A Guided Inquiry Approach to Learning the Geology of the U.S.

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ABSTRACT

A guided inquiry exercise has been developed to help teach the geology of the U.S. This exercise is intended for use early in the school term when undergraduate students have little background knowledge of geology. Before beginning, students should be introduced to rock types and have a basic understanding of geologic time. This exercise uses three maps: the U.S. Geological Survey's "A Tapestry of Time and Terrain" and "Landforms of the Conterminous United States" maps, and a geologic map of the United States. Using these maps, groups of 3 to 5 students are asked to identify between 8 and 12 geologic provinces based on topography, the age of rocks, and rock types. Each student is given a blank outline map of the contiguous U.S. and each group is given a set of the three maps and colored pencils; as a group, students work to define regions in the U.S. with similar geology. A goal of 8 to 12 geologic provinces is given to help establish the level of detail being asked of students. One member of each group is asked to present their group's findings to the class, describing their geologic provinces and the reasoning behind their choices.

INTRODUCTION

This exercise is intended to introduce undergraduate students to the geology of the United States during one of the first class meetings of the quarter or semester — ideally students approach this exercise without much or any prior knowledge of geology (concept based on Egger, in review; and Sawyer, 2002). Using three maps (see Table 1), students identify and characterize 8 to 12 geologic provinces in the U.S. based on the topography, age of the rocks, and rock types in these regions. Through this exercise, students will: (1) become familiar/comfortable with reading maps and legends; (2) learn basic rock types and how geologic time is divided; (3) define geologic provinces that will form an outline for learning the geology of the U.S.; and (4) be able to discuss the maps they create based on what they have learned.

This exercise was developed for use during the first class meeting of an upper division undergraduate general education course on the geology of the National Parks; the course is organized around plate tectonics using the model of the new textbook "Parks and Plates: How Earth's Dynamic Forces Shape Our National Parks" (Lillie, in press). The course teaches about the National Parks and Monuments in terms of plate boundaries (convergent, divergent, and transform), hot spots, and sites not on plate boundaries (figure 1). The map that students work to create in this small group exercise breaks out the general geologic regions of the contiguous United States based on plate tectonics (see figure 2); these geologic provinces will outline many of the same regions shown in figure 1 (compare figures 1 and 2 for similarities). Students will learn the geologic significance of their map of the geologic provinces of the U.S. from the content of the course. The exercise is easily adaptable for multiple grade or learning levels using the suggestions here. The map of geologic provinces of the U.S. and the structure of the course are an effective way to organize what would otherwise be a large amount of seemingly unrelated geologic information.

PEDAGOGY

This exercise incorporates cooperative learning into a guided inquiry-based exercise (see Johnson et al., 1991; McKeachie, 2002). Cooperative learning involves students working in teams to accomplish a common goal under conditions that include positive interdependence in which team members rely on one another to achieve the goal; individual accountability for students doing their share of the work and to learn all of the material; face-to-face promotive interaction; and the use of collaborative skills (Johnson et al., 1991). The jigsaw method approach to this exercise, which is described later, meets all of these criteria for successful cooperative learning (Johnson et al., 1991; McKeachie, 2002) and is successful in general geology courses (Tewksbury, 1995; Sawyer, 2002). The quided inquiry aspect of this exercise whereby students work to create a map of the geologic provinces of the U.S. before the intended lesson is revealed by the instructor, results in a deeper understanding of the material compared to traditional lecture-based instruction (McKeachie, 2002).

The use of cooperative group learning in undergraduate science, mathematics, engineering, and technology (SMET) courses has a significant and positive effect on academic achievement, more favorable attitudes toward learning, and students persist through SMET courses compared to their traditionally taught counterparts (Springer et al., 1998); an analysis of 39 courses incorporating small-group learning showed that even minimal group work can have these positive effects (Springer et al., 1998).

