[redacted]

THE GEOLOGICAL SURVEY OF WYOMING
GARY B. GLASS, STATE GEOLOGIST

TEACHERS' SUPPLEMENT OF ACTIVITIES TO ACCOMPANY WYOMING GEOMAPS [ES-1]

by
Sheila Roberts

Geological Survey of Wyoming Educational Series 1-Supplement

Laramie, Wyoming
1991

This and other publications available from:
The Geological Survey of Wyoming
P.O. Box 3008, University Station
Laramie, Wyoming 82071-3008
(307) 766-2286

Printed on 50% recycled fiber paper.

Front cover: Pen and ink drawing by Phyllis A. Ranz.

THE GEOLOGICAL SURVEY OF WYOMING
GARY B. GLASS, STATE GEOLOGIST

TEACHERS' SUPPLEMENT OF ACTIVITIES TO ACCOMPANY WYOMING GEOMAPS

by
Sheila Roberts

Geological Survey of Wyoming Educational Series 1-Supplement

Laramie, Wyoming
1991

CONTENTS

INTRODUCTION

If you teach Earth science in Wyoming, you and your students are blessed with a big backyard laboratory that is unexcelled anywhere. But teachers are busy people and geologic information about the State is often scattered in different publications that may not be readily available. Textbooks created for national use often use a few Wyoming geology examples because the state has some classic locations (for example, Devils Tower is a textbook example of an exhumed volcanic neck), but they do not treat Wyoming geology systematically. Maps can be especially difficult to collect and compile in a useable format because they are produced at different scales that make comparisons difficult. They may also be relatively expensive and they rarely come with explanatory text intended for nonspecialists. Finally, teachers may not have much time to devote to finding a variety of Earth-science related maps and creating activities for using them. *Wyoming geomaps* and this accompanying list of ideas for classroom activities and questions was specifically designed to help bring Wyoming geology into the classroom. This supplement was not written for students (with pages to xerox, etc.), but for teachers, who can pick, adapt, and revise to suite themselves.

Organization and use of the teachers' supplement

Wyoming geomaps offers a smorgasbord, including basic geology, geophysics, economic geology, and related subjects like vegetation and surface water, from which you can choose your own emphasis. The activities and questions are intended to provide an idea base for classroom use of the maps, but are obviously not an exhaustive list. At least some of the maps would fit into other studies, for example, the economic geology maps could help explain Wyoming business and politics, and the Ice Age map could shed some light on the earliest stage of human occupation of Wyoming. The magnetics and gravity maps could be used in physics classes, etc.

Each map is a portrait of a different aspect of Wyoming. Many of the activities suggest some kind of comparison of information from one map with information from another map. You can compare details of different maps by:

1. Making transparent or translucent overlays, either with a xerox machine or hand tracing. (A high-quality set of color overhead-projector transparencies of the maps can be purchased from the Geological Survey of Wyoming.)
2. Using two slide projectors to overlay projections of different maps.
3. Hand transferring information from different maps to compile a new map of your own design.

There are three categories of activities and questions for each section. **This map** has questions and activities dealing with the specific map and with understanding and using maps and mapped information. **Comparison with other maps** is intended to help students relate the maps in the book to each other. **The world around us** suggests ways to relate the maps to the real world, including outside research activities and field trip ideas for the lucky few who can take trips with their students.

The book and activities were designed for sixth grade and up, and had, at this writing, been used in fourth grade to college level classrooms. On the advice of a majority of teachers asked, the individual activities were not rated for grade level. Most teachers said they preferred to range freely through the suggestions to find and modify what would be useful to them and their students. I have attempted to order the activities within each section from least to most advanced, but not all activities sections have a broad range of difficulty levels, and my perception of difficulty may be different from yours.

Some questions asked in the activities have answers provided in brackets. Others, especially those which have no specific correct answers, have suggestions of ways to approach the questions.

Several teachers warned me "not to assume too much" about teachers' Earth-science training or the Earth-science resources available to teachers in Wyoming, especially in elementary schools. I would love to have added the additional explanatory text they suggested, but was unable to do so without having to charge for what would then have been a much-expanded pamphlet. As an alternative assistance, I added a briefly annotated bibliography of references that can be obtained from most public libraries in Wyoming (or purchased from the Geological Survey of Wyoming).

Acknowledgments

The activities were reviewed, on a volunteer basis, by teachers all over the state, some of whom used *Wyoming geomaps* and the activities in their classrooms. A special thanks goes to Dana Van Burgh and Terry Logue, both of Casper, whose advice and encouragement spanned the time from my first appearance at the 1987 Wyoming Multidisciplinary Conference with a few preliminary maps for the *Geomaps* publication until the completion of this project. Teachers in several summer Earth science classes at the University of Wyoming reviewed the activities and their comments helped improve the final product. I regret that I was unable to use all of their suggestions, especially the request to make actual lesson plans.

The following teachers submitted detailed verbal or written reviews that were used in revising the teachers' supplement for publication. I am indebted to them all. The names are listed in alphabetical order:

Brent Breithaupt, University of Wyoming, Department of Geology and Geophysics
Richard Deen, Evanston Middle School
Janet Gerking, Laramie High School
Greg Hammons, Worland Middle School
Tom Logan, Johnson Jr. High School (Cheyenne)
Terry Logue, CY Jr. High School (Casper)
William Mead, Fox Park School
Wallace W. Rice, Central High School (Cheyenne)
Judy Snoke, Thayer Elementary (Laramie)
Dana Van Burgh, Dean Morgan Jr. High School (Casper)

Some materials appearing in the activities booklet were prepared by other people, whose assistance I appreciate. Lawrence M. Ostresh, Jr., of the University of Wyoming Department of Geography and Recreation, produced the computer-generated topographic contour maps, which Phyllis Ranz modified for this printing. Thomas Satterly did the computer-generated graphic illustrations.

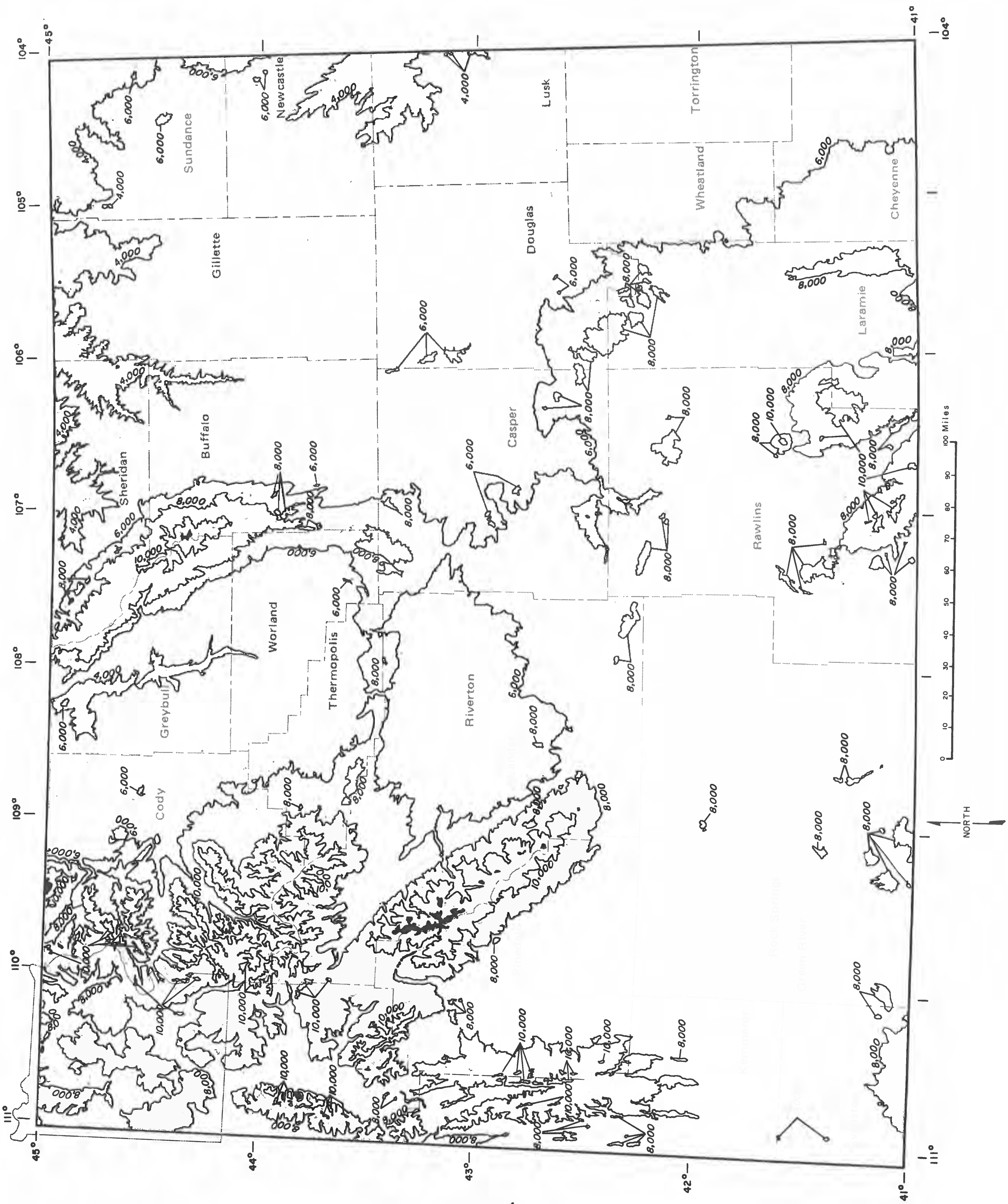
TOPOGRAPHIC CONTOUR MAPS ACTIVITIES

The three computer-generated topographic maps (next pages) do not appear in *Wyoming geomaps* because at the time of publication of the booklet they were not yet available. They were created especially for the *Teachers' supplement* by Lawrence M. Ostresh, Jr., of the University of Wyoming Department of Geography, and modified for printing by Phyllis Ranz. The activities can be done in conjunction with the shaded relief/topographic map in *Wyoming geomaps,* which offers a more easily visualized representation of Wyoming topography. The contour numbers appear only on the map that shows 2,000-foot contours. Numbers for the others can be inferred. Larger, more detailed topographic maps of Wyoming at 1:500,000, 1:250,000, 1:100,000, and 1:24,000 scale are available from the Geological Survey of Wyoming and often from local sporting goods stores, etc.

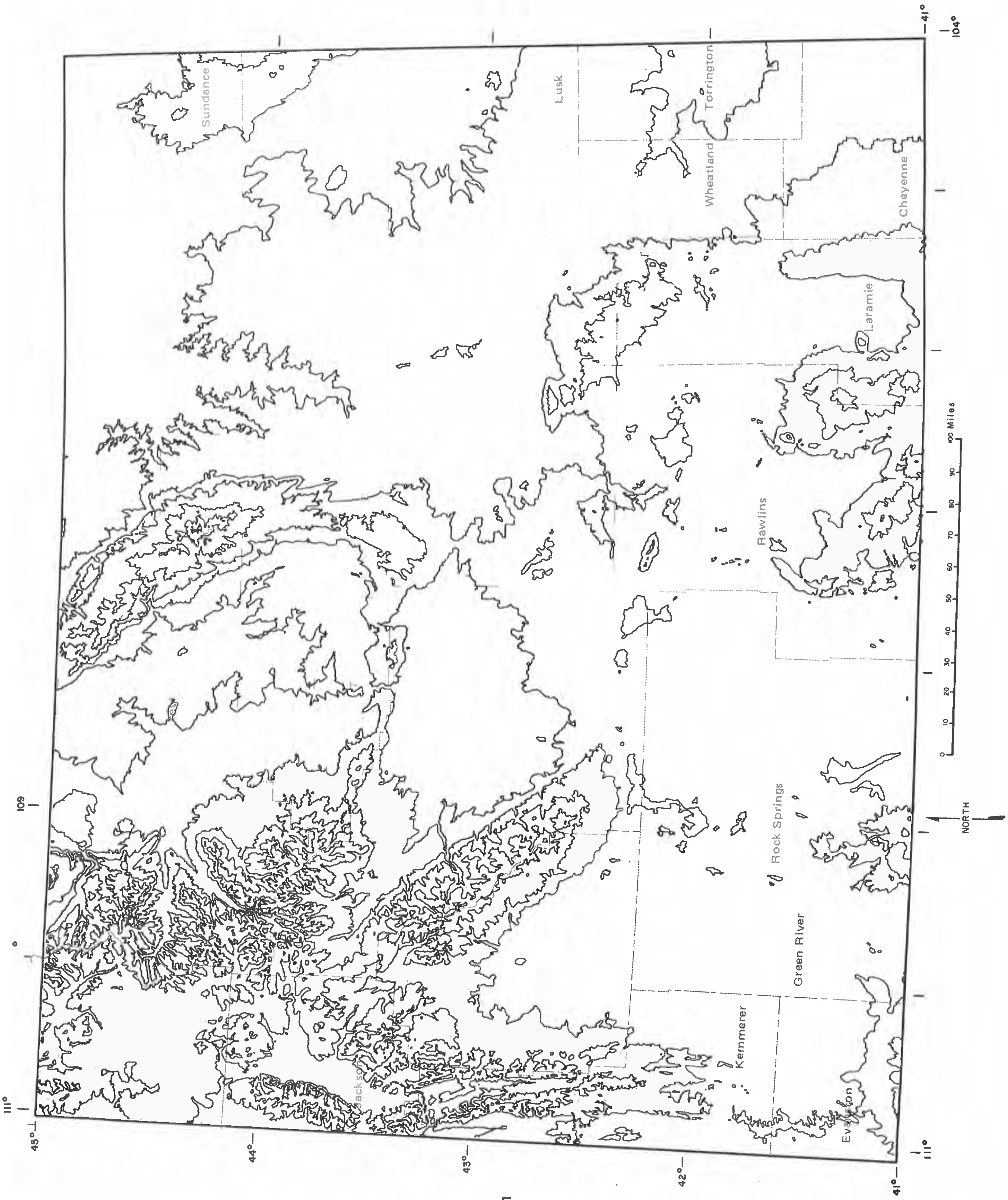
This map

1. This is a good time to review basic map-reading skills. (With younger groups, you may also need to introduce or review the symbolic concepts of maps.) What are the important aspects of these maps?
   •General location can be discerned from the latitude and longitude lines and numbers around the edges of the maps. Discuss latitude and longitude. Find Wyoming on maps of the U.S. and the world. Use a globe or world map to discover other places in the world that are at the same latitude as Wyoming.
   •Scale is provided at the bottom of the page as a 0 to 100 miles scale bar. What is the relative scale of this map, i.e., 1 inch (or foot) on the map equals how many inches (or feet) on the ground the map represents? This is usually shown as a ratio 1:X. For example, if 1 map inch = 100,000 ground inches, the ratio is 1:100,000. On this map, the scale bar shows that 2.4 inches on the map = 100 miles on the ground. Therefore:
   1 inch = 41.67 miles (100 divided by 2.4)
   = 220,017 feet
   = 2,640,211 inches
   and therefore the relative scale is approximately 1:2,640,000.
   If your students have trouble with the concept of scale, it might be possible to get the idea across by having them draw scale models of themselves, the classroom, their houses, etc. (things they are already familiar with) at a simple scale like 1 inch on the paper = 1 foot or 100 inches in real life. They might also relate well to trying to calculate the scale of a picture of themselves.
   •If your class is learning to use metric conversions, convert the bar scale on the map to kilometers.
   •Direction is traditionally provided by an arrow that points to geographic north, as on this map. Usually, maps are oriented on the page so that north is up, but that is not always the case. Orientations of south, east, and west are implied once you know north. If you have a compass, use it to show the directions in your classroom and orient the north arrow on one of the maps to compass north.
   The declination to magnetic north is not shown, but would make a good topic for class discussion, either here or with the magnetic map activities. Magnetic declination is shown on more detailed topographic maps.

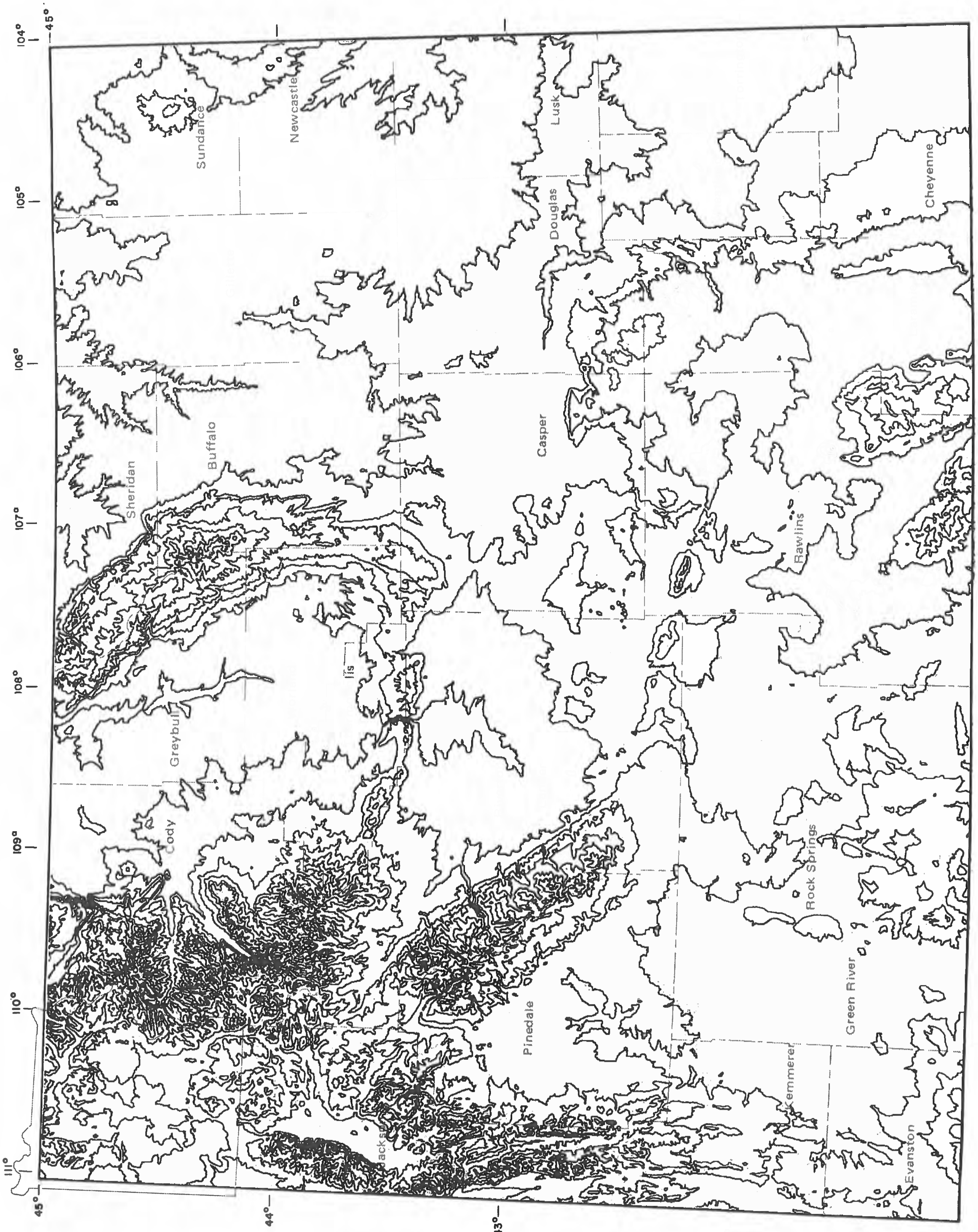
2,000 foot contours



1,500 foot contours



1,000 foot contours

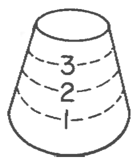


•<u>Cultural points of reference.</u> On this map there are some major towns, county boundaries, and the boundary of Yellowstone National Park. What other cultural items could be added if there was room?

