, it is difficult to locate a single area that shows exposures of all the features we teach in introductory geology courses. Indeed, even the Grand Canyon is somewhat limited in the structural features it displays. Lacking a nearby field area that classically illustrates most of the features of a geologic map and facing logistical and financial concerns that prevent us from taking all students on long field trips, our next best solution was to build the ideal geologic field setting. GeoScape is our first attempt at building such an area.

GeoScape is a landscape design consisting of colored gravel, strategically placed flagstone and boulders, and two vertical features, that simulates the geology of some fictitious region (a combination of geologic features in Utah, Arizona and Nevada). The landscape is constructed adjacent to the Physical Science Building at Glendale Community College (Figure 1). GeoScape provides our students the opportunity to investigate three-dimensional structures at different scales. We have also built a level of versatility in GeoScape that allows our students to explore how the interpretations of structures change with different internal configurations, such as a change in fault dip or slip direction. We hope GeoScape will provide our students multiple visits to a familiar area and thus, more effectively develop their spatial visualization skills.

THE MAP PATTERN AND EDUCATIONAL OBJECTIVES

Our goal in developing GeoScape was to create a single geologic map incorporating a wide variety of basic geologic features that would serve as the foundation for field based problem solving exercises similar to those described by other workers (Tewksbury, 1992; Hollocher, 1994; Searight and Malone, 1996; and Baily,

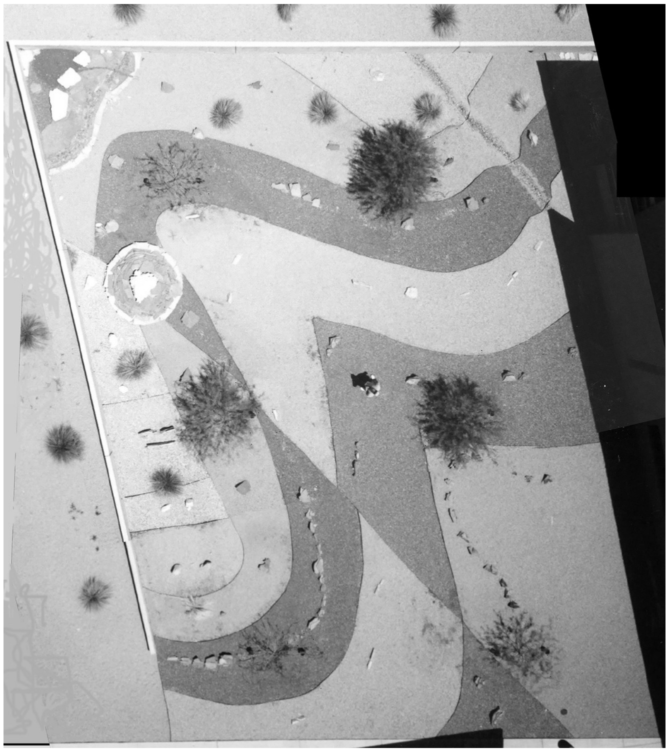

Figure 1. Aerial photograph of the GeoScape area adjacent to the Glendale Community College Physical Science building. North is at the top. Steve Kadel of the GCC faculty provides scale in the center of the map.

1998). We were tempered, however, by the number of different types of flagstone and boulder lithologies we could obtain from local landscape suppliers, the cost of materials and labor, and our desire to limit the length of time that students would spend doing repetitive exercises. We also endeavored to make the landscape useful to a wide variety of instructors and courses, including lecture courses that normally wouldn't have field examples in such close proximity. The result is the map shown in Figure 2.

The map pattern represents a faulted plunging anticline and syncline duplex that has been eroded to a nearly horizontal surface. This structure is overlain by horizontal layers that have been "eroded" to form a butte and mesa topography (see Figure 3). Post-erosion volcanism has formed a cinder cone on the mesa. A lava flow emanates from the cone and flows down the face of the eroded mesa. A dry stream valley traverses the northeastern portion of the map area and is constructed to illustrate the pattern formed by tilted layers as they cross the drainage.