Using cooperative learning techniques to supplement lectures provides students with different learning styles better access to the material being taught (Macdonald and Korinek, 1995). Informal cooperative activities incorporated into lecture-based courses, such as the extensions for use of this exercise near the end of a course suggested in this paper, provide time for reflection and cognitive processing of the material being learned, get students to apply what they have learned in a different way, and build relationships among students (Johnson et al., 1991; Macdonald and Korinek, 1995). In undergraduate general geology lab sections, cooperative learning results in students working harder, being more

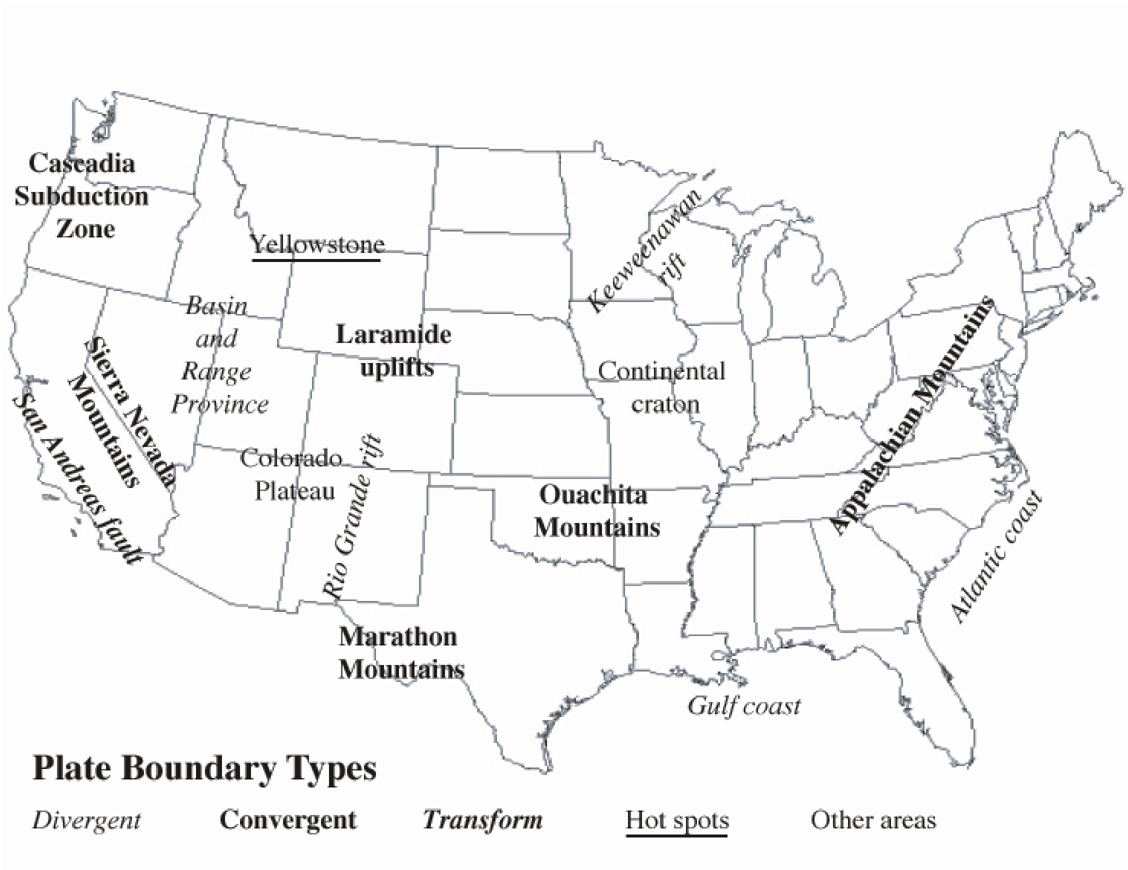

Figure 1. Map of general plate tectonic regions of the U.S. and areas not at plate boundaries (based on Lillie, in press) that correspond to the regions students will identify in this exercise (see figure 2). This map includes several features that may be discussed in detail during the course and in the textbook (e.g., Lillie, in press); some features such as the Ouachita Mountains will likely not be apparent to students doing this exercise at the beginning of a course, but many features such as the Appalachian Mountains will immediately stand out (see figure 2). This map is better displayed in color on a shaded relief map of the U.S. where features associated with different boundaries are more apparent.

persistent when tackling difficult tasks, perform better on exams, and enjoy the labs more (Bykerk-Kauffman, 1995). Over two-thirds of students in one study of seven general geology courses using cooperative learning techniques report an increase in interest in geology and feel more confident in their ability to do and understand science (Bykerk-Kauffman, 1995).

INSTRUCTOR PREPARATION AND INSTRUCTIONS FOR STUDENTS

Before class, instructors should group tables together for a large work area where maps (see Table 1) can be laid out, or hang copies of the maps on the walls near where groups will be working. At the start of class, several minutes should be spent reviewing basic rock types, the geologic time scale, and how to read map legends. On an overhead or Powerpoint slide, list the materials each group and each student will need and the instructions for the in-class exercise. Divide students into groups of 3-6 students; once in groups, ask students to work together to define the geologic provinces of the United States.