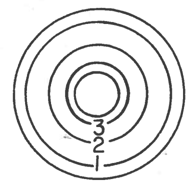
2. Topographic contours appear on maps at three different contour intervals, 1,000, 1,500, and 2,000 feet. You can see at a glance how much more detail the smaller contour intervals show. Here are two ideas for introducing topographic contour maps:

•Have students draw and label 1-inch height interval lines on white paper or plastic cups. Look directly down on the lines to see the map view. Draw the map view. Do the same thing at 1/2-inch intervals.

side view



map view



•Make a clay model of a mountain, island, or whatever, and score contour lines around the model at equal "elevations" off the table with a toothpick. Look directly down on the model to see the map view. Draw the map.

3. Color a copy of one of the topographic contour maps using the colors suggested below or ones of your choice. On this map, all *areas completely surrounded by a single contour line are higher than the number on the surrounding contour,* so they should be colored as if they were between the contour shown and the next higher one. If the area inside the contour was lower, the surrounding line would be marked with straight lines parallel to the contour like this:

Some areas lie between a contour and the edge of the map. Most of these are lower than the contour interval shown (see below).
Color the contour intervals starting with the lowest and working toward the highest areas on the map.

•Color the contour lines first:

4,000	Blue	10,000	brown
6,000	green	12,000	red
8,000	yellow		

•Next color the intervals between the contours:

Color areas below 4,000 feet blue. (The spaces between 4,000-foot contour intervals and the map border are less than 4,000 feet.)
Color areas between 4,000 and 6,000 feet green.
Color areas between 6,000 and 8,000 feet yellow
Color areas between 8,000 and 10,000 feet brown.
Color areas between 10,000 and 12,000 feet red.
Areas enclosed by a 12,000-foot contour are already black. (These are above 12,000 feet.)

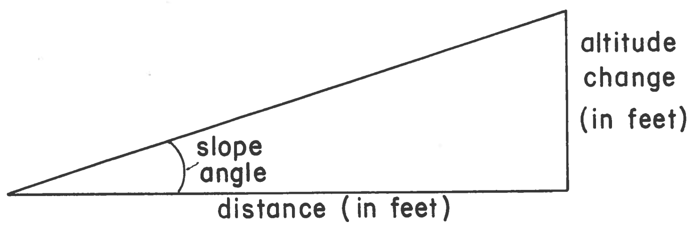
Comparison with other maps

1. Compare the colored contour map with the printed map on page 4, *Wyoming geomaps.*
2. Using other maps in the book, label some of the topographic features that appear on the colored map (e.g., mountains, basins).

Throughout this booklet, there are activities that require use of, or comparison with, the topographic map, so no other separate ones are listed here.

The world around us

1. Perhaps the most effective way to arouse students' interest in topographic maps is to show them a map of their home town or a larger, but still local, area. Inexpensive U.S. Geological Survey topographic maps at scales of 1:24,000, 1:100,000, and 1:250,000 are available for the entire state from the Geological Survey of Wyoming and local maps are frequently sold at sporting goods stores, etc.
   •Have students find the school, their homes, hills or mountains, rivers or streams, any familiar landmarks. In the process, you can show them how the intervals get closer together on steeper slopes and wider apart on gentler slopes.
   •Figure the slope of a familiar place by making a cross section that shows the altitude gained or lost over a particular distance. The angle of slope can be measured directly from your cross section (if you use the same vertical and horizontal scale) or calculated geometrically or trignometrically:



   •Ask students to figure the altitude of a familiar spot that is not exactly on a contour line [assume that a point halfway between two contours in distance on the map is also halfway between them in altitude, etc.].

2. An interesting activity for more advanced students could be designed by you or your class. Use a topographic contour map that has a mountain on it and does not have roads to the top. Pick a low point on the map as a starting point and plot a good route to the top of the mountain, using evidence from the map. Discuss the difficulty of crossing major streams or rivers, swamps, ice fields, and heavily vegetated areas seen on the map. See how far you could get by vehicle and where you would have to walk. Determine slopes that would be too steep to climb without special equipment or skills. You can assign point values to the obstacles (highest number of points for the most difficult obstacles) and plot routes with the most and fewest points. Add handicaps, like the requirement of pushing a wheelbarrow up your route (so that some obstacles become impassable).

GEOLOGIC MAP ACTIVITIES

On this map, the geology at the surface of Wyoming is shown by blocks of different sizes and shapes with different colors and patterns, each one of which represents a different rock unit. There are also heavy black lines that represent faults. Cultural items on the map include roads, major towns, the boundary of Yellowstone National Park, and county boundaries.

The first geologic map of Wyoming published in color in 1917 by State Geologist Loyal Trumbell, had only 7 units. It was a simplified, but useable geologic map for studying regional geology. With time and much more mapping in the field, geologists have added detail. There is an interesting display on the first-floor walls of the Geological Survey of Wyoming Building in Laramie that shows the progressive development of the geologic map of Wyoming from the first black-and-white version, created by pioneer Wyoming geologist Wilbur Knight (see a reduced version on p. 2, *Wyoming geomaps*), to the present wall-sized color version (Love and Christiansen, 1985).

This map

1. One of the first things to do with this map is to overcome the possible impression that it is too complicated to make any sense.

   •A tracing project will help students sort out the general order of the units and gain confidence in their ability to understand the map. Put a piece of tracing paper over the map and stick it down on one side with masking tape so it doesn't slide around. Now <u>color the five major units</u>. These colors are fairly standard on geologic maps, but you could use others, especially if there are color-blind students:

   Cenozoic igneous rocks -- pink.
   Cenozoic sediments and sedimentary rocks -- yellow.
   Mesozoic sedimentary rocks -- green (or gray)
   Paleozoic sedimentary rocks -- blue.
   Precambrian igneous and metamorphic rocks -- brown.

   Because some of the Cenozoic unconsolidated sediments (very light yellow on the map), especially the river alluvium, appear as thin stringers that cross older units, you might want to omit or greatly simplify that unit for this project. If you do, simply fill in the unit that surrounds it. Discuss why it is acceptable to do it this way, pointing out how stream sediments, sand dunes, etc. are important, but they are often rather thin cover over the older bedrocks. The geologic map has already been simplified by ignoring much of the thin soil cover.

   •Discuss the patterns of the traced geologic map. You can see the ancient rocks in the high mountain cores (brown), the sedimentary rocks that rim the mountains (blue and green), the young sedimentary basins (yellow), a few of the stream and river valleys (yellow ribbons that crosscut other rocks), and the volcanic rocks of the Absaroka Mountains, Yellowstone National Park, the Black Hills uplift, and elsewhere (pink).

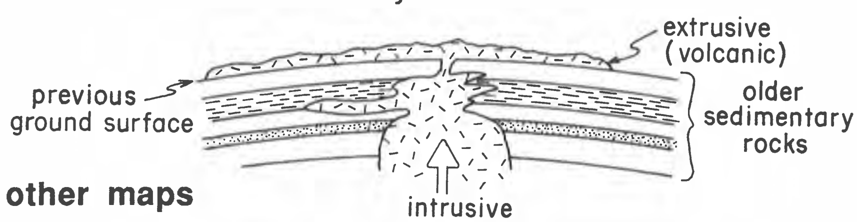
   •With a younger group, combine all sediments and sedimentary rocks for just three different units (Cenozoic igneous rocks, sediments and sedimentary rocks, and Precambrian igneous and sedimentary rocks) and let the students generalize boundaries even more.

2. Cross section. One of the most respected and useful tenants of geology is the very simple notion that younger rocks are deposited on older rocks (the "Law of Superposition"). If you see a stack of sedimentary rocks in a cliff, you can generally assume the oldest ones are on the bottom and the youngest ones are on the top (providing nothing has happened to turn them over or otherwise disrupt the order). The cross section shows this order. Compare what you see on the cross section, which gives a glimpse into the Earth's crust like cutting into a layered cake, with what you see on the geologic map at a few key places, for example:
•Look at the simplest areas first. The eastern part of the cross section, through the Powder River Basin, dramatically illustrates the layer-cake relationships of the rocks, which are only very slightly tilted.
•The Wind River Range and surrounding basins. Note how the Precambrian rocks in the mountain range are displaced up over much younger rocks along a fault that arcs along the south and west sides of the mountains. You can see evidence of this on the map of the surface, where older rocks abruptly abut younger rocks, and it is "explained" by the cross section. Examine the map pattern and cross section of the east side of the mountains. There, the pattern of tilted rocks follows the expected succession of oldest to youngest from the center of the range toward the basin. When mapping rocks, geologists often suspect the presence of a fault or fold where the expected age succession is disrupted or where rock units are unexpectedly repeated or missing. Until almost the middle of the Twentieth Century, the only evidence of what was under the ground, for most places, was what could be seen on the surface and sometimes in a few wells or mines.
•The cross section shows folded rocks. Some of the most spectacular folds on the cross section are in the basins. Compare the surface expression of these folds with what they look like in the cross section. How do you suppose geologists came up with the interpretation of the large fold in the Powder River Basin? What evidence did they have from the surface geology? In several places on the map there are smaller folds that were drilled for oil and gas many years ago. Can you identify the surface pattern of rocks that clued the geologists about the location of a fold?

3. You can model many of the structures seen on this map with colored modeling clay (more on this in the activities that accompany the structure map). First make a simple, flat-layered model, and then disrupt it in ways that mimic faults and folds in the Earth's layered crust. One especially useful demonstration is to show what exposed folds look like on the ground. Make a layer cake of thin layers of colored clays and fold them. Then take a knife, wire, or piece of dental floss and cut off the top of the folds to produce a flat "ground" surface. This is a fairly realistic depiction of what happens to folded rocks when they are eroded in nature. Compare the cross sectional view with what would appear on the surface. What is the "age" order on the surface that is the clue to the nature of the fold? [answer: The surface expressions of eroded upfolds (anticlines) have oldest rocks in the center; eroded downfolds (synclines) have youngest

rocks in the center.] Do this with both an upfold and a downfold. The diagrams on the next page illustrate what you may see.

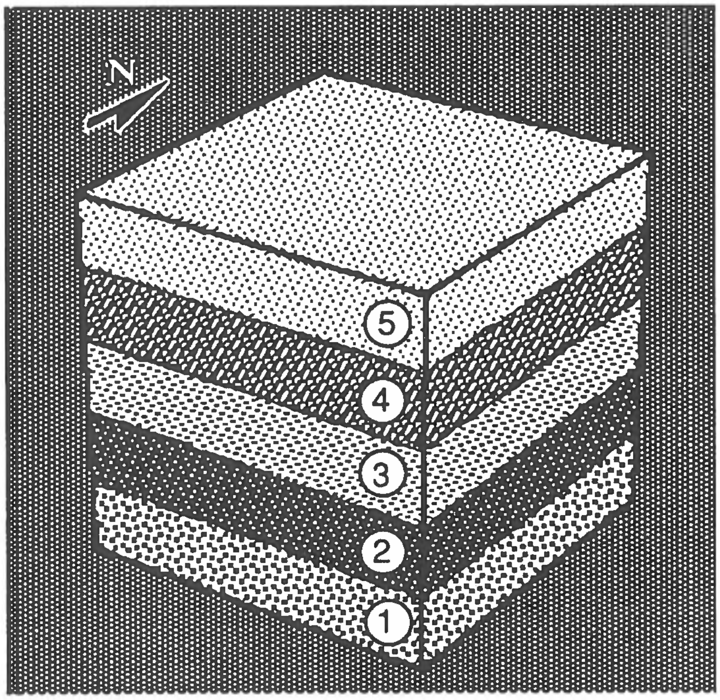
4. Igneous rocks. Rock melts deep within the Earth and then tends to move up toward the surface where it eventually cools and crystallizes.
•If the melt reaches the surface, the rocks that crystallize are called "extrusive" because they extruded (pushed out) from the ground. Find some of the extrusive igneous rocks shown on the map (most of the rocks in the Yellowstone region and most of the Absaroka Volcanic Supergroup).
•"Intrusive" igneous rocks crystallized before they got to the surface of the Earth. The molten rock (magma) forced itself into cracks and larger chambers in older rocks and solidified there under ground. In some places, these rocks have been exposed at the surface by erosion. There are several places on the map to see this relationship of young igneous rocks intruding older rocks. For example, in the Black Hills region, upper Tertiary to Cretaceous (?) intrusive rocks are surrounded by older rocks. What are the older rocks? [Paleozoic and Mesozoic sedimentary rocks] In the Medicine Bow and Laramie Mountains, Middle Proterozoic intrusive granitic rocks are in contact with older Early Proterozoic and Archean rocks they intruded.



Comparison with other maps

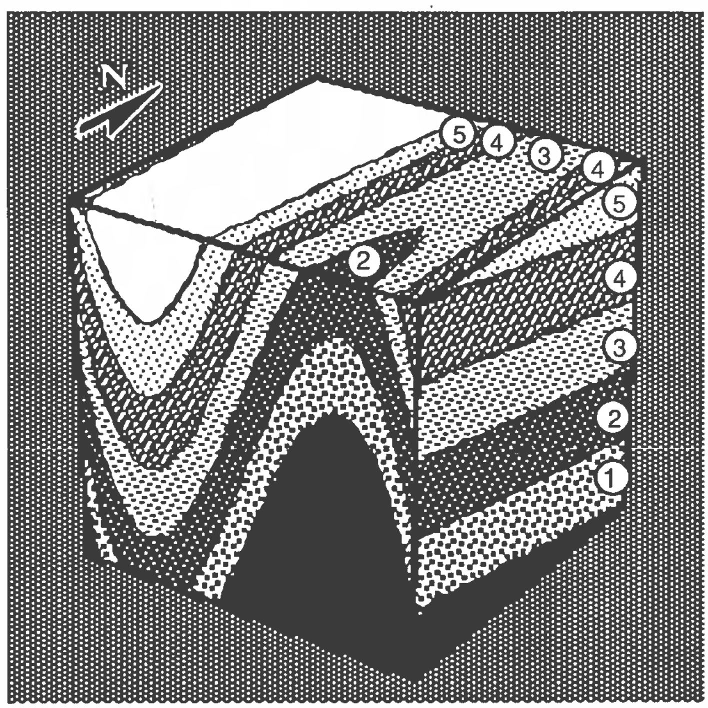
1. The other maps have activities that use comparisons with the geology map. Compare this map with any other in the series because they are all the same scale. You will note differences in the maps that may confuse you at first. There are several good reasons for the differences. One is that different maps are drawn to emphasize different aspects of geology and have features that can't be shown on others because they would be too crowded. For example, folds are not shown with blue lines on the geology map (as they are on the structure map), not because they are not there, but because they couldn't be clearly seen against all the other colors and patterns. Another reason for differences is that the maps were taken from different sources and different-scale originals. Also, maps of this scale have to be quite generalized and in the process of generalization some things become a little exaggerated while others are left out--like caricature drawings in political cartoons. Each author or map compiler will accomplish this task in his or her own way. Authors have their own interpretations and they use various sources to compile their maps. This should not be too disconcerting; it reflects the fact that geology is a healthy science with a wide variety of ideas, methods, and interpretations.

2. Use the geologic time scale (p. 1, *Wyoming geomaps*) to discuss what kinds of rocks and fossils you would expect to see in the different -aged rocks on the map.



This block represents undisturbed layers of sedimentary rocks. Layer 1 is the oldest and layer 5 is the youngest.

This block shows the rocks after they have been folded. Note the age relationships of the rocks as they are exposed on the surface in the fold.



The world around us

1. This would be a good place to introduce rocks and minerals to your class and discuss the distribution of rocks in Wyoming. If your school has a collection, discuss sedimentary, igneous, and metamorphic rocks in relation to where they occur in the State. If you don't have a collection, this is a great time to start one and the place to begin is your own back yard. *Minerals and rocks of Wyoming* (Hausel, 1986) is a good reference for collecting in the state.

2. This is also an opportunity to introduce fossils. Students could relate the fossils to the age of the rocks in which they are contained and to where the rocks of those different ages are found in Wyoming. "Places to see geologic exhibits" (p. 35-38, *Wyoming geomaps*) might help you find displays of fossils in your community. *Fossils of Wyoming* (Hager, 1970) might also be useful.

3. If this geologic map interests you, look for others that give more detail of your area. The *Geologic map of Wyoming* (Love and Christiansen, 1985) is a good place to start. Its scale is 1:500,000, which gets the whole state into a map that fits conveniently on a wall. Depending on where you live, there may also be geologic maps at more detailed 1:250,000, and (or) 1:24,000 scales. Some places have been mapped at other scales as well by the Geologic Survey of Wyoming, the U.S. Geological Survey, and others. There are geologic map indexes for Wyoming (see Geological Survey of Wyoming Map Series 9B-9S) that show areas for which different types of geologic maps are available. Personnel at the Geological Survey of Wyoming can help you find out if there are detailed geology maps of your area. With these maps, you can go to the field and look at rocks and structures or create classroom activities geared to your own area.

4. Investigate Wyoming's place in the U.S., the Northern and Western Hemispheres, the solar system, Milky Way galaxy, local group of galaxies, etc. A wonderful reference for this is *Journey into the Universe through time and space* (Supplement to the *National Geographic*, June, 1983, v. 163).

STRUCTURE MAP ACTIVITIES

Faults, folds, and other rock structures result from the continual jostling of materials in the Earth's crust. Rocks are shoved together, pulled apart, slid past each other, and generally disturbed by the forces of gravity and internal Earth processes driven by heat. The long geological history of Wyoming encompasses several major episodes of mountain building (orogeny) and uncountable minor events. We know about them because they left decipherable marks on the rocks--folds, faults, metamorphic events, igneous intrusions and extrusions, surfaces of erosion, etc. A short, understandable geologic history of Wyoming is contained in Blackstone (1988, *Traveler's guide to the geology of Wyoming,* Geological Survey of Wyoming Bulletin 67). Dr. Blackstone compiled the structure map in *Wyoming Geomaps.*)

On this map, faults and folds in the Earth's crust are symbolized with different colored lines shown in the orientation and position of the structures as they intersect the ground surface. Understanding the map requires thinking three dimensionally about what is going on below the ground and what may have been eroded above. The block diagram can help. So can the cross section that accompanies the geology map.

