Teacher's Name: ____________________________

School: ____________________________________

SALT LAKE COUNTY - LANDFORMS

A textbook primarily for teachers in Salt Lake County, Utah who want to learn more about geologic features and the processes, including earthquakes, that create them.

By: Genevieve Atwood
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30 U Street
Salt Lake City, UT 84103

draft edition

Looking southeast: Ensign Peak in the foreground, Salt Lake Valley in the mid-ground; Wasatch Range in the background, east; and the Traverse Mountains in the background, south.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Table of Contents

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

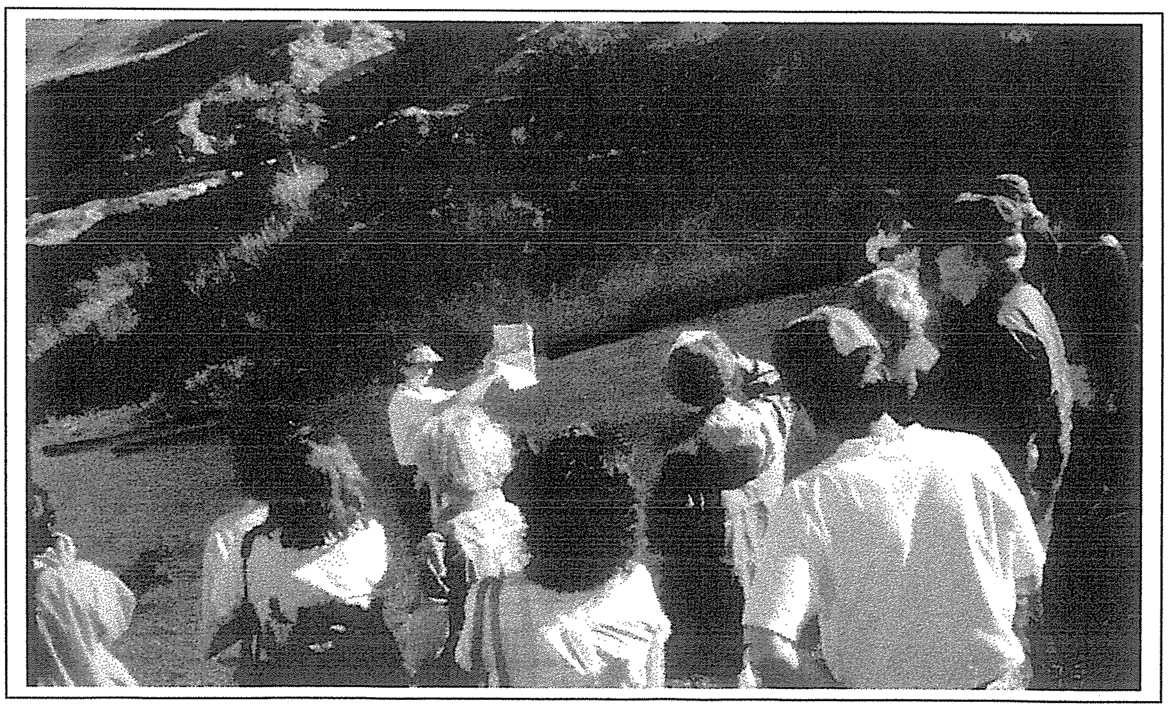
INTRODUCTION
The purpose of this book

Earth Science Education teaches summer courses especially for 3rd-grade and 5th-grade teachers who teach "Geologic Features" and "Physical Features" as part of Utah's core science curriculum. The course consists of three 3-hour and 20-minute sessions taught outside using Salt Lake County's outstanding landscapes.

Our goal is for teachers to gain with confidence and competence telling the earth-science stories that landforms tell. Every component of a landscape has a history. We teach teachers how to "read" the stories of landscapes, to decipher clues of distinctive features including profile, size, location, and what the features is made of to tell the story the landscape tells about its recent and distant past and its probable future.

Technical terms in *italics* are defined in the Glossary. We make every effort to use common terms and apologize if any of this text does not make sense to you.

Acknowledgements: (incomplete)
Earth Science Education appreciates the support we receive from individuals, corporations and foundations including: Kennecott Utah Copper, Quinney Foundation, Redd Foundation, Steiner Foundation, Utah Power Foundation, and the Wheeler Foundation. We appreciate John Wiley and Sons, publishers, and Brian J. Skinner and Stephen C. Porter, authors of *The Dynamic Earth* for permission to duplicate illustrations and text as part of this project.



Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
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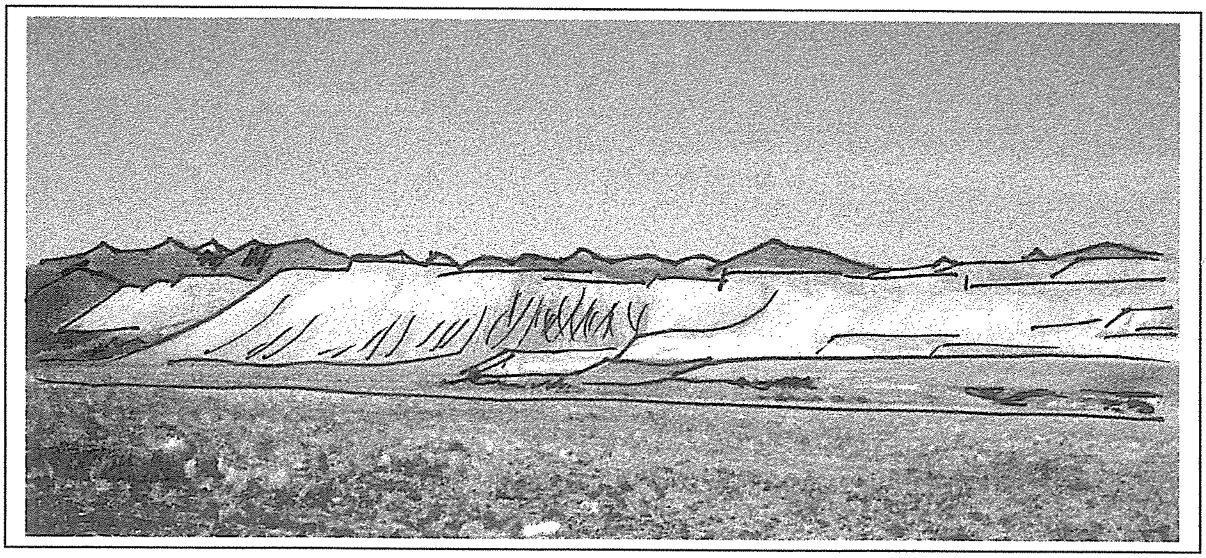
What we mean by a "*landform*"

This text uses "*landform*" as a friendly, common-sense, good-to-know word that embodies two components of the science core curriculum taught in Utah's 3rd and 5th grades... "geologic features" and "physical features."

Landforms are *"any physical, recognizable, form or feature of the earth's surface, having a characteristic shape and produced by natural causes."*



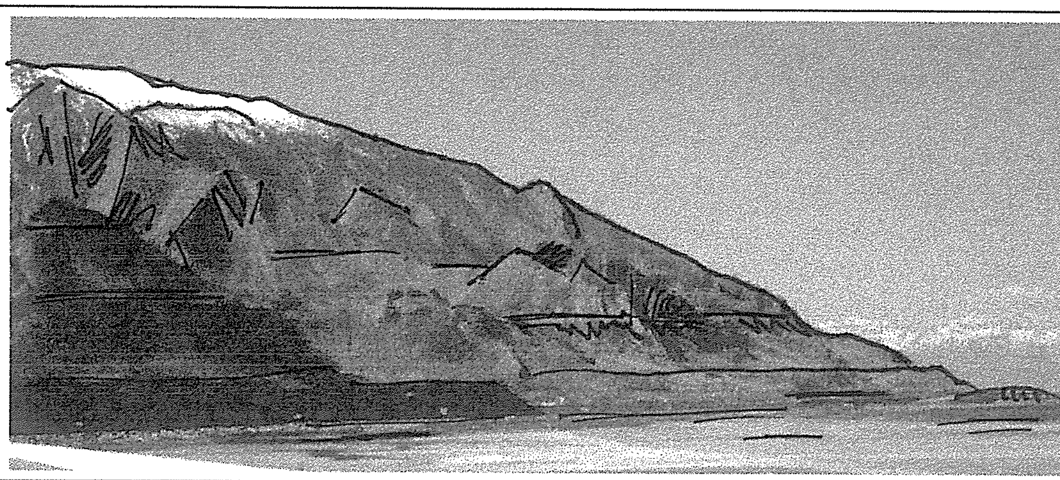
Landforms are the *surface* expression of geologic features. A geologic feature at depth is not a landform. For example: folded rocks deep in a mountain range, or a fault 50 feet below the land surface are geologic features but are not landforms. The feature must be *natural*. The Bingham Copper Mine is a physical feature but not a landform. And the feature must be on the earth's surface, so tree tops are not a landform.

TEACHING MOMENT: Landforms are everywhere.
If you were asked to map the surface of the earth at your school yard, what would you map as the ground level? When you map, even mentally, the surface features of a place on the earth, you are mapping landforms.

Landforms can be big or small. They are the landmarks of our environment. They teach us how to better observe our environs, how to describe them, and how to decipher the recent and more distant environmental conditions that created them. They can provide a sense of direction. They give us a sense of place.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Examples of landforms:
the Wasatch Range
sand dunes along the shore of Great Salt Lake
the stream bed of the Jordan River
Salt Lake Valley



North end of the Oquirrh Range, background: note the Bonneville shorelines.
South Shore of the Great Salt Lake, foregound.

Geomorphic Questions:
Why is the Great Salt Lake located where it is? *Because it is the lowest area of the basin.*
Why is the Great Salt Lake the lowest area of the basin? *Because of the down-dropping of the valley along faults.*
What caused the Bonneville shorelines? *Shore processes associated with Lake Bonneville.*

The branch of earth science that studies landforms is "geomorphology," the overlap discipline of geology and geography. The word "geomorphology" comes from "geo" meaning earth and "morph" meaning shape.

Geomorphology is the study of:
- the **shapes** of the land, and
- the **processes** that make the land look the way it does.

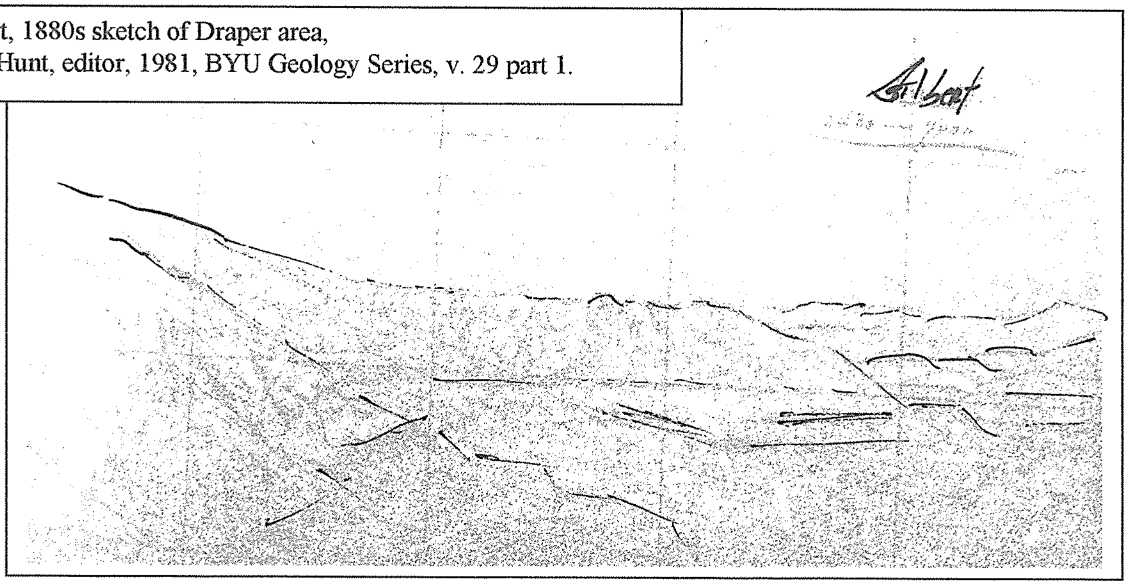
Examples of subjects of interest to geomorphologists:
The Wasatch Range... and the processes that formed it.
The Great Salt Lake... and its fluctuations.
The Jordan River... and why it isn't in the center of Salt Lake Valley.
Salt Lake Valley... why it is lower than the mountains, and how it changes.

07/31/97 **DRAFT** *Geologic Features of Salt Lake County*
Earth Science Education, 30 U Street, SLC, UT 84103

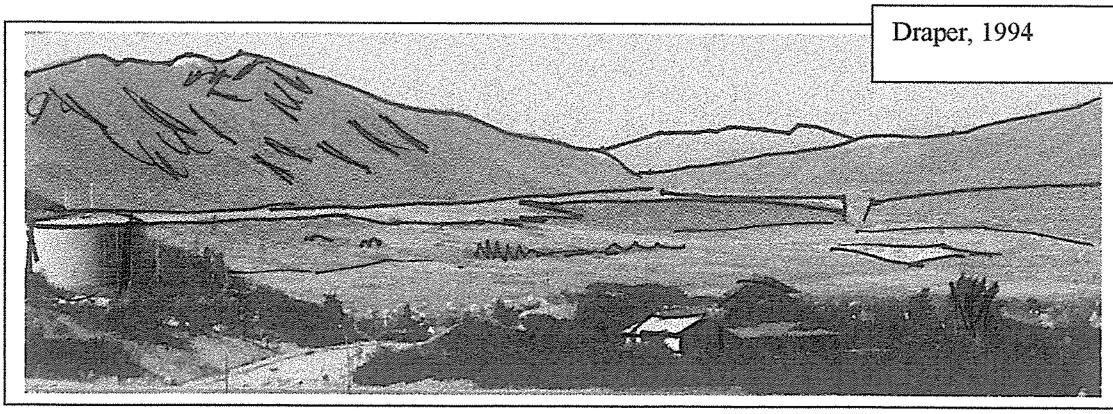
SECTION 1
Descriptive Geomorphology

CONTENTS

G.K. Gilbert, 1880s sketch of Draper area,
from: C.B. Hunt, editor, 1981, BYU Geology Series, v. 29 part 1.



Draper, 1994



Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

How to recognize a landform

Landforms are everywhere.

Voltaire, a famous French philosopher, once quipped that children speak "prose" without even knowing what prose is. You see landforms whether or not you recognize them. We describe landforms in every-day language. We use landforms to give directions. We chose vacation spots because of their landforms. We see movies, read books, and see art with landforms.

A landform is simply a describable component of the physical landscape, however big or small.

- A continent is a describable component of the physical landscape, particularly if you are in a space shuttle. A continent is an enormous landform.
- Lone Peak is a describable component of our Salt Lake County landscape. Mountains are large-scale landforms.
- A sand dune is a describable component of the physical landscape whether or not it is a named feature. It is a small-scale landform.
- A desert area such as the West Desert (west of Great Salt Lake) is made up of hundreds of landform types including thousands of sand dunes.

Writers and movie directors set the stage for their dramas with images of landforms. Landscape artists capture the visual essence of landforms. Photographs and satellite images document landforms and how they change through time. Topographic maps and digitized elevation models depict landforms using mathematical and spatial symbols.

Every landform tells a geologic story. When you tell a landform's story, you are teaching earth science.

Gouging from glaciers.
Wasatch Range.
View east from Holaday, UT.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Mega-landforms... continents vs. ocean areas

The concept of scale is important in almost every aspect of earth science and especially important in analyzing landforms. The "big picture" often shows up at a coarse scale (sometimes called large-scale or mega-scale features) and not at a fine scale (small scale). Whereas, fine-scale features often are the clues to landform processes. Satellites have given a fresh perspective to landform analysis. From space, an obvious classification of "the describable components of the physical landscape" would be the land (continents) versus the water (oceans).

Every landform tells an earth science story and the continents and oceans are no exception.

- Stories about the physical and chemical properties of the Earth:

For example: The earth's crust that underlies oceans (oceanic crust) has different physical and chemical properties than continental crust. Continental crust is somewhat lighter (it floats higher on Earth's mantle) and thicker (although still very thin in comparison to the Earth's diameter).

- Stories about the geologic history of the Earth:

For example. Mega-landforms tell almost mind-boggling stories of continental drift (see Section __ Chapter __). The size and shapes of oceans tell us about global climate change.

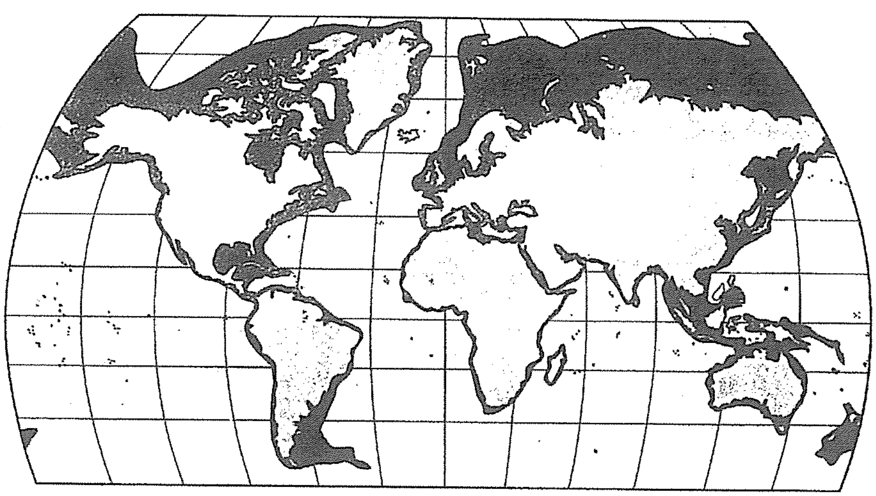


FIGURE 1.6 The continental shelves and slopes (shown in gray), together, form about 15 percent of the continents. The map projection exaggerates the shelves in the arctic region, which are nevertheless extensive.

From: *The Dynamic Earth*, first edition, p. 10, used with permission.

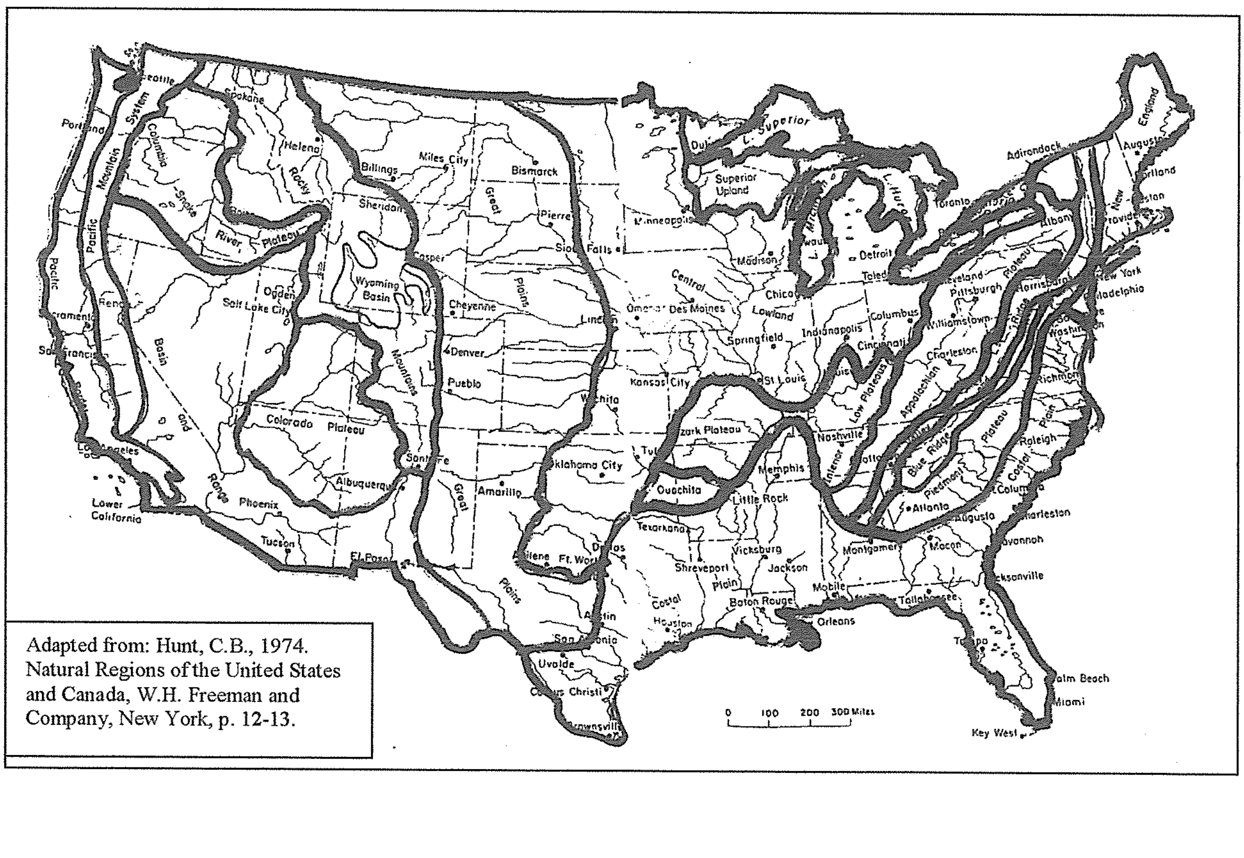
Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Landforms of the United States

Continents can be subdivided into "describable components of the physical landscape." Physical geographers and geologists divide the world, including the United States, into "physiographic provinces," areas with landforms fundamentally different from their neighbors. For example, the Rocky Mountain area contrasts markedly with the Great Plains.

Landforms reflect the stories of their geologic past. Fundamental geologic histories result in different rock types and structures. Different geologic histories result in dissimilar landforms and therefore contrasting landscapes.

TEACHING MOMENT: What physiographic provinces have your students visited or seen on television? What landforms do they remember? Can they describe the landforms of Iowa? Or western Colorado? Or the coast of California? What landscapes / landforms have been in the news recently (for example: terrible floods, great skiing, vacation highlights, scenery in advertisements for automobiles).