Ask students to choose ~8-12 regions that are geologically distinct based on the patterns seen in these maps. Each region should be described in terms of topography, the age of the rocks, and the rock types (sedimentary, igneous, or metamorphic). Each student should record all of this information on their copy of the map of the U.S. using colored pencils to outline or color in the regions; each region should be numbered to correspond to its description (see Fig. 2 and Table 2). Individual students are responsible for taking their own notes and producing their own map based in part or in whole on the group effort.

IMPLEMENTING THE EXERCISE

To begin, tell students to first look at the maps as an image — what kind of patterns do they see? Ask students to determine what the different colors on the maps mean by using the legends. Remind students to only make observations and to avoid interpreting the maps; students should only use the information contained within these maps. Instructors should circulate around the room, asking leading questions if students are having trouble getting started, and clear up any misconceptions.

Several features on these maps will stand out to most students and make the first few choices of geologic provinces relatively easy: on the shaded relief map, students can easily identify the Appalachian mountain belt; on the geologic and age maps, the eastern coastal plain, the plains region, and the midwest craton will be picked out quickly based on regions with similar colors. Ask students to record how they are defining these areas

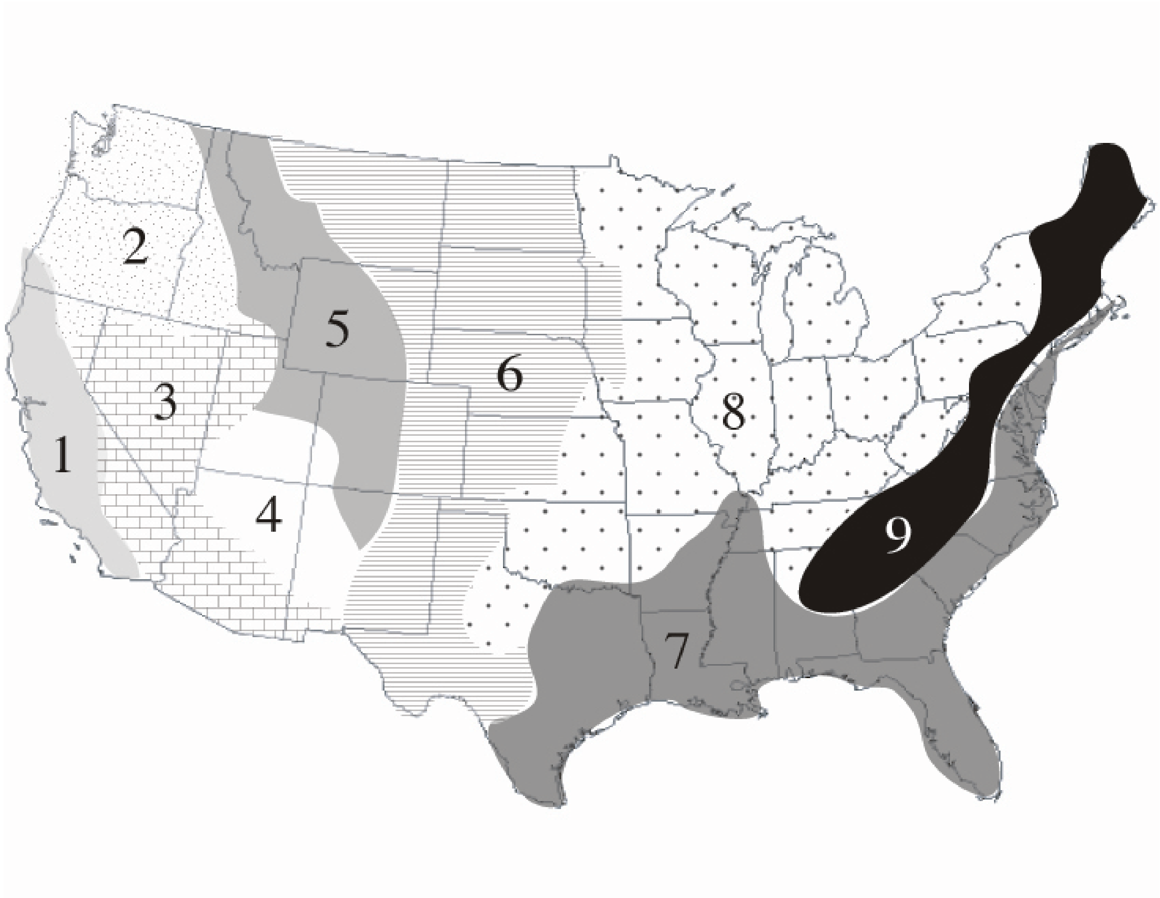

Figure 2. Example of a map of the geologic provinces of the U.S. that students generate at the end of this exercise. Regions numbered 1 to 9 refer to the geologic provinces listed in Table 2 that are characterized by distinctive differences in the topography, age of the rocks, and rock types in that region.