This map

1. Becoming familiar with the symbols used to indicate structures and beginning to visualize what they mean about the three-dimensional rocks will help students read this map. Refer to the block diagram opposite the structure map (and also to the cross section with the geologic map and Earth science textbooks) to visualize the meaning of these structural terms. Here are a few definitions of terms used to describe geologic structures.
   Anticline - upfold of layered rocks, in which the oldest rocks are in the center of the fold and the youngest rocks are in the outside of the fold.
   Syncline - downfold of layered rocks, with the youngest rocks in the center of the fold and the oldest rocks in the outside of the fold.
   Fold axis - a line that defines the trace of the bottom of a syncline or the top of an anticline. A "basin axis" line on the map marks the approximate trace of the structural bottom of the basin. It does not necessarily mark the lowest topographic point in the basin (see cross section with the geologic map).
   Thrust fault - a break in the rocks along which older rocks move up over younger rocks.
   Normal fault - a break in the rocks along which younger rocks move down next to and on top of older rocks.
   Strike-slip fault - a break along which rocks are displaced mostly horizontally in (relatively) opposite directions.

2. Answer some questions using the map:
   •Is your town on or near one of these major structures? What kind?
   •Are there any thrust faults shown in extreme northeast Wyoming? [no]
   •Which sides of the Laramie Mountains have thrust faults? [west and north]
   •What is the dominant direction of movement on the thrust faults in the Overthrust Belt? [west to east. Use the geology map cross section to see this better.]

3. Now try to visualize what some of the places on the map look like under ground. Take the region around your town and draw your own approximate cross section using just the information about faults and folds and Precambrian basement that appears on the map. Pick another area if yours is too complicated or if it doesn't have any nearby structures on the map. [This can be done very generally. Avoid areas where the map doesn't tell you which way the rocks have moved on faults (unspecified displacement).]

Comparison with other maps

1. The structure map, like the geology map, is such a basic tool of geology that it can be compared to almost any of the others. There is comparison discussion with the gravity and magnetic maps that show how interdependent these maps are. What major structures are apparent, in different ways, on all these maps? [Compare the maps using transparent overlays if you have them.]

2. Many of the faults are shown on the geology map and you can see there how they were mapped from surface evidence of rock units that seem to be cut by older or younger units. For example, the thrust fault northwest of Rawlins cuts and offsets rock units.

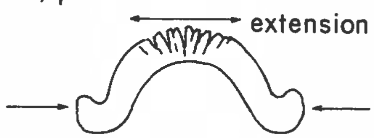
3. By comparing some of the folds with the geology map you can see what the surface expression of folds looks like. For example, see the anticlines in the southern Wind River basin.

4. Compare this map with the active faults and earthquakes map to see which of the faults shown on this map are probably still active. [Do not expect perfect agreement of the different maps in terms of precise location of the folds and faults or interpretation of their movement because these maps were constructed by different authors, at different times, and at different original scales.]

The world around us

1. Experiment with faults and folds. This can be done with modeling clay, soft taffy (made in the lab), foam rubber sheets, or fancy mixtures of layers of materials with different properties (which is how a lot of structural geologists do it). You need materials that can be fairly easily bent, broken, stretched, and otherwise distorted without completely coming apart. It doesn't matter that they are not rocks, you can observe the same effects from the same relative applied forces. The main reason to use these materials is that they speed up the time of the reaction and reduce the amount of force you have to apply.
   •Create a fold. Take your layered material and slowly push it together. This can be done in many ways. For example, if you are using modeling clay stick a couple of sheets of it together and put them on a sheet of waxed paper. Push two opposite ends. Part of the clay will fold up (*anticline*) and part will fold down (*syncline*). The compressive force you applied requires the material to shorten itself in the direction of the force, which was accomplished by piling up in the other direction.

If your material broke instead of folding, it may be too stiff or thick or you may have forced it too quickly. The difference in response to rate of strain is especially evident if you used silly putty. Never mind. There is a real-world lesson in that too. When relatively slippery, pliable rocks like shales are pushed they will often fold, whereas relatively stiff and brittle rock like granite is likely to break (fault). Also, a force that is applied very suddenly is more likely to break rock than one that is applied very slowly. Most of your students will already be familiar with that concept from playing with silly putty, but they may not realize that rocks work the same way. While you are at it, notice where the breaks occurred. Was the material being pushed together or pulled apart at those spots? Even though the force you applied was compression, places in the folds were experiencing extension.



•Create a fault. This can be a little more difficult to show, and you will probably want to cut planes of weakness (faults) into your material before you demonstrate the movements. This is actually acceptably realistic because many rocks have pre-existing planes of weakness along which they are more likely to break. For example, make several low and higher angle cuts clear through a stick of clay and grease them well with vaseline. Put the blocks back together and squeeze them together until you cause some blocks to move up. Compression is frequently the cause of *thrust or reverse faults.* Slide them sideways against each other to simulate strike-slip movement. Raise the block a little above the table and gently pull it apart so that one side begins to fall down relative to the other side. Extension is frequently expressed by *normal faults* like this.

2. Nearly anywhere in the world where rocks are exposed for people to see there are faults and folds. You can probably see some near where you live if you know what to look for. It is convenient that they come in so many different scales. In Wyoming, rocks contain microscopic folds; folds a few inches, feet, or miles across; and folds the size of the Powder River Basin. Faults share the same range of scales. You can also see them in other Earth materials besides rocks: loose sediments in road cuts often display them; road cuts into snow banks also show faults and folds. Look for material that has been layered in such a way that you can see different colors, compositions, or textures (most sedimentary and many metamorphic rocks) or where something different separates similar layers (like dirt separates snow layers). As a class, try to point out some of the places where you can see faults and folds in your own area. Allow students to be creative, not confined to rocks.

BASEMENT MAP ACTIVITIES

This is another kind of structure map, in which only the oldest rocks are shown. On this map, the Earth's surface is of no particular interest except where it is composed of basement rocks. Imagine you baked a cake and then cut it up, smashed it down in some places, or folded pieces of it. Then you put this jumbled mass back in the pan and poured icing over it, not quite entirely covering the cake. The cake could be the basement and the icing all the younger sediments and sedimentary rocks that now cover up most of it. If you scraped the icing back off the surface, what you would uncover would be like the surface described by this map. Since geologists cannot actually scrape off the rocks that cover the basement, they use other sources of information like deep wells to discover where it is and then construct maps like this to create a picture of the hidden surface.

This map:

1. Use the basic information on the map:
   •If you were standing on the highest point in the Wind River Mountains, how much sedimentary rock would separate you from the basement rocks? [None, Precambrian rocks are at the surface (outcrop) there.] Note that the higher contours in the mountains reflect theoretical pre-erosion elevations.
   •Find the two places on the map where the top of the Precambrian basement is at least 30,000 feet below sea level. [northeastern Green River Basin and Hanna Basin]
   •Of the basins named on the map, which has (have) the shallowest maximum basement depth in sea level elevation? [the Laramie Basin and Shirley Basin, where the greatest depth to the top of the basement, is sea level]
   •If you were standing in the Yellowstone caldera, how far below would the basement be? [Can't tell from this map—there are no contours in the caldera.]
   •In the southern Wind River Basin, the basement contours are repeatedly offset by what kind of structure? [a series of northwest trending thrust faults]

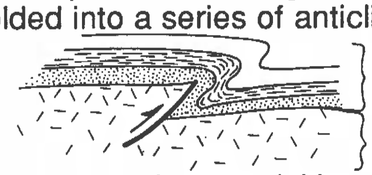
2. Use the contours to determine relief and slope of the basement surface.
   •What is the relief on the top of the Precambrian basement between the highest contour in the Black Hills uplift and the lowest one in the Powder River Basin? [+5,000 to -15,000 = 20,000 feet of relief]
   •Calculate the slope in vertical feet per horizontal foot.
      1. How much horizontal distance is between these contours? [about 110 miles or 580,800 feet]
      2. You already found out that vertical relief is 20,000 feet, so slope is 20,000 feet divided by 580,000 feet or.034 vertical feet per 1 horizontal foot.
   •For more advanced mathematics: If this same slope continued for 250 miles, how deep would the basement be?
   What is the angle of the slope? [if you want to do a little geometry or trigonometry]

3. Look ahead at the gravity map activities and read about the construction of a gravity cross section. Try constructing a cross section showing the top of the Precambrian basement along the same line across the map as the topography or gravity cross section. (See appendix of sample cross sections.)

Comparison with other maps

1. Using one of the topographic maps of Wyoming, compare local ground-surface elevations with the Precambrian basement elevations in the same places to see how much rock covers the basement. (Also, the official Highway map of Wyoming records elevations of towns.) For example, the elevation of Laramie is 7,185 feet and the town is very close to the +5,000-foot basement contour; therefore the basement at Laramie is covered by about 2,185 feet of younger rocks and sediments.

2. Basement rocks in the southern Wind River Basin are offset by a series of northwest trending thrust faults. Turn back to the structure map and see how those faults are expressed at the ground surface. [Sedimentary rocks at the surface are folded into a series of anticlines over the basement faults.]



3. Many of the other maps have activities for comparison with the basement map. If you make cross sections from information on these maps, it would be useful for comparison to locate them along the same line of section across the maps.

The world around us

1. Several of the maps, including this one, show the areas in Wyoming where Precambrian basement rocks are exposed at the ground surface. If it is possible, try to visit an outcrop of basement rocks and collect samples. You may already have samples available in a school collection. There is something wonderful about holding a chunk of such overwhelmingly old rock in your hands. Some of these old igneous and metamorphic rocks are very interesting, with a variety of identifiable mineral crystals, small folds, etc.

2. Precambrian rocks have been important in minerals exploration in Wyoming. Perhaps some of your students would be interested in researching the occurrences and origins of Wyoming jade, beryl, iron ore, or other Precambrian-hosted deposits. [I suggest *Minerals and rocks of Wyoming* (Hausel, 1986) for beginning this research.]

3. Nearly all the Precambrian rocks in Wyoming belong to the Wyoming Province, a very ancient block of early Earth crust that was incorporated into the North American Continent. Advanced students might be interested in studying more about the Wyoming Province or the other Archean provinces that make up the oldest-preserved basement of the Earth's crust worldwide.

GRAVITY ANOMALY MAP ACTIVITIES

A word or warning at the start: the concepts for using the gravity map may be too complex for students at the younger age range. For them, it is enough to see that the force of gravity is a measurable, mappable property that varies in predictable ways across the surface of the Earth.

The contour lines on the gravity map delineate zones of equal gravity values in the same way that contours on a topographic map are lines of equal elevation. If you have been using the topographic contour maps already, your students will find gravity contours easier to understand. If you have not used the topographic contour maps yet, this is another place to introduce them and create a basis for working with the gravity contour map.

Although all the values are expressed as negative numbers, some are less negative than others. In general, less negative numbers indicate denser rocks and more negative numbers indicate less dense rocks. With your students, emphasize the contrasts between areas on the map, not the actual values.

This map

1. Construct cross sections with contoured map data, starting with a simple topographic cross section using the topographic map (see instructions below). Then, using the same principles, construct a gravity cross section with gravity contour data. Locate your cross sections along the same line for the topographic and gravity maps so you can compare them. (If you also construct basement and magnetics cross sections, use the same line.)

   •<u>Instructions for constructing a topographic (or other contoured data) cross section</u> (see diagram, next page, and appendix of sample cross sections):

   A. Decide where you wish to make your cross section, and draw a line across the map. You might find it useful to construct your cross section along the same line as the geologic cross section that accompanies the geologic map, but that is not necessary.
   B. Tape the edge of a piece of graph paper immediately above the line and draw (on the graph paper) two lines exactly perpendicular to the cross section line at each end point. These are your vertical scale lines.
   C. Chose a vertical scale to represent feet (for the topography map) or milligals (for the gravity map), or whatever your contour map measures. For example, in the gravity cross section shown, 100 milligals = .8 inch. Mark scale interval points on the vertical scale at exactly the same spot on both sides. Adjust the scale for more or less vertical exaggeration.
   D. Working across the line of section, mark a small dot on the paper to represent the value of each contour where it crosses the section line (to simplify this process, mark only the major contours).
   E. Connect the dots to create a line that shows how the values rise and fall. If you used a topographic map, you will have a cross section of the rising and falling ground elevations along your line of section. If you used a gravity map, the line represents the rising and falling gravity measurements. In either case, the cross section converts the plan-view information on the map to side-view information showing vertical relief.

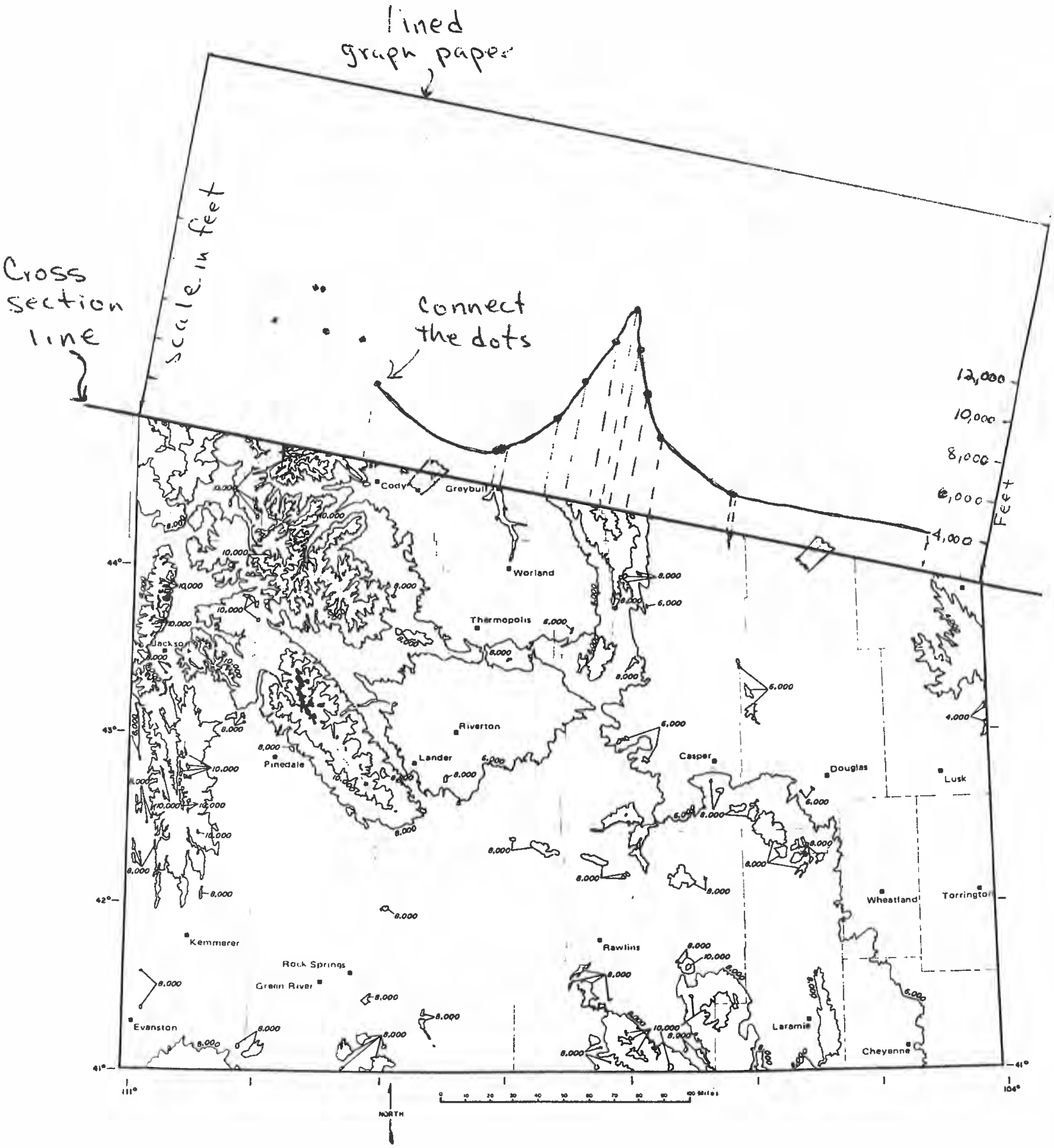
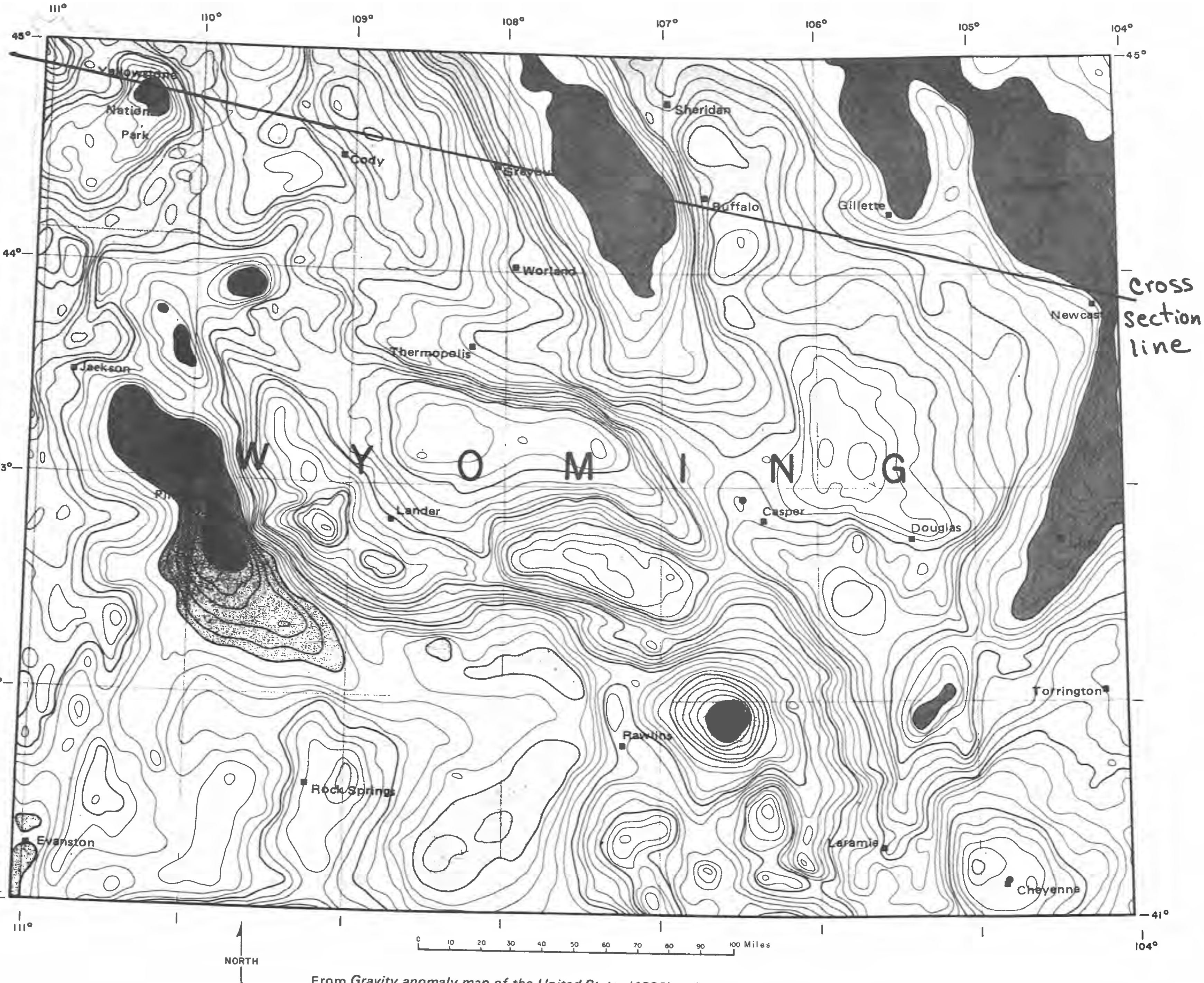
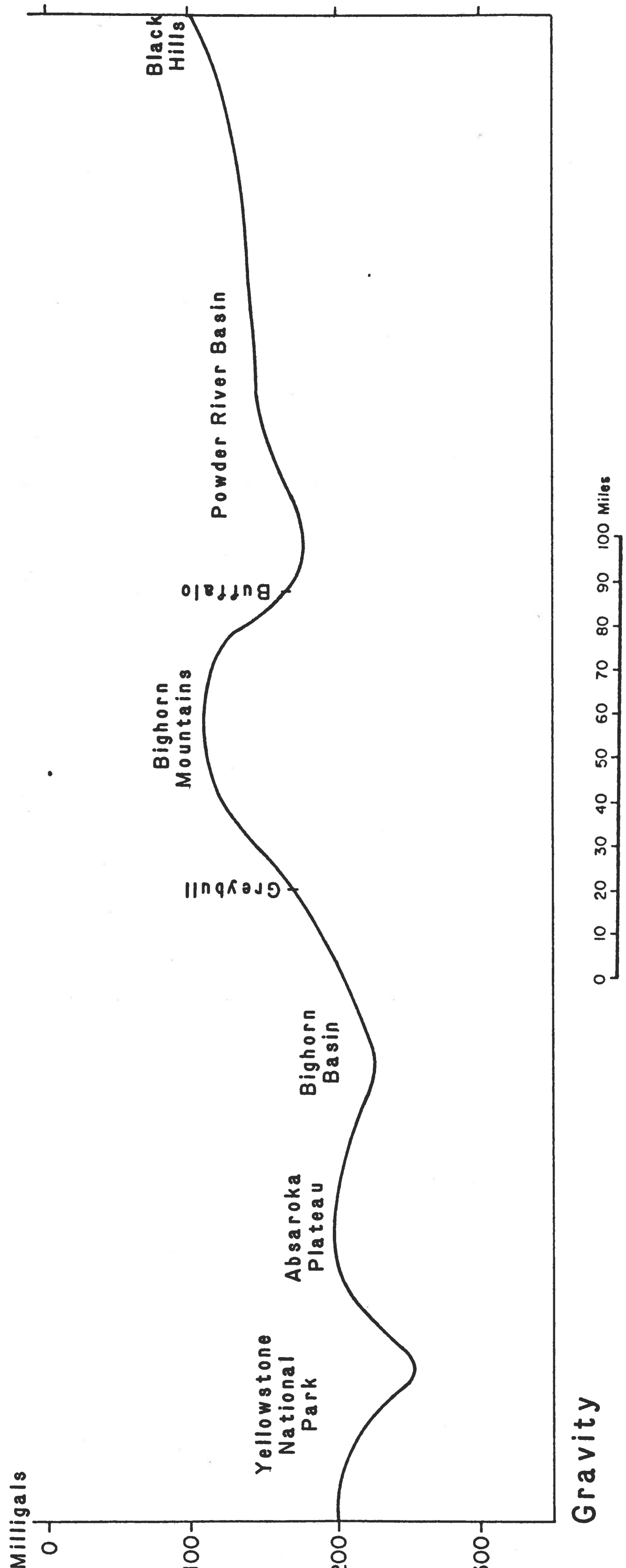