Adapted from: Hunt, C.B., 1974. Natural Regions of the United States and Canada, W.H. Freeman and Company, New York, p. 12-13.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Landforms of Utah

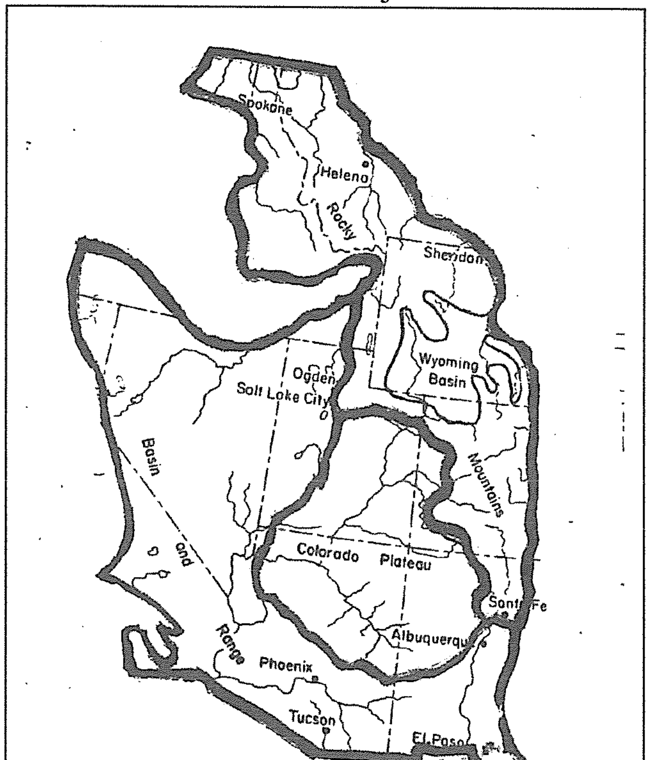
Picture the canyon country of southeastern Utah, the valleys and mountains of western Utah, and the mountain country of the high Unitas. How do the scenes differ?

TEACHING MOMENT: Draw the boundaries of the physiographic provinces that appear in Utah on the landform map of the United States. Note how the boundaries of the physiographic provinces differ dramatically from Utah's political boundaries.

TEACHING MOMENT: Draw the boundaries of Utah's three major physiographic provinces on a more detailed map of Utah. Remember: landforms tell stories of their geologic past. Areas with decidedly different geologic histories that look different belong in different physiographic provinces.

Where would you draw the boundaries of:

- Utah's portion of the Basin and Range,
- Utah's portion of the Rocky Mountain province, and
- Utah's portion of the Colorado Plateau.



Adapted from: Hunt, C.B., 1974. *Natural Regions of the United States and Canada*, W.H. Freeman and Company, New York, p. 12.

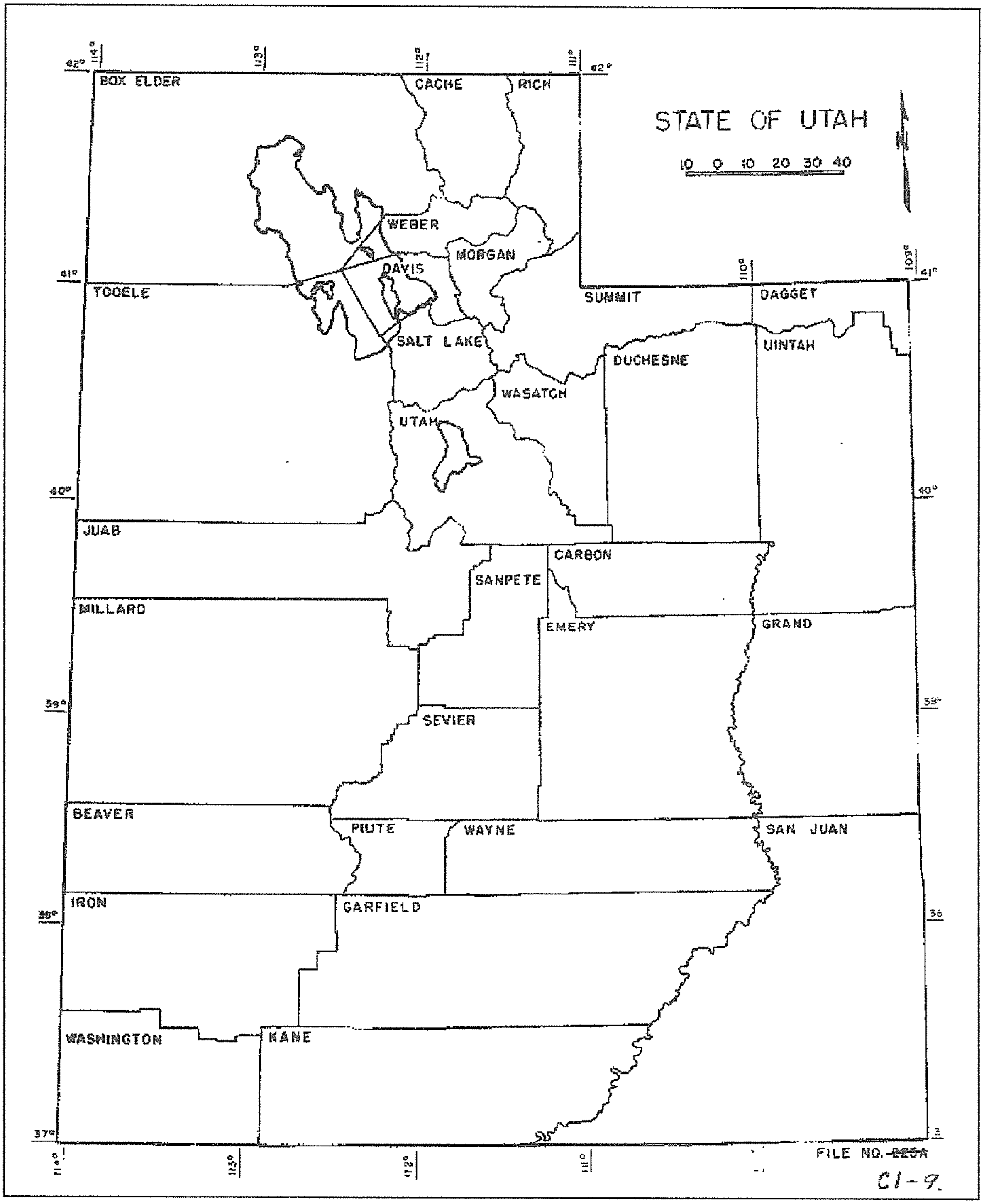
There is no right or wrong in drawing the boundaries if there is good logic backing the delineation. For example, physical geographers might include the Uinta Basin in the Colorado Plateau physiographic province whereas a geophysicist might include it with the Uinta Mountains in the Rocky Mountain province. (See Hintze map of the geology of Utah, next pages.)

Many maps of Utah's landforms show three or four main provinces: an area of the Rocky Mountain province, an area of the Colorado Plateau province, an area of the Basin and Range province, and a transition area between the Colorado Plateau and Basin and Range provinces (often not segregated). Other maps show as many as a dozen or more sub-provinces. (See Stokes map of the physiographic subdivisions of Utah, next pages.) The provinces and sub-provinces indicate that their landforms have had different geologic histories.

Digitized elevation model of Utah.
Elevation data, topographic information, fed into a computer, resulted in this image. Note how the western portion of the state (the Basin and Range) contrasts with the southeastern portion (Colorado Plateau) and the northeastern (Rocky Mountain).

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Map of Counties of Utah



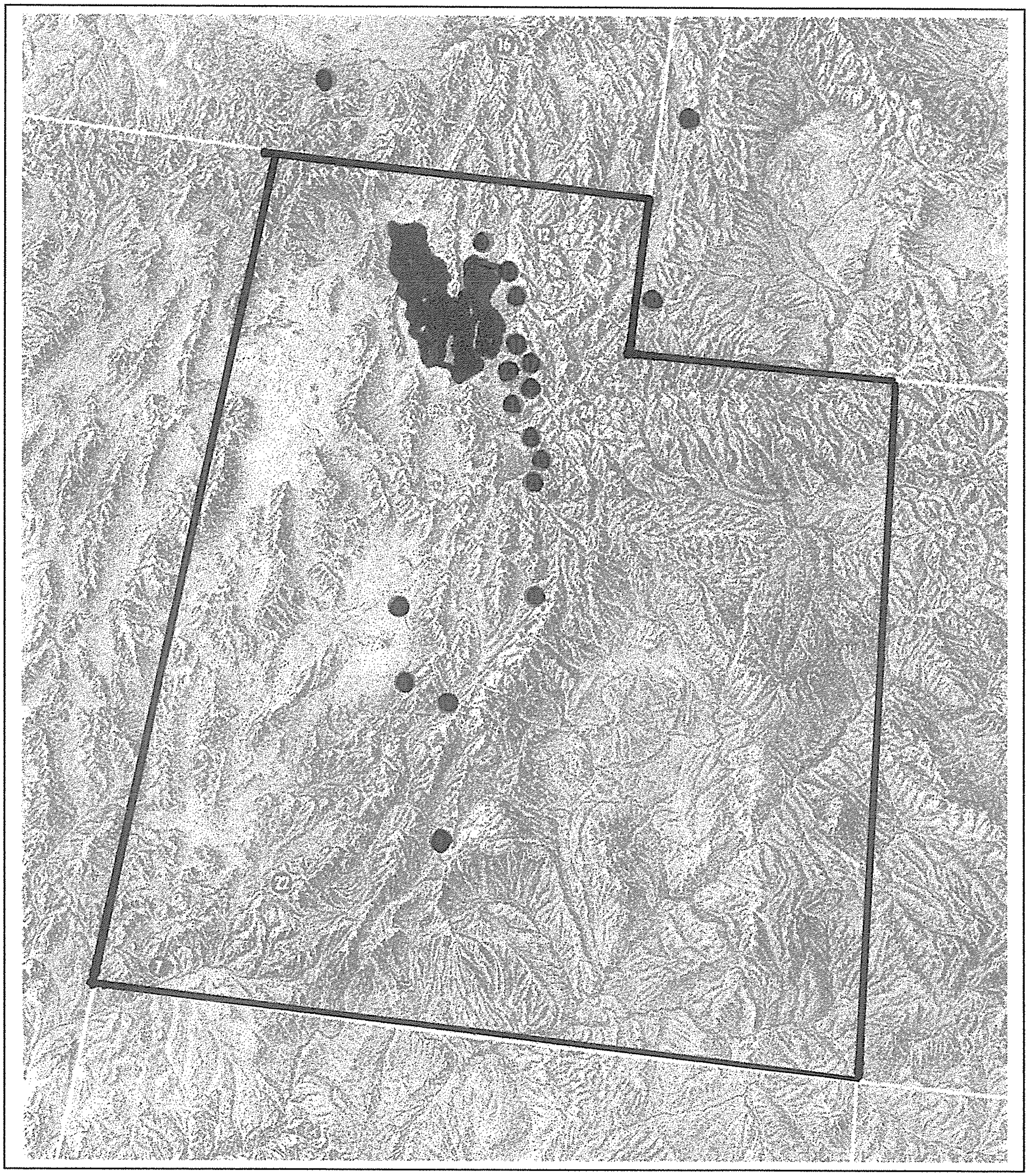
From: Utah Geological Survey.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

INSERTS

GEOLOGIC MAP OF UTAH (Hintze)
PHYSIOGRAPHIC SUBDIVISIONS of UTAH (Stokes)

(IN MAP SET IN FRONT OF TEXT)

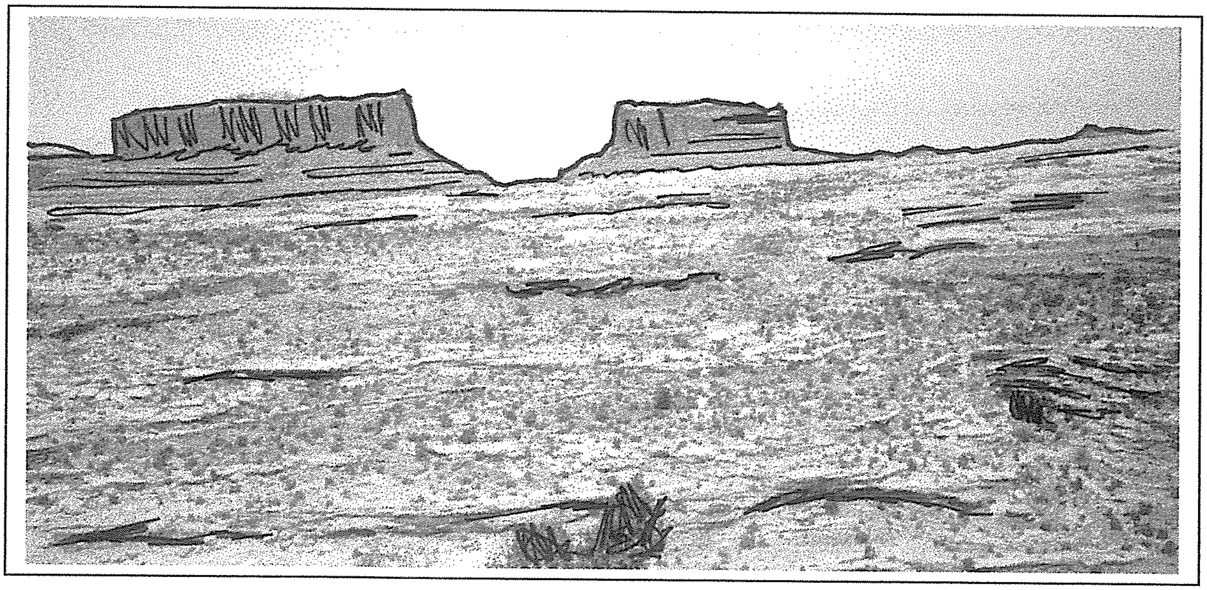


Landforms and human geography
This illustration from an Intermountain Health Care annual report shows the distribution of IHC facilities. Note how Utah's physical geography influences the location of population centers.

Used with permission.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Example of Utah's portion of the Colorado Plateau,
Canyon country, the Monitor and the Merimac, northwest of Moab.



TEACHING MOMENT: List 10 observations about this scenery. What do you observe?
For example:

- The colors of the scenery,
- the shapes of the landforms,
- the details of the landscape.

1.
2.
3.
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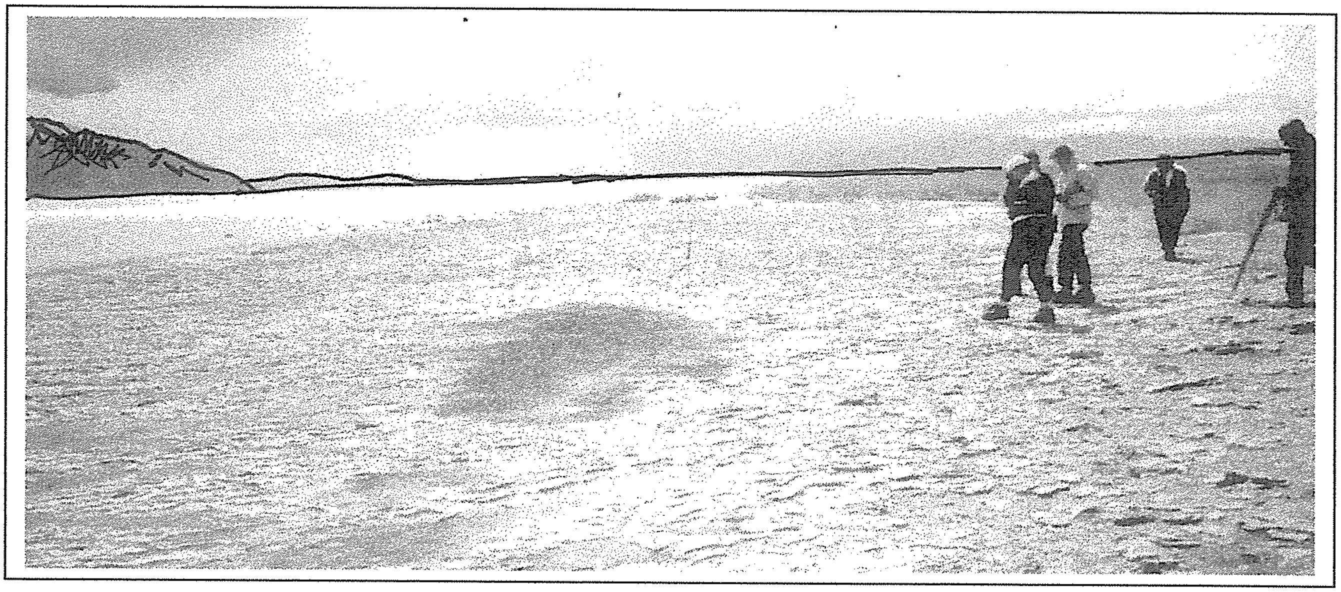
5.
6.
7.
8.
9.
10.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Example of Utah's portion of the Basin and Range:
Shoreline of Great Salt Lake looking west.



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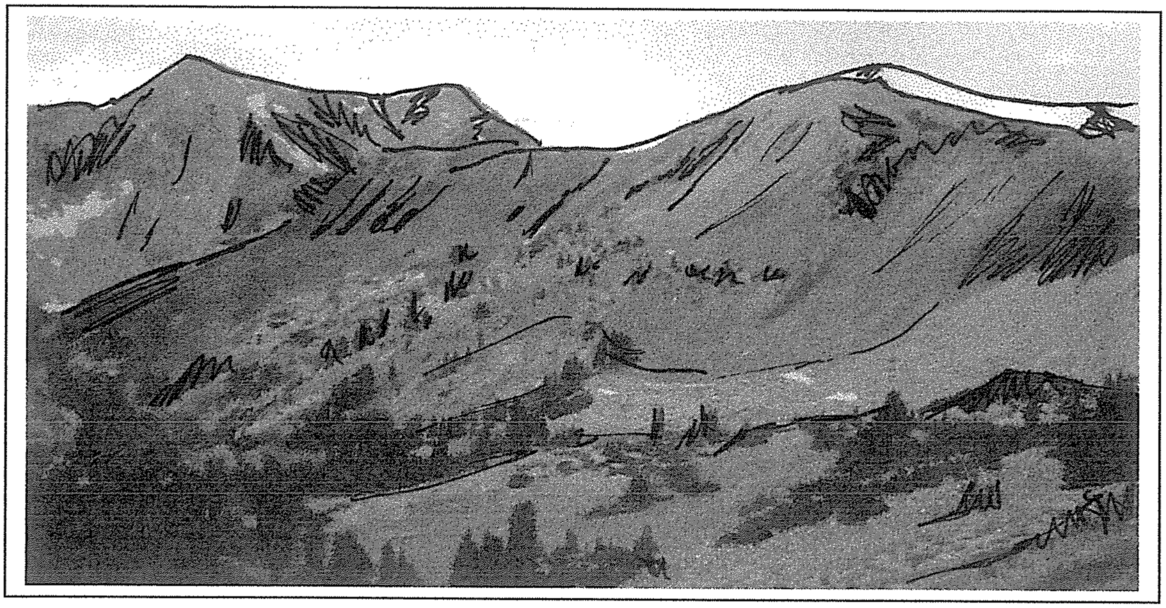
Example of Utah's portion of the Rocky Mountain province, Mineral Basin of the Wasatch Range southeast of Snowbird.



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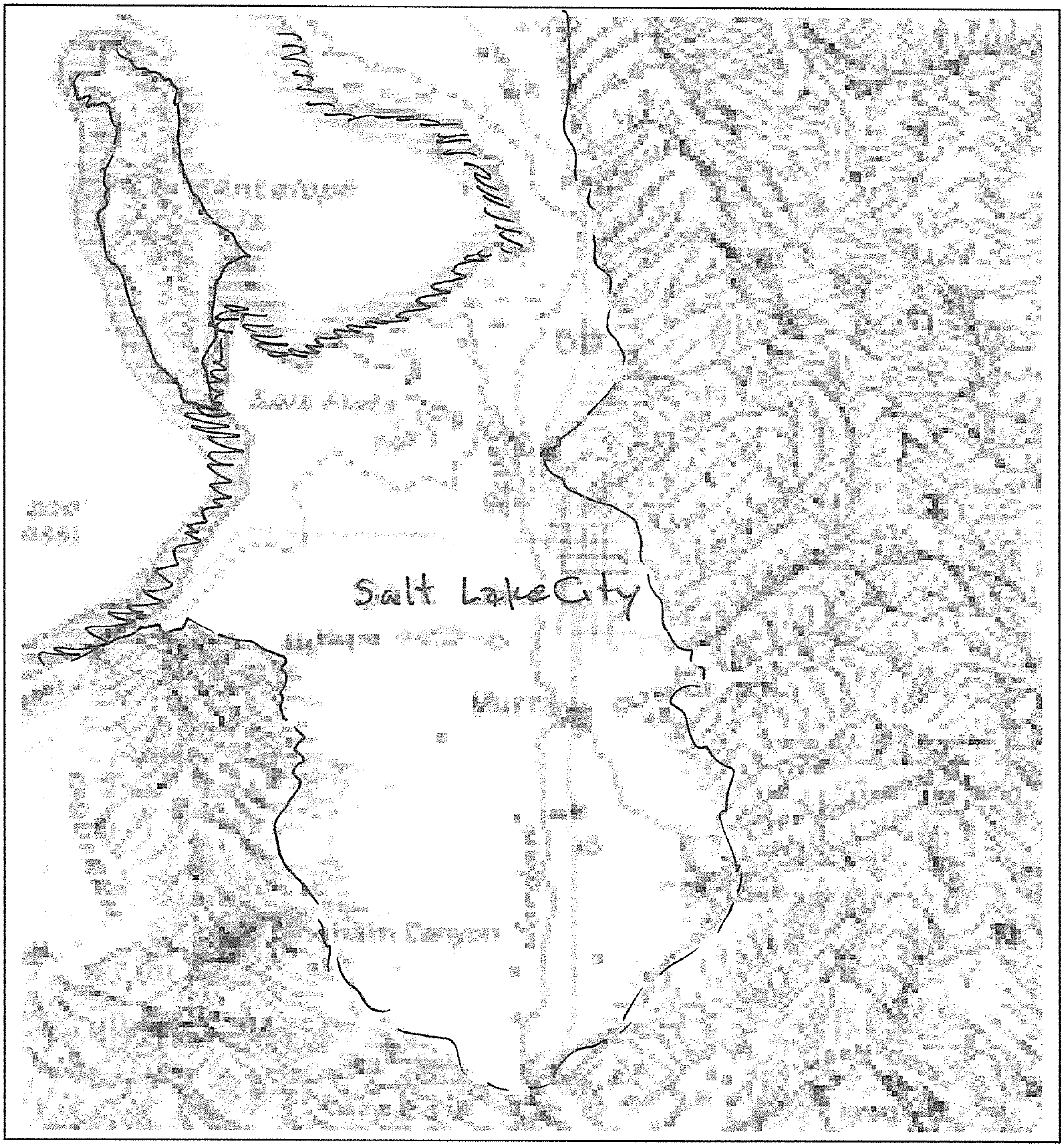
10.