as they go. Provinces in the western U.S. will be more difficult to define; remind students they are trying to generalize based on the information they have in front of them.

At the end of the exercise, have one student from each group present the geologic provinces their group defined to the class. When all groups have had a chance to present their results, the instructor should give an introductory lecture on the geologic provinces of the U.S. using one group's map as a guide. This map and introduction will provide an outline for what students will learn in the course.

STUDENT REACTIONS AND RESULTS

Student's initial reactions may range from feelings of frustration (possibly resulting from a lack of knowledge of geology or from the large degree of freedom they are given to complete the exercise) to some form of smug overconfidence (thinking they already know everything about the geology of the U.S.). For reactions such as: "This is impossible — I don't know anything about geology" or "I've never done this before", students should be reminded that all of the information they need for this exercise is contained within these three maps and legends. Whatever provinces students define should make sense to them and will be valid choices if they use the maps and legends at hand. These frustrated students will benefit from the support of other group members (Johnson et al., 1991; McKeachie, 2002) and gain confidence during the exercise. For the confident student, ask them to assist their fellow students and to search for patterns where they do not have a ready explanation.

Students who have some prior knowledge of geology tend to break down the U.S. into a larger number of geologic provinces (e.g., breaking out California's great valley); encourage these students to limit themselves to 8-12 regions maximum and to focus on why those 8-12 regions are similar. These students may also attempt to interpret the geology they are describing for the group (e.g., relating the volcanoes of the Pacific northwest to subduction); these students should be asked to refrain from interpreting the information contained within the maps because it not only detracts from the goals of the exercise for the other members of that group, but many times student's interpretations are incorrect or misleading.

All groups should able to create a map that resembles figure 2. Groups doing the best work took a more complete set of notes on the characteristics of different regions (topography, age of the rocks, and rock types); these groups are able to discuss their decisions and seem to better understand and enjoy the exercise. Perhaps predictably, smaller groups (3 or 4 students) work best together; larger groups (5 or 6 students) are more likely to contain one or two students who are just

Item(s)	URL
Standard approach **For each group**	
Landforms of the Coterminous United States - A Digital Shaded-Relief Portrayal*[1]	http://www.usgs.gov/reports/misc/Misc._Investigations_Series_Maps_(I_Series)/I_2206/I_2206.html *(for an explanation)* http://www.usgs.gov/reports/misc/Misc._Investigations_Series_Maps_(I_Series)/I_2206/usa_dem.gif *(for downloading)*
Tapestry of Time and Terrain: The Union of Two Maps - Geology and Topography*[2]	http://tapestry.usgs.gov/ *(for the Tapestry web site)* http://geopubs.wr.usgs.gov/i-map/i2720/ *(to download map)* http://tapestry.usgs.gov/ages/ages.html *(to download legend)*
Generalized Geologic Map of the Coterminous United States*[3] or Two-sheet 1:2,500,000 "Geologic Map of the United States" and legend*	
Assorted colored pencils	
For each student	
8.5x11" blank outline map of the U.S.	http://geo.stanford.edu/~mlleech/usgp/us_outline.pdf
8.5x11" blank note-taking sheet	http://geo.stanford.edu/~mlleech/usgp/notes.pdf
Jigsaw approach **For each group**[§]	
Four rock type maps	http://geo.stanford.edu/~mlleech/usgp/rocks-sed.pdf http://geo.stanford.edu/~mlleech/usgp/rocks-volc.pdf http://geo.stanford.edu/~mlleech/usgp/rocks-plut.pdf http://geo.stanford.edu/~mlleech/usgp/rocks-metm.pdf
Four rock age maps	http://geo.stanford.edu/~mlleech/usgp/tapestry_cz.pdf http://geo.stanford.edu/~mlleech/usgp/tapestry_mz.pdf http://geo.stanford.edu/~mlleech/usgp/tapestry_pz.pdf http://geo.stanford.edu/~mlleech/usgp/tapestry_pc.pdf