Diagram showing construction of a cross section
(using the 2,000-foot topographic contour map).



From *Gravity anomaly map of the United States* (1982), printed with permission of the Society of Exploration Geophysicists. Wyoming portion redrafted by Phyllis A. Ranz.


Milligals
0
-100
-200
-300
Yellowstone National Park
Absaroka Plateau
Bighorn Basin
Greybull
Bighorn Mountains
Buffalo
Powder River Basin
Black Hills
0 10 20 30 40 50 60 70 80 90 100 Miles
Gravity

Comparison with other maps

1. •Trace or xerox a transparent overlay of all or part of this map and lay it on top of the basement map. See if you can find features that appear to coincide and try to suggest reasons for the coincidence. [Look at mountain ranges and basins.] Can you spot areas where the dense crystalline rocks are probably very close to the surface? [gravity highs]
   •Construct a basement map cross section, noting where faults cut the Precambrian crystalline basement rocks (see cross section appendix at the end of the booklet for a vertically quite exaggerated example). Compare it to the gravity and topography cross sections. Do you see how the gravity map might be useful in interpreting depth to basement even if there was no other data available?

2. Overlay the simplified tracing you made of the geology map on the gravity map. See how the dense Precambrian cores of mountains are generally over gravity highs. See how the young, less dense sediments in the basins are generally over gravity lows.

The world around us

1. Do an experiment to show how materials of different densities float in liquids of different densities (water, corn syrup, cooking oil (or whatever). Use the same and different sizes of ice, wood, plastic, stone or brick, glass, or whatever in the same and different flotation materials. The points to make are (1) In the same liquid, different sized blocks of the same material will float with the same percentage of material submerged, (2) in the same liquid, same sized blocks of different materials will float with different amounts submerged, (3) shape has nothing to do with it; although optical illusions can be created, (4) materials will not float in liquids that are less dense than they are, (5) the viscosity of the flotation material affects the speed with which the material settles into it.
   •Why does ice float in water? [It is one of the few materials for which the solid phase is less dense than the liquid phase.]
   •Why does the crust of the Earth float on the mantle? [Check the rock density chart to see that materials that make up the crust are less dense than the mantle materials.]

2. If you have equipment and time, measure the densities of different materials (procedures should be available in high school physics or chemistry texts).

MAGNETIC ANOMALY MAP ACTIVITIES

Another warning: using this map requires more advanced students than any of the other maps. With most students, it is probably enough to simply convey the message that rocks have measurable and mappable magnetic properties and perhaps to review magnetism in general. Activities below could be done without mathematics and physics requirements. Physics teachers, or earth-sciences teachers who want to work physics applications into their instruction, will be able to create more advanced activities.

This map

1. Find the places discussed in the last paragraph of the map explanation.
2. Create a magnetic anomaly cross section along the same principles as the gravity anomaly map and through the same location (see example, end pages for this section).

Comparison with other maps

1. North of Sundance, Wyoming there is a circular-shaped magnetic anomaly high that appears to correlate fairly closely with an igneous intrusion on the geology map. What might be the cause of the magnetic high? [more magnetic minerals in the igneous rock than in the sedimentary rocks surrounding it].

2. Gravity and magnetics maps are often used together (or in conjunction with other maps like geology and topography) to make interpretations because a coincidence of two or more separate lines of evidence makes the interpretation more likely. Overlay the structure, gravity, and basement maps on the magnetic map to find correlations that seem to make sense to you. Can you find some places where the gravity and magnetic maps seem to be telling similar stories? Start with the broad outlines of basins and mountain ranges. Look for faults and other structures also. [Look at the Bighorn and Wind River mountains, the Powder River and Wind River basins, etc.] Use the structure map or basement map to help confirm some of those interpretations. Next, bring the geology map and cross section into the comparisons.

3. If you have made cross sections of the same areas for topography, basement rocks, and gravity they may all be compared here. Try to explain some of the coincidences at whatever level your students are prepared to discuss them. Perhaps you can enlist the assistance of a physics teacher or local geologist or geophysicist.

The world around us

1. Remanent magnetism is a concept that will probably need more explanation, although your students are already familiar with it if they have ever used a common iron magnet, which has an independent force field (its magnetism does not depend on the Earth's field or an induced electromagnetic field). Igneous rocks commonly acquire remanent magnetism at the time the magma solidifies. As the tiny magnetite crystals

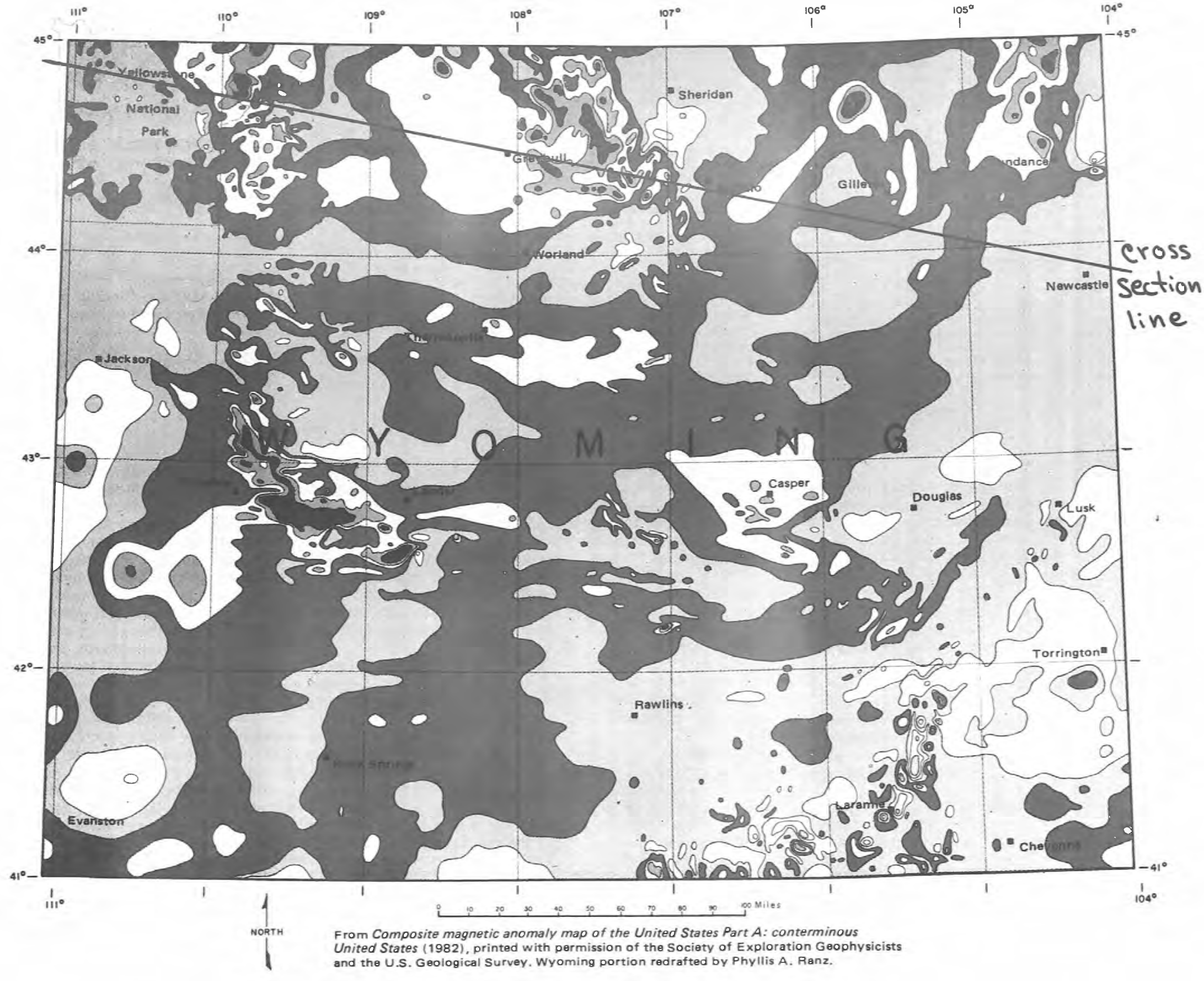
form, they acquire a magnetic polarity that is exactly parallel to the Earth's field at that particular time and place. When the rock solidifies, that alignment is permanent unless the rock is reheated above the temperature at which rocks cease to be magnetic (the Curie point, somewhere around 600 °C for most rocks). Metamorphic and sedimentary rocks that contain magnetite or other magnetic minerals can also acquire remanent magnetism when they form. If the magnetized rock is later folded, tilted, or otherwise moved, the magnetic alignment folds or tilts with it. If the polarity of the Earth's magnetic field reverses, the rock's polarity does not change.

•Try this demonstration/experiment to show how magnetic orientation is "frozen" into a rock. Get two or three small bar magnets, a glass or aluminum pan of water, wooden rod, and some string. Set the rod over the pan of water and tie the magnets to the rod with just enough string to allow them to dangle freely in the very top of the water. Keep the magnets spaced far enough apart so that they do not attract or repel each other. The magnets will behave like tiny compass needles and align themselves with the Earth's magnetic field. Turn the pan so that one side is aligned exactly magnetic north and mark the north, south, east, and west sides on the edge of the pan. Does the north end of a magnet in the pan attract the south end and repel the north end of another magnet?

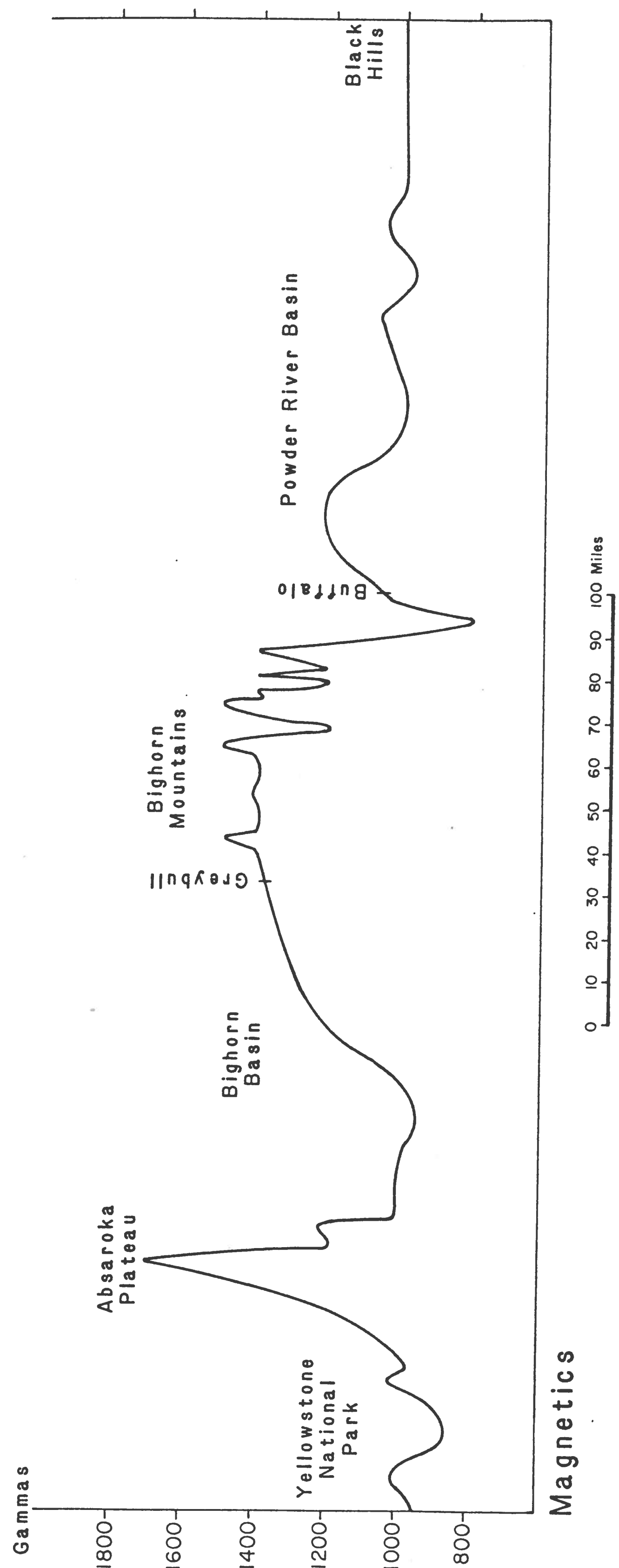
•Keeping that alignment, freeze the pan of water with the magnets in it. You have solidified the "rock" with its magnets, creating remanent magnetism. When you remove the frozen pan of water and magnets you can turn it in any direction and it retains the field that was frozen into it. Check to see if the magnets still work when they are oriented opposite to the Earth's field (i.e. north pointing south) and at some other orientations. Does the north end of the frozen magnet still attract the south end of another magnet at different orientations of the pan?[yes] This experiment can also be done with melted wax instead of water if it is easier to heat wax in your classroom than freeze water. The melted wax is not hot enough to disturb the field of the magnets.

2. If at all possible, bring a chunk of magnetite into the classroom and demonstrate its magnetic properties by showing that it attracts a compass needle and a magnet. A single small piece of Wyoming magnetite can be obtained for your classroom by writing to the Publications Division, Geological Survey of Wyoming, Box 3008, University Station, Laramie, WY 82071.

3. The magnetic properties of rocks provided the compelling evidence for sea-floor spreading, a key concept upon which the theory of plate tectonics is based. After studying the magnetic anomaly map of Wyoming, students may be better prepared to appreciate the very different magnetic anomaly patterns of ocean crust.



From *Composite magnetic anomaly map of the United States Part A: conterminous United States* (1982), printed with permission of the Society of Exploration Geophysicists and the U.S. Geological Survey. Wyoming portion redrafted by Phyllis A. Ranz.


Magnetics
Gammas
1800
1600
1400
1200
1000
800
Yellowstone National Park
Absaroka Plateau
Bighorn Basin
Greybull
Bighorn Mountains
Buffalo
Powder River Basin
Black Hills
0
10
20
30
40
50
60
70
80
90
100 Miles

EARTHQUAKES AND KNOWN OR SUSPECTED ACTIVE FAULTS MAP ACTIVITIES

This is the only map in the book that deals directly with geologic hazards. It could be used as a takeoff point for discussions of land use issues such as siting of homes, schools, hospitals, dams, etc. Earthquakes and faults are also directly related to some landslide and flooding hazards. The primary reference for this map (Case, 1986) includes more information on earthquakes in general and a map with detailed information on the sizes and dates of the Wyoming earthquakes. This reference will also help you find newspaper accounts of historical earthquakes in Wyoming.