Landforms of Salt Lake County

Salt Lake County has portions of two great physiographic provinces. The Wasatch fault is boundary of the Basin and Range province to the west and the Rocky Mountain province to the east. So it's no surprise that teachers in Salt Lake County have wonderful opportunities to teach about geologic features and geologic processes.



From: Merrill K. Ridd, Landforms of Utah in proportional relief, for sale at Utah Geological Survey.

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:


TAILINGS POND
SALT EVAPORATOR
INTERNATIONAL AIRPORT
SALT LAKE CITY
Magna
Granger
Kearns
Taylorsville
Murray
Holladay
Midvale
West Jordan
Salt Lake City Municipal Airport No 2
Sandy City
South Jordan
Riverton
Draper
Herriman
Bluffdale
UTAH STATE PRISON
LONE PEAK WILDERNESS
Cottonwood Heights
Copperton

How to describe landforms

Describing landforms challenges us to observe the world aggressively and in detail.

Landforms are the components of landscapes.
To describe a local landform:

- look at a landscape,
- identify the components (landforms) within it,
- including smaller landforms that make up larger landforms.

Basic characteristics of landforms are:

- shape,
- profile,
- relief,
- what it is made of,
- its geologic past, and
- the on-going processes that shape it now.

Shape:

Look at the landform's skyline. Is it smooth? jagged? rounded? flat? long? short-segmented? symmetrical? horizontal? steep?

Profile:

Look at the landform's profile from the highest elevation of the feature to its base:
Is it curved? if so does it curve up (concave up) or curve down (concave down)? is it smooth? stepped? gently sloped? steep?

Relief:

What is the elevation difference between the highest and lowest features of the landscape (called *relief*)?
Is the local relief gentle? steep? great? or small?
Is the regional relief gentle? steep? great? or small?

> (*Relief* is a good technical term to learn. It is the difference in elevation between two points or areas. Local relief is the elevation difference between the highest point of a landform to its base. Regional relief, usually just called "relief" is the difference in elevation between the highest points of area and its low points.
>
> TEACHING MOMENT: The regional relief of Salt Lake County is ______ feet. The lowest area is Great Salt Lake at 4200 feet or so (it varies) and the highest point is _____ at ______ Peak. According to your topographic map, what is the elevation at your school? About how much relief do you think there is on your school's property? HINT: How tall is a typical student? Have students estimate the relief based on their heights.

What the landform is made of:

Is the landscape dominated by bedrock (the crust of the earth) or sediments (loose pieces of dirt and rock)?
Is the landform easily eroded? Or resistant?
Can you see bedrock characteristics such as layering?
How old is the rock the landform is made of?
Can you see geologic features such as fractures and folds of rock layers?

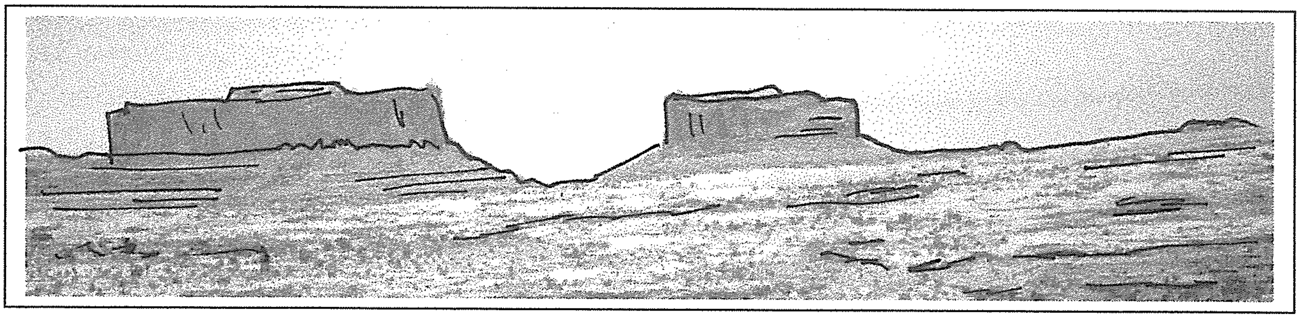
Clues to the landform's geologic past:

Can you get a sense of how old the landform is (in contrast to how old the bedrock or sediments that the landform is made of)?

What on-going processes change this landform:

What is sculpting the landform now... water, wind, glaciers, gravity, and / or humans?
Which of these processes is making the most changes, doing the most work?

TEACHING MOMENT:
Describe landforms typical of Utah's Colorado Plateau.



Shape

Profile

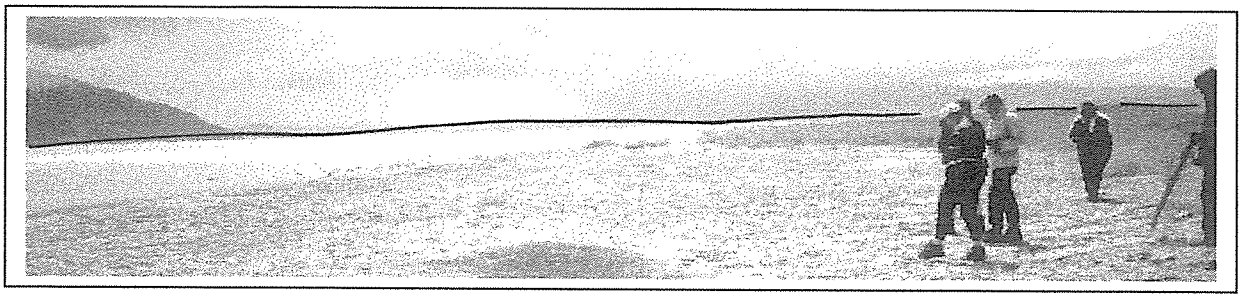
Relief
- local relief
- regional relief

What is the landform made of?
What are the clues to its geologic past?
- mostly bedrock or sediment?
- what kind of bedrock?
- how resistant to erosion?
- geologic structure?
- how old are the landforms?
- colors and color patterns?
- vegetated or not?

What on-going processes change this landform:
- water
- wind
- glaciers
- gravity
- human activity

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

TEACHING MOMENT:
Describe landforms typical of Utah's Basin and Range.



Shape

Profile

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- human activity

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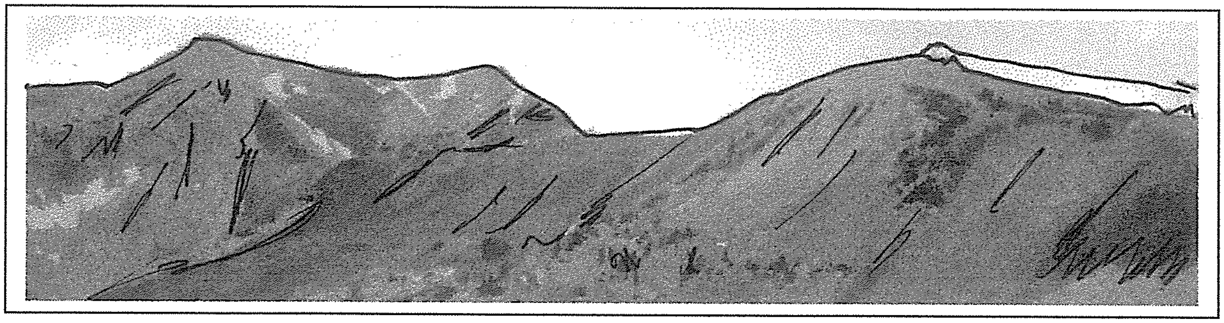
TEACHING MOMENT:
Describe landforms typical of Utah's Rocky Mountain province.



Shape

Profile

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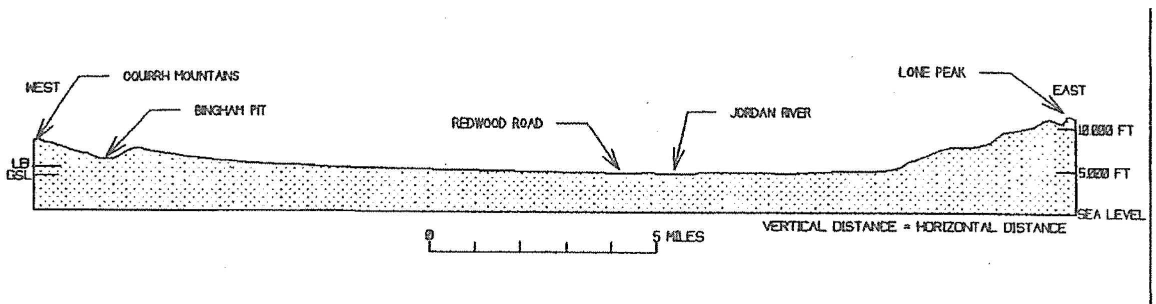
- water
- wind
- glaciers
- gravity
- human activity

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Describing Landforms of Salt Lake County

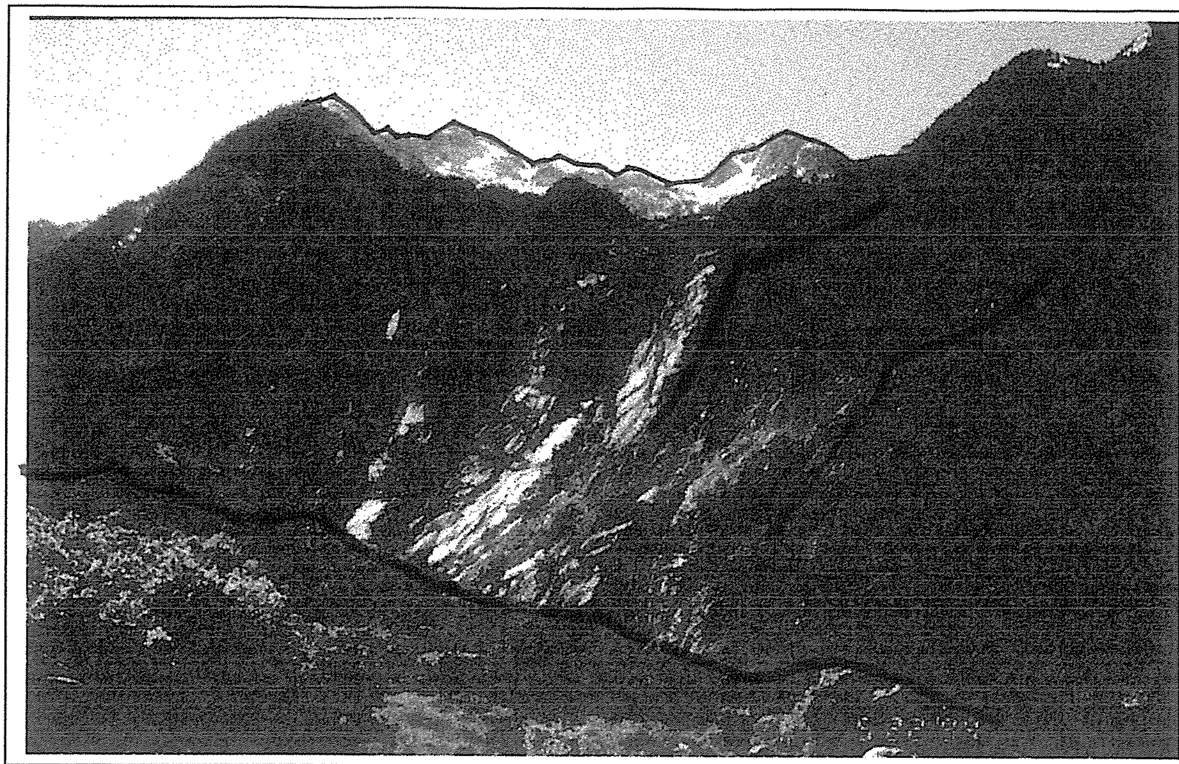
The big, the bold, and the obvious.
Salt Lake County's landscapes are dominated by its mountains and by Salt Lake Valley.

The mountains are mostly *bedrock*, exposed *crust* of the earth.
The valley is mostly *sediments*, material eroded from bedrock and deposited mostly by water in low places of the landscape. In some places, the sediments of Salt Lake Valley are over a mile thick.



WASATCH RANGE	OQUIRRH RANGE	SALT LAKE VALLEY
Shape	Shape	Shape
Profile	Profile	Profile
Relief Local relief Regional relief	Relief Local relief Regional relief	Relief Local relief Regional relief
Made of?	Made of?	Made of?
Geology clues?	Geology clues?	Geology clues?
On-going processes?	On-going processes?	On-going processes?

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:



Little Cottonwood Canyon looking east.

Name of the feature	**Short description... what is it**
Mountain Landforms	
1) Lone Peak	mountain peak
2) Bell Canyon cirque	bowl-shaped valley at mountain ridge
3) Cliffs of Mount Olympus	cliffs
4) Big Cottonwood Canyon	canyon
5) *Moraines* of Little Cottonwood Cnyn	dirt and boulders dumped by glaciers
6) Hang-gliders' haunt, Traverse Mts.	hills
7) Table Mountain SE of Herriman	flat-topped hill
8) Oquirrh Mountains	mountains
9) Salt Lake *salient*	nose of a range projecting into a valley
10) Red ridges of Red Butte Canyon	ridges

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
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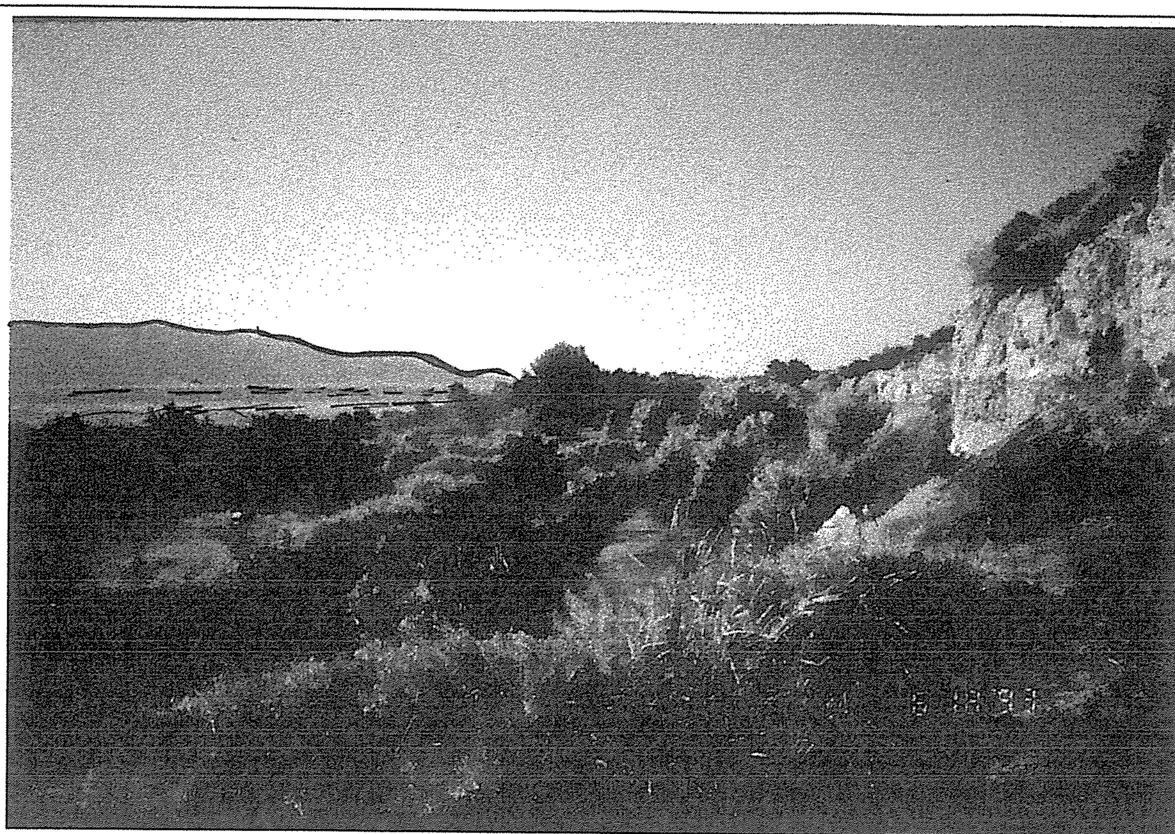

Jordan River looking southeast to Point of the Mountain.

Name of the feature	**Description, what it is**
Valley Landforms	
1) Bonneville shorelines	*shorelines*
2) Delta of Little Cottonwood Canyon	inactive *delta*
3) Dimple Dell drainage	big gully
4) West Ridge... WVC water tower	ridge with a thin veneer of sediments
5) Landslide, Ensign School (SLC)	small landslide or slump
6) Wasatch fault *scarp*	wall-like expression of fault
7) Flood plain of Jordan River	floodplain
8) Jordan River	stream
9) Sand dunes along Great Salt Lake	sand dunes
10) Great Salt Lake	lake

Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

SECTION 2
Tectonics

The engine that determines mega-landforms
And influences all landforms, even micro-scale landforms

CAUTION

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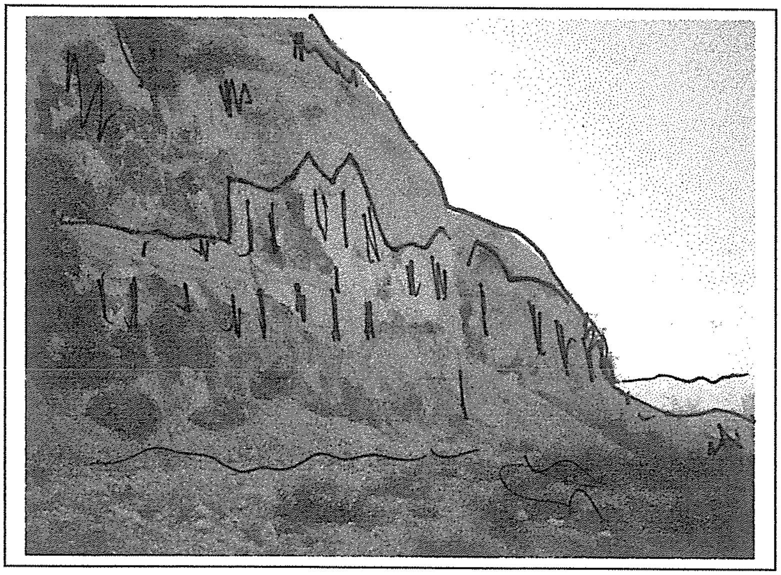
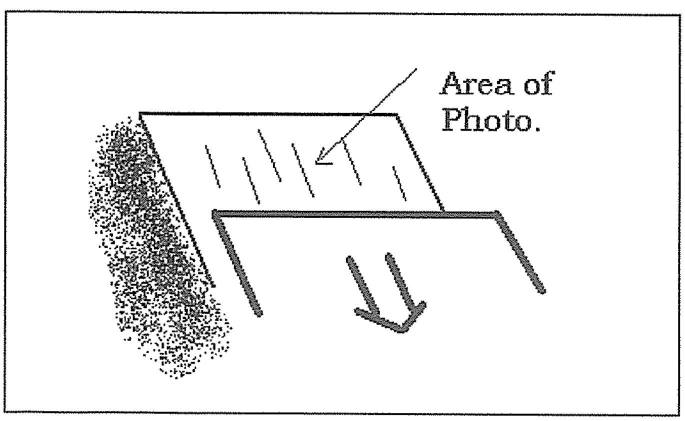


Wasatch Fault at Beck Street, SLC. Note the shear, steep, polished face of light-colored rock. The surface is the fault plane. The light colored rock is on the mountain (up-side) of the fault. The rock that was on the down-side has dropped literally out of the picture and is in the process of being buried by valley sediments.