Although the basic design of the map pattern is "set in stone", a number of other features have been left intentionally vague to allow individual instructors to change the interpretation for different courses or different sections of the same course. The fault, for example, is purposefully ambiguous on the map. We can change the rake of slickensides information that we give to the students to consequently change the fault from dip-slip to strike-slip. If we choose to make the fault dip-slip, we can further change the dip direction that we

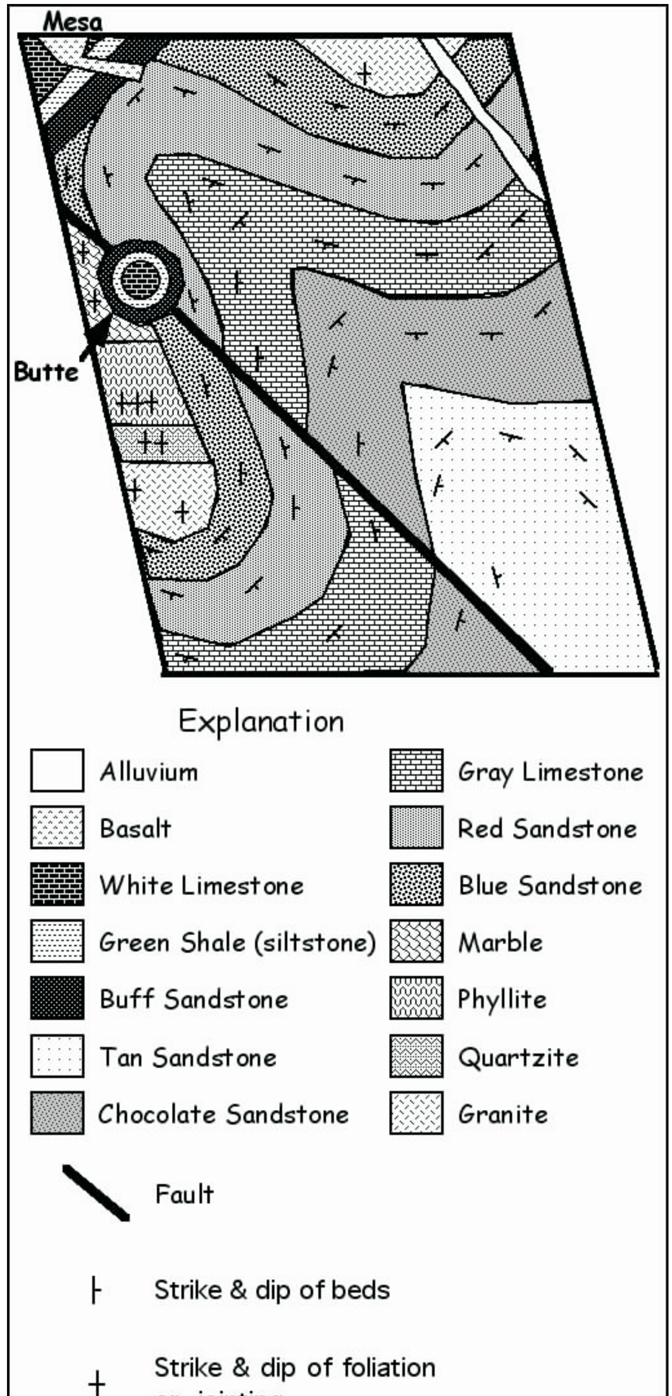

Figure 2. Cartoon geologic map of the GeoScape area.

Figure 3. Construction of the butte in GeoScape. The mesa is constructed similarly.

give to students to alter the hanging wall designation and thus, the type of fault.

Similarly, the details of the igneous and metamorphic complex at the core of the plunging anticline are left vague to allow variation in the interpretation of this area. For example, veins of quartz emanating from the granite body can crosscut the metamorphic rocks to make the granite/quartzite contact intrusive; or, we can eliminate these and force the granite/quartzite contact to be nonconformable. Likewise, there are no geopetal structures in the vertically dipping quartzite-phyllite-marble sequence. We can thus provide information to the students to vary the interpretation of the sedimentary protoliths from a transgressive to a regressive marine near-shore sequence. Additionally, sedimentary structures and fossils can be added to, or subtracted from, the sedimentary layers to vary depositional environments and create geologic time scale correlations if desired.

The actual scale of GeoScape was problematic. Our chief academic objective was to landscape an area large enough so that the students would have to do field work and check contacts and other relationships. We also desired, however, to have an area that was feasible to map during a lab period (2.5 hours) or in parts of several lab periods. Further complicating the issue was that of cost. Larger areas simply cost more to cover with gravel and flagstone. The compromise that best suited our goals and budget was an area of about 4400 ft^2 (see Figure 1). The area is large enough to easily accommodate a typical lab class of 24 students engaged in mapping exercises. The area has also been used to illustrate three dimensional structures in lecture classes consisting of about 48 students.