This map

1. Answer some basic questions about earthquakes:
   •What counties in Wyoming have not had a recorded earthquake during the years they have been monitored? [Bighorn and Crook]
   •What counties have had more than 10 earthquakes since 1871? [Albany, Fremont, Park, Sweetwater, Sublette, Lincoln, Teton, (and Yellowstone National Park)] What do you notice about the geographic distribution of these earthquake-prone counties? [All except Albany are in the west half of the state.]
   •Look at earthquakes in your own or another county. How many? How large? How recent? Where?
   •Earthquakes have occurred within 5 miles of which towns shown on the map? [Jackson, Evanston, Rock Springs, Lander, Thermopolis, Rawlins, Laramie, Cheyenne, Casper, Buffalo, Sheridan] How many of these were since 1966? [only Jackson]

2. Faults in different parts of the state appear to be oriented in different directions. What general compass orientation are most of the faults on the western side of Wyoming? [very generally, north-south] Central Wyoming? [very generally, east-west] Eastern Wyoming? [very generally, northeast-southwest] South-central Wyoming? [very generally, northwest-southeast]

3. Using only information from this map, find a few localities where recent earthquakes appear to be related to known or suspected active faults. [Look for places where earthquakes are located on or very near fault lines.]

Comparison with other maps

1. Compare this map with the structure and geologic maps, which show the major faults recognized from geologic evidence. Some of the faults on those maps have been inactive for hundreds of millions of years. Which ones correlate with known or suspected recently active faults?

2. Overlay a tracing or clear xerox of this map on any of the maps that show labeled mountain ranges. Can you see evidence for the contention that the Teton Range may still be growing? [yes, a suspected active fault and recent earthquakes]

3. You recognized the different orientations of faults in the section above. Now, compare faults on this map with the geology map to see how the geology in the different areas corresponds to these fault orientations. [For example, in western Wyoming, where most of the faults are oriented generally north-south, the geologic units also are elongated north-south.]

The world around us

1. Read about the 1959 Hebgen Lake earthquake and landslide, the most recent major natural disaster related to earthquakes in the Wyoming area.

2. Some faults are known to have been active recently because we have seen or measured movements along them. Others displace deposits that are geologically young. The evidence for motion on *suspected* recently active faults is not quite as clear. Fault motion is, in any case, younger than the youngest displaced deposits. Actually seeing a fault in the Earth's surface is a very impressive experience. Geologic maps of your area show locations of faults and your county planning board should have information on active faults in your area if there are any identified.

3. Discuss issues of current importance, like the siting of dams in earthquake-prone areas of western Wyoming.

4. If earthquakes interest you and your class, there are many good sources of further information. You might want to explore the various causes of earthquakes (sudden ground motion on faults, volcanic eruptions and the movement of magma in the crust, natural and manmade explosions, etc.). The distribution of earthquakes worldwide is very interesting and can lead to a discussion of plate tectonics.

5. Read about some of the important active faults in the world (e.g., the San Andreas fault of California).

6. Find out about the relationships between earthquakes and landslides. There are several good new references available on landslides in Wyoming from the Geological Survey of Wyoming, with maps available at scales of 1:24,000, 1:250,000, and 1:1,000,000.

7. Your class can receive updated information on earthquakes by accessing the U.S. Geological Survey National Earthquake Information Center with a computer and modem. There is a (free) 800 number. Contact the National Earthquake Information Center, Box 25046, Mail Stop 967, Denver, Colorado, 80225 (phone 303-236-1500).

GEOTHERMAL MAP ACTIVITIES

The primary reference for this map (Breckenridge and others, 1978) contains much more information on the thermal springs of Wyoming, including the apparent structural and hydrological phenomena that created the springs, water chemistry, flow rate, temperature, access, and history. Go there first for further study.

This map

1. Use the map to answer some basic questions about hot springs:
   •Where is the thermal spring nearest to your town? How far is it?
   •What spring is nearest latitude 41° 30' and longitude 107°? [Saratoga Hot Springs]
   •Where would you go to see the most thermal springs in a 50-square-mile area? [Yellowstone National Park]
   •Are there any thermal springs in the Precambrian cores of the mountain ranges? [no. See the geothermal systems diagram, which shows cold water <u>entering</u> the system in the mountains.]

Comparison with other maps

1. Make a transparent overlay of the structure map and see how many thermal springs appear to be related to folds or faults on that map. Do not expect to see exact correlation of all thermal springs with major structures because many of the thermal springs are related to structures that are too small to show on the structure map. Also, the conditions that created some of the thermal springs are not well understood. However, some of the springs show good correlation with structures:
   •Compare with anticlines: Sheep Mountain Springs, Conant Creek, Fort Washakie, Alcova Hot Springs, Shoshoni Hot Spring.
   •Compare with faults: Hot Springs State Park (also fold), Horse Creek Spring, Abercrombie Warm Springs, Astoria Springs (also fold), Boyles Hill Springs, Jackson Lake Hot Springs.

2. Do you think any of these thermal springs might be related to active faults: (See earthquakes and suspected active faults map.)

3. Are there natural thermal springs shown in the middle of any of the basins? [no. Use the geothermal systems diagram and the structure map to help explain why. The water in the middle of the basins, having followed basin-dipping beds, is very deep, and there are not many anticlinal folds or big faults to provide upward conduits to the surface.]

4. Are there natural thermal springs shown in any of the Precambrian mountain cores? [no. Use the geothermal systems diagram again to show why.]

The world around us

1. Here is a mathematical application. Scientists use the term "geothermal gradient" to discuss how rapidly the temperature of the Earth heats up with depth. The rate varies a great deal, but an "average" geothermal gradient is about 14 °F per 1,000 feet of depth. An "average" surface temperature in Wyoming could be, for example 45 °F. Try some calculations:

   •What temperature would you expect at the bottom of a 5,000-foot well?

   The basic equation is:

   $$\text{Temperature at the bottom} = \text{surface temperature} + \frac{14\ ^\circ F \times \text{depth}}{1000}$$

   Therefore:

   $$\text{Temperature at the bottom of the well} = 45\ ^\circ F + \frac{14\ ^\circ F \times 5{,}000\ ft}{1000\ ft}$$

   $$= 45\ ^\circ F + 70^\circ F = 115^\circ F$$

   •About how deep is a well that is 250 °F at its bottom? [14,643 ft]

   •What is the thermal gradient of an area if a 10,000-foot well has a bottom temperature of 300 °F? [25.5 °F per 1,000 ft]

2. If you can, visit a warm or hot spring:

   •Take the temperature of the spring at (or as close as you can get to) the point (or points) where it issues from the ground. Measure the temperature at regular intervals (e.g.. every 10 feet) moving away from that point. How fast does it cool off? Is other water mixing with the spring water?

   •Collect some of the water. If you can, analyze the water for the presence of calcium carbonate, silica, sulfur, iron and other minerals in your school laboratory. If you can't do those analyses on the water, try to get enough of the water (a gallon or more) to take back and evaporate; then perform a few simple tests on the residue: Does it fizz in 10% hydrochloric acid? [If it does, it contains calcium carbonate (CO_2); if it doesn't, it may contain silica (SiO_2]. Does it have a reddish or orangish stain? [probably iron] Does it smell like sulfur?

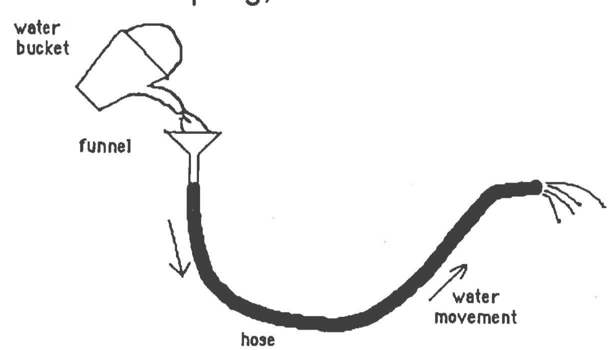
   •Look at the rock deposits around the spring if there are any. What are they made of? The most common deposits are calcium carbonate and silica. Calcium carbonate will fizz if you put dilute (10%) hydrochloric acid on it. Sulfur may also be present around some springs. The deposits may be stained by other minerals (e.g. red, black, or brown iron oxide stain) or coated with colorful algae or bacteria (green, yellow, orange, etc.).

3. Do an experiment on the heat insulating/conducting properties of different solid materials, using rock (different kinds if possible), metals, glass, sand, etc. Heat identical thicknesses on a hot plate and measure the top surface temperature rise with time. Construct a graph like the sample below. Which materials were the best and worst insulators/conductors? Now try the same experiment with water or other noncombustible liquids. Does heat travel as fast through rocks as through water? [no. Water does not have to remain stationary, but can flow to the surface with its heat (convection). For this reason, water moving through the Earth's outer crust moves heat to the surface much more efficiently than rocks can conduct it.]

What other interesting thing do you notice about the water curve? [The temperature does not continue to rise after it begins to boil.] Why? [Heat escapes in steam.] Discuss the use of pressure cookers and how that information might relate to geysers. [Pressure cookers work by raising the boiling point of liquids in them, thus they cook hotter. Water under pressure in the ground will be hotter than the normal boiling temperature of water. When pressure is release, it can flash quickly to steam, causing a violent eruption of hot water and steam--a geyser.]

4. Do a porosity/permeability experiment to find out what kinds of materials make the best aquifers and seals. Use sand; mixed gravel and sand; clay; mixed sand, gravel, and clay; angular pieces of crushed rock, etc. How much water will each material hold and how much will pass through it? Use a can with a removable bottom covered with cheesecloth. Fill it with the dry sand or whatever and then pour as much water as you can without letting it run over the top. Measure how much water goes into the can. Now remove the bottom of the can (retaining the cheesecloth so the material doesn't run out too) and measure how much water flows out. How long does it flow? Sediments through which water passes into and out of more quickly make good aquifers. Sediments that do not accept much water, or ones that hold what they take in are good seals (tight).

5. Do an experiment to show that water will flow uphill if it is contained in such a way that the weight of overlying water pushes it up. This can be done very simply with a clear plastic tube or hose. Relate this to the behavior of water in a confined aquifer in nature. The funnel and bucket of water are the recharge areas in the mountains, the hose is the confined aquifer, and the mouth of the hose is the spring, where the water returns to the ground surface.
If you want to simulate a hot spring, use copper tubing with a flame at the lowest point of the curve.



6. What other factors besides price might be important if you were trying to decide whether or not to buy a thermal springs or development as a tourist spot? [Temperature, flow rate and constancy, mineral content, cause of the spring -- for example if it sits on an active volcano, etc.]

7. While solar heat is the major driving force of the Earth's atmosphere and hydrosphere, heat produced by the Earth drives its internal processes. With an advanced class, discuss the major sources of the Earth's internal heat (radioactive decay and gravitational compression) and some of the plate-tectonic processes that are run by the internal heat of the Earth.

OIL AND GAS MAP ACTIVITIES

The new *Oil and gas map of Wyoming* (Geological Survey of Wyoming MS-35, 1991) shows updated locations of fields, pipelines, refineries, gas-processing plants, etc.

This map

1. Answer some basic questions about oil and gas in Wyoming:
   •Judging from simple dominance of red or green color, what basins appear to be primarily gas-bearing? [Wind River, Green River, Great Divide, Washakie] Oil bearing? [Powder River, Bighorn, Denver-Cheyenne]
   •Are there any oil or gas wells in the Precambrian cores of Wyoming's mountains? [no]
   •Locate the four fields that are referred to in the text. [These are Dallas Dome, Salt Creek, Beaver Creek, and Whitney Canyon-Carter Creek.]

Comparison with other maps

1. Which towns host the five oil refineries? (use a map with towns) [Newcastle, Casper area, Cheyenne, Rawlins area (actually Sinclair)]

2. Use the structure map to determine which oil fields appear to correlate with major structures, especially folds. You may need to create a transparent overly of the structure map to answer this. The structure map does not necessarily have <u>all</u> the known structures, so that not finding a correlation does not mean that the field is over a stratigraphic trap. [Among the fields that show an obvious correlation are those on the Rock Springs uplift and Moxa arch, Salt Creek Field, and many fields around the Bighorn Basin.]

3. Make a transparent overlay of the oil and gas map and compare it to the geology map. At the surface, what ages are most of the rocks in fields of the Powder River Basin? Would you expect the rocks that contain the oil to be older, younger, or the same age as those at the surface? [Hint: apply the Law of Superposition and the geologic cross section to answer this. The Law of Superposition is described with the geologic map activities.]

4. Compare the location of the oil shale with the geology map. What age is the oil shale-bearing rock? [Eocene, assuming it is at the surface]

5. Other than the fact that it is a national park, why do you suppose it is unlikely that commercial-sized oil and gas deposits will be found in Yellowstone? Use the geology and geothermal springs maps to help you with your answer. [Hints: (1) sedimentary rocks are the primary source and most common reservoir of oil and gas, and (2) excessive heat destroys petroleum deposits.]

6. If you hit oil in a 6,000-foot well in the Powder River Basin, about what temperature would you expect the oil to be? [Assume oil would be the same temperature as water and use the geothermal systems diagram with the Geothermal map or the equation in that section. Temperature would

be between 120° and 160°F using the diagram, or 129 °F using the equation.]

The world around us

1. It is important for students to understand the terms *porosity* and *permeability* (and the difference between them) in order to understand how fluids and gases travel through rocks. (Many of them probably think water and other fluids travel through giant underground rivers.) If you haven't already conducted experiments to demonstrate these two concepts this is another good place to do so [see geothermal activities].

2. There may be some students who are not aware that oil floats on water and they may not have considered that air and other gases float on liquids. Conduct this activity as a demonstration or experiment in class:
•Fill a jar about 1/3 full of colored water and 1/3 full of cooking oil. Cover the jar and shake it until the water, oil, and air are mixed up. Let it sit and watch the components separate based on density differences.
•Why does the oil float on water and the air on both? Weigh equal volumes of air, water, and oil. Use the jar again and this time weigh it empty (i.e., filled with air), filled with water, and filled with oil. Which one is heaviest (and therefore densest, since they were all the same volume)?
•Pour a mixture of water and oil into a jar filled with loose sand or gravel. The oil and water will separate if you let it stand a while, just like they do in a real oil reservoir.

3. Demonstrate the two different types of oil traps shown on the diagram using sand, modeling clay or whatever. Create the layered materials and then use a hypodermic needle to insert the fluids into the "reservoir" from the bottom. If the upper "trap" layer is impermeable, you can even show gas. An ant farm that isn't in use is very handy for observing these demonstrations. A large glass jar will also work.

4. The history of oil and gas development in Wyoming is very interesting and would make a good cross-disciplinary class research activity, combining geology, history, economics, and politics. [For example, the Teapot Dome/Salt Creek Field history, which included a national political scandal.]

5. Perhaps the best sources of information about specific oil or gas fields are the annual conference guidebooks published by the Wyoming Geological Association. Write to them at Box 545, Casper, Wyoming 82601, or check you local library. The Geological Survey of Wyoming and Wyoming Oil and Gas Commission are also good sources of information.

6. Processing, refining, and transportation are also important aspects of the oil and gas industry in Wyoming. A new publication, *The Wyoming oil and gas industry in the 1980s: a time of change* (Geological Survey of Wyoming Public Information Circular 28) describes new developments in the 1980s. The Wyoming Oil and Gas Commission and Wyoming Department of Commerce are additional sources of information.

COAL MAP ACTIVITIES

Since *Wyoming geomaps* was printed, the Geological Survey has produced a new wall-sized (1:500,000-scale) coal map of Wyoming that has much more information (see Map Series 34, Jones, 1991).

This map

1. Which counties have strippable coal deposits? Do any of Wyoming's 23 counties appear to be completely without potential for coal mining? [no]

2. According to the map, what rank is most of the coal in the Northern Great Plains Province? [subbituminous] Hams Fork coal region? [bituminous]

3. Judging from the plants shown in the inset, what do you think Wyoming's climate was like in the early Tertiary? [warmer, probably wetter]

4. Using just the information on this map, decide where you would put a coal-fired electric generating plant in the Bighorn Coal Basin and the Hanna Coal Field. [consider proximity to strippable deposits]

Comparison with other maps

1. Using the geology map:
   •Assuming that most of the strippable deposits of coal are at or near the ground surface, what ages are the coals in the Powder River Basin? [Paleocene-Eocene] The Hams Fork coal region? [Cretaceous]
   •Look at some of the areas where there is no coal indicated and try to explain, from the geology, why these areas are barren of coal. [In general, the rocks in the white zone on the coal map are either older than Wyoming's known coal deposits (see chart) or they are igneous rocks.]
   •Find out where Cretaceous coals might crop out at the surface. [In other words, where are Cretaceous sedimentary rocks found at the surface?] Where are lower Tertiary rocks exposed at the surface?
   •Look at the geologic cross section. Could you mine Cretaceous or lower Tertiary coal beds for a profit in the center of the Powder River Basin? [probably not, too deep]

2. Using a Wyoming highway map and perhaps other states' maps:
   •Locate railroads in relation to coal mines and coal-fired electric generating plants. What routes do you think the coal from different mines might take to power plants? to Texas? to your town?
   •Where do power lines go from the electric generating plants?

3. Does the information from 2. above help you locate the new electric plants from question 4 ("this map", above)? Does it completely change your mind about the locations you chose? Why does availability of transportation matter?
   •Check your new electric power plant siting against the earthquakes and active faults map, and move it again if it looks like there is a risk of damage from earthquakes and/or faulting.

4. In what county might you find both a coal miner and an oil field worker? [Hot Springs County, Grass Creek.]

5. Using the geologic time chart on p. 1, *Wyoming geomaps,* determine what was being deposited in Wyoming during the Permian and Pennsylvanian, when coal swamps covered the eastern United States. [windblown sand, gypsum, etc.—arid climate deposits; coal forests unlikely in that climate]

The world around us

1. Collect some coal. If you live in an area where there are coal mines you may be able to take your class on a tour of a mine where you would have a guide. Also, in many parts of Wyoming there are coal beds that are exposed in road cuts or natural outcrops where students could collect a sample. If you can't collect your coal directly, you can probably get some from a local residence or business that burns coal for heating. Students could investigate coal rank and report to the class. On the basis of their report and this map, try to decide the rank of your coal sample.