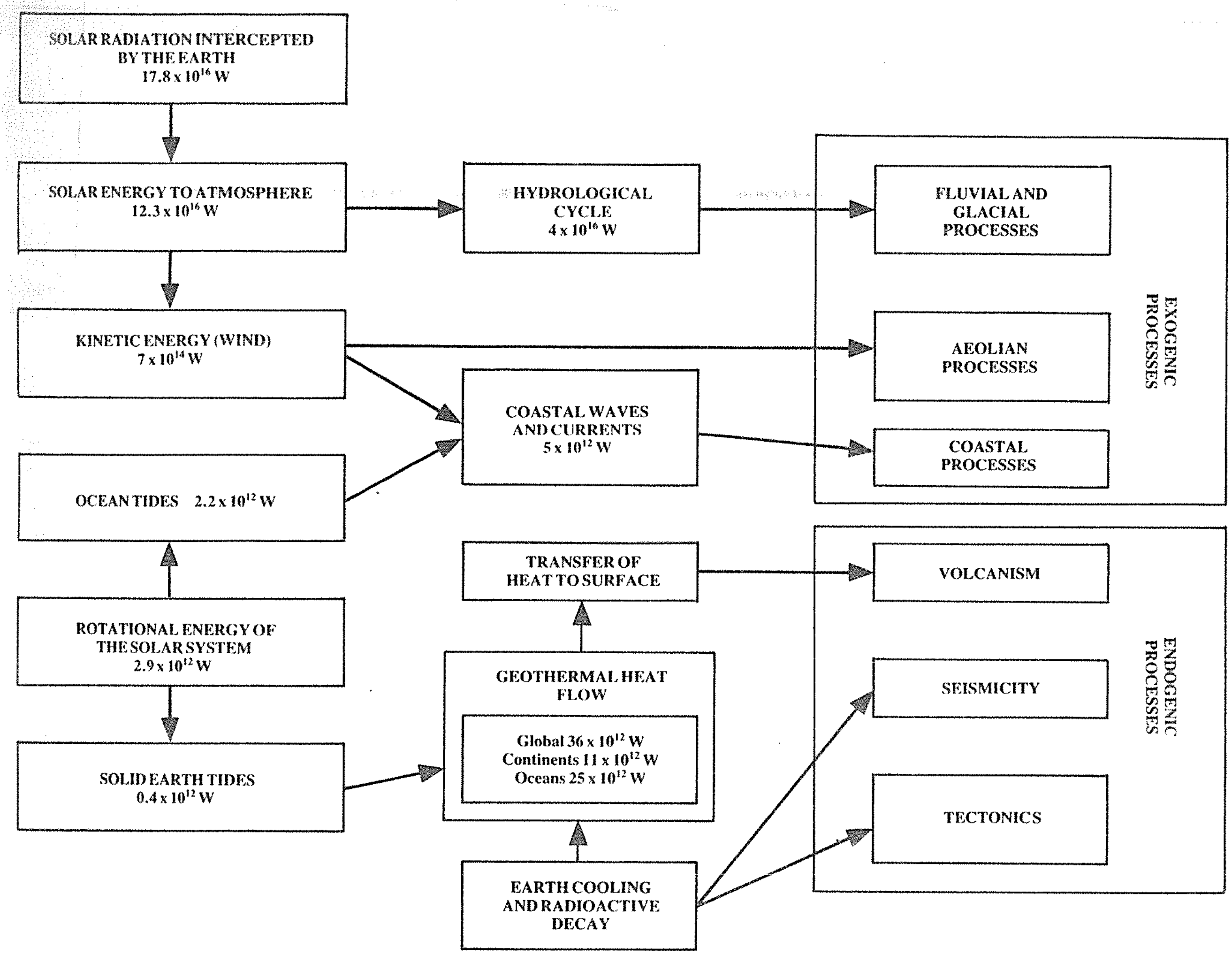


Fig. 1.13 Estimated energy flows relevant to various geomorphic processes (data from various sources).

This chart is from:
Summerfield, M.A., 1992. *Global Geomorphology*, (Longman Scientific & Technical *and* John Wiley and Sons, New York).

Energy is consumed as landforms are changed. Where are the energy inputs? Landforms change because the unequal distribution of heat in the earth (endogenic processes) results in major adjustments of elevation of portions of Earth's surface. Unequal distribution of heat in the atmosphere (exogenic processes) causes weather... which sculpts landforms.

"Exogenic" refers to processes acting on Earth's surface.
"Endogenic" refers to processes acting within Earth.
Landforms are cumulative features... what is there today influences what will be there tomorrow. Exogenic and endogenic processes constantly act to modify landforms.

Structure of the earth

Layers defined on physical characteristics

Layers defined on chemical characteristics

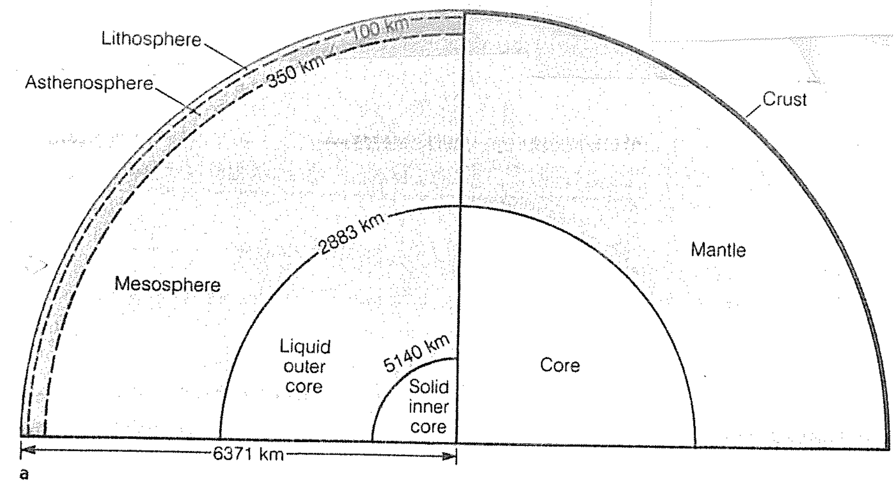
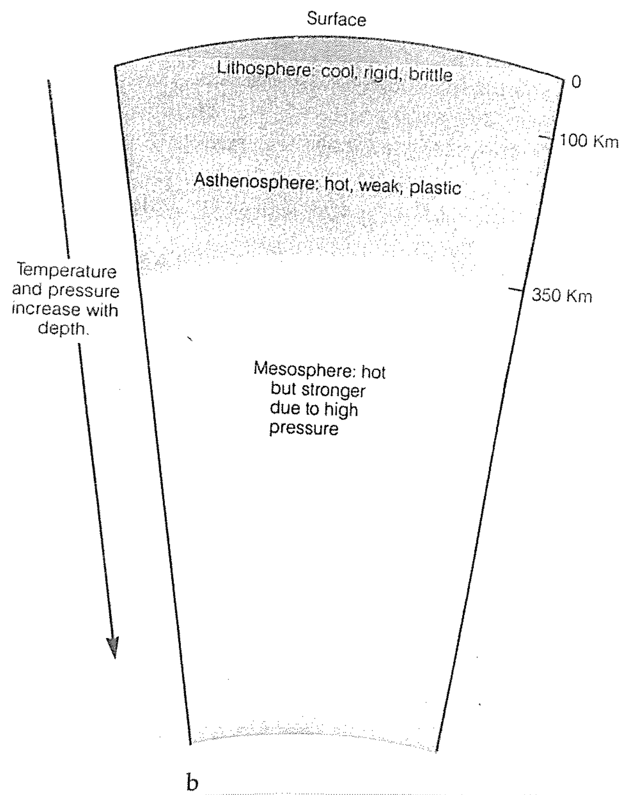


FIGURE 1.3 Layering of physical properties in the Earth. (a) Right side shows the compositional layering of crust, mantle, and core. Left side depicts changing physical properties with depth. Note that compositional changes and physical property changes do not coincide. (b) Expanded view of the upper portion of the left side of part a.

The Earth, Inside and Out 7



Teacher feedback:

Plate tectonics...
How the plates move

PLATE TECTONICS AND THE EVER-MOVING LITHOSPHERE

All of the major features on the Earth's surface, whether submerged or on land, arise as a result of internal processes. By far the most important result of internal processes is the lateral motion of the lithosphere over the asthenosphere. Such motions involve complicated events, all of which are embraced by the term *tectonics.*

Tectonics. The word *tectonics* is derived from a Greek word, *tekton,* that means carpenter or builder. ***Tectonics*** is the study of movement and deformation of the crust on a large scale.

Teacher feedback:

Plate Tectonics. The special branch of tectonics that deals with the processes by which the lithosphere is moved laterally over the asthenosphere is called ***plate tectonics.*** The strong rocky lithosphere not only moves, but it does so in a series of platelike pieces; it is the movement of the plates that causes continents and ocean basins to be where they are and to have the shapes they do. The plates range from several hundred to several thousand kilometers in width.

The very suggestion that a process such as plate tectonics might occur was first made in the late 1960s. Plate tectonics has now been proven, but recognition of the process is so new many of the details are still being investigated. The discoveries and new understandings that have come from plate tectonics are so profound, however, that the concept has sparked a modern geological revolution.

Continental Drift

Today the lithosphere is broken into six large plates and numerous smaller ones. The plates move at speeds ranging from 1 to 12 cm a year (Fig. 1.10). As a plate moves, everything on the plate moves too. If the cap of a plate is partly oceanic crust and partly continental crust, then both the ocean floor and the continent move with the same speed and in the same direction.

The idea that seafloor might move was first proposed in the early 1960s. But the realization that continents might move is much older and goes back to the early years of the present century. The idea of continental movement was most forcefully proposed by a German scientist, Alfred Wegener. The concept came to be called ***continental drift.*** When first proposed the idea did not receive widespread support because at the time no adequate explanation could be offered as to how it could happen. Plate tectonics provided the answer.

The original suggestion for continental drift was that continents must somehow slide across the seafloor. It was soon realized that friction would not allow this to happen. Rocks on the floor of the ocean basin are too rigid and strong for continents to slide over them. Eventually, following the discovery that the seafloor also moves and that the asthenosphere is weak and easily deformed, geologists realized that the entire lithosphere was in motion, not just the continents.

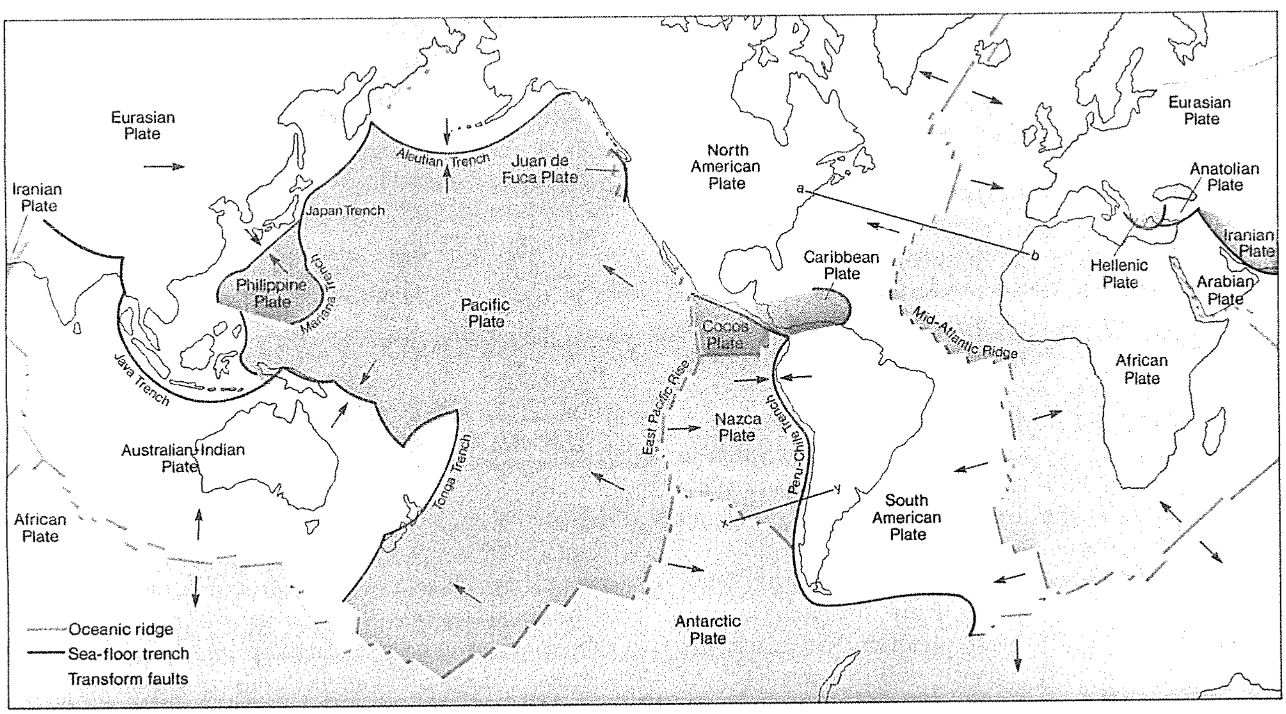


FIGURE 1.10 Six large plates of lithosphere and several smaller ones cover the Earth's surface and move continuously, in the direction shown by arrows. Plates have three kinds of margins: (1) spreading centers delineated by midocean ridges; (2) subduction zones, delineated by seafloor trenches; and (3) transform faults. The profile shown in Figure 1.5 lies along the line a–b, that in Figure 1.8 lies along the line x–y.

Teacher feedback:

Unanswered questions still exist concerning plate tectonics. For example, what were the shapes and sizes of plates from past ages? The evidence is convincing that at times in the past sometimes fewer and at other times more plates were present. Plates change both in size and shape because new, smaller plates can form through the breaking up of larger plates. Also, larger plates can form by the collision and welding together of smaller plates. As discussed in later chapters, past breakups and weldings can be inferred from the geological record, but the evidence is rarely easy to decipher.

Plate Motions and Plate Margins

When we examine how plates move a good analogy is conveyor belts. In a conveyor, the belt continually appears from below, moves along the length, then turns down, and passes temporarily from sight as it completes its circuit. Although broad and irregular rather than long and narrow, a plate of lithosphere acts like the top of a slowly moving conveyor belt. One edge or margin of most plates is a long fracture in the oceanic crust that coincides with the midocean ridge. The plate moves away from the ridge just as if it were a continuous belt rising up the fracture from the mantle below. The analogy is only partly correct, because the plate is not rising as a solid ribbon. It is being created by the formation of new oceanic crust along the midocean ridge.

Formation of Oceanic Crust at a Spreading Center

It is not possible to see into the mantle beneath the midocean ridges, but it is possible to infer what must be happening. Hot, plastic rock in the asthenosphere rises toward the surface beneath the ridges and some small portion of the asthenosphere melts, giving rise to magma. ***Magma*** is defined as molten rock material that forms when temperatures rise and melting occurs in the mantle or crust. The magma that forms beneath the midocean ridges rises upward to the top of the lithosphere where it cools and hardens to form new oceanic crust (Fig. 1.11).

Another disparity in the analogy between a plate and a conveyor is that at the midocean ridge two plates are moving away in opposite directions. The central rift valley that marks the center of a midocean ridge is actually the surface expression of the join between the two plates. Because plates move, or spread outward, away from the midocean ridge,

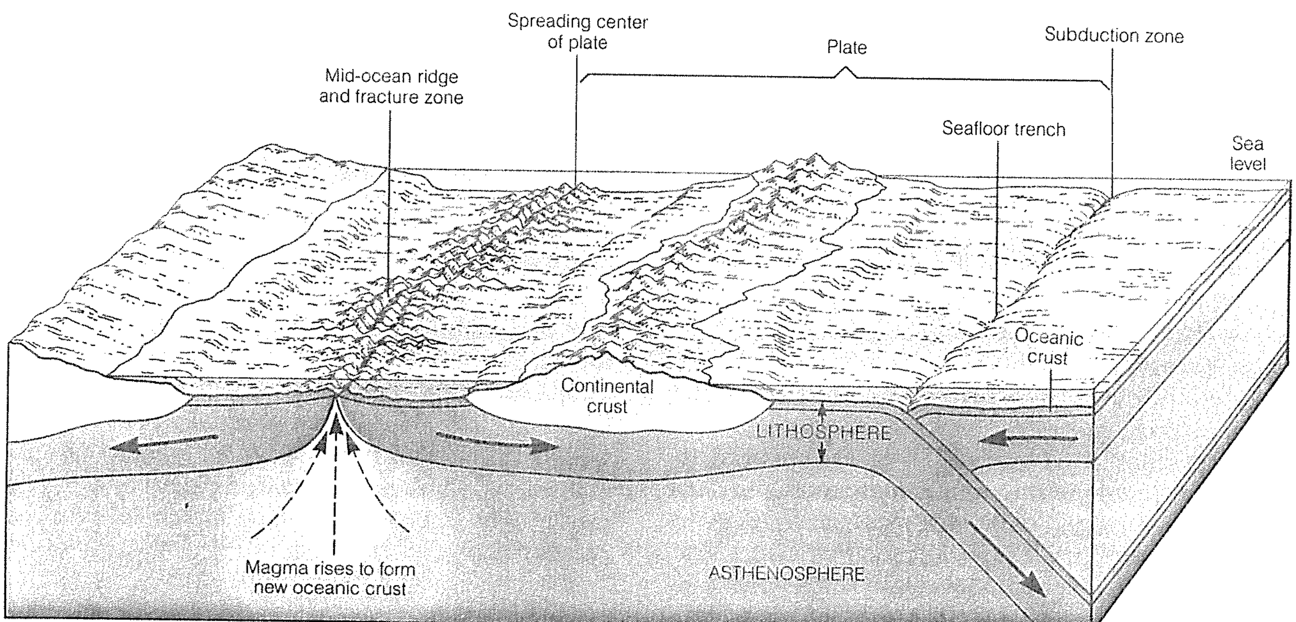


FIGURE 1.11 Section through the Earth's outer layers, showing how magma (dashed arrows) moves from the asthenosphere upward into spreading centers in the ocean floor, and cools there to form new oceanic crust. To accommodate the new materials, the lithosphere (solid arrows) moves away from the fracture zone and eventually sinks slowly down into the asthenosphere again, where it is reheated and eventually mixed again with the mantle.

Teacher feedback:

the new, growing edge of a plate is called a ***spreading center.***

Removal of Oceanic Crust at a Subduction Zone

Formation of new oceanic crust is a continuous process. Movement of lithosphere away from the oceanic ridge, like the movement of a conveyor belt, is a continuous process also. Near the spreading edge the lithosphere is thin, and it has a low density because it is heated and expanded by the rising magma. As the lithosphere moves away from the spreading edge it cools, contracts, and becomes denser. Also, the depth of the boundary between the lithosphere and the asthenosphere increases. Finally, at a distance of a thousand or more kilometers from the spreading edge, the lithosphere and its capping of oceanic crust is so cool it is more dense than the hot, weak asthenosphere below and it starts to sink downward. Like a conveyor belt, old lithosphere disappears back into the mantle. The edges along which plates of lithosphere turn down into the mantle, called ***subduction zones,*** are marked by deep trenches in the seafloor.

As the moving strip of lithosphere sinks slowly through the asthenosphere into the depths of the mantle, it passes from view. Consequently, what happens next is still largely conjecture. On one point, however, we can be quite certain: The lithospheric plate does not turn under, as a conveyor belt does, and reappear at the spreading edge; rather, it is reheated and slowly remixed with the material of the mantle.

Continental Crust

The process described is for plates of lithosphere capped by oceanic crust. All oceanic crust is geologically young because old crust is all returned to the mantle. Unlike oceanic crust, continental crust is not recycled into the mantle; it takes a shorter trip that ends more suddenly. Continental crust is lighter and less dense than even that part of the mantle in the hot asthenosphere. As a result, continental crust is too buoyant to be dragged downward on top of the sinking lithosphere. So, in continent-sized pieces, such crust moves from place to place on the Earth's surface, much as an ice floe floats on a lake or river. Movement stops when one continental mass collides with another, or a plate changes direction when a new spreading center splits the continental crust apart. Because continental crust does not sink down into the mantle, most of the evidence concerning ancient plates and their motions is recorded in the scars carried by ancient continental rocks.

Orogeny. Evidence can be found in the long, more-or-less linear belts of highly deformed rocks in mountain ranges such as the Alps, Appalachians, and Urals. The term ***orogeny*** refers to the tectonic processes by which large regions of the crust are deformed and uplifted to form such mountain ranges. The causes of orogenies were obscure before plate tectonics established that such mountain ranges form along the margins where continental masses collide.

Continental Splitting. Further evidence can be found in rocks on both sides of the Atlantic Ocean. When a new spreading center splits a large mass of continental crust, a new strip of growing oceanic crust separates the two pieces. Africa and Europe on one side, with the Americas on the other, provide an example. Two hundred and fifty million years ago there was no Atlantic Ocean. Instead, the continents that now border it were joined together into a single huge continent (Fig. 1.12). The place where New York now stands was then as far from the sea as central Mongolia is today.

About 200 million years ago a new spreading center formed. We do not yet fully understand why this occurred, but presumably it involved changes in the mantle below. The spreading center split the ancient continent into the pieces we see today. These fragments then drifted slowly into their present positions. At first the Atlantic Ocean was a narrow body of water that separated North America from Europe and North Africa. As movement continued the ocean widened and lengthened, splitting South America from Africa and then growing to its present form. The Atlantic is still growing wider by about 5 cm each year.

Evidence is abundant to mark where the torn edges formerly fitted together. In one region, pieces of mountain ranges that once formed a long, narrow mountain belt, like the Rocky Mountains of today, have been pulled apart so that now they lie on the two sides of the Atlantic. If these pieces are fitted back together the continental slopes on each side of the ocean, and the now deeply eroded mountains, fit like the matched pieces of a jigsaw puzzle (Fig. 1.12). The line of match follows the present Mid-Atlantic Ridge.

Transform Faults

Besides spreading centers and subduction zones there is a third kind of plate edge, analogous to the sides of a conveyor belt, along which plates simply slip past each other. These edges of slipping are great vertical fractures—or to use a term de-

Teacher feedback:

fined in chapter 15, ***transform faults***—that cut right down through the lithosphere. One transform fault, much in the public eye because of the threat of earthquakes along it, is the San Andreas Fault in California. This fault separates the American Plate, on which San Francisco sits, from the Pacific Plate, on which Los Angeles sits. As the two plates slide past each other, Los Angeles is slowly moving northwest toward San Francisco.