CONSTRUCTION OF GEOSCAPE

Prior to construction, the faculty and staff at Glendale College surveyed the map pattern of Figure 2 onto the ground and chose the appropriate flagstone and gravels from the stocks of local suppliers. Most of GeoScape was constructed in approximately one week by a commercial contractor working closely with the geology faculty.

The butte and mesa were constructed using flagstones placed as a facade in front of compacted dirt (see Figure 3). Limestone boulders cap these features. "Outcrops" of flagstone and boulders representing each of the rock units in the relatively flat portion of the landscape were installed and similarly colored gravel was spread in the designated pattern (see Figure 1). It is important to note that using gravel made of the same material as the boulders is impractical. Gravel composed of sandstone fragments is not particularly durable even in the arid southwest deserts. Thus, although the gravel color may resemble that of the rock, it is a much different lithology and students must be made aware of this "flaw" in our simulation. Metal dividers separating different colored gravel have been effective in preventing "bleeding" of one color gravel into another by foot traffic. The "volcano" is constructed of raw cinders. The lava flow emanating from its base is made of low viscosity, dyed cement poured over the "cliff" to simulate actual flow. The stream channel is constructed of rounded cobbles and pebbles and sand is used to create "bars" along the channel sides. Finally, we scattered the scraps of the flagstone used to make our "outcrops" around those same outcrops to represent eroded material.

The total cost of the project is difficult to report because to save money, the Glendale Community College Geology faculty performed several phases of the operation themselves (e.g. surveying, stream construction, volcano construction). Still, it should be possible to produce a similar size and quality landscape for under $20K.

SAMPLE EXERCISES

The most attractive aspect of GeoScape is the myriad of ways in which it can be used. Indeed, we will probably be finding new ways to use it for years to come. While many of the exercises are still under development, we report several examples of trial exercises employed or developed in the Spring 2001 semester.

Physical Geology Lab Sections - Our first example illustrates a series of exercises developed for a Physical Geology lab period in the Spring 2001 semester. Our lab periods last for 2.5 hours and a typical lab class consists of 24 students. Throughout the semester, we usually have students work in teams of two. For this exercise, however, we allowed two teams to merge, if the students so desired, to make a maximum team size of 4 students. Students were encouraged to exchange information using a cooperative jigsaw method (Constantopoulos, 1994). Because we had only recently completed the GeoScape, these lab exercises took place at the end of the semester and these students had already "mastered" the basic Physical Geology lab competencies of rock and mineral identification, and topographic and geologic map interpretation. It should be noted that the exercises as described below are very difficult to complete in a single lab period. Two lab periods or integrating the exercises throughout the semester are more viable alternatives.

The students were provided with an air photo of the area (similar to Figure 1) and standard mapping tools including tracing paper, colored pencils, a compass with clinometer, a tape measure and a couple of tent stakes.

The exercises include: construction of a topographic map, construction of a geologic map, interpretation of the geologic map and the history it represents (cross section, map key and written report), and solution of practical problems related to resources (coal, metal, groundwater, etc.) exploration. Following the lead of Peter Kresan (1995) at the University of Arizona, who designed a set of laboratory exercises to discover the Lost Continent, these exercises are prefaced or introduced with the idea that the students are now the geologists in a remote, geologically unmapped territory and it is they who must apply what they have learned to serve their society. While many of these exercises are directed to help students build science skills specific to geologic investigations, students also experience inquiry and problem solving by analyzing data and manipulating mental models to unravel the geologic history of the area (see Alcock, 1994, and Siebert and McIntosh, 2001 for other examples and background). The field mapping requires the student to synthesize new information from the observations and from their knowledge of earth materials and processes.