Table 1. List of materials and web links required for the geologic provinces of the U.S. Exercise. Visit the companion web site for the materials used in this exercise: http://geo.stanford.edu/~mlleech/usgp. *These maps may be purchased at the U.S.G.S. or may be downloaded for printing without cost from the above links. The outline map of the U.S. is the only material consumed in this exercise; all other maps may be reused. [1]Click on the map and hold the mouse button down until a small menu appears; select "Save Image As" to save the image to your hard drive. [2]To download the Tapestry map to your hard drive, click on "i2720.pdf". To download the legend, click on the image of the legend and hold the mouse button down until a small menu appears; select "Save Image As" to save the legend to your hard drive. [3]Click on "Geologic map (1.6 MB)" and "Map unit chart (17 KB)" to download pdf files of the map and legend to your hard drive. You will be able to open and print these files using a graphics program[1,2] (e.g., Adobe Illustrator) and Adobe Acrobat[2,3]. [§]In addition to the other materials listed for the standard approach, these eight maps may be used in place of or in conjunction with the complete Tapestry of Time and Terrain and geologic maps of the U.S.

"hitchhikers" that tend not participate in discussion and essentially copy down notes from other students.

TIPS FOR SUCCESS

This exercise is best completed with plenty of time — a 2- or 3-hour lecture/lab period or 3- or 4-50 minute sessions are necessary. To encourage students to actively participate, assign a point value to this exercise; while this is intended as an exploratory exercise, many students may need this motivation. As stated before, smaller groups (3 or 4 students) work best; the only limitation for group size should be whether there are enough materials (if using the Jigsaw method initial groups of three are necessary [see instructions below]).

MODIFICATIONS FOR A 1-HOUR CLASS PERIOD

To complete this exercise in a 1-hour class period, review rock types and geologic time in a class period preceding this exercise. One full class period should be dedicated to group work followed by group presentations in a subsequent class. Immediately following group presentations, the instructor should summarize the results of the exercise using one group's map as an outline for an introductory lecture on the geologic provinces of the United States.

THE JIGSAW METHOD APPROACH

The concept of the jigsaw method is to first assign students to a specialty group where they will become "experts" on one part of the overall exercise; these "experts" then reassemble into different groups with students from each specialty group to complete the exercise (e.g., Sawyer, 2002; McKeachie, 2002; Tewksbury, 1995). The jigsaw method creates individual accountability in students by requiring them to bring certain information to the group in order for the group to succeed (Johnson et al., 1991). First, students should assemble in their specialty groups with their respective maps: Petrologists at the Geology and/or Rock type maps (see Table 1), Geochronologists at the Tapestry of Time and Terrain and/or Rock age maps (see Table 1), and

Region	Geologic province*	Topography	Age	Rock type(s)
1	West coast	Partly mountainous	Mostly Mesozoic	Sedimentary & Plutonic
2	Pacific Northwest	Mountainous	Cenozoic	Volcanic
3	Basin and Range	Mountainous	Mostly Cenozoic	Sedimentary & Volcanic
4	Colorado Plateau	Mountainous	Paleozoic & Mesozoic	Sedimentary
5	Rocky Mountains	Mountainous	Cenozoic & Precambrian	Sedimentary & Plutonic
6	Plains	Flat	Mesozoic & Cenozoic	Sedimentary
7	Eastern coastal plain	Flat	Cenozoic	Sedimentary
8	Midwest craton	Flat	Precambrian & Paleozoic	Sedimentary
9	Appalachians	Mountainous	Paleozoic	Plutonic

Table 2. Example of students' descriptions of geologic provinces. *Geologic province names are provided only as an instructors' guide; students will not likely be able to give appropriate geographic/geologic names to these regions and should simply number them.