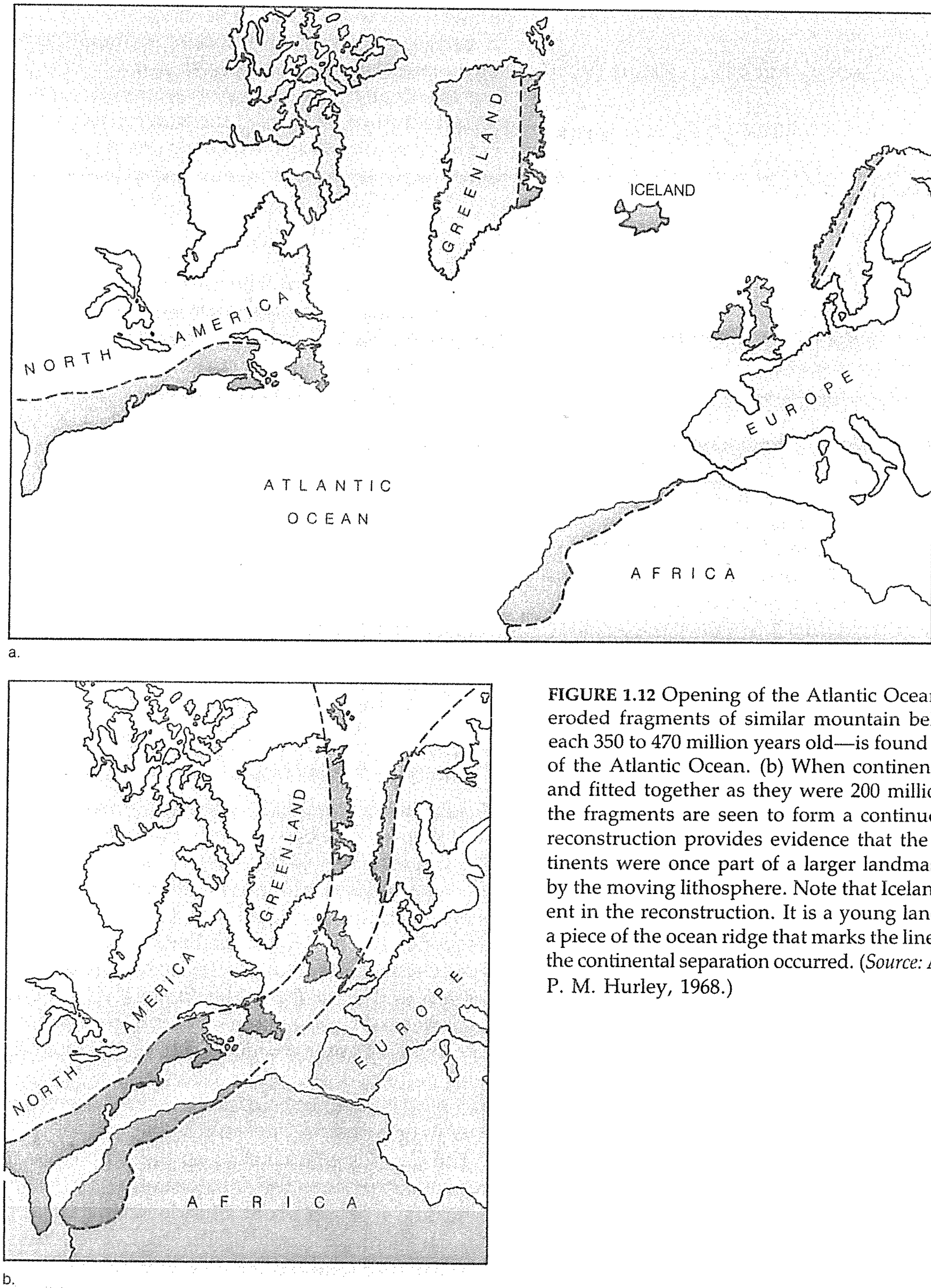


FIGURE 1.12 Opening of the Atlantic Ocean. (a) Rock in eroded fragments of similar mountain belts (brown)—each 350 to 470 million years old—is found on both sides of the Atlantic Ocean. (b) When continents are moved and fitted together as they were 200 million years ago, the fragments are seen to form a continuous belt. The reconstruction provides evidence that the present continents were once part of a larger landmass broken up by the moving lithosphere. Note that Iceland is not present in the reconstruction. It is a young landmass and is a piece of the ocean ridge that marks the line along which the continental separation occurred. (*Source:* Adapted from P. M. Hurley, 1968.)

Teacher feedback:

The earth's crust accommodates change in a variety of ways:

* Vertical displacement... the surface of the earth can rise a couple miles. (Note the following map showing what areas of the conterminous United States are moving up and down with respect to each other.)

Gravity pulls objects on the earth's surface (including the rock layers of the earth's surface) toward the center of the earth. When sections of the earth's crust are in isostatic equilibrium they float like icebergs. When they are "too light" they attempt to "float higher." Sensitive instruments measure the pull of gravity... and give indications of those areas of earth's surface with less dense rock layers and sediments; and areas of the earth's crust that are anomalously high or low.

* Horizontal displacement... the surface of the earth gains surface area (stretches) in some areas and loses surface area (shrinks) in others. Compressional forces, resulting in folding and faulting shorten the distance between two points on the earth's surface. Tensional forces, resulting in faulting, lengthen the distance between two points on the earth's surface. (Note the types of faulting and folding described by the following diagrams.)

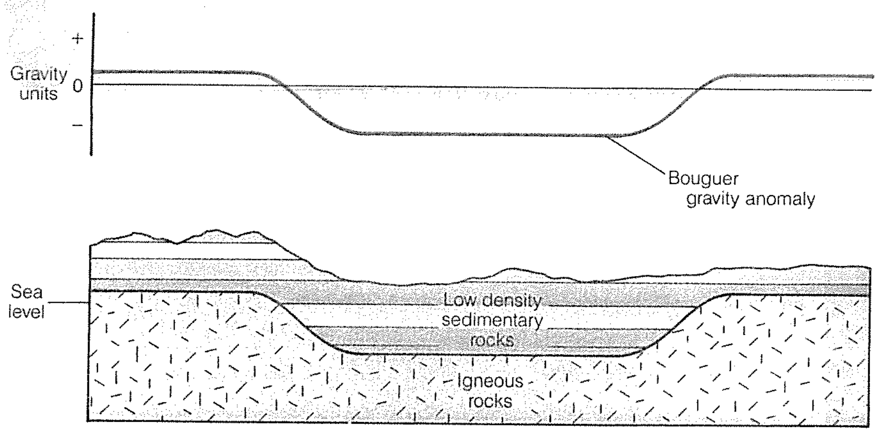


FIGURE 14.23 Example of a gravity anomaly; a basin filled with low-density sedimentary rocks sitting on a basement of dense igneous rocks. Gravity measurements, corrected for latitude, free-air, and Bouguer effects, reveal a pronounced gravity low. The magnitude of the Bouguer anomaly can be used to calculate the thickness of rocks of the basin.

GRAVITY ANOMALIES AND ISOSTASY

The Earth is not a perfect sphere; careful measurement reveals that it is actually an ellipsoid that is slightly flattened at the poles and bulged at the equator.

The radius at the equator is 21 km larger than it is at the poles. Therefore, the pull exerted by the Earth's gravitational attraction is slightly greater at the poles than it is at the equator. Thus, a man who weighs 90.5 kg (199 lb) at the North Pole would observe his weight decreasing slowly and steadily to 90 kg (198 lb) by simply traveling to the equator. If the weight-conscious traveler made very exact measurements as he traveled, he would observe that his weight changed irregularly, rather than smoothly. From this he could conclude that the pull of gravity must change irregularly. If the traveler went one step further, and carried a sensitive device called a ***gravimeter*** (or ***gravity meter***) for measuring the pull of gravity at any locality, he would indeed find an irregular variation.

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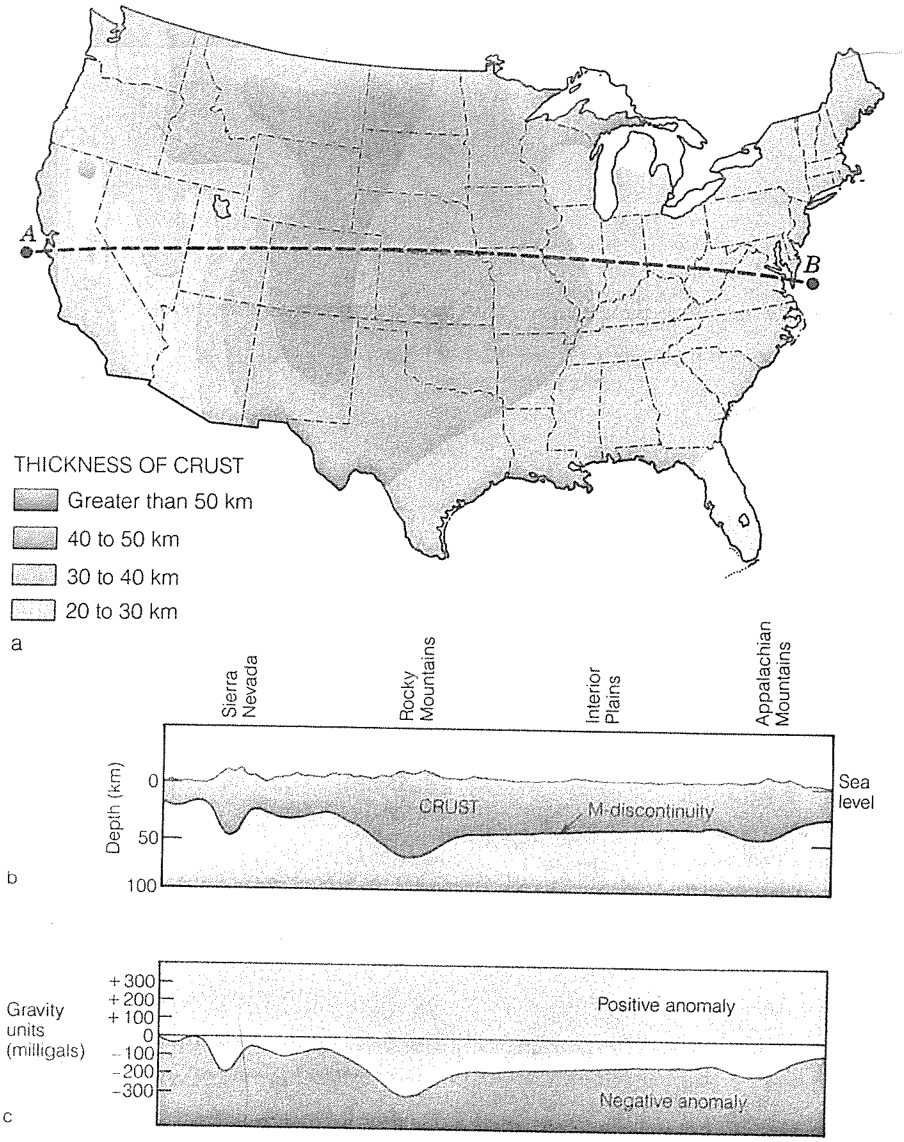

FIGURE 14.14 Crust beneath the United States. (a) Thickness of crust beneath United States, determined from measurements of seismic waves. (b) Section through the crust along the line *A–B* (above). The crust tends to thicken beneath major mountain masses such as the Sierra Nevada, the Rocky Mountains, and the Appalachians. (c) Profile of gravity traverse, adjusted for latitude, free air, and Bouguer corrections. The negative gravity anomalies over the Sierra, the Rockies, and the Appalachians are due to the roots of low-density rocks beneath these topographic highs.

Teacher feedback:

Isostasy

The property of flotational balance among segments of the lithosphere is referred to as ***isostasy.*** The great ice sheets of the last glaciation provide an impressive demonstration of isostasy. The weight of a large continental ice sheet, which may be 3 to 4 km thick, will depress the crust. When the ice melts, the land surface slowly rises again. A spectacular example of glacial depression and rebound is shown in Figure 14.24. The effect is very much like pushing a block of wood into a bucket of thick, viscous oil. When the wood is released, it slowly rises again to an equilibrium position determined by its density. The speed of its rising is controlled by the viscosity of the oil. Just like the block of wood, glacial depression and rebound mean that somewhere in the mantle, rock must flow laterally when the ice depresses the crust, and then must flow back again when the deforming force is removed (Fig. 14.25). The flow must be slow because parts of northeastern Canada and Scandinavia are still rising, even though most of the thick ice sheets that covered them during the last glaciation had melted away by 7000 years ago.

Continents and mountains are composed of low-density rock, and they stand high because they are thick and light; ocean basins are topographically low because the thin oceanic crust is composed of dense rock. Isostasy and differences in the density of rocks beneath the continents and the oceans, therefore, are the reasons that the Earth has two pronounced topographic levels, as shown in Figure 1.4. The important point to be drawn from this discussion of isostasy is that the lithosphere acts as if it were "floating" on the asthenosphere. (*Floating* is not exactly the correct word, because the Earth is solid, but the system is buoyant and acts as though it were floating.) Sometimes gravity measurements suggest that a mountain seems to be top heavy and has too little root of low-density rock to counterbalance its upper mass. Sometimes, as in the seafloor trenches, it is observed that low-density crust has been dragged down to form a root without a mountain mass above it. These and many other situations lead to local gravity anomalies. The anomalies do not seem to become very large. This suggests that the Earth is always moving toward an isostatic balance. Indeed, isostasy is the principal explanation for vertical motions of the Earth's surface, just as plate tectonics is the principle explanation for lateral motions.

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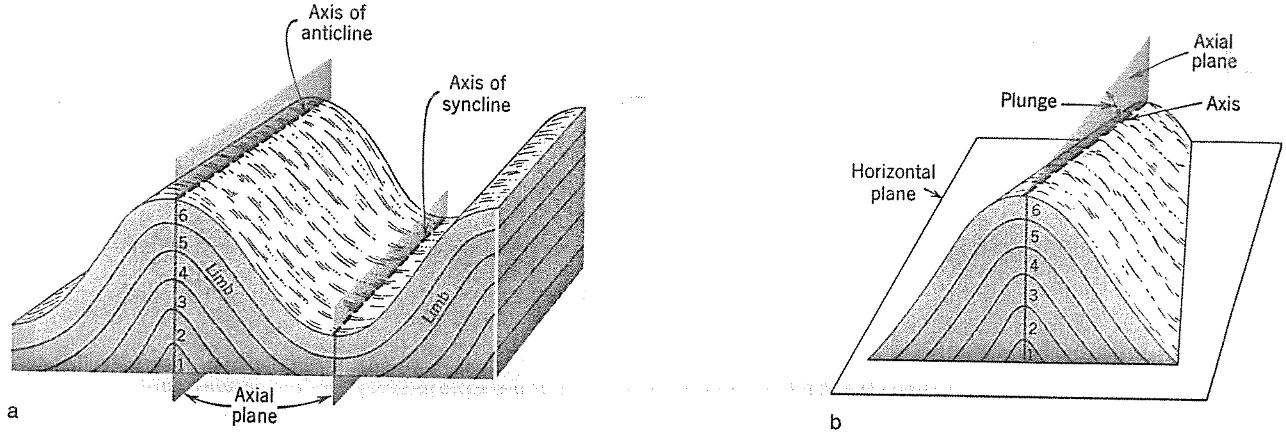
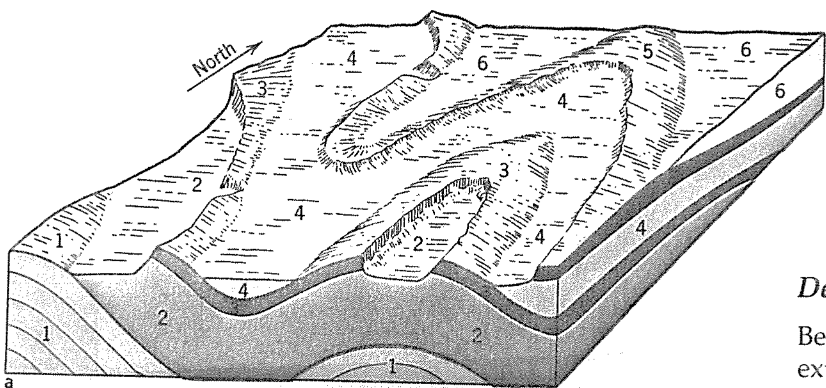


FIGURE 15.16 Features of simple folds. Upper surface of the youngest layer (6) slopes toward the axis of the syncline but away from the axis of the anticline. (a) Fold axis horizontal. (b) Fold axis plunging.

Folding



Deformation by Bending

Bending may consist of broad, gentle warping that extends over hundreds of kilometers, or it might be close, tight flexing of microscopic size, or anything in between. Regardless of the volume of rock involved or the degree of warping, the bending of rocks is referred to as folding. Before discussing folds and folding, it is necessary to become familiar with the terms used to describe them.

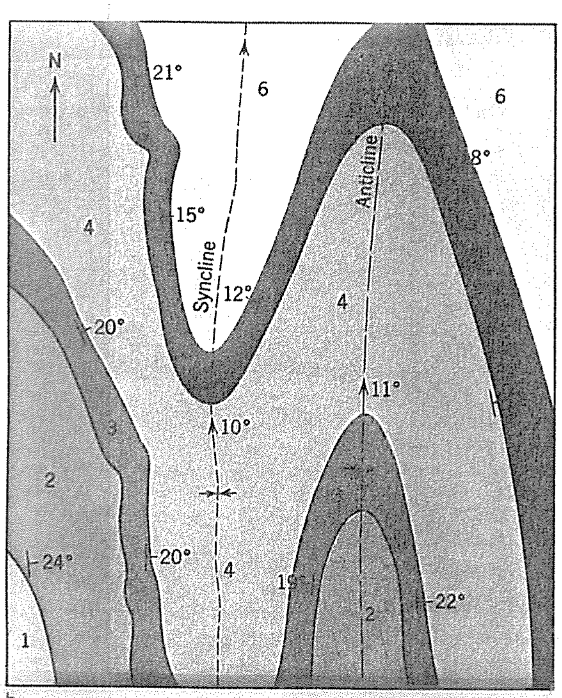


FIGURE 15.18 Distinctive topographic forms and patterns in the distribution of various kinds of rock reveal the presence of plunging folds. (a) Block diagram showing topographic effects. (b) Geologic map of area shown in part a.

Teacher feedback:

Faulting

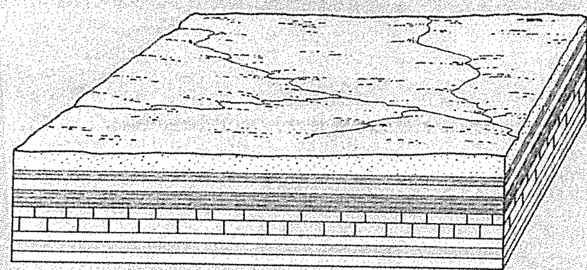
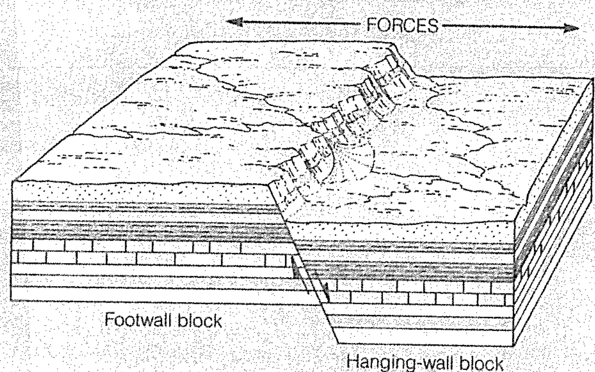
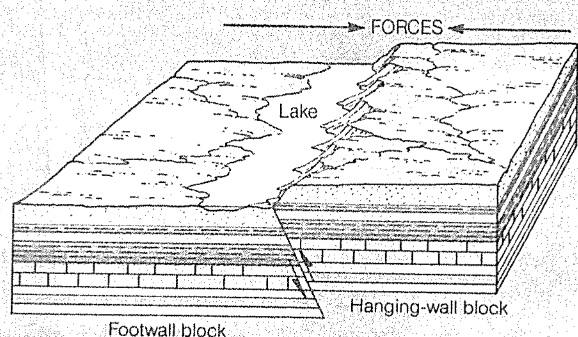
Block diagram	Name of fault	Definition
		Reference block before faulting Drainage is from left to right.
	*Normal fault*	*A fault, generally steeply inclined, along which the hanging-wall block has moved relatively downward.*
	*Reverse fault*	*A fault, generally steeply inclined, along which the hanging-wall block has moved relatively upward.* A normal or reverse fault on which the only component of movement lies in a vertical plane normal to the strike of the fault surface is a *dip-slip fault.*

FIGURE 15.8 Principal kinds of faults, the directions of forces that cause them, and some of the topographic changes they cause.

Teacher feedback:

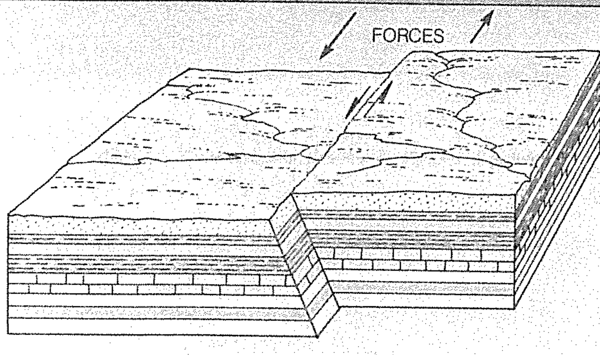
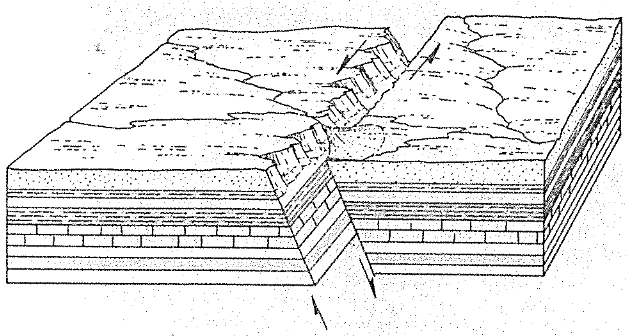
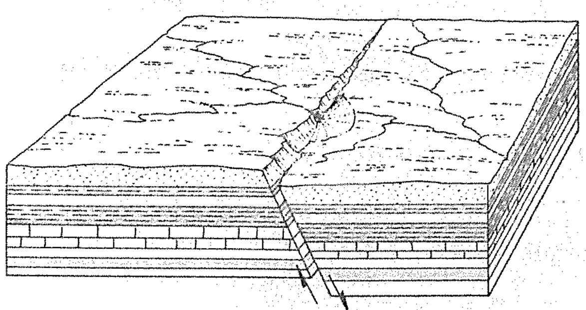
Block diagram	Name of fault	Definition
	*Strike-slip fault*	*A fault on which displacement has been horizontal.* Movement of a strike-slip fault is described by looking directly across the fault and by noting which way the block on the opposite side has moved. The example shown is a *left-lateral fault* because the opposite block has moved to the left. If the opposite block has moved to the right it is a *right-lateral fault.* Notice that horizontal strata show no vertical displacement.
	*Oblique-slip fault*	*A fault on which movement includes both horizontal and vertical components.* Forces are a combination of forces causing strike-slip and normal faulting.
	*Hinge fault*	*A fault on which displacement dies out (perceptibly) along strike and ends at a definite point.* Forces are the same as those causing normal faulting.

FIGURE 15.8 (continued).