Construction of a Topographic Map - The goal for this exercise was for students to construct a topographic map on a piece of tracing paper overlain on the aerial photograph. This map was to contain information similar to that shown on a standard United States Geological Survey (USGS) map. We decided to begin with the most basic of data, the determination of geographic North and magnetic declination. Students were instructed to determine True North using the motion of a shadow produced by a vertical stake (the change of the position of the shadow's tip after 15 to 20 minutes is approximately a west-east line). Once True North was established, students compared this direction to the direction shown by the compass needle to determine magnetic declination. Students quickly learned that magnetic measurements are adversely affected by the proximity of strongly magnetic objects like the metal stakes they used for their solar determinations. Although this method of determining True North often had errors approaching ± 10° (depending on the patience and care of the students), every group was able to show that that the magnetic declination was not zero and was to the east of true north as is the case in Glendale, Arizona. Many groups actually estimated the magnetic declination within ± 5° of its actual value. These data were placed in the appropriate location on their new topographic map. While waiting for the shadows cast by the vertical stakes to move, students determined a scale for their map by measuring a feature common to both the aerial photo and the actual ground. The area is barely large enough for accurate determination of latitude and longitude using new hand-held GPS receivers (10 meter resolution). Consequently, we are able to have students determine latitudes and longitudes for each corner of the map and show them the utility of GPS. For topography, we told the students that surveyors visited the area beforehand and placed different colored stakes marking elevations (bench marks) in the relatively flat area of the map. The colors of the stakes indicate specific elevations. In the future we will probably install more realistic benchmarks into the landscape or have the students actually determine elevations with a transit and trigonometry. Neither the butte nor the mesa, however, was staked although one stake was placed at the base of the butte. The students were instructed to use their tape measures to measure the heights of the features, determine a contour interval appropriate to the data and draw the contours on their map. Finally, the students added standard USGS colors for vegetation, water, etc., and had fun creating fictitious names for the surrounding quadrangles.

Construction of a Geologic Map - The goal for this exercise was to construct a geologic map on a piece of tracing paper overlain on the aerial photograph. The aerial photograph made it easy to see and trace geologic contacts. The area was large enough and the structures complex enough, however, that students could not immediately interpret it. Thus, most of the work involved visiting the outcrops to determine the rock type and description for the map key. It was very important in this phase to instruct students to identify the rock outcrops (the boulders and flagstone) rather than the gravel. As previously mentioned, for practical reasons, most of the gravel is hard igneous or metamorphic rock chosen simply to match the color of the flagstone. Once the rock units were identified and named, students colored their maps. Strikes and dips of representative strata were measured and included on the geologic map. By this time, the fault is generally obvious and students are able to label it in standard fashion, although they may not know the fault type yet.

Interpretation of Geologic Map - Upon completion of their fieldwork, students had to produce a report outlining the geologic history of the map area. This exercise is designed to have the students apply their knowledge of geologic structures to identify the structures present, determine relative ages of rock units, identify unconformities, and reconstruct the sequence of events that took place to produce the observed geologic relations. It is during this phase that students develop the key to the map and construct topographic and geologic cross sections.

Practical Problem Solving - In this final exercise students achieve one of the ultimate goals of learning geology - the practical use of the knowledge and skills they have acquired during the semester. We asked students to apply their knowledge to explore for natural resources. GeoScape is flexible enough to allow placing a lens-shaped layer of coal in one of the units deformed in the plunging fold structures. Students are then confronted with the problem of dwindling coal reserves and asked to design a coal exploration program. With some direction, they can calculate the depth to the coal beneath a specified tract of available land. In a similar fashion, valuable metal commodities (e.g. big chunks of chalcopyrite) can be placed in the igneous-metamorphic complex at the center of the plunging anticline. Students can determine an exploration strategy to discover more of these "ore bodies".

HISTORICAL GEOLOGY LAB SECTIONS

Historical Geology lab exercises that use GeoScape are under development. Students in Historical Geology can use GeoScape to work out depositional environments and paleogeography given placement of appropriate sedimentary structures and fossils within various rock units. Marine transgression and regression problems can be solved in both the sedimentary and meta-sedimentary rock sequences. In addition, fossil assemblages can be added to GeoScape for student identification and correlation to the geologic time scale. In this manner, disconformities can be defined and interpreted.

ENVIRONMENTAL GEOLOGY LAB SECTIONS

GeoScape-based environmental geology exercises are also in development. Students can use GeoScape to work out numerous real world environmental problems, such as: (1) choosing the optimal site for a waste disposal facility from a suite of available locations, (2) conducting site assessment for buildings or towns, and (3) identifying a reasonable supply of ground water and where a well should be drilled. Environmental geology students also spend time working with the impact of the difference between geographic and magnetic north in navigation, or measuring property boundaries with a standard compass that had not been corrected for magnetic declination. In Glendale, with a magnetic declination of ~14°E, the difference works out to be approximately 10 feet over the long dimension of the GeoScape area.