2. Discuss the carbon cycle in relation to fossil fuel deposits.

3. The amount of "ash" (inorganic residue left after burning) is an important economic factor in coal mining. You can get a rough idea of weight percent ash by weighing some coal, burning it as completely as possible, and weighing the residue:

$$\frac{\text{weight of ash}}{\text{weight of unburned coal}} \times 100 = \text{weight percent of ash}$$

4. Investigate the formation of coal and create a display that shows the stages of coal formation: woody material, to peat, to coal. Peat can often be purchased at greenhouses. If materials are available, you could show the progression of coal ranks (lignite, subbituminous, bituminous, anthracite) and link this display to the first activity.

5. Try a simple experiment to show some of the products of coal: coal gas, tar, and coke. Do this outside or indoors where ventilation is good.
•Put some pieces of Wyoming bituminous or subbituminous coal in a tin can or other container that can be heated.
•Place the coal in its container on a source of heat and watch what happens as the coal heats up: You will see and smell the release of coal gas. A dark liquid, coal tar, will eventually form at the bottom of the container. Smell and touch it and discuss some of the uses of tar. The other residue is a form of coke. Discuss uses of coke.

6. It may surprise your students to discover the varied uses of coal in addition to fuel for heating. The Wyoming coal industry would probably be happy to provide you with information for a good multi-disciplinary research project.

INDUSTRIAL MINERALS, CONSTRUCTION MATERIALS, AND URANIUM MAP ACTIVITIES

This map

1. Answer basic questions about the map:
   •What kinds of deposits (shown on this map) are nearest your home town?
   •Where would you probably live (in Wyoming) if you worked in a plant that produced phosphate for fertilizer? [southwest Wyoming; the nearest large town is Green River]
   •What is the Nation's number one trona-producing county? [Sweetwater}]
   •Find the geographic center of the state. What kind of deposit is found nearest that point? [uranium]
   •List the different kinds of deposits that occur between the 41st and 42nd parallels of latitude? [clay, trona, phosphate, perlite, construction aggregate, zeolites, gypsum, cement rock, crushed rock (ballast)]

2. According to this map, if you were building a new building in Newcastle (or pick a town of your choice) and wanted to use Wyoming products, how far would you have to go for cement? granite? marble? limestone? [measure straight-line distances on the map and perhaps also figure road miles or railroad miles, which would be important in actual transport of the materials]

Comparison with other maps

1. Plot some of the commodities on the geology map, e.g. trona [should be mostly on Eocene], uranium, [mostly Tertiary], bentonite [mostly Cretaceous], construction aggregate [Cenozoic sediments--quite a few are in Quaternary river sediments], limestone [look for Paleozoic associations]. Refer to the chart on the back page of *Wyoming geomaps*, "Wyoming's mineral and energy resources in geologic time." [Note that comparing deposits to surface geology is especially useful for commodities that are mined by surface pits, but will not necessarily be reliable for commodities that are mined from deep underground tunnels below the surface rocks.]

2. Some of Wyoming's counties are particularly rich in energy materials. Using just the maps in this series, see if you can decide which counties appear to have the most combined oil, natural gas, coal, and uranium resources (the maps don't describe how thick, extensive, high-grade, etc., the deposits are, so your estimate is limited to areal extent unless you bring in outside information). [Campbell, Converse, and Sweetwater should definitely be on your list.]

3. Why do you suppose the areas around rivers might be good sources of sand and gravel? [Rivers carry, sort, clean, and deposit gravel and sand as a normal part of their channel activity.]

The world around us

1. Visit a gravel pit, mine, quarry, etc. near you. Many of the commercial operations will give guided tours if you give them enough notice.

2. Make a collection of some products of the raw materials mined in Wyoming (especially trona, bentonite, gypsum). If you can, get samples of the raw material itself. Groups could be assigned to make the collections and research the processes that create the finished products.

3. How many of these finished products are manufactured in Wyoming? How does this affect the economy of Wyoming? [This will change. Contact the Wyoming Mining Association or the Wyoming Department of Commerce as a first start for information.]

4. There is information available on the formation of the different deposits on the map. Some of them would be interesting research projects for students. Among the best for this approach is trona, an enormous resource many people in Wyoming are not even aware of. Bentonite, uranium, and gypsum are also interesting.

5. Why do you suppose there are so many construction aggregate pits? (Hint: Long-distance transportation costs could be higher than the value of the materials.)

6. In addition to local mine or quarry operators, you may wish to contact the Geological Survey of Wyoming, the Wyoming Mining Association, or the Wyoming Geological Association for more information.

7. There is a new Geological Survey of Wyoming publication on *Decorative stones of Wyoming* (Public Information Circular 31, Harris, 1991). It has color photographs of many beautiful stones, with descriptions and locations.

METALS, PRECIOUS STONES, AND SEMIPRECIOUS STONES MAP ACTIVITIES

This map

1. Answer some basic questions about the map:
   •What commodity on the map covers the largest area? [agates and (or) petrified wood]
   •In what county might you find gold, jade, sapphires, rubies and agates? [Fremont]
   •In what rock units are most of the copper occurrences? [Precambrian igneous and metamorphic rocks and Cenozoic volcanic rocks]
   •If you live between Casper and Torrington, where would you look for jade? [see green dot in northwest Platte County]
   •Find the four occurrences of tungsten on the map. [One is tungsten and rare earth metals combined.]
   •In what quadrant of the map are all of the beryl occurrences? [southeast]
   •Mining of lead (with silver and zinc) has never been important in Wyoming, but the state does have two occurrences. Where are they? [Look in the northern Medicine Bow Mountains and the Black Hills uplift.]
   •What county has by far the greatest extent of gold occurrences? [Fremont]

Comparison with other maps

1. Use the geology map to find out in what age rocks the agate and petrified wood of the Green River Basin occur. [Occurrences are in Eocene and Quaternary sediments and sedimentary rocks. Source is probably the older Eocene rocks; Quaternary sediments acquired agates as they were washed into river gravels, etc, during erosion of the older rocks.]

2. If you worked for a company that wanted to mine copper and iron and be close to a large source of electric power, where might you look in Wyoming? [Use the coal map, look in the area around the Laramie River Power Plant.]

3. Campbell, Weston, Washakie, and Uinta counties show no mineralized areas or occurrences on this map (although there may be some undiscovered or small unmapped ones). Use the other economic maps to try to determine what mineral or energy resources occur in those counties.

The world around us

1. This is an excellent opportunity to encourage your students to bring in for display any examples of <u>Wyoming's</u> precious or semiprecious stones, crystals, mineral samples, etc., they may have collected. If they do bring in things for display, try to find out where they came from. If nobody knows where they were collected, try to guess where it might have been on the basis of the map. If you offer a secure place to display them, students, parents, or local rock and gem collectors would probably be willing to let your class look at some other examples.

2. If you are lucky enough to have some samples you can work with as well as look at, test them for their identifying characteristics of color, hardness, streak, crystal shape, etc. Books on rocks and minerals are usually available in libraries, but if you want one that deals specifically with Wyoming, I suggest *Minerals and rocks of Wyoming*, by W.D. Hausel (1986, Geological Survey of Wyoming Bulletin 66).

3. How minerals become concentrated in mineable deposits is a fascinating study. Even younger students should be able to understand the basic idea of placer deposits and mining, because the mechanism is familiar [heavy (dense) things sink]. Read about the formation of placer gold deposits in class and perhaps something about the history of placer gold mining in Wyoming. Then set up a "gold" panning operation for your class in a large galvanized tub or other big container that will hold water.
   •Since you probably won't have gold nuggets around, mix steel shot with sand and gravel to create your "pay dirt". The shot will act like gold because, like gold, it is denser than the other materials. You could even spray paint the shot with a thin coat of waterproof gold paint (but the paint will rub or flake off with extended use). Put your "pay dirt" in the bottom of the tub and fill it about half full of water so there is plenty of room to submerge your gold pan in water while you work. Gently swash the mixture of sand, gravel, and shot around in a gold pan, pie plate, or whatever until the shot has had plenty of time to settle to the bottom, then tip the pan and gradually allow the lighter material to fall back in to the tub. If you do this correctly, most of the shot will remain in the bottom of the pan, while most of the sand and gravel are removed. This is how prospectors hand-pan for gold nuggets.
   •Try it a few times before you show the class. There are lots of books with pictures and explanations of gold panning. Don't worry if you lose some of the shot because the main thing is for your students to observe the concentrating process. Panning has never been 100 percent efficient; in fact, old placer tailings are often remined for the gold that was missed the first time.

4. You and your class may wish to research other kinds of metal deposits. Most students will have heard of vein deposits. More advanced classes can research contact metamorphic deposits, deposits in which minerals have been concentrated by solution and weathering of rocks that contained less concentrated mineralization, or others.

5. The formation of agates and petrified wood is worth researching.

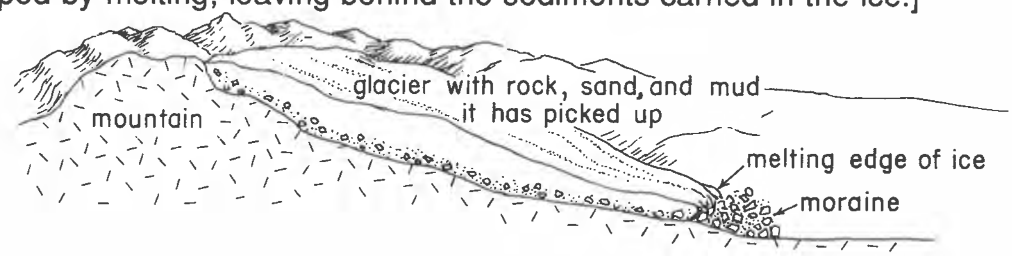
6. The Geological Survey of Wyoming, Wyoming Geological Association, and Wyoming Mining Association are all good sources of more information on mining and mineral deposits in the State. Ask the Wyoming Mining Association about *Mining, minerals, and me* if you don't already have a copy available in your school; designed for grade school use, it is a good source of information and ideas for activities.

ICE AGE (PLEISTOCENE) MAP ACTIVITIES

This map

1. Did Pleistocene glaciers reach the site of your town? If not, how close did they get?

2. Where are most of the glacial deposits in relation to the mountains and maximum extent of glaciation? (There are also some smaller glacial deposits in Wyoming that are not on the map because of the scale.) [Most of the glacial deposits shown here are at the margins of the mountains and in valleys separating mountain ranges, just inside what is shown as the maximum extent of the ice. That is where the glacier "conveyor belt" was stopped by melting, leaving behind the sediments carried in the ice.]



3. If the strip of yellow north of Rock Springs is dune sand, what was the dominant wind direction when the dunes formed? (You may only be able to answer it as which of two possible directions.) [generally east-west] What about dunes north of Casper? [same]

4 Where are the human occupation sites in relation to the maximum advance of the ice? Can you suggest some reasons why? [They are all outside the ice boundaries, probably because people avoided the glaciers and also perhaps because the passage of the ice destroyed the evidence or covered it with moraines.]

5. Are there any periglacial ice wedges in areas that were covered by ice? Why? [no. Wedges formed where ground was exposed.]

6. What is the meaning of the arc of glacial deposits that lies inside the maximum extent of glacial ice coming out of Yellowstone National Park on the south? [Hint: Could the glacier have retreated to that spot and held there for a while, leaving a ring of moraines before retreating further?]

Comparison with other maps

1. Compare with the topographic contour map. Is there a relationship between the extent of glaciation and topography? [Yes, higher areas were glaciated.]

2. Compare the location of caves with the geological map. What age rocks have most of the caves? [Paleozoic sedimentary rocks contain most of the thick limestones and dolomites in which a majority of the caves formed.]

3. Do you think any of Wyoming's first human residents took a soak in a hot springs? Which thermal springs on the geothermal map are near Pleistocene human occupation sites? [the Cody and Douglas areas are possibilities]

4. Compare the extent of glacial ice with the precipitation contours on the surface water and precipitation map. Can you see any similarities? [rough correspondence with areas where maximum precipitation is now greater than 30 inches] Do you think that the amount of snowfall could have had anything to do with where glaciers formed? [yes. To form glaciers, average annual snowfall must be greater than melt.] Does it look like the general pattern of most and least precipitation is similar now to what it was in the Pleistocene? [Yes, on the basis of correspondence of glacier distribution and modern maximum precipitation.]

The world around us

Glaciers pick up rocks, dirt, and anything else moveable in their paths. They are not just clean masses of ice. Because glaciers contain so much rock and dirt, they leave behind great heaps of unsorted sediments where they melt. These deposits are called moraines. Since most other processes of deposition sort sediments by size, the mixed material in glacial moraines is fairly unique and makes them easier to identify than some deposits. There are also usually some rivers or streams that develop at the melting edges of glaciers and they move and deposit sediments in much the same way as any other stream or river, sorting, layering, and creating ripples that are observed in the deposits as cross bedding.

1. If you live anywhere within reasonable distance of a glacial moraine, try to take a field trip to see it, or at least get some photographs to show the class. Some of the important details to notice include:
•The material you will see is a mixture of loose rocks, sand, silt, and clay, but in Wyoming, Ice Age glacial deposits have not themselves been cemented together to form a solid rock. It is too recently deposited and too shallowly buried to have been turned into rock. What would you call this material if it was rock? [conglomerate]
•The sediments that compose the deposits are unsorted in terms of grain size. Expect to see boulders floating in finer grained sediment without any apparent order. Do not expect to see much good layering. If you do, suspect that in that place running water melting from the glacier was the dominant resorter of the sediments.
•Look at the general shape of the moraine. You can probably find a book in your school or town library that describes the different kinds of moraine shapes and what they mean. If the moraine is quite young it may have an extremely lumpy surface, with lots of boulders sticking up and small depressions with ponded water. In these places, it is easy to imagine a glacier melting and leaving these heaps of debris behind. At the edge of the moraine there may be a very abrupt slope up onto the glacial deposit.
•During the Pleistocene, there were several glacial periods separated by warmer interglacial periods. Deposits of different ages often look different

enough to be identifiable. A discussion of characteristics of these different deposits at Bull Lake, Wyoming is in Mears (1986, *A geologic tour of Wyoming from Laramie to Lander, Jackson and Rock Springs,* Geological Survey of Wyoming Public Information Circular 27.)

•In addition to leaving characteristic deposits of sediment, glaciers carve characteristic landforms in the rocks they move past. If there is solid bedrock exposed, the glacier may have reshaped it and also left behind polished and grooved surfaces. Look for the evidence. Blackstone's *Travelers' guide to the geology of Wyoming* (1988) offers descriptions, diagrams, and photographs of glacial landforms in Wyoming.

2. Periglacial wedges are exciting to find. If you are interested, get a copy of Mears (1987), which has localities of the places where he found wedges. You might even check the nearest landfill dump and look at the cut in the earth to see if there are any wedges.

3. The great Pleistocene mammals always hold a fascination for us. You could probably get a class to research these animals, perhaps with groups taking their favorites. There has been quite a bit of scientific discussion about the demise of these animals that could even turn into a debate (influence of human hunting pressure vs. climatic change, etc.).

4. How do solid ice glaciers form from snowfall? A simple experiment can demonstrate that loose snow will recrystallize to ice under pressure. If it is winter, you can do this experiment with real snow; if snow is not available, use shaved ice. Fill a coffee can, bucket, or other relatively deep, straight-sided container with snow. Fit the cut-out lid of the coffee can or anything else that leaves just enough space at the edges to slide down the container freely. Now weight the top of the lid so that it presses fairly evenly on the snow, and as it compacts the snow add more weight. Keep the container in a freezer or outside if it is freezing - do not allow the snow to get warm and melt. Check it at regular intervals to see how it turns to ice. The kind of snow you start with and amount of weight you use will influence how long the process takes.

   When snow falls on a glacier it is soon covered by the next snowfall, and so on until it is under enough pressure from the overlying snow to begin to recrystallize to solid ice. Why does it recrystallize? (Hint: Which takes up more room for the same amount of water, snow or ice? Check this by melting equal volumes of snow and ice and seeing which is actually more water.) The recrystallization of snow to ice is similar to metamorphic recrystallization of rocks under pressure.

5. A useful poster illustrating glacial features in Glacier National Park is available from the Montana Bureau of Mines and Geology in Butte, Montana (Geologic Map 27, James, 1982).

SURFACE WATER AND PRECIPITATION MAP ACTIVITIES

This map

1. Follow a drop of water that falls on Casper out of the state. Do the same with other spots that interest you. Try the opposite direction, following a river from where it leaves the state back to a source area in the mountains.

2. Where do you think most of the water that flows into the Great Divide Basin comes from? [Contours indicate that there is more rainfall on the southeast and northeast sides of the basin than elsewhere.]

3. What river changes its name when it goes through a canyon? [Wind River/Bighorn River]

4. Make a xerox copy of this map and color the rainfall contour intervals. If you can, use tracing paper or other transparent or translucent material so it can be overlain on other maps. Devise your own grouping of precipitation intervals and colors or try:

   <u>Older group</u>
   60-41 inches=dark blue
   40-21 inches=light blue
   20-17 inches=dark green
   16-13 inches=light green
   12-9 inches=brown
   8-7 inches=orange
   6-0 inches=yellow

   <u>Younger group</u>
   60-21 inches=blue
   20-13 inches=green
   12-9 inches=brown
   8-0 inches yellow

5. Do the Laramie Mountains separate drainage basins as shown here? [no. Rivers flow through and around the Laramie Mountains and water that falls on both sides of the mountains ends up in the North Platte River.] Is there anything strange about the path of the Laramie River? [It cuts right through the Laramie Range. See Mears and others (1986, p. 6) for a possible explanation.] Do the Bighorn Mountains separate drainage basins? [Yes, a second-order divide between the Bighorn and Powder Rivers, both of which flow into the Yellowstone River out of the state.]

Comparison with other maps

1. Use a map of the United States that shows rivers to see where Wyoming rivers go after they leave the state.

2. Use the U.S. map again. The North Platte and Bighorn rivers leave the State in nearly opposite directions. What happens to the water in these rivers? [It all ends up in the Mississippi River.]

3. Compare the colored precipitation contour map you made (above) with the topographic, vegetation, and soils maps.

4. If you have a good drainage map of another state, try to divide it off according to drainage basins. Look for the high areas and then see where

headwaters start. Follow the drainages downstream to see which ones eventually merge and keep all the ones that merge in the same drainage area. You will need to look at maps of adjacent areas to see which drainages merge after they leave the state.
•Do a similar exercise with a detailed map of own area.

The world around us

1. Your class could keep a precipitation gauge and gather their own statistics about the monthly precipitation. There are monthly averages for different areas in Martner (1986) with which you could compare measurements.

2. On an official Wyoming Highway map, trace the route of the Oregon Trail through Wyoming. What need appears to have influenced their route? [Water. The trail follows rivers and streams as much as possible. People and animals had to have water to drink and there was probably more plentiful grass near the rivers. Also, the route along streams is generally an easier grade than elsewhere.]