Teacher feedback:

SECTION 3

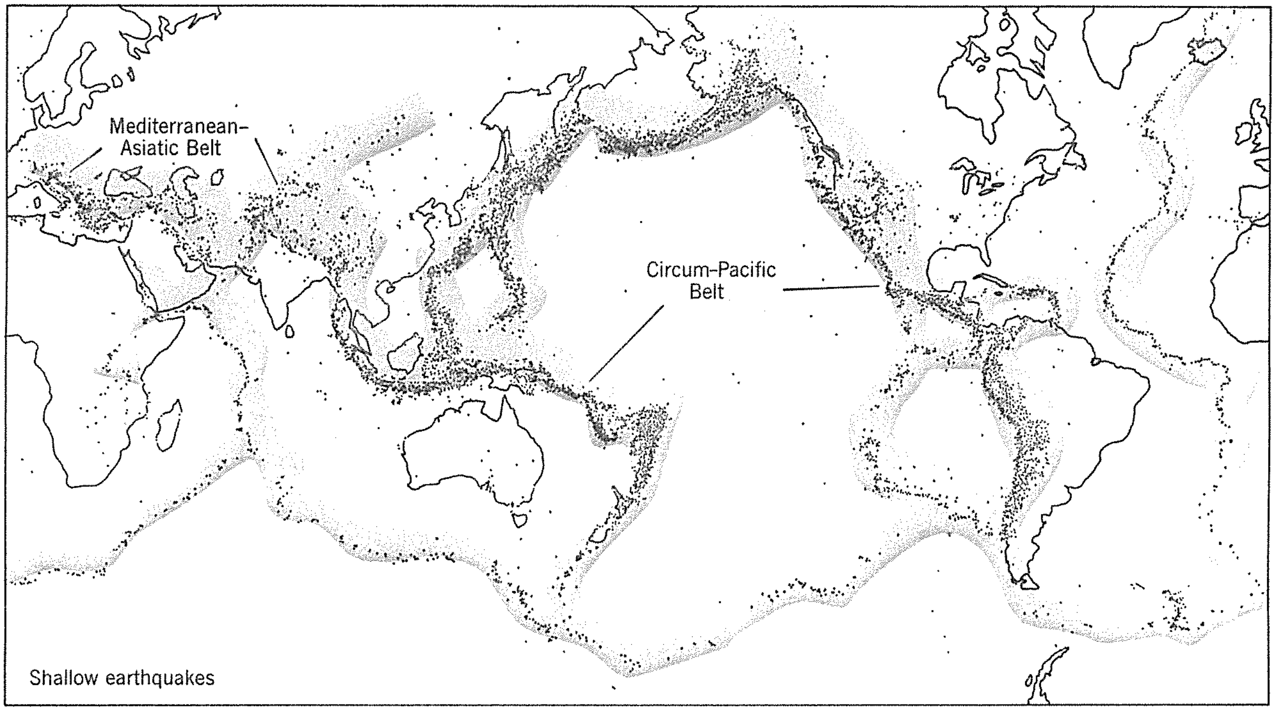
EARTHQUAKES

earthquakes in general

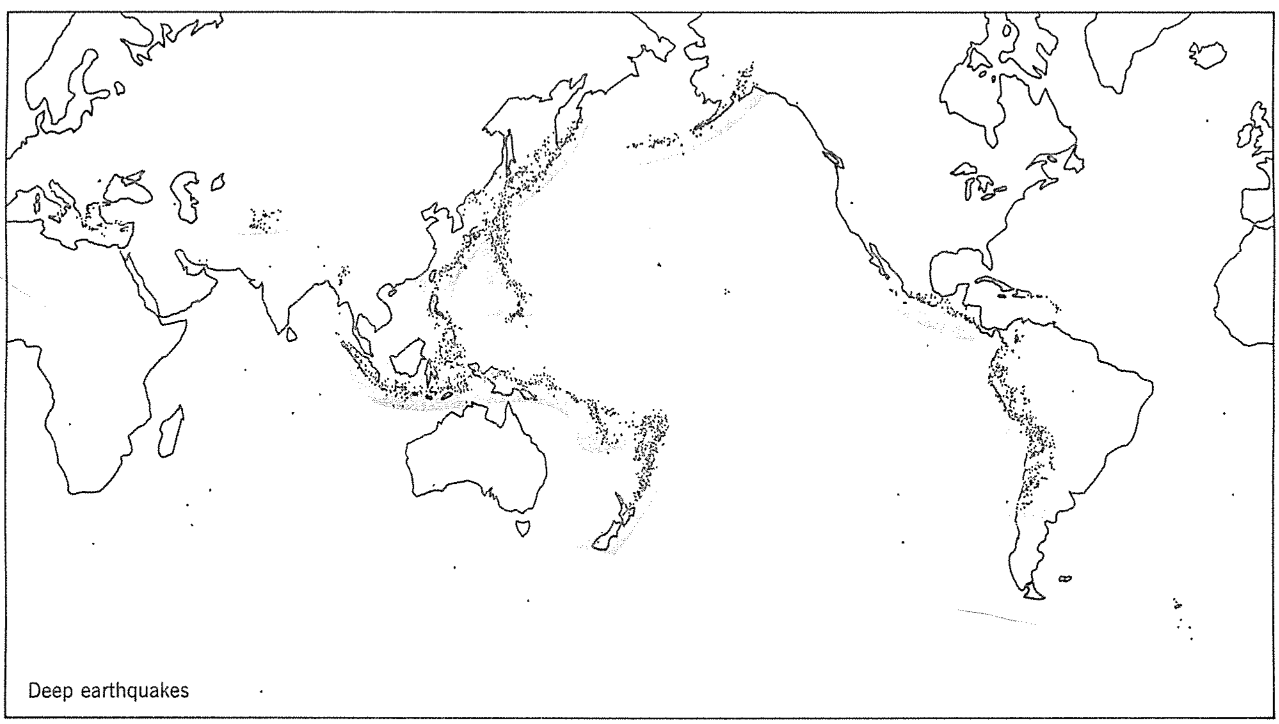
* distribution of earthquake worldwide
* map of plates... showing their motions
* earthquake risk map of the United States
* earthquake-produced waves (P and S)

earthquake hazard of Utah

* earthquake hazards and safety in Utah - definitions
* seismic safety and Salt Lake County
* strategic plan for earthquake safety in Utah



a



b

FIGURE 14.19 Epicenters of earthquakes recorded by the U.S. Coast and Geodetic Survey between 1961 and 1967. Each dot represents a single earthquake. (a) Earthquakes of all depths are plotted. Most are shallow, with foci within 100 km of the surface. The epicenters fall into well-defined seismic belts (blue shading) that coincide closely with the margins of plates of the lithosphere. (b) Epicenters of earthquakes having foci deeper than 100 km. They form belts that coincide closely with the seafloor trenches.

Teacher feedback:

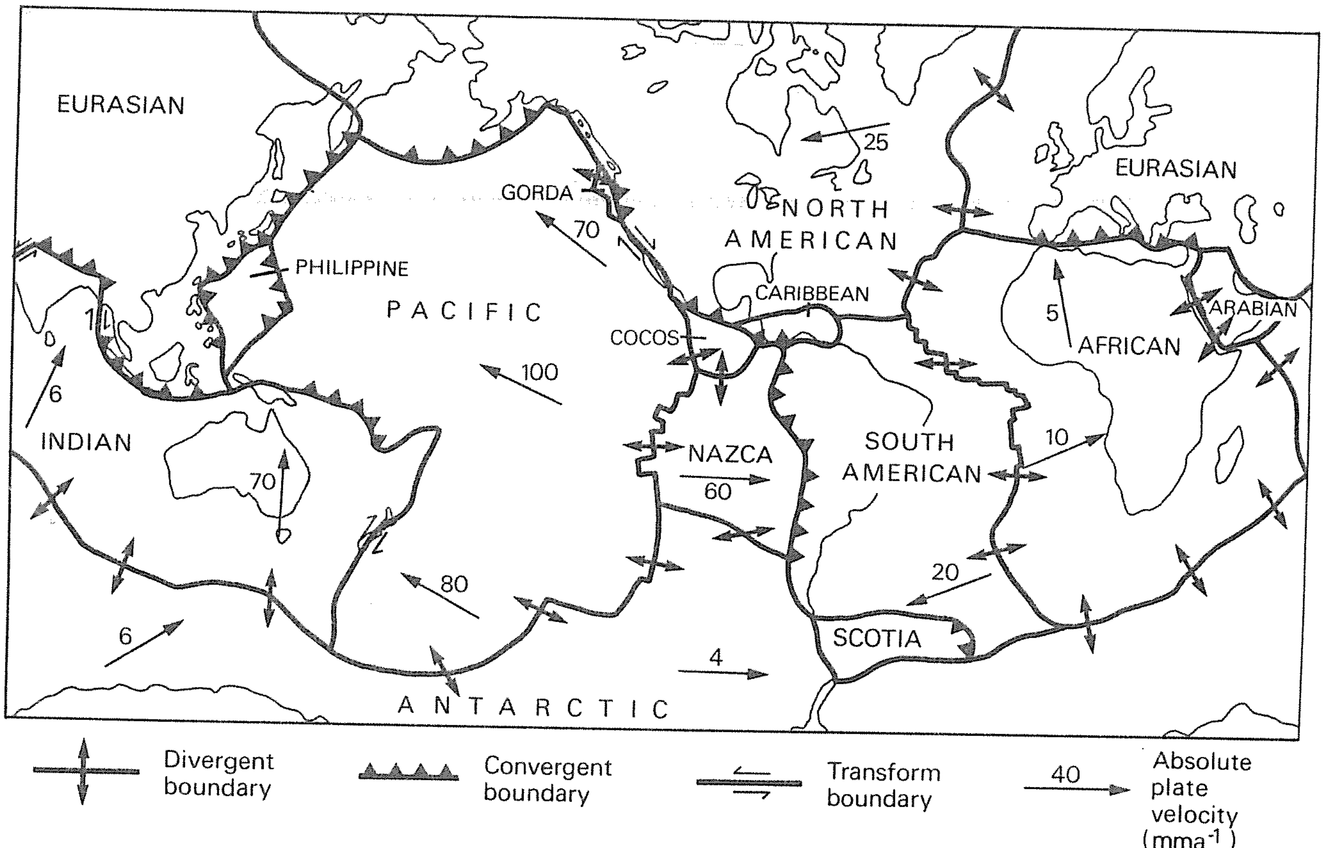


Fig. 2.14 Map of the major lithospheric plates. The various types of plate boundary are shown and the estimated current rates and directions of plate movement are indicated by arrows (rates in mm a^{-1}.)

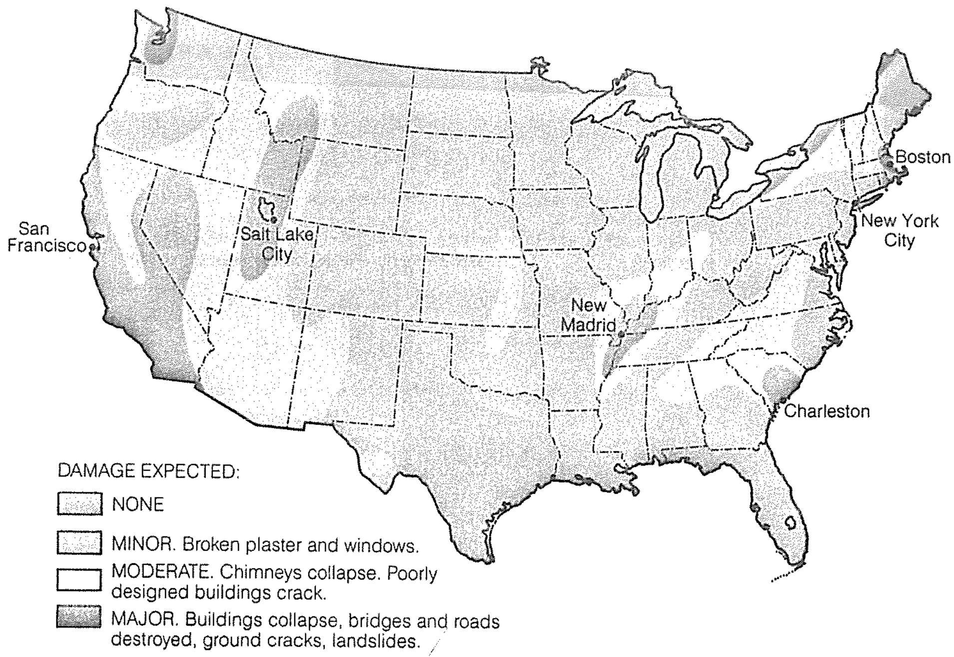


FIGURE 14.1 Earthquake-risk map of the United States. Zones refer to maximum earthquake intensity and, therefore, to maximum destruction that can occur. The map does not indicate frequency of earthquakes. For example, frequency in southern California is high, but in eastern Massachusetts it is low. Nevertheless, when earthquakes occur in eastern Massachusetts, they can be as severe as the more frequent quakes in southern California.

Teacher feedback:

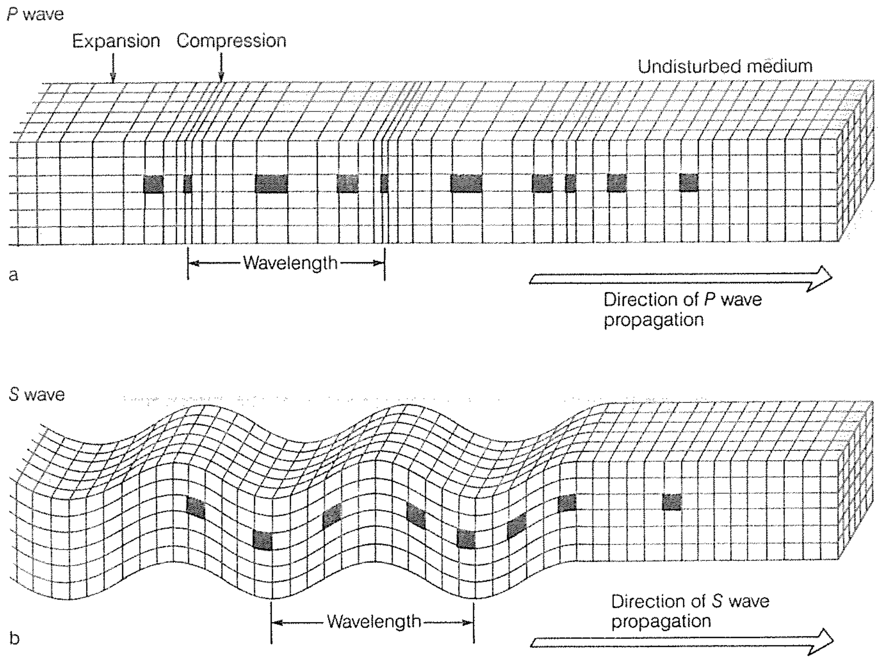


FIGURE 14.6 Seismic body waves of the *P* and *S* types. (a) *P* waves cause alternate compressions and expansions. An individual point in a rock will move back and forth parallel to the direction of *P*-wave propagation. As wave after wave passes through, a square will repeatedly change its shape to a rectangle, then back to a square. (b) *S* waves cause a shearing motion. An individual point in a rock will move up and down, perpendicular to the direction of *S*-wave propagation. A square will repeatedly change to a parallelogram, then back to a square again.

Seismic Waves

How is the energy of an earthquake transmitted from the focus to other parts of the Earth? As with any vibrating body, waves (vibrations) spread outward from the focus. The waves, called ***seismic waves,*** spread out in all directions from the focus, just as sound waves spread in all directions when a gun is fired. Seismic waves are elastic disturbances, so unless the elastic limit is exceeded, the rocks through which they pass return to their original shapes after passage of the waves. Seismic waves must be measured and recorded while the rock is still vibrating. For this reason, many continuously recording seismograph stations are installed around the world.

Body Waves

Seismic waves are of two kinds. ***Body waves*** travel outward from the focus, passing entirely through the Earth. ***Surface waves,*** on the other hand, are guided by the Earth's surface, with only a loose constraint imposed by the atmosphere and the ocean.

P Waves. Body waves are of two kinds. **Compressional** waves deform materials by change of volume in the same way that sound waves do, and consist of alternating pulses of compression and expansion acting in the direction of travel (Fig. 14.6a). Compression and expansion produce changes in the volume and density of a medium. Compressional waves can pass through solids, liquids, or gases because each can sustain changes in density. When a compressional wave passes through a medium, the compression pushes atoms closer together. Expansion, on the other hand, is an elastic response to compression and it causes the distance between atoms to be increased. Movement in a solid, subjected to compressional waves, is back and forth in the line of the wave motion. Compressional waves have the greatest velocity of all seismic waves—6 km/s is a typical value for the uppermost portion of the crust—and they are the first waves to be recorded by a seismograph after an earthquake. They are therefore called ***P*** (for ***primary***) ***waves.***

S Waves. The second kind of body waves are **shear waves.** They deform materials by change of shape but not change of volume. Because gases and liquids do not have the elasticity to rebound to their original shapes shear waves can only be transmitted by solids. Shear waves consist of an alternating series of sidewise movements, each particle in the deformed solid being displaced perpendicular to the direction of wave travel (Fig. 14.6b). A typical velocity for a shear wave in the upper crust is 3.5 km/s. Shear waves are slower than *P* waves, and reach a seismograph some time after a *P* wave arrives, so they are called *S* (for ***secondary***) ***waves*** (Fig. 14.7a).

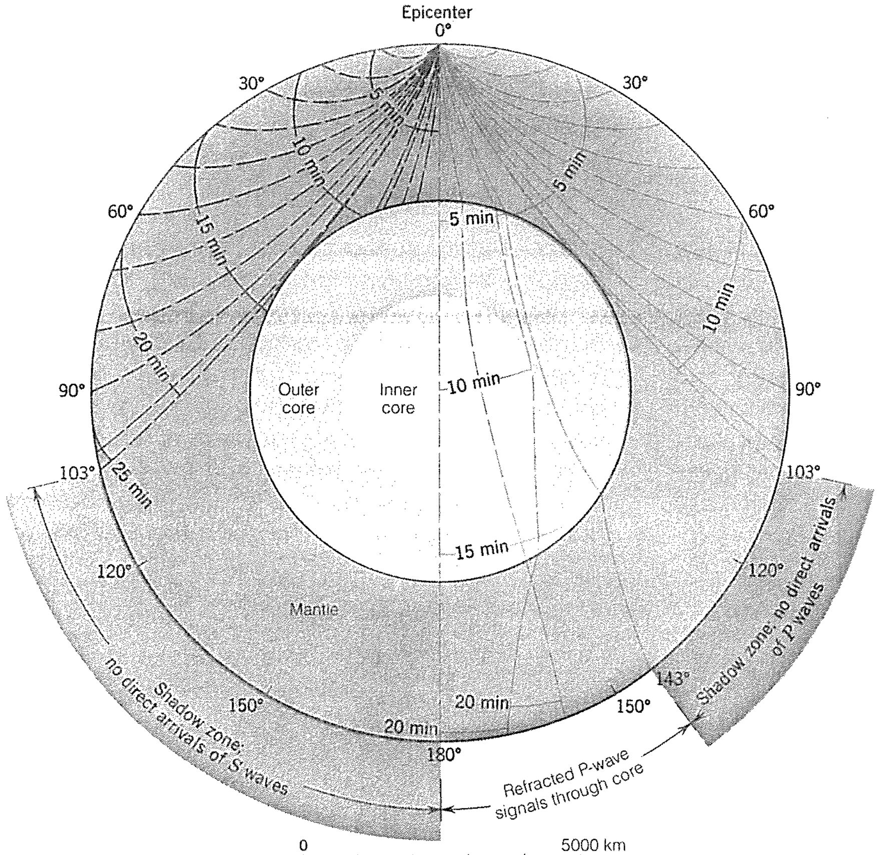


FIGURE 14.12 *P* waves radiating from an earthquake in the upper mantle. Seismographs at some places receive both direct *P* waves as well as reflected and refracted *P* waves. A *P* wave reflected off the surface is called a *PP* wave; one reflected off the core–mantle boundary is a *PcP* wave; one refracted through the liquid outer core is a *PkP* wave. *S* waves also show reflection and refraction effects.

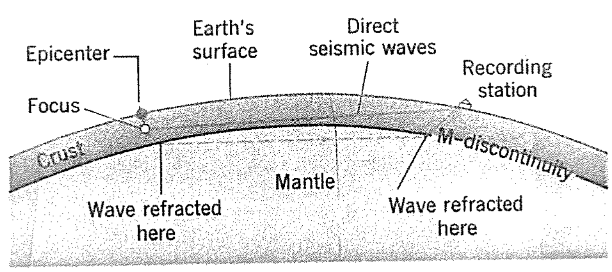


FIGURE 14.13 Travel paths of direct and refracted seismic waves from shallow-focus earthquake to nearby seismograph station.