PHYSICAL GEOLOGY LECTURE SECTIONS

The close proximity of GeoScape to our classrooms permits use of the area even within the short duration (50-75 minutes) of a geology lecture period. Groups of 48 students were introduced to the concepts of strike and dip of layers by actually measuring these quantities. The map patterns of plunging folds, and the rules of dip direction and age associated with folded strata were easily demonstrated with GeoScape.

INSTRUCTOR OBSERVATIONS AND STUDENT RESPONSES

Because GeoScape and the exercises that employ it were both developed late in the Spring 2001 semester, we were unable to develop instruments to quantitatively evaluate their effectiveness on student learning. We do use standard course evaluations, however, and responses to the question, "What has the instructor done especially well?" were riddled with positive comments about "hands on" learning. There were no negative comments on the GeoScape exercises. Lacking quantitative analyses, we are forced to rely on anecdotal evidence as reported below.

During the GeoScape mapping exercises, the instructors informally prodded the students with questions like "What do you think of this exercise?" or "So do you want to be a geologist now?" Physical Geology lab student responses were resoundingly favorable, in spite of the above average Phoenix temperatures in late April and early May and the fact that none of our lab students at the time were geology majors. We had introduced the map area as the "North Park Quadrangle" with an obvious nod to the popular cable television show "South Park". Several groups jumped into the spirit of the parody and began naming lithologies using South Park's characters or references (e.g. the Cartman Sandstone). In short, most of the students seemed to have fun with the freedom of being able to choose their own names for discoveries.

It became immediately obvious from the instructors' perspective that even the top performing students in the class were challenged by the mapping exercise. Those students who had struggled with the concept of map scale indicated that measuring objects on the ground and the photo to determine the map scale made the concept much easier to understand. Other students commented that they really hadn't understood the concept of faults being covered by other units until they saw such an obvious example. Still other students seemed to take pride in being able to "put it all together". One student related,"[When I first heard we were going to map the courtyard] I thought it was going to be some little tiny thing. It's cool that you can't see it all at once and have to walk around -kinda like I imagine [geologists] do". Our favorite comment, however, was this one: "So this isn't just a bunch of rocks that happened to look like this. Someone put a lot of thought into this, huh?"

EDUCATIONAL BENEFITS

GeoScape has already proven to be an excellent collaborative learning resource in the development of curriculum that fosters critical thinking and problem solving skills. Exercises can be developed for a single lab, a series of labs, or an entire semester class. The proximity of GeoScape relative to our classrooms and labs has made it possible to use it not only as a lab tool but also as a mini-field trip locality that can be used in traditionally lecture-oriented classes. GeoScapes can be relatively easy to design and construct depending on the size and scope of the project.

Although we do not generally advocate using simulated landscapes in lieu of actual field trips to geologic localities, there are circumstances in which we feel that the GeoScape simulated field experience is an excellent substitute. For example, students with disabilities might otherwise be prevented from participating in a longer or less physically accessible geologic field trip (Cooke and others, 1997). Furthermore, we offer many evening classes in which trips to local field localities are precluded by darkness. Our GeoScape is lit well enough at night to be useful as an evening field exercise. Finally, we note that in many regions of the country, the nearest exposures of geologic structures such as those illustrated by GeoScape may be hundreds of miles away.

ACKNOWLEDGEMENTS

The original GeoScape map pattern was conceived and designed under a National Science Foundation (NSF) educational grant DUE #9552505. Construction was funded mostly by the Arizona Collaborative for Excellence in Preparation of Teachers (ACEPT), a NSF educational grant (DUE #9453610). Further construction funding was provided by Glendale Community College via Jean Ann Abel, Dean of Instruction, Joyce Elsner, Dean of Administrative Services, and the Applied Science Department. Dr. Ramon Arrowsmith, Associate Professor of Geology at Arizona State University provided the balloon-mounted aerial photography. We thank the following personnel of Glendale Community College for their efforts above and beyond the call of duty in the completion of this project: John Winters (Chair, Applied Science Department), Regis Della-Calce and Herman Gonzalez (Business Services), and Al Gonzales (Maintenance and Operations). Without the efforts of these individuals and their staffs, this project would probably never have materialized. Arimax Landscaping (James Worsnup, proprietor) did an outstanding job of constructing GeoScape under very tight time and logistical constraints. We thank Steven Good, William Stattely, and Laura Crossey for their constructive reviews of an earlier version of the manuscript.

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