3. This is a good place to review the water cycle, which is described in science textbooks at many levels.

4. The pattern of many of the drainages is called dendritic, because it looks like a branching tree. See, for example, the many drainages coming out of the east side of the Wind River Range that come together to form the "trunk" Wind River. Show how water naturally forms this pattern. Use a large tilted plate of glass or other smooth surface and sprinkle water at the top of the slope over a fairly broad area or in several spots. Put on enough water to start little drainages flowing, In a while they will start to merge to form "trunks" like the big rivers shown on the map.

5. In Wyoming, water is almost always in the news. Have your students read newspapers or watch TV to discover some current water controversy (there are usually two or more opinions about everything involving this precious resource.)

6. Water quality is always an important consideration in Wyoming. Schools can have a sample of water analyzed for free (for things like total dissolved solids, etc). Contact: Wyoming Department of Agriculture, Analytical Services, 1174 Snowy Range Road, Laramie, Wyoming, 82070. Call first to discuss your objectives and sampling procedures with Kenneth McMillan, Director and State Chemist.

7. As an advanced class project, try to decide where you would put a new reservoir for Wyoming. Discuss water use; supply; suitable topography; potential loss of agricultural land, human and animal habitat, etc.

8. *The Wyoming water atlas* (L.M. Ostresh and others, 1990: Wyoming Water Development Commission and University of Wyoming) is an important new resource for anyone interested in water in the state.

SOILS MAP ACTIVITIES

This map

1. Answer a few basic questions about Wyoming soils:
   •On what soil association does your town lie?
   •Estimate the percentage of land in Wyoming that belongs to each of the three major associations. [This will be easier if you make a color tracing of the three associations, lumping the smaller units.]
   •If you were standing on land 20 miles directly east of Rock Springs what might be its major use? [livestock grazing or wildlife habitat] Thirty miles west of Lander? [recreation,wildlife habitat, grazing] In the area around Wheatland? [grazing or irrigated cropland] (Create any number of questions along this order.)

2. If you wanted to run a few cattle, have a small lumbering operation, and you liked soils formed over residual materials but didn't want to be adjacent to the eastern plains, where might you want to buy land? [Hint: see distribution of units 1 and 3.]

Comparison with other maps

1. Place a tracing or transparent xerox copy of the surface water and precipitation map over this map. Where do modern streams appear to have had the most influence on soil association type? [eastern plains]

2. Another Geological Survey of Wyoming publication, *Land status map of Wyoming*, 1987 (Map Series 25), shows irrigated agricultural land and other land uses. If you have that map or a similar one, locate the irrigated cropland on this map and compare it with some of the other mapped information. For example: Where is the irrigated land in comparison to reservoirs? What kinds of soil associations are being utilized? How much precipitation falls there annually? Compare soil associations to other kinds of land uses.

3. The vegetation and soils maps are very closely interrelated. Soil partially determines what nutrients are available for plants to grow in, how stable the ground will be for plant growth, how well it receives and transports water, and other things. On the other hand, vegetation largely determines how much humus (organic matter) is in the soil, which affects soil color and fertility; organic compounds are very important in rock-weathering processes; and plants help hold soil in place and prevent erosion. Nevertheless, the two maps are not exact mirrors of each other. Compare them and bring in any evidence from other maps to help explain the similarities and differences. [for example, geology, elevation, and precipitation.]

The world around us

1. If you can collect a pot full of several different soil types, try an experiment to see how well they sustain plant growth. Pick a plant that is important in your area, either a cultivated crop or a simple wild plant that you can grow

fairly quickly from seed. Make it a controlled experiment by planting several seeds from the same plant or packet in each pot, planting the same number of seeds in each pot, giving the pots exactly the same amount of water, sunlight, etc. Use distilled water if you want to. Do not use fertilizer. Keep records for each plant with the date the seed was planted, when it sprouted, how fast it grew, if and when it produced fruit, seed, etc., and in how much volume. Different plants prefer different soils, so it would be interesting to expand this experiment to include more than one kind of plant. You may be able to guess about the causes of the differences in growth.
•Schools can get 1 soil sample analyzed for free at: Soil Testing Laboratory; Plant, Soil, and Insect Sciences; College of Agriculture, University of Wyoming, Laramie, Wyoming, 82071. Call first and request an information sheet that explains how to take your sample. (Ask for a standard fertility test.)

2. Bring in some outside reading about formation and classification of soils. This could be a very productive and interesting class project. The University of Wyoming and County Agricultural Extension Agents should be excellent sources of information and assistance. Do a soil survey of an area and identify and classify your soils. This would be even more interesting if it could be combined with a vegetation survey.

3. Alkaline soil is a problem in parts of Wyoming. In some areas, white crusts of mineral salts form at the ground surface and the soil is barren or supports very few plants. If your area has alkaline soil, students may be interested enough to want to investigate its composition and causes.

VEGETATION MAP ACTIVITIES

This map

1. Answer some basic questions about the map:
   •According to this map, what is the natural vegetation of your general area?
   •What appears to be the dominant vegetation in eastern Wyoming? [mixed-grass prairie] Central Wyoming? [sagebrush steppe] Northwestern Wyoming? [several types of forests, with lodgepole pine most common]
   •Which counties in Wyoming appear to be at least half forested? [Teton, Crook, possibly Park and Lincoln]

Comparison with other maps

1. From information on the vegetation map, guess where the driest parts of Wyoming are located. [Most students will probably guess, correctly that the desert shrublands are the driest vegetation indicators.] Check your guess with the precipitation map.

2. The vegetation map can be compared to the topographic map to see how the locations of mountain ranges and basins correlate with vegetation patterns. [As you would expect, alpine tundra generally matches the highest mountains, forests occur in mountainous areas generally, and grasses and sagebrush dominate the basins.]

3. Vegetation could also be compared with soils, geology, precipitation and surface water, and population. Which factors appear to coincide best with vegetation type? Why?

The world around us

Vegetation in Wyoming is, of course, much more complex than this simplified map shows. For example, major vegetation changes can occur in a matter of a few feet near small streams, over rapid changes in soil type, and with very small differences in elevation or sun exposure. Investigate the vegetation of your area:

1. •<u>In rural areas</u>, a good class project would be to go out to one or several nearby areas and collect the natural vegetation. Use a detailed map of the area (1:24,000), if possible, to plot your data. Get teams of students to mark off 10-foot-square areas (or whatever seems appropriate), collect samples of the plants in those squares, and make notes describing their occurrences. For example, are they in clumps, a few isolated individuals, or scattered throughout? Do they grow in low spots, high spots, sunny areas, shady zones, etc. Note which plants seem to dominate each square. Make some notes describing the general appearance of the area, i.e., is it relatively open, densely forested, barren, sunny, wet, near a stream, or far from surface water, or whatever? Have there been any observable disturbances like recent fires, floods, construction activities?
   In the field, or back in the classroom, identify the vegetation you collected and try to classify the areas you collected. Use the dominant

vegetation in the 10-foot-square grids to determine the statistically dominant vegetation types.

Decide on a general classification for your area if you can. Is it the same as the map indicates? If it isn't, try to determine (1) Why the area you studied is different [for example, maybe it is in a particularly sheltered area or along a stream] and (2) where you could go to find the type of vegetation the map indicates for the general area.

•In a more urban setting, you may be able to take a field trip to a place where you can sample natural vegetation. If this isn't possible, visit a park, or collect from a few city blocks. You could probably get permission to visit people's yards and homeowners might be happy to tell your students the types of vegetation they are growing. Although this won't be applicable to the natural vegetation map, it will be enlightening to see what kinds of domestic plants grow well in your area. The students should ask questions and take notes about how healthy the plants are, whether they are annuals or perennials (survive winters), and if they take any special care to grow where they are.

2. If at all possible, combine this vegetation survey with a survey of soil types (see soils activities). It would also be interesting to find out about the annual precipitation of the area (see surface water and precipitation map) and the bedrock (see geology map).

POPULATION MAP ACTIVITIES

This map and the 1990 census data

The 1990 census was completed after *Wyoming Geomaps* was printed. The new data for population by county is provided on the next page and more information is available from the U.S. Census Bureau. The information presented here came from The Survey Research Center, Box 3925 University Station, Laramie, Wyoming 82071.

1. Use the 1990 census data to create a new population map in the same format as the old one.

2. Compare the 1980 and 1990 census data:
   •Have the lowest and highest population counties changed?
   •Which counties have gained and which have lost population?
   •Do you see regional patterns of change?

Comparison with other maps

1. The 1990 census confirmed that Wyoming has the lowest population of the 50 states in the U.S. What factors related to the maps in this book might help explain Wyoming's low population? [you could discuss high altitude (with attendant cold climate and short growing season), dry climate, sparse vegetation in some areas, etc.]

The world around us

1. Consider the positive and negative aspects of low population for the people of Wyoming. [Let the students make up their own list.]

2. Discuss your own county population and the factors that influenced the change observed.

1990 Census: Preliminary 1990 Results For Wyoming Counties

Below is a list of 1990 census population counts for Wyoming Counties including the 1980 count for comparative purposes.

County	1980	1990 Preliminary	Change 1980-90	% Change
Albany County	29,062	30,496	1,434	4.9%
Big Horn County	11,896	10,462	(1,434)	-12.1%
Campbell County	24,367	29,190	4,823	19.8%
Carbon County	21,896	16,629	(5,267)	-24.1%
Converse County	14,069	11,100	(2,969)	-21.2%
Crook County	5,308	5,277	(31)	-0.6%
Fremont County	38,992	33,342	(5,650)	-14.5%
Goshen County	12,040	12,319	279	2.3%
Hot Springs County	5,710	4,794	(916)	-16.0%
Johnson County	6,700	6,129	(571)	-8.5%
Laramie County	68,649	72,319	3,670	5.3%
Lincoln County	12,177	12,514	337	2.8%
Natrona County	71,856	60,962	(10,894)	-15.2%
Niobrara County	2,924	2,488	(436)	-14.9%
Park County	21,639	22,727	1,088	5.0%
Platte County	11,975	8,137	(3,838)	-32.1%
Sheridan County	25,048	23,527	(1,521)	-6.1%
Sublette County	4,548	4,836	288	6.3%
Sweetwater County	41,723	38,567	(3,156)	-7.6%
Teton County	9,355	10,631	1,276	13.6%
Uinta County	13,021	18,624	5,603	43.0%
Washakie County	9,496	8,321	(1,175)	-12.4%
Weston County	7,106	6,514	(592)	-8.3%
Wyoming	469,557	449,905	(19,652)	-4.2%

SELECTED PUBLICATIONS ABOUT WYOMING GEOLOGY AVAILABLE FROM THE GEOLOGICAL SURVEY OF WYOMING

Most of these publications were used in the production of *Wyoming Geomaps*. Some are more recently published items that are appropriate for classroom use. You do not have to be a professional geologist to use these publications. Many of them were produced specifically for the general public and all have material that is accessible to any educated reader.

General Geology

Geologic map of Wyoming - J.D. Love and Ann Coe Christiansen, 1985: U.S. Geological Survey, scale 1:500,000 (1 inch = approximately 8 miles).

This full-color map is the starting point for any study of Wyoming geology. Recent revisions make it the most up-to-date state geologic map in the region. Excellent wall-poster item for classrooms. The map comes with two extra sheets: a key to map colors and symbols, and references.

Wyoming geologic highway map - compiled by R.D. Christiansen, revised 1991: Western GeoGraphics, scale 1:1,000,000 (1 inch = approximately 16 miles).

The perfect companion for road trips in Wyoming. It is a scaled-down version of Love and Christiansen's (1985) geologic map of Wyoming, folded to fit in the glove compartment of your car or in a shirt or jacket pocket. The reverse side is a satellite photo map of Wyoming with references and notes on rock collecting and prospecting, energy and mineral resources, geologic history, and Grand Teton and Yellowstone Parks. Color.

Precambrian basement map of Wyoming - outcrop and structural configuration - Blackstone, D.L., Jr., 1987: Geological Survey of Wyoming Map Series 27, scale 1:100,000.

A more detailed version of the map in *Geomaps*; shows well data points. Wyoming's Precambrian basement rocks occur at aver 13,000 feet above sea level in the mountains to over 35,000 feet below sea level in the basins. This map contours that varied surface and shows faults that cut basement rocks.

Landsat image mosaic of Wyoming - 1982: Geological Survey of Wyoming Map Series 11, scale 1:500,000 (1 inch = approximately 8 miles).

Satellite view of Wyoming. Includes a structural index map. It is a great item to place on a wall next to the state geology map, and since they are the same scale they are very easy to compare.

Minerals and rocks of Wyoming - W.D. Hausel, 1986: Geological Survey of Wyoming Bulletin 66.

This is a recently thoroughly revised and updated version of one of the Survey's most popular books. Major divisions include introductions to the geologic history of Wyoming and methods of mineral and rock identification and longer sections on minerals and rocks of Wyoming. The book describes about 100 minerals and rocks and notes localities where they are found. Color photographs, references, glossary, and index.

Index maps to geologic maps of Wyoming: Geological Survey of Wyoming Map Series 9.

Not geologic maps themselves, these 18 maps provide locations and complete bibliographic listings of geologic maps of Wyoming that have been produced by the Geological Survey of Wyoming, the U.S. Geological Survey, various universities, etc. Wide variety of scales.

Guidebooks

Traveler's guide to the geology of Wyoming - D.L. Blackstone, Jr., 1988: Geological Survey of Wyoming Bulletin 67.

This popular book has recently been completely revised. A brief description of major physiographic features of Wyoming precedes a mini introductory geology textbook. This extensive introduction provides the nongeologist with a background for understanding the last part of the book, 32 geologic sketches of areas in Wyoming that are easily accessible to travelers on State highways.

[Geologic] Road log, Jackson to Dinwoody and return - J.D. Love and J.M. Love, 1983: Geological Survey of Wyoming Public Information Circular 20.

The Loves bring their many years of work in western Wyoming to this informative road log through one of the most spectacular regions in the country. Photographs, fold-out correlation diagram of Eocene strata in the area.

Self-guided tour of the geology of a portion of southeastern Wyoming - W.D. Hausel and R.W. Jones, 1984: Geological Survey of Wyoming Public Information Circular 21.

A geologic map in the back pocket of this book locates the route and provides a continuous geologic reference for the trip. Points of interest described and illustrated in the text. Cretaceous rocks are a highlight of this tour.

Tour guide to the geology and mining history of the South Pass gold mining district, Fremont County, Wyoming - W.D. Hausel, 1984: Geological Survey of Wyoming Public Information Circular 23.

Colored geologic map with illustrated tour-guide text; printed on one large sheet folded to handy pocket size. Visits this historic gold mining district detailing 17 points of interest that include mines, mills, placers, and towns.

A Wyoming geologic tour from Laramie to Lander, Jackson, and Rock Springs - Mears and others, 1986: Geological Survey of Wyoming Public Information Circular 27.

A synopsis of Wyoming's geologic history is followed by a geologic description of the route. Fifty illustrations include photographs, simple geologic diagrams, a stratigraphic chart, and maps. This book developed from a field trip Dr. Mears has lead for many years for geology students at the University of Wyoming. Descriptions and illustrations represent decades of study and a delightful attempt to communicate geology to the public. Highlights Wyoming landscape.

A field guide to the Casper Mountain area - Wyoming Field Science Foundation, 1978: Geological Survey of Wyoming Reprint 45.

The complete naturalist's self-guiding road log of the Casper Mountain - Muddy Mountain area. Notes on the fauna, flora, and history as well as the geology take you from turkey vultures to asbestos mining. Well illustrated and easy to follow.

Illustrated geologic history of the Medicine Bow Mountains and adjacent areas, Wyoming - S.H. Knight, 1990: Geological Survey of Wyoming Memoir 4.

Reviews events in the geologic history of the Medicine Bow Mountains and adjacent areas. Forty elaborate block diagrams show the changing landscapes of southeastern Wyoming through geologic time. Accompanying sketches of former animals and plants and present-day animals.

Economic Geology

Oil and gas map of Wyoming - R.H. De Bruin and C.S. Boyd, 1991: Geological Survey of Wyoming Map Series 35, scale 1:500,000 .

Full-color map shows locations and names of oil and gas fields, types of production, pipelines, refineries, and gas processing plants. Also designates ages and names of producing rock formations and shows some pertinent geologic information.

Coal map of Wyoming - R.W. Jones, 1991: Geological Survey of Wyoming Map Series 34, scale 1:500,000 .

Full-color map shows the latest information on the extent of coal-bearing rocks, outcrops of coal beds, and revised boundaries of many of the coal fields in the State. Coal mines, railroad routes and unit train loadouts, coal-consuming facilities, planned coal development projects, and electrical generation plants and transmission lines are included.

Wyoming's oil and gas industry in the 1980s: a time of change - R.H. De Bruin, 1989: Geological Survey of Wyoming Public Information Circular 28.

Petroleum is still a giant in the State's economy even after the ups and downs of the 1980s. This publication describes oil and gas exploration and production in Wyoming during the decade, from the boom times of the early 1980s to the slowed development of the mid and late 1980s.

Metallic and industrial minerals map of Wyoming - compiled by R.E. Harris and others, 1985: Geological Survey of Wyoming Map Series 14, scale 1:500,000.

Colors and symbols indicate mineral occurrences, prospects, mines, and mills or processing plants. Types of mineral deposits, host rocks, and exploration or mining activities also designated. Mining districts outlined. Production figures.

Mineral resources of Wyoming - F.W. Osterwald and others, 1966: Geological Survey of Wyoming Bulletin 50.

Discussions of 80 mineral resources of Wyoming alphabetically arranged from alum minerals to zircon. Text includes a description of each mineral resource, its uses, production, prospects, and occurrences. An older book that still contains lots of useful information.

The geology of Wyoming's precious metal lode and placer deposits - W.D. Hausel, 1989: Geological Survey of Wyoming Bulletin 68..

The most complete description available for Wyoming's precious metal deposits. Photographs, geologic maps, assays; production data, and other information for nearly 400 mines and prospects in about 50 districts.

Ore deposits of Wyoming - W.D. Hausel, 1982: Geological Survey of Wyoming Preliminary Report 19.

Wyoming ore deposits of similar age are grouped together under discussions that place them in the context of (1) the geologic settings characterizing rock of that age and (2) the major geologic events in that time period. Each deposit is then described separately.

Geothermal resources of Wyoming - compiled by H.P. Heasler and others, 1983: United States Department of Energy, scale 1:500,000 (1 inch = approximately 8 miles).

Map indicates areas where geothermal ground waters occur, locations of thermal springs and wells, and measured thermal data. Short annotations of geothermal resource areas.

Construction materials map of Wyoming - compiled by R.E. Harris and J.E. Meyer, 1986: Geological Survey of Wyoming Map Series 21, scale 1:500,000.

Wyoming construction materials occurrences, quarries, and mills depicted with colors and symbols. Map shows sand, gravel, granite, limestone and dolomite, basalt, gypsum, clinker, and other dimension, decorative and ornamental stones.