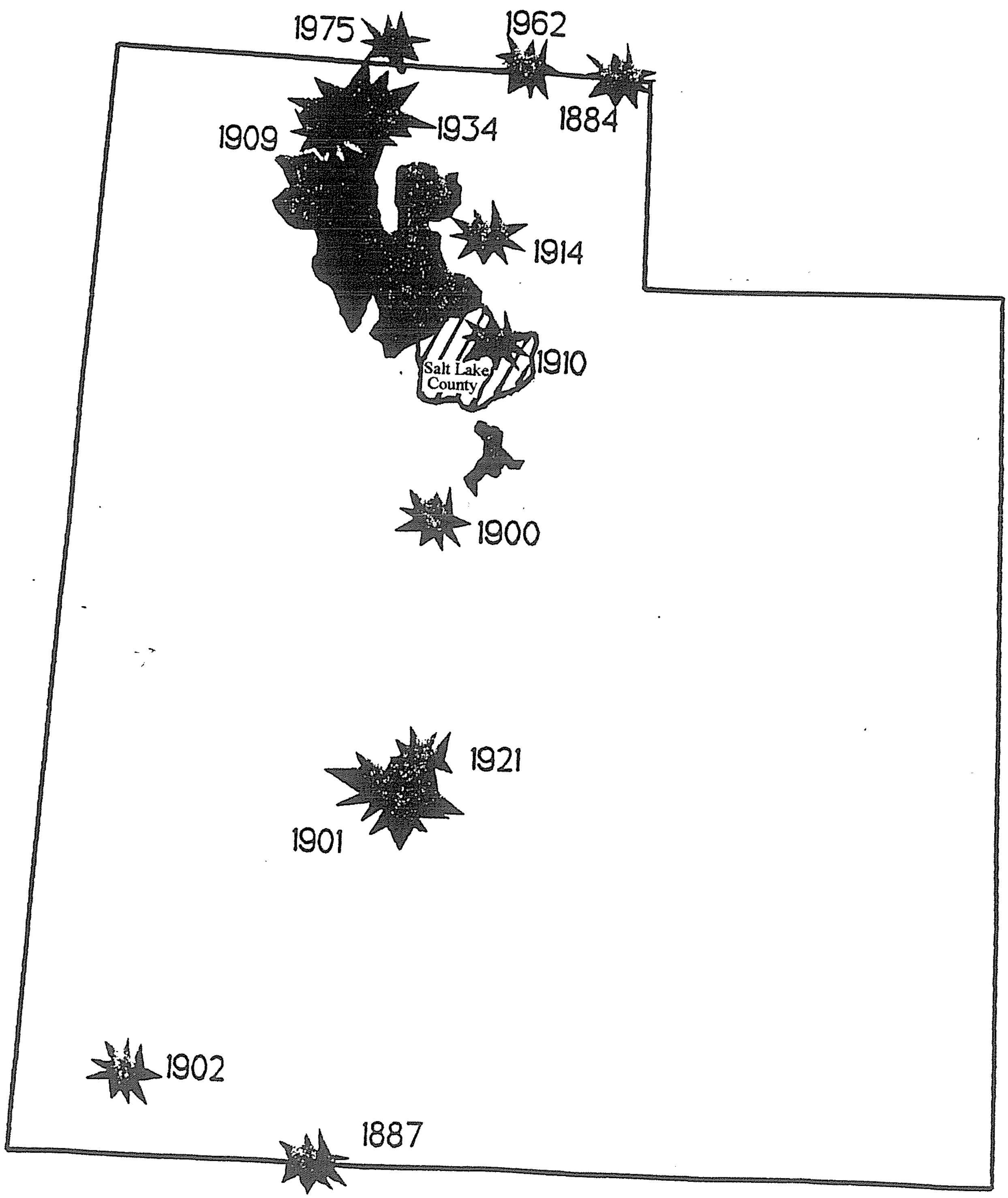
Using seismic waves to learn about the structure of the earth.

Teacher feedback:

SALT LAKE COUNTY EARTHQUAKES

by
Genevieve Atwood
Earth Science Education

(Adapted from: *Salt Lake County League of Women Voters Study Guide: Seismic Safety and Salt Lake County* by Genevieve Atwood, May 1995)



SALT LAKE COUNTY EARTHQUAKES

BY GENEVIEVE ATWOOD **Chief Education Officer, Earth Science Education**

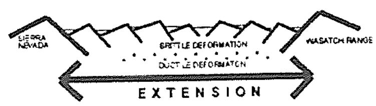
<u>(adapted from:</u> *Salt Lake County League of Women Voters Study Guide: Seismic Safety and Salt Lake County* by Genevieve Atwood May 1995)

Living in earthquake country...

A package deal: the Wasatch fault and the Wasatch Range

The Wasatch Range rises about a mile above the floor of Salt Lake Valley. The high mountains capture the precipitation and provide the water for Salt Lake County's people and industries. Salt Lake County's communities exist because of the Wasatch Range. The range also provides spectacular beauty and a variety of recreational opportunities. Earthquakes are essential to forming and maintaining the Wasatch Range and other ranges such as the Oquirrh Mountains. The difference in the elevation of the valley floor and the mountain tops has developed over the last several million years. This movement has occurred a few feet at a time. A large earthquake has accompanied each movement. The "greatest snow on earth" is brought to you thanks to the Wasatch fault zone.

Tectonics and our dynamic Basin and Range



Spreading of the Basin and Range

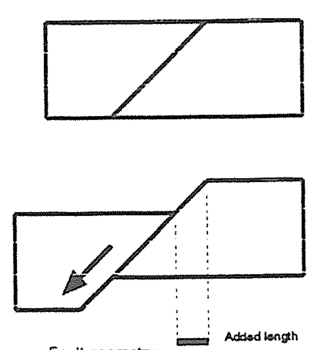
The Wasatch fault zone is at the eastern edge of the Basin and Range geological province, an area of alternating ranges and valleys that extends west about 500 miles to Reno, Nevada. This area of the earth's crust is being extended by forces in the earth and by processes referred to as tectonics. The Basin and Range province has been extending in an east-west direction for about the last seventeen million years. Today the distance between the Wasatch Range and the Sierra Nevada may be twice what it was at the start of the extension. Orbiting satellites have actually measured the change in distance from the mountain tops east of Salt Lake to the mountain tops west of Reno. The rate is about the rate that your fingernails grow. Research shows that much of the extension over the last few million years has been accommodated along the Wasatch fault zone.

Earth structure: brittle vs. ductile processes

The outer-most part of the earth's crust is "brittle"... it is solid rock. The next layer is taffy-like. This lower part of the earth's outer crust deforms in a "ductile" mode, stretching without breaking. It stretches and periodically the outer layer has to catch up. The outer, brittle, layer of the crust can't stretch without breaking. As Reno and Salt Lake have been stretched apart, the outer, brittle crust has accommodated the movement by breaking into a series of blocks elongated in a north-south direction. The breaks are faults. The movements of the blocks along the breaks produce earthquakes.

Fault geometry: how movements on faults lengthen earth's crust

The breaks that separate the blocks are not vertical. The movement of one block down and away from its neighboring block lengthens the outer crust and allows it to catch up to the underlying, stretched, ductile crust. The downdropped blocks, because they are lower, become valleys such as our Salt Lake Valley and the various depressions that contain Great Salt Lake. They partly fill with materials eroded from the mountains. The blocks that remain high become mountain ranges such as the Wasatch Range, Antelope Island, and the Oquirrh Mountains.

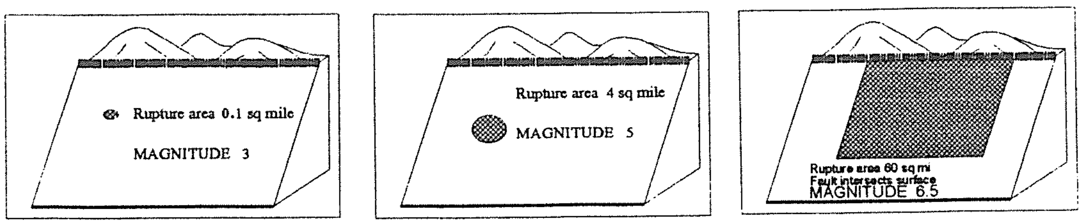


Fault geometry

Caution: Many people see high mountains and low valleys and assume the mountains are lifted up. Some are. Many aren't. It only takes a **relative** difference in height to make a mountain. Most of the mountains of the Basin and Range are formed by dropping the basins rather than by uplifting the mountains.

Energy release: why small vs. big earthquakes

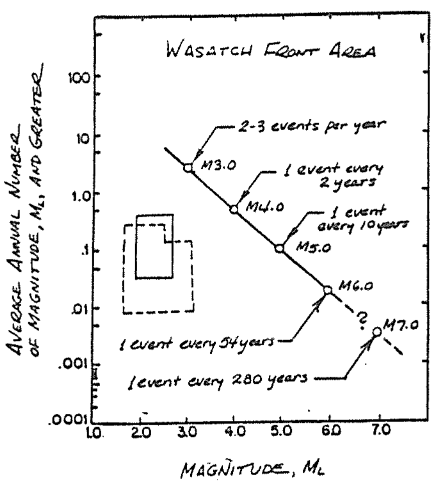
The movement along the faults, the boundaries between the blocks is not continuous. As the brittle crust is stretched, strain accumulates across the fault until movement occurs and releases the pent-up energy. In some areas of the earth's crust, the strain builds up only a little and is released as small earthquakes. Along other boundaries, considerable strain builds up and is released suddenly as a large earthquake. The amount of energy released by the movement along a fault is a function of how far the blocks move with respect to each other and how much of one block moves with respect to the other block. The following diagrams show why even a magnitude 5 earthquake does not rupture the ground. Fault scarps (the surface expressions of faults) record **big** events and are convincing, visible evidence of Salt Lake County's earthquake hazard.



adapted from Arabasz and Mabey

Recurrence: when to expect small and big earthquakes

Earthquakes that concern Salt Lake County residents can be grouped into three general categories... small, medium, and large intensity. Intensity is a subjective measure of the severity of ground shaking in an earthquake based on observations of the effect on objects and humans versus magnitude which is the measurement of the energy released at the origin of the earthquake.



from Arabasz and Mabey

Every few decades small local earthquakes or relatively large earthquakes that originate outside of the county cause damage totaling thousands of dollars.

Every hundred years or so: moderate size earthquakes that originate in Salt Lake County or greater magnitude earthquakes from somewhere in northern Utah result in emergency conditions, cause damage totaling millions of dollars, and disrupt transportation and services in parts of the county.

Every few hundred years: a highly destructive earthquake will devastate areas of the county and cause billions of dollars of damage. This large earthquake will probably originate within Salt Lake, Utah, Davis, or Weber County. Damage will extend into adjacent counties. Lives will probably be lost. Many people will need shelter. Transportation and other services will be disrupted and may not be restored for days for weeks.

Caution: Earthquakes do not occur at regular intervals and Wasatch Front earthquakes cannot be predicted with our present state of knowledge. Geologic evidence indicates that over the last few thousand years a major earthquake has impacted the Salt Lake County area on the average of once every few hundred years -- 450 years is a reasonable number for hazard assessment. We are not "overdue" for an earthquake. Destructive groundshaking could happen today, next year, or hundreds of years from now. It is a question of ... not "if" but "when".

What to expect: Borah Peak earthquake, 1983, our design earthquake

Geologic events repeat themselves. Faults appear to have "characteristic" earthquakes. For example, movements along the Salt Lake segment of the Wasatch fault appear to happen less often but cause greater magnitude earthquakes than along the Provo segment of the Wasatch fault. California's earthquakes differ from ours. The Borah Peak earthquake in east-central Idaho in 1983 occurred in a geologic setting similar to the Wasatch Front and it provides information on what Salt Lake County should expect from an earthquake on the Wasatch fault.

What to expect: Direct versus indirect effects
Earthquakes almost never kill people directly. The direct effects (ground shaking, surface rupture) occur during a period of at most a few minutes following the start of the earthquake. The indirect effects (building collapse, ground failures, hydrologic effects) can occur during the earthquake or for several days after. People get killed by collapsing construction... walls, ceilings, freeway bridges and by tidal waves and landslides.

Ground shaking is the most widespread, pervasive, and destructive effect of earthquakes. GROUND SHAKING causes the collapse; therefore GROUND SHAKING is OVERWHELMINGLY Salt Lake County's greatest earthquake hazard.

Why?
Buildings are designed to resist gravity and wind. Gravity pulls structures vertically. Energy waves caused by earthquakes move buildings sideways, "laterally". As the structure attempts to move laterally with its foundation that is moving in response to the earthquake waves, it is subject to lateral forces much greater than those generated by wind and may collapse. Very large earthquakes cause lateral accelerations that nearly equal the vertical force (acceleration) of gravity. Think of it as expecting a building to stay intact if it were pulled and pushed laterally with the same force as gravity.

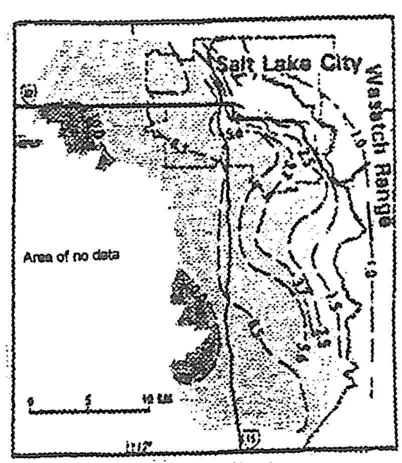
Caution: The goal of incorporating seismic resistance in buildings is to save lives... to prevent buildings from collapsing. A seismically resistant building may be so damaged that it needs to be replaced, but its occupants should not be killed or injured by its failure.

Key concept: Ground shaking occurs everywhere in the vicinity of moderate and severe earthquakes. It is unavoidable... but its consequences can be mitigated.

The Mexico City effect
The structure of valleys and the nature of unconsolidated sediments they contain can greatly amplify motion of the ground at some periods of motion. Buildings act like tuning forks. They have their own periods of motion. Engineers are trained to avoid designing buildings that have approximately the same period of motion as the motion of the ground caused by an earthquake.

This map of only a portion of Salt Lake County shows how shaking in the central part of the valley can be 10 times that of the foothills. It is based on recordings of very slight shaking in the valley caused by nuclear tests in Nevada and from blasts at Kennecott's Bingham Copper Mine. This type of map is most difficult to generate for severe shaking expected from large earthquakes because we don't have large shakes often and we have barely begun to deploy the type of equipment that measures strong ground motions. Ground shaking maps for large earthquakes have not been developed for any Wasatch Front county... but they would be very useful for building codes and seismic design.

Note: The renovation of the City and County Building included the installation of the equivalent of shock absorbers underneath the foundation to damp the motion from earthquake waves. This "base isolation" has been built into some new construction such as at least one of Evans and Sutherlands' buildings at Research Park.



Site amplification. (Adapted from Hays.)
Contours indicate amplification of ground motion.

Surface Rupture

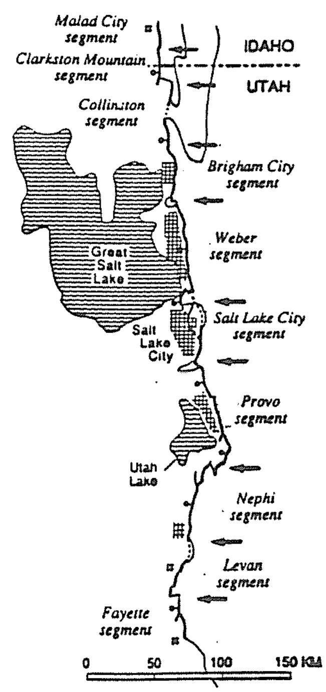
Fault rupture captures the public's imagination. It is the most dramatic and, in the area of deformation, the deformation zone, the most destructive direct effect of earthquakes. It is more easily understood than other earthquake effects because it can be seen, photographed, and easily described. Hospitals, schools and other essential public buildings should avoid Salt Lake County's fault rupture zones. Some essential lifelines such as Interstate freeways, transmission, gas, and water lines cannot avoid fault rupture zones if they enter the Wasatch Front from the east.

Many people imagine surface rupture as a snapping motion of the earth that captures innocent children and unsuspecting animals. This makes great movies, but reality will be sufficiently exciting. Imagine ... the valley from Point of the Mountain, continuing along the fault zone that hugs the foot of Wasatch Range through Draper and Sandy, then in Holiday and Cottonwood area stepping into the valley and following Wasatch Boulevard and 1300 East all the way to the Avenues ... dropping 8 to 20 feet, like unzipping a very long (20 -25 mile) zipper in about one minute.

Caution: That image is so captivating it is hard to remember that fault rupture at any site in an active fault zone is an infrequent event. The Wasatch fault is one of the more active faults zones in the world, but fault rupture occurs at a site in the fault zone on the average of only once every 2000 to 4000 years. Thus, if a structure with a 100-year life is built in the fault zone, the probability of its being affected by fault rupture is less than five percent.

Salt Lake County fault zones

Two active fault zones have been identified in Salt Lake County. "Active" means the fault has moved in the last 10,000 years. (Note that we assume that future movements will occur where they have in the past... and that is a good general assumption, but geologists recognize that other faults also are capable of generating large earthquakes.) Both of the active fault zones trend generally north - south, parallel to the mountain ranges. The West Valley fault zone, near the center of the valley, drops the valley to the east down (making the Oquirrh Mountains higher relative to the valley). Although individual faults in the West Valley fault zone are easy to identify if you know where to look and what to look for, the fault zone is not an impressive topographic feature. The Wasatch fault zone along the east side of Salt Lake Valley is one of the premiere faults in the world. The Wasatch fault (actually a zone of many faults) extends for about 200 miles along the east side of the Wasatch Range. Our segment is called the Salt Lake segment and our best geologic judgment is that it ruptures independently of its neighbors... i.e. the Weber-Davis segment will not rupture at the same time as the Salt Lake segment.



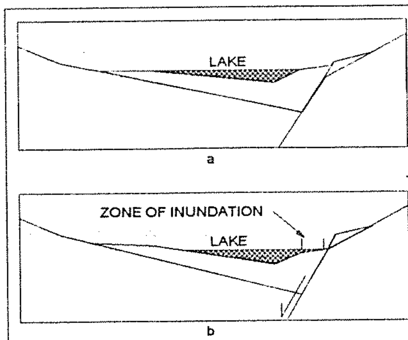
from Arabasz and Mabey
source: Machette and others

Caution: Remember to think of the Wasatch fault as a surface, not a line. It angles down and westward for miles from its surface expression along the East Bench and mountain front. It dives deep under Salt Lake Valley to the general area that earthquakes begin... the boundary of the earth's crust between ductile and brittle deformation. This puts the location of where a large earthquake starts several miles (5 or so miles) underneath the west side of the valley. Earthquakes that have occurred under Magna and Herriman may be on the Wasatch fault.

And... Remember: Avoiding the fault zone does not avoid the **greatest earthquake hazard, ground shaking**. Although the destruction is intense in the zone of surface fault rupture the area of the zones is small relative to the areas affected by ground shaking. In a typical large earthquake on a segment of the Wasatch fault, a zone of about two square miles in area would be affected by fault rupture while a zone of several hundred square miles would be subjected to **intense** ground shaking and an area of several thousand square miles would be subjected to **damaging** ground shaking.

Other earthquake effects

Tectonic tilt. When movement occurs along a fault such as the Wasatch fault, the down-dropped block is usually tilted toward the fault. The measured deformation on the down dropped block in the Borah Peak earthquake was about 3 feet and in the Hebgen Lake earthquake was about 20 feet. At Hebgen Lake several miles of the lakes shore line was permanently depressed below the normal water level of the lake and several miles emerged above the previous water level. Similar deformation in Salt Lake Valley could have serious consequences. A change in the slope of the lands surface could seriously impact bodies of standing water such as Great Salt Lake and low-gradient sections of sewage systems. The extent of the change in the area inundated by Great Salt Lake will depend upon the elevation of the lake and the amount of tectonic deformation that occurs.



TECTONIC TILT DISPLACING LAKE

Ground failure. Landslides, earthflows, debris flows, and rockfalls are a suite of geologic hazards where gravitational forces often with the assistance of water overcome frictional resisting forces and masses of material move downslope. Utah has many kinds of ground failures under static conditions without the jolt of an earthquake. The ground motion and shifting hydrologic conditions of earthquakes exacerbate the potential for ground failures. A dramatic example of the destructive power of earthquake-triggered landslides occurred in the Hebgen Lake earthquake when a large rock landslide in the Madison River Canyon dammed the river and covered a campground where 28 people were killed including 12 Utahns.

Liquefaction is a special kind of ground failure. Much of the damage in Kobe, Japan was from liquefaction. Liquefaction occurs when water-saturated unconsolidated sediments, usually with a large sand content, are subjected to shaking and turn into quicksand. The result may be the loss of ability to support or contain structures above or within the liquefied zone or the failure of slopes underlain by the liquefied sediments. The slope failures may be lateral movements spreading on gentle slopes or the triggering of landslides or debris flows on steeper slopes. Buildings or other structures can tilt, pipelines rupture, buried tanks rise to the land surface, and roadways, railroads, runways, canals, dikes, and dams shift. Large areas of the valley floor of Salt Lake Valley are susceptible to liquefaction, particularly those at low elevations along Great Salt Lake. Extensive development, which has largely ignored the hazard, has already occurred on areas susceptible to liquefaction and development of these areas is likely to continue.

Hydrologic effects. Earthquakes cause widespread and long lasting changes to regional ground water hydrology. Some of the hydrologic effects are closely related to liquefaction and are sometimes considered as liquefaction phenomena. Hydrologic effects are poorly understood and difficult to predict. The 1983 Borah Peak earthquake in east central Idaho provides the best information available on the hydrologic effects that might result from a major earthquake on a segment of the Wasatch fault. This earthquake had a significant effect on the geothermal systems in Yellowstone National Park 150 miles east of the epicenter. In the vicinity of the earthquake epicenter, ground water erupted from fractures, and altered the flow of springs, wells, and water in mine workings over an area of hundreds of square miles with corresponding major changes in stream flows. New springs developed and some stopped flowing. Hydrologic changes comparable to those observed in the Borah Peak earthquake may result from a major earthquake effecting Salt Lake County, but even the approximate nature or extent cannot be predicted. Serious effects will likely be on the floors of valleys underlain by confined aquifers. In addition to the hydrologic changes, water wells may be damaged or destroyed by an earthquake.

Significant water waves may be generated on large lakes and reservoirs as well as the permanent change in water level of lakes and reservoirs caused by tectonic tilt described earlier. The 1909 Hansel Valley earthquake caused a wave on Great Salt Lake that overtopped the Southern Pacific Railroad Causeway and the beach houses pier at Saltair. Such a wave will likely cause the water level in the lake to oscillate (with decreasing amplitude) for several days. In the 1959 Hebgen Lake earthquake several oscillations of waves overtopped the dam that formed the lake, but the dam did not collapse.

Other construction- related hazards:

Dams and water impoundments: No major dam upstream from Salt Lake County has been identified as likely to fail as the result of an earthquake. The US Bureau of Reclamation has made seismic safety a major factor in the design and construction of the Jordanelle Dam on the Provo River and is convinced that it will not fail in any earthquake that is likely to occur. Older dams designed and built by the Bureau of Reclamation were not built to the same seismic standards, and the Bureau has a program to evaluate the seismic safety of these dams and take remedial action if necessary. Some dam constructing organizations in Utah have had less concern for seismic safety and less expertise to cope than the Bureau of Reclamation. Hundreds of smaller water impoundment structures, water tanks, canals and other water conveying systems have been constructed, many without significant concern for seismic resistance.

Caution: the "high risk" category for a dam refers to the size of the dam and downstream development, not the engineering or geologic conditions of the dam.