Geomorphologists at the digital shaded relief map; have students count off from 1 to 3 as they go around the room to assign their specialty groups (e.g., 1 — Petrologist, 2 — Geochronologist, 3 — Geomorphologist). If the class size is large, limit these initial groups to no more than six and create multiple groups for the same specialty (e.g., two Petrology groups — one with six students, another with three). Instruct students to familiarize themselves with their map(s) and learn what the legends represent. In their specialty groups, students should make observations about their maps (taking notes as they go) and avoid trying to interpret their maps. When students in these specialty groups have become sufficiently "expert" with their maps, they will reorganize into new groups that contain one specialist from each field (it may be necessary to have two specialists from the same field if there are an odd number of students). In their specialty groups, have students count off from 1 to *n* to identify the geologic province group into which they will reassemble (the total number of groups will depend on class size). In the new geologic provinces groups, students from each specialty group will in turn share their expertise with the other students in the group. Students will then work together using their combined observations in these new groups to produce a geologic provinces map of the U.S., answer questions about their maps, and/or make detailed observations about a specific area (or geologic province, e.g., the Appalachians) in the U.S. following the possible extensions for this exercise in the next section.

The Petrologist and Geochronologist specialty groups may additionally use the four rock type maps (sedimentary, volcanic, plutonic, and metamorphic rocks are separated onto individual maps) and the four rock age maps (Cenozoic, Mesozoic, Paleozoic, and Precambrian rocks are separated onto individual maps), respectively (Table 1). If the class is particularly large, the single Petrologist group may be divided into four separate Sedimentary, Volcanic, Plutonic, and Metamorphic Petrologist groups (likewise, for the Geochronologist group). These additional maps may help groups to mentally/visually organize the information contained within the geologic and *Tapestry of Time and Terrain* maps.

POSSIBLE EXTENSIONS FOR THIS EXERCISE

This exercise was designed for use in an upper division undergraduate general education class on the geology of the National Parks. Modifications can easily be made to adapt this exercise for use at the middle or high school levels and for adult or teacher education.

(1) Add a question sheet to help guide student's eyes around the different maps early in the exercise. Questions might include: What rock types do the yellow colors represent on the geologic map?; What ages of rocks are represented by the color purple?

(2) Add a set of more probing questions for the end of the exercise or for the following class period such as: Where are the oldest rocks in the country?; What characteristics do the rocks have in the mountainous regions of the country?; What is the most common rock type?; What is the relationship between the ages of the rocks and where they are located (geographically or topographically)?; How are the west and the east parts of the country different?; Why is the west so broken-up looking?; In terms of ages of exposed rocks, list the following U.S. states in order of age, youngest to oldest: Florida, Maine, Minnesota, Oregon, and New York.; Many volcanic rocks run north-south. Do any run east-west?; Can you identify any overlap relationships?; Do you see any odd features? What are they?

(3) Run this exercise as a computer-aided lesson by using the resources available on the U.S.G.S. web site [http://tapestry.usgs.gov].

(4) In the class session following this exercise, assign a specific geologic province that the students identified (e.g., the Appalachians or the Eastern coastal plain) to each group for more focussed discussion and discovery.

(5) In addition to referring back to this exercise throughout the term, have students repeat this exercise at the end of the quarter/semester; repeating the exercise with more advanced goals or expectations will reinforce concepts learned in the term and help students realize how much they have learned. A question sheet such as that

suggested in extension (2) above can be effective during an end of term exercise.

(6) To increase the amount of inquiry in this exercise near the end of a term, ask students to hypothesize about the results of the activity before they begin. For example, how might you expect the topography of an area underlain by sedimentary rocks to differ from that of an area underlain by igneous rocks or do you expect the topography of an area with very old rocks to look different from relatively young rocks?

FOR MORE ADVANCED STUDENTS OR BEGINNING GEOLOGY MAJORS

Lower division geology majors or students who have had prior geoscience courses can also be challenged by this exercise by including a more advanced set of questions to answer such as: Can you find dinosaur fossils in Florida?; Can you explain the origin of the concentric pattern of colors defining the Black Hills?; What is the circular mass in the Sacramento Valley?; Why is the Cordillera in the west much wider than the Appalachian mountains in the east?; Are the topographic surfaces of old rocks flatter than the surfaces of young rocks?; Along the coasts, are rocks generally older or younger than rocks in the interior?; How do the extent of the glaciers compare to topography?; Can you explain the dendritic patterns exposing Ordovician rocks in Ohio and Indiana?; Can you estimate the age of the Rocky Mountain uplift? Based on what evidence?; Speculate on the origin of the north-pointing, anvil-shaped feature in northeast South Dakota.

More advanced students could use their maps of the geologic provinces of the U.S. to investigate a real-world problem. For example, ask students to look more closely at the gulf and Atlantic coastlines (region number 7 in figire 2). How would climate change, global warming, and the subsequent rise in sea-level effect this region?

ACKNOWLEDGMENTS

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