Decorative stones of Wyoming - R.E. Harris, 1991: Geological Survey of Wyoming Public Information Circular 31.

Beautiful full-color photographs of some of the most colorful stones anywhere, locations, descriptions.

Special Interests

Caves of Wyoming - C. Hill and others, 1976: Geological Survey of Wyoming Bulletin 59.

Part I focuses on cave formation and general features, and the history and origin of Wyoming caves. Part II contains descriptions of 245 caves, listed by area. Cave maps and land ownership information included. Appendices on caving techniques and safety, mapping, photography, and more.

Thermal springs of Wyoming - R.M. Breckenridge and B.S. Hinckley, 1978: Geological Survey of Wyoming Bulletin 60.

Everything you wanted to known about Wyoming's thermal areas. Short description of the origin of thermal springs and an inventory of springs by county. Separate chapters on Yellowstone National Park and the vegetation of thermal springs.

Fossils of Wyoming - M.W. Hagner, 1970: Geological Survey of Wyoming Bulletin 54 .

A useful short introduction to Wyoming fossils. Brief descriptions of the dominant life forms through time, followed by chapters on invertebrate and vertebrate animal fossils and plants. Many illustrations.

Earthquakes in Wyoming - Jim Case, 1986: Geological Survey of Wyoming Public Information Circular 26.

An introduction to the causes of earthquakes and the methods of measuring them is followed by sections that describe earthquake potential in Wyoming, historic Wyoming earthquakes, and some of the geologic hazards related to earthquakes.

Land inventory map of Wyoming - 1987: Wyoming Department of Agriculture and Geological Survey of Wyoming.

Shows cropland, rangeland, forests, sand dunes, barren land, urban and built-upland, and lakes and reservoirs.

Late Pleistocene periglacial wedge sites in Wyoming - B.M. Mears, Jr., 1987: Geological Survey of Wyoming Memoir 3.

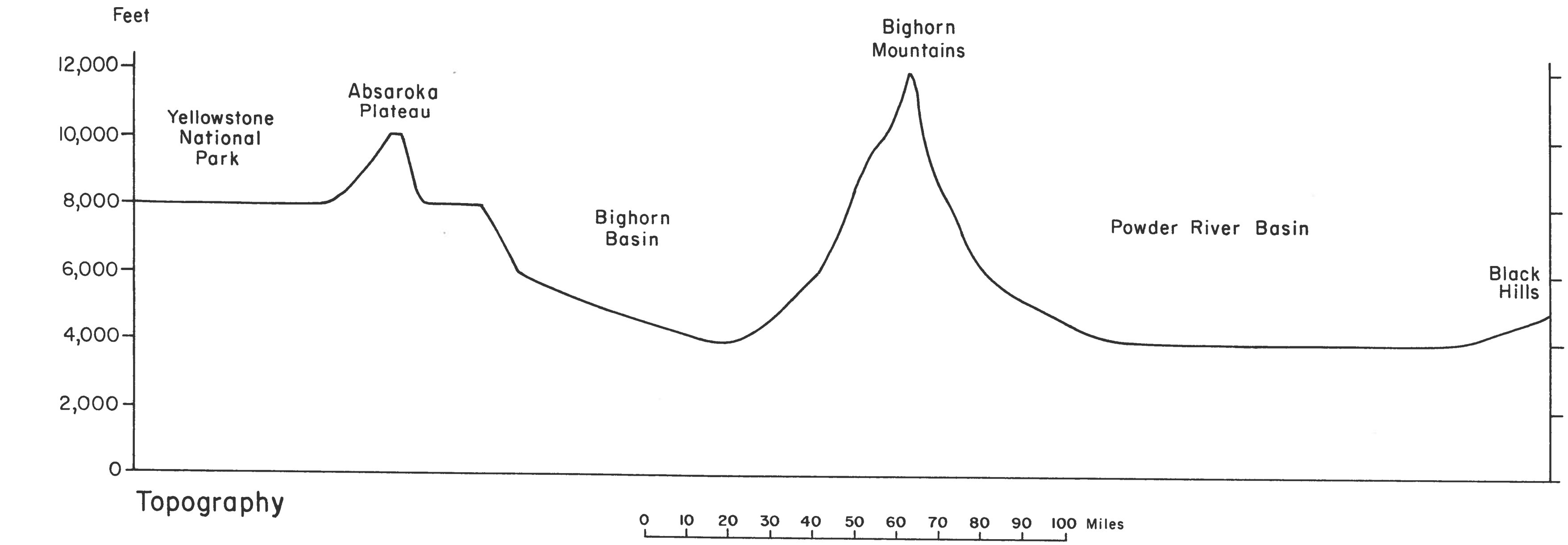
During the Late Pleistocene (Ice Age) the surfaces of Wyoming's arid, cold, windswept basins were cut by wedges of ice like those seen today in Alaska. Dr. Mears documents the evidence of these wedges in this fascinating report--many photographs and locations.

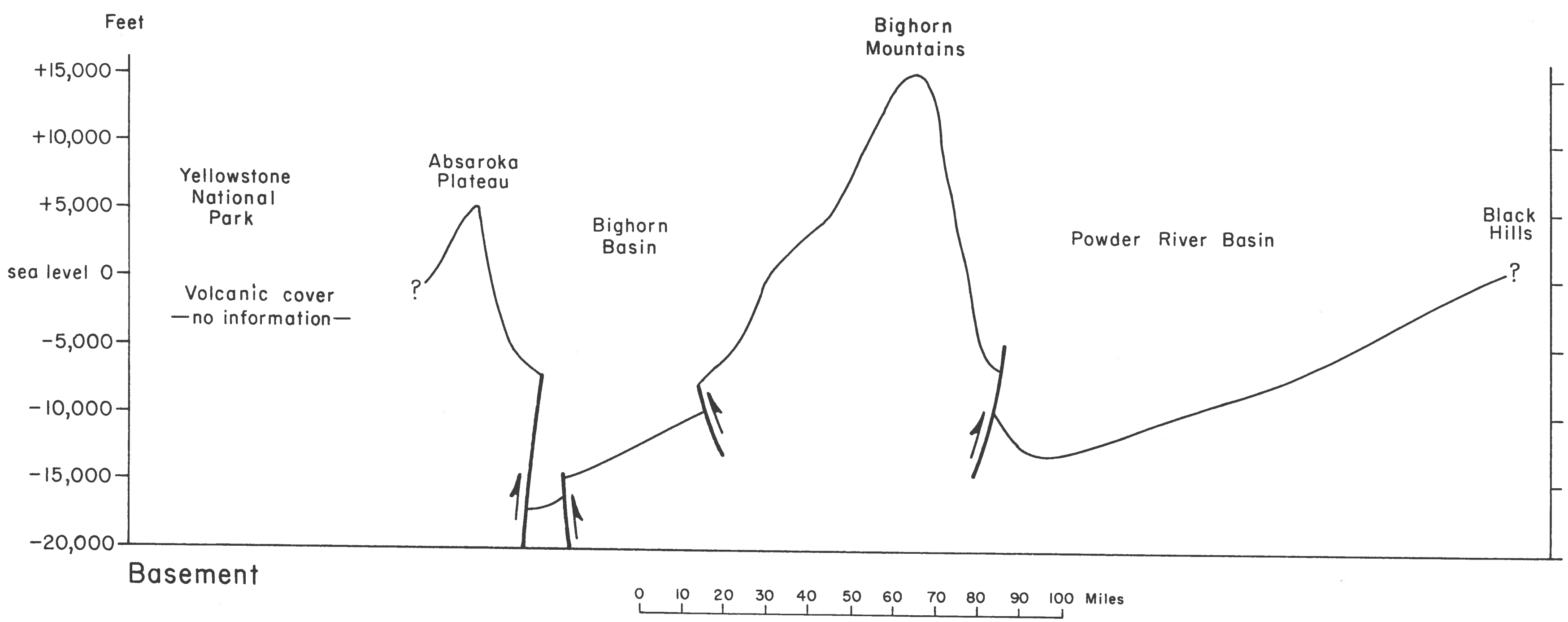
SCHOOLS PLEASE NOTE: The Geological Survey of Wyoming gives a 30 to 40% discount on large **prepaid** orders

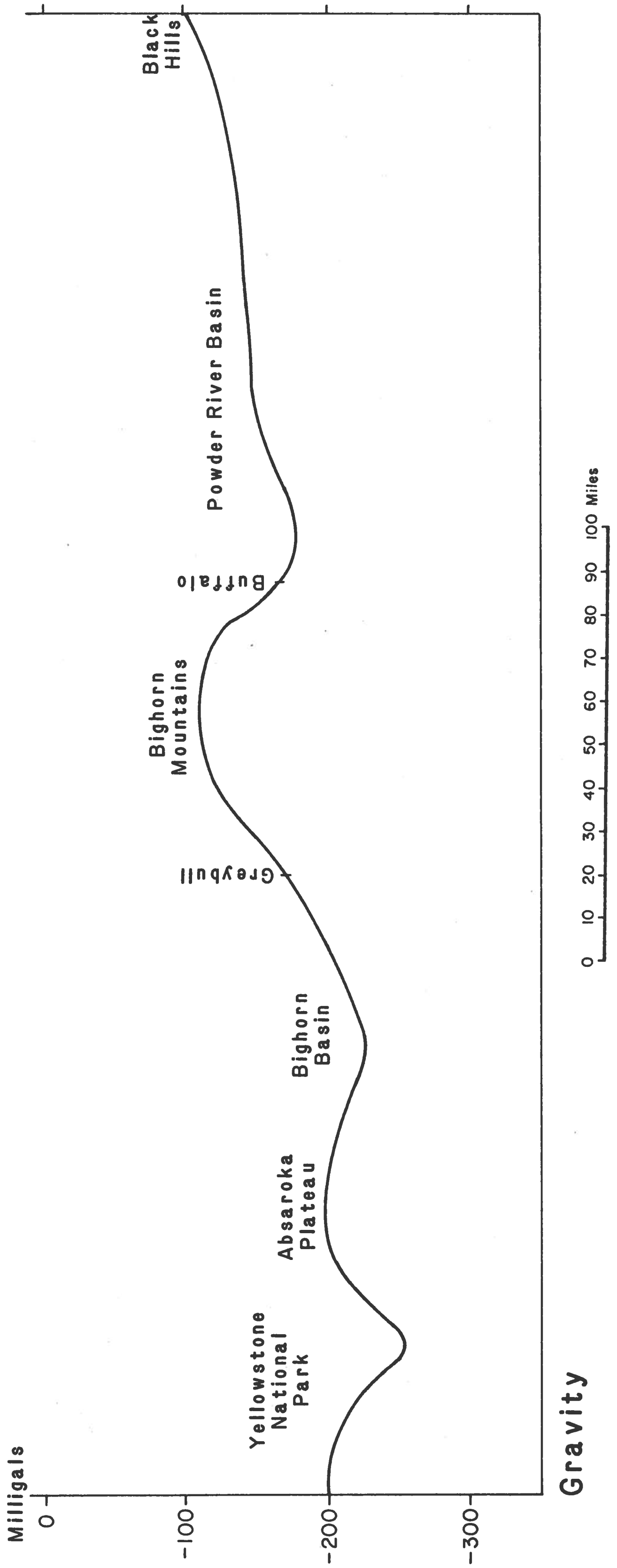
APPENDIX. SAMPLE CROSS SECTIONS

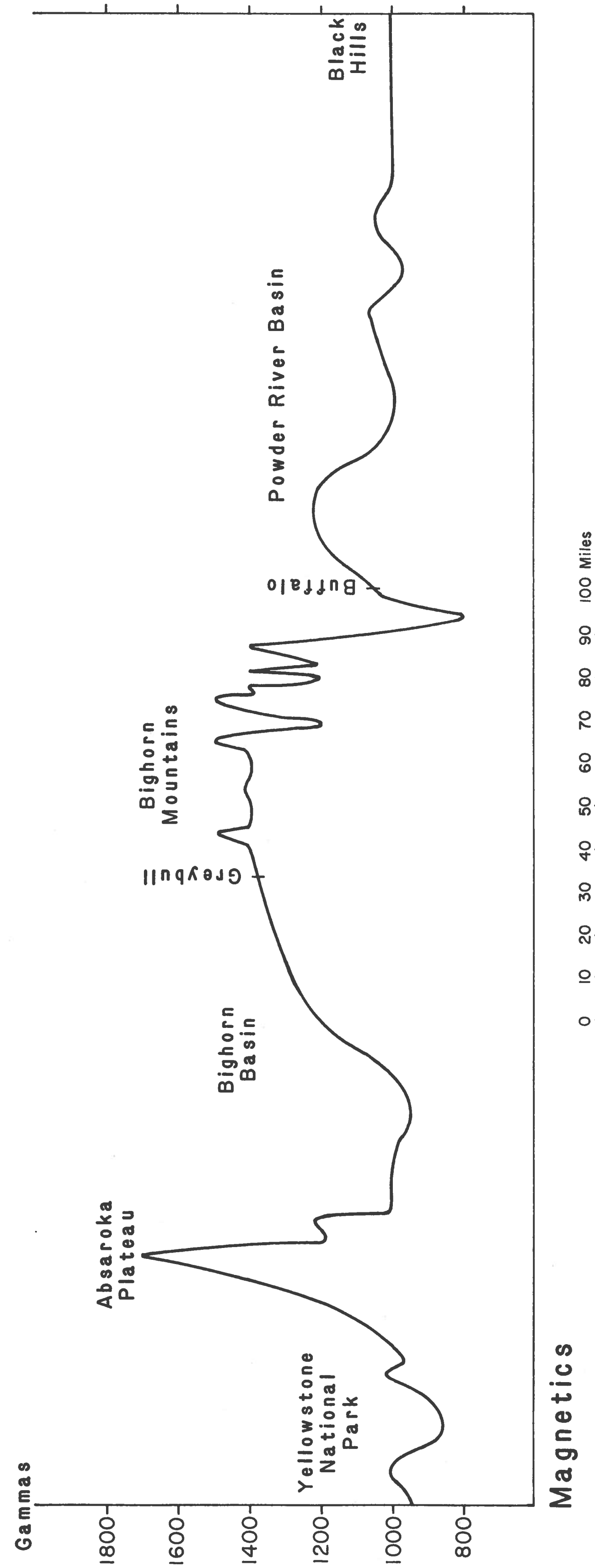
(based on the same line of section in northern Wyoming,
see gravity and magnetics chapters for location)

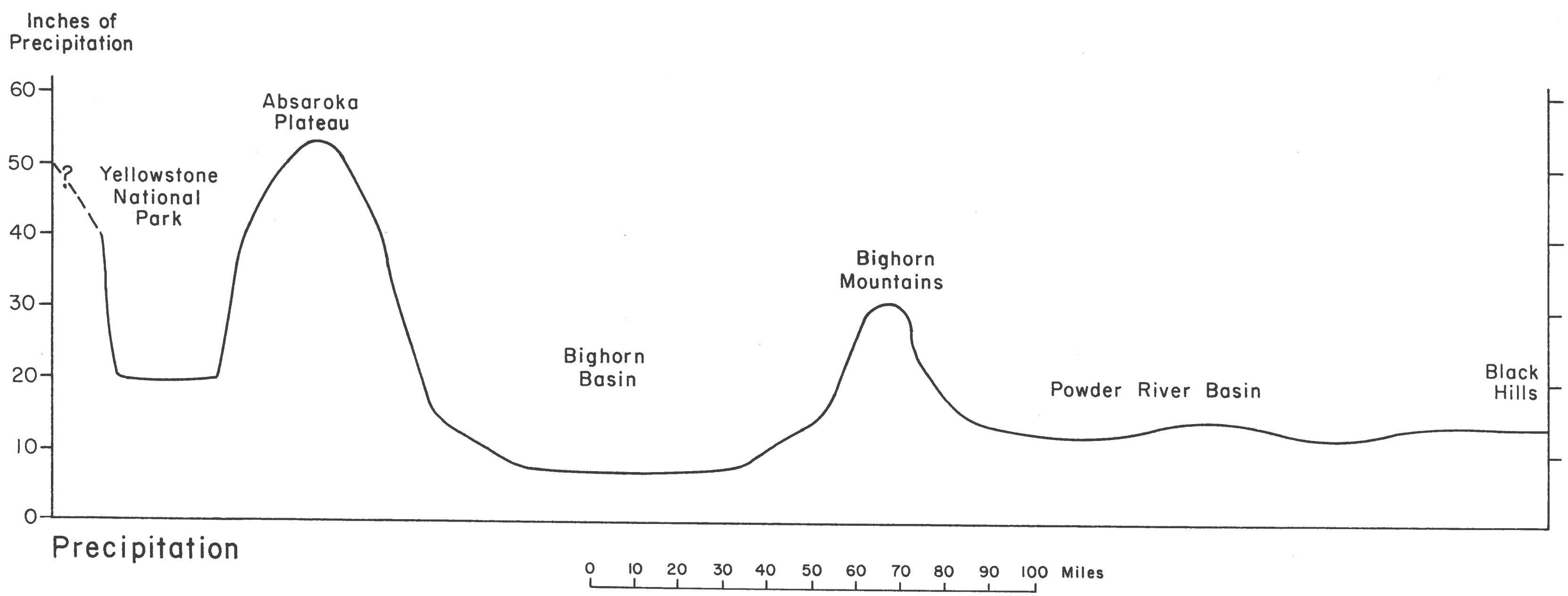
2,000-foot topographic contours
Basement contours
Gravity contours
Magnetics contours
Precipitation contours


Feet
12,000
10,000
8,000
6,000
4,000
2,000
0
Yellowstone National Park
Absaroka Plateau
Bighorn Basin
Bighorn Mountains
Powder River Basin
Black Hills
Topography
0 10 20 30 40 50 60 70 80 90 100 Miles


Feet
+15,000
+10,000
+5,000
sea level 0
-5,000
-10,000
-15,000
-20,000
Yellowstone National Park
Volcanic cover
—no information—
Absaroka Plateau
?
Bighorn Basin
Bighorn Mountains
Powder River Basin
Black Hills
?
Basement
0 10 20 30 40 50 60 70 80 90 100 Miles


Milligals
0
-100
-200
-300
Yellowstone National Park
Absaroka Plateau
Bighorn Basin
Greybull
Bighorn Mountains
Buffalo
Powder River Basin
Black Hills
0 10 20 30 40 50 60 70 80 90 100 Miles
Gravity


Gammas
1800
1600
1400
1200
1000
800
Yellowstone National Park
Absaroka Plateau
Bighorn Basin
Greybull
Bighorn Mountains
Buffalo
Powder River Basin
Black Hills
0 10 20 30 40 50 60 70 80 90 100 Miles
Magnetics



Precipitation

Teachers supplement - Wyoming geomaps ES 1-S

STATE OF WYOMING
1933
GEOLOGICAL SURVEY

Geology -- Interpreting the past to provide for the future