Fire: In the 1906 San Francisco earthquake, the property damage from fires that burned for three days following the earthquake accounted for over 90% of the damage. Many earthquake fires start when a short of an electrical circuit or a pilot light ignites gas from a ruptured gas line (so make sure your water heater won't tip over and rupture the gasline). Salt Lake County's wide streets will reduce the spread of fire. Even so, fires remain a potential cause of significant damage following a major earthquake.

Chemical spills such as spills of petroleum and other products, toxic chemicals and waste, resulting from damage to tanks and pipelines: Petroleum refineries have huge volumes of spillable fluids. Even small laboratories use and store significant volumes of toxic material. Ground shaking Can topple and break containers of all sizes.

Earthquakes and Salt Lake County –
What we know and how we know it:

Our knowledge of the earthquake hazard in Salt Lake County comes from three primary sources: 1- earthquakes that have occurred elsewhere, 2- studies of geology and related phenomena in Salt Lake County and adjoining areas, and 3- theoretical studies.

Almost every major earthquake anywhere in the world contributes something to the understanding of the earthquake hazard in Salt Lake County. What happens to soils and buildings in an earthquake in California or Japan provides an indication of what might happen to soils and buildings in an earthquake of similar intensity in Salt Lake County. The large earthquake in central Idaho (Borah Peak, 1983) and in southwest Montana (Hebgen Lake, 1959) have been particularly important because their geologic conditions are more similar to the Wasatch Front than the geology along the Pacific Ocean's margin.

Geologic studies in and around Salt Lake County provide conclusive evidence that large earthquakes have occurred in the past. Trenching across faults gives a good indication of how often earthquakes have occurred on those fault and their magnitude. Seismic recordings obtained in the last thirty years by the University of Utah Seismograph Stations provide data on the frequency, depth, location, and structures associated with small and moderate earthquakes in the Intermountain region. Geologic mapping, sample analysis, geophysical studies, recordings of the ground motion of seismic waves generated by large explosions such as nuclear testing in Nevada and timed mine blasts at the Bingham Copper Mine provide an indication of ground response to earthquakes in different parts of the county. The deformation that is the ultimate cause of earthquakes is actually being measured.

Theoretical studies, many by the US Geological Survey and universities including the University of Utah, of the mechanisms of earth movements (tectonics) indicate how when and where earthquakes in and around Salt Lake County originate, how the seismic energy they generate is propagated, and the kind of motions produced at the earth's surface. Materials, structural, and civil engineering research in the United States and Japan has greatly enhanced the knowledge and professional standards for construction.

STATUS OF UNDERSTANDING

Frequency and magnitude of large earthquakes impacting Salt Lake County

known: Moderately well known for earthquakes on the Wasatch fault and West Valley fault zones.
Information is adequate to determine recurrence interval and magnitude of large earthquakes with sufficient accuracy to develop mitigation strategies.
Available in publications and maps.

unknown: Other faults may exist that are capable of producing high intensity earthquake effects in Salt Lake County.
Additional studies will likely reveal more events and increase the estimates of the earthquake hazard.

Fault rupture hazard

known: Major fault rupture zones active in the last 10,000 years are well defined and some older fault rupture zones are partly defined.
Available in publications and maps.

unknown: Older fault rupture zones that may be reactivated in future earthquakes have not been defined. Trenching and excavation studies will likely define such zones.

Ground shaking hazard

known: Ground shaking will occur everywhere in Salt Lake County in a large earthquake and the hazard of groundshaking associated with areas underlain by thousands of feet of unconsolidated saturated sediments of Salt Lake Valley is recognized.

unknown: The quantitative measure of the likely intensity of ground shaking at individual sites in the county is not known. Unlike California which has many earthquakes and a well-funded program to delineate strong ground motions, Utah does not have the information needed by engineers in Salt Lake County to design structures for expected ground motion.

Liquefaction

known: The general distribution of areas of Salt Lake County susceptible to liquefaction in an earthquake have been defined.
Available in publications and maps.

unknown: Liquefaction hazard at specific sites. Site investigations are required to make this determination.

Ground failure

known: Many landslide prone areas have been identified as part of the state's effort to map Utah's geologic hazards.
Available in publications and maps.

unknown: Slopes that have not previously failed but might fail in future earthquakes have not been identified.

Tectonic deformation

known: Tectonic tilt of the bed of Great Salt Lake and the floor of Salt Lake Valley could be a problem particularly in areas of low surface relief in the northwestern Salt Lake County.

unknown: The magnitude of the tilt and the facilities that might be impacted has not been defined.

Hydrologic effects

known: Only the flooding by Great Salt Lake associated with tectonic tilt has been investigated.

unknown: The possible effects of a large earthquake on the surface and ground water in Salt Lake County have not been investigated. This is a difficult problem.

Accolade and Good News: Your County Geologist is located in the Salt Lake County government complex in the County Planning Department. Several earthquake related maps are available from them as well as the County's (not cities') hazards ordinances. This is a wonderful resource for individual home owners, realtors, and developers.

Scenario for Salt Lake County... major earthquake disaster

General conditions that are likely to exist following a major earthquake:

* Many people will be injured requiring a wide range of medical care.
* People may be trapped by collapsed buildings and other structures and require immediate rescue efforts.
* Thousands of residences will be destroyed or damaged to the extent that they are uninhabitable and may be hazardous. Thousands of people will be without shelter.
* Many buildings and other facilities will be damaged interrupting normal employment and the and the delivery of services.
* Interruptions of delivery systems of water, electricity, and natural gas will be widespread and telephone service will be interrupted. Many days will be required to restore all of these systems.
* Normal sources of food and other supplies may not operate and businesses such as banks may not function.
* Transportation within and into areas most severely impacted will be disrupted as roads are blocked by falling debris, landslides, and bridges and overpasses that have failed or are damaged.
* All emergency response capabilities will be overtaxed.

Effect of season, time of day

The loss of life and injuries will be substantially less if the event occurs when most people are at home and the problem of reuniting families also will be minimized. The problems of providing emergency housing will be much less if the weather is mild.

Some of the physical impacts of a major earthquake will depend on conditions existing at the time of the earthquake. The severity of snow avalanches and their impact will depend on the extent and nature of the snow cover. The potential of water in lakes and reservoirs to cause damage will depend on the water levels. Ground failure will be influenced by soil moisture and the level of the ground-water table. The volume of water flowing in streams and rivers will determine the danger from damming and diversion. The potential for the earthquake to cause injury and loss of life from the failure of several types of structures is strongly dependent on the time that the earthquake occurs. Many buildings, such as schools, that at times contain many people are vacant or nearly vacant much of the time. This contrasts with buildings such as hospitals and jails that are continuously occupied. The loss of life from the failure of bridges and overpasses is greatest during periods when travel is heaviest.

Loss estimates

Decisionmakers want to know the consequences of earthquakes... the probable consequences during a given period of time and also worst case consequences. Earthquake loss estimations combine data on the intensity and frequency of earthquakes with population, economic, and construction information to calculate losses. Developing probabilistic loss estimates and scenarios for specific earthquakes on specific faults was one of the five major elements of the state's earthquake program with the US Geological Survey during the 1980s. The goal was to involve cities and counties in collecting and updating information that would show which actions would and would not do the most to reduce losses from earthquakes. Loss estimation models can also be used to monitor the progress of loss reduction programs.

Loss estimations studies, particularly worst-case loss estimates, have been effective in increasing the general awareness of the earthquake hazard in Salt Lake County. The 1976 US Geological Survey report of loss estimates that indicated that a major earthquake would kill 2300 people, seriously injure 9000, and leave 90,000 homeless attracted the attention of legislators and led to the creation of Utah's 1977-81 Seismic Safety Advisory Council. That report's estimates of damages to hospitals contributed to improving the seismic safety of Salt Lake County hospitals. More recently (1988), the US Geological Survey estimated that a major earthquake on the Wasatch fault would cause $5.5 billion dollars in damage to buildings from ground shaking and that over 70 percent of the losses to dwellings from ground shaking would involve masonry construction.

Example of the dilemma:

However, loss estimation models based on likelihood of earthquake events, i.e. that include probabilistic modeling, do not appear to guide major decisions on actions to reduce earthquake losses. For example, the decisionmaking process on retrofitting Salt Lake County Schools to provide seismic resistance appears to be something like this: the "worst case" major earthquake that will occur every few hundred years will damage schools, some students in the damaged schools will be killed or injured; therefore millions of dollars should be spent immediately to retrofit schools to make them safer in an earthquake. A loss estimation model that includes probabilities of such an event as well as the effects of more likely earthquakes would provide a quantitative estimate of the risk facing the students. Decisionmakers would then have to evaluate the effectiveness of several possible strategies of retrofitting and phasing out high risk school buildings factoring in student exposure to earthquakes. If a student attends school for eight hours a day for 180 days each year, the chances are one in six that the student will be in the school when the earthquake occurs. If an earthquake of the size concerned is expected every 450 years, only once in 2700 years will the student be in the school when the earthquake occurs. The calculation would be quite different for a facility that is continuously occupied, such as a hospital. Also factored in would be the percentage of occupants expected to be killed and injured. A study of state owned buildings in Salt Lake County estimated that in a major earthquake three percent of the occupants of these buildings would be killed and an additional four percent seriously injured. Similar estimates could be made for Salt Lake County schools, and a quantitative estimate of the exposure of a student spending thirteen years in the school system computed. In April, 1995 a frustrated Salt Lake County parent was quoted in the newspaper as saying; "The school district doesn't know what they're doing. They worry about the school falling down in an earthquake, but they walk our kids across dangerous streets." Loss estimation models provide a way to compare the effectiveness of investing in earthquake risk reduction programs to protect children as opposed to investing in other programs designed to protect children from the many hazards that threaten them.

Impact of a major damaging earthquake on individuals in Salt Lake County

A large destructive earthquake can be a traumatic experience for those involved. In a few seconds family members or friends may be killed or seriously injured; homes, churches, schools, or business may be destroyed or severely damaged; the very earth that has seemed stable for a lifetime may have been significantly changed. In addition to life loss, injury, and the direct losses of homes and belongings from an earthquake there will be a large indirect impact. The normal functions of some businesses will be disrupted because of damage to their facilities or because access to sources of supplies, services or markets are affected by the earthquake. The length of the disruption may be short, long, or even permanent. The value of land shown to be particularly susceptible to the effects of earthquakes may be decreased.

Most people recognize that earthquakes are a natural phenomena whose physical cause will eventually be understood and that, to a considerable degree, the major impacts upon humans are the result of their own actions and can, to a great extent, be controlled. In Salt Lake County, it is significant that this position is supported by the actions of the LDS Church which builds earthquake resistance into their buildings and encourages their members to be prepared for an earthquake. The public in Utah has been moderately well educated on the earthquake hazard and most appear to have accepted earthquakes as a part of living in Utah. Most are more willing to support actions to mitigate the hazard than their representatives in the legislative and executive branches of government (USU study).

Impact on government - The demands on government following a destructive earthquake will be enormous, and damage to government buildings and equipment and injury to personnel may seriously compromise the ability to respond to these demands. The cost to government of emergency response and reconstruction will be great at a time that revenues from industry will be diminished.

Impact on industry - Some industries will be severely impacted by a destructive earthquake both by damage to structures and their contents and by interruption of supplies and services essential to their operations. The degree to which public utilities survive an earthquake and how quickly they recover will be a major factor in determining how well the entire community functions following an earthquake.

Costs resulting from these disruptions and in restoring or replacing damaged facilities may place a serious financial strain on some companies. The interruption of electrical power and communication networks will disrupt service industries that are highly automated. Skilled workers may need to be imported from other areas to assist in restoring essential services. For example, in the earthquake in the San Francisco area in 1989, employees of Mountain Fuel Supply Company were sent from Salt Lake City to the San Francisco area to help restore natural gas service. If some manufacturing industries are forced to stop production for a long period of time they may lose some of their markets as customers develop other sources of supply. Companies with financial interest in damaged structures may experience a major loss in the value of their investments.

Tourism: The impact on tourism will be mixed but on the balance negative. Some visitors will come to see the effects of the earthquake, but many will stay away to avoid exposing themselves to a perceived hazard.

Reconstruction:
Ironically, disasters are major stimulants to the construction industry and related activities. The value of some undamaged buildings will increase as will items in short supply. The recovery of Utah communities extensively damaged by an earthquake will be heavily dependent on the availability of Federal assistance. Reconstruction following a destructive earthquake offers an opportunity to develop a community that is less vulnerable to earthquakes and other natural disasters. In the past there has been significant resistance in Utah to land use planning. It remains to be seen if the experience of a major earthquake will overcome this resistance. Transportation systems may not be reconstructed as they were before the earthquake. Schools may be rebuilt in different locations with different attendance boundaries. Business and industrial developments may be located in new areas.

Role of news media
The way the local news media reports the effects of the earthquake will be important in determining how the community responses. The Utah news media responded responsibly to the emergency conditions related to flooding and debris flow events in 1983 with reporting that was factual and informed the residents of the nature of the threat. Some of the efforts by the media in Utah to inform the residents of the earthquake threat has been outstanding (for example KSL Television's production "Not If, But When"). There is reason to believe that in an earthquake disaster this responsible reporting on the part of the news media in Utah will continue.

HOW TO REDUCE LOSSES

(also see summary of State of Utah's 1995 Strategic Plan at end of this study)

An earthquake occurring 200 years ago in what is now Salt Lake County would have frightened the Native Americans in the area, but it would not have been a major threat to their lives or their livelihood. The earthquake threat to the current residents of Salt Lake County is the result of landuse and construction practices of the last 150 years. People building in the county have made a natural phenomenon into a hazard to life and property, and people can reduce the hazard to whatever degree they wish. Many hazardous areas can be avoided. We know how to build safe buildings.

Avoiding the hazards - land use planning

Earthquakes are one of several natural hazards that affect Utah. They have the potential to cause greater loss of life and property than any other of the natural hazards. However, several other natural hazards cause damage much more frequently than do earthquakes. Programs will be more effective if they take a multi-hazards approach rather than dealing with each hazard separately. Moving from a fault rupture zone into the path of a debris flow is not a wise action. Generalized geologic hazards maps have been published for the state of Utah. Counties and most urban areas have more detailed information available from the county planning department. Industry and individual property owners should know the geologic hazards of their property. Disclosure of geologic hazards information is not presently (and should be) virtually automatic in land transactions.

Land use planning and zoning, based on a good definition of all the natural hazards, and an informed public are the ways to incorporate avoidance of hazardous areas for earthquake hazard reduction. Many geologic hazards involve well defined areas that are small relative to the total area that is available for use. Fault rupture zones can and should be avoided for many kinds of development. Most landslides also can and should be avoided for development. Ground shaking is a pervasive hazard and cannot be completely avoided by utility lines, Interstate freeways and other lifelines. However, the intensity of shaking at frequencies that are particularly destructive to engineered structures varies considerably with location. In selecting sites for structures, avoid areas whose most intense shaking is that which is most destructive to the structure.

Large areas of the valleys of the Great Basin are vulnerable to liquefaction. Excluding all of these areas from development is not an acceptable loss-reduction strategy. Construction in areas of high and moderate liquefaction potential should consider special design and construction practices that have proven effective in protecting buildings. Hazards associated with tectonic tilt cannot be avoided but some construction that has been proposed would vastly increase the risk. Diking and developments such as Lake Wasatch must factor in tectonic tilt, ground shaking and ground failure by liquefaction as part of study plans and meet the same standards for water impoundment as dams.

The likely effects of an earthquake on the subsurface hydrology and the impact on springs and stream flow are not well enough understood to develop a strategy to mitigate these effects. The primary strategy to reduce the hazard from dam failures should be to minimize the possibility of major dams failing rather than avoiding the areas that would be inundated. In the development of sites near small dams, water tanks, and areas where large petroleum or chemical spills might occur, avoiding areas that might be impacted is a valid loss reduction strategy.

Minimizing the hazards - construction practices

Salt Lake County is no different than any of the communities that have been hit by major earthquakes in the last decade. For example, in Kobe, Japan buildings and structures built to modern codes and modern standards (post 1970) performed well under difficult conditions. Those that were not built to withstand earthquakes with modern construction techniques were those that collapsed or toppled. Internationally, there is consensus that engineers and architects can build structures that are safe, and generally the cost is an additional 1 to 2%.

State, county, and municipal government agencies are responsible for adopting and enforcing building codes and for zoning, subdivision, and retrofitting ordinances. Federal agencies control or influence a substantial part of the construction in Utah. State government funds millions of dollars of construction each year. Our state government has the responsibility of leadership as well as regulation of many engineering practices. For example, state government should identify geologic hazards when selecting sites and require highest professional standards for state facilities' design and construction. To some this is a controversial statement and can be summarized as: should state funded construction build to the minimum standards of Seismic Zone 3 or build to Seismic Zone 4 standards?

The evidence is conclusive that structures built to conform to UBC seismic zone 4 standards will perform substantially better in a large Wasatch Front earthquake. A large majority of the scientists familiar with the earthquake hazard in Salt Lake County have concluded that the Wasatch Front region should be reclassified from seismic zone 3 to 4 and construction, public and private, meet those criteria. Some practitioners argue that large earthquakes are so infrequent that that the extra cost of construction is not justified. Should state government build to the higher standards?

The state of Utah has not set a good example in siting and construction of facilities financed with state funds. The record of local governments is mixed. For example, school construction is exempt from normal building inspections. The cost of retrofitting most buildings (upgrading them later) can approach or exceed the cost of building a new structure. Retrofitting is even more controversial than building to Seismic Zone 4 standards because the knowledge base of how to retrofit older buildings is not as extensive and has not had rigorous testing by large earthquakes.

Caution: Utah is not California. We can learn much from California's experiences but California's earthquakes are much more frequent. Not all actions taken in California can be justified in Utah. However many actions can be taken without undue expense.

An accolade: Geneva Steel designs and upgraded its facilities to Seismic Zone 4. Says President and Chief Operating Officer, Robert J. Grow in the 2/26/95 Salt Lake Tribune: "We probably have more experience than any industry in Utah on the cost of upgrading to zone 4. The cost to any one project never exceeded 1.5% and the average cost was one-half to three-quarters percent. ... Stronger design is just not very expensive."

Personal preparedness

The Utah Division of Comprehensive Emergency Management provides excellent speakers and materials for preparedness, 538-3770. Here are my suggestions: personalize personalize and personalize. Think about your house, your family, your job, your neighborhood. What will be YOUR responsibilities. If you live in Salt Lake County and commute to Bountiful, you may need to walk home. Stash some sneakers in your desk at work so you can. Will you participate in rescue efforts? If so, you may want to stock up now with leather gloves. I will want to take photographs of short-lived geologic phenomena... I have a storage program of film. Look around your house. If you can't stand your great-aunt's china, put it at the very top of an open hutch and maybe you won't have to keep it forever. Walk around your house... what is heavy or tall that could cause your problems. I have stabilized a grandfather's clock by screwing the sounding board into a stud. If you have a food storage program, make sure it is not in wobbly metal bookshelves that will dump two years of peaches, cherries and other bottled items onto the floor. Do the obvious... the most important single action is to make sure your water heater won't tip over and rupture the gas line. Establish someone outside the area to be your contact person and your news disseminator. Take your 72-hour kit seriously... any special medicines? how about a favorite toy for your child. Personalize personalize personalize. Think about your lifestyle, your home, your workplace. Even a very large earthquake will last no longer than about two minutes. Duck and cover. During this time quick actions may be possible that will protect you and your loved ones. The goals... protect yourself and those you care about from falling objects... avoid fire... be prepared to be on your own for 72 hours.

Organizational preparedness:

Government (and industry, too):

Focus on the problems and opportunities presented by a major earthquake. What will the role of the agency / business be during the emergency and during reconstruction? Effective response will largely depend on plans and preparations made before the earthquake. Although leadership, some coordination, and communication of accurate information will come from the state and regional levels, much responsibility and initiative will fall to local leaders and individuals.

Learning from the earthquakes

As much as possible should be learned from each earthquake. Knowledge gained will be important in minimizing losses from future earthquakes both in Utah and elsewhere. The State of Utah has developed plans for collecting information on the effects of an earthquake. Many of the earthquake phenomena will be observable only during the earthquake or shortly after the earthquake. Natural processes and reconstruction efforts will soon obscure many effects of the earthquake. Following a major earthquake, not enough professionals trained to observe and document the effects of an earthquake will be available to conduct investigations. However, observations by non-professional both during and after the earthquake will be of great scientific and historic value.

Recognizing the window of opportunity

If a society is prepared for a natural disaster the effects of the disaster are usually reduced. Many of the preparation strategies for earthquakes are similar to those for other natural or human-caused disasters and the earthquake hazard is added justification for such preparation. A unique opportunity will exist to build a safer community at the same time that great pressure exists to rebuild as quickly as possible without taking the extra time and expense required to take advantage of what was learned in the earthquake experience. State agencies such as the Division of Comprehensive Emergency Management, the University of Utah Law School can draft sound legislation now so it will be ready for legislative consideration in the immediate aftermath of an earthquake.

Recommended reading and recommended resources

The 1994 legislature authorized the **Utah Seismic Safety Commission**. They have developed *A Strategic Plan for Earthquake Safety in Utah*. The complete strategic plan is available from either the Utah Geological Survey or the Utah Division of `Comprehensive Emergency Management.

The **Utah Geological Survey** (UGS) collects and publishes earthquake hazards information pitched at all levels of geologic sophistication. Enclosed is their: *Earthquake Hazards & Safety in Utah.* In May 1995, they will publish a home owner's guide to earthquake safety, free of charge to the public. If and when you are there, check out their other publications such as *Engineering Geology of Salt Lake County*, William R. Lund, editor which identifies Salt Lake County's multi-hazards.

Contact: 467-7970
2363 South Foothill Blvd, SLC, UT 84109

Comprehensive Emergency Management (CEM), an agency in Utah's Department of Public Safety, is the source for preparedness information. I particularly like their publication, *Earthquakes, what you should know when living in Utah*. It is short, well illustrated, and pitched to laypeople.

Contact: 538-3400
1100 State Office Building, SLC, UT 84114

The **University of Utah Seismograph Stations** (UUSS) and the University of Utah are two additional and essential data collection and publication sources for accurate technical and research information about Utah's geologic hazard.

Contact: 581-6274
705 W.C. Browning Bldg, University of Utah, SLC, 84112

I was helped in preparing this text by my husband, Don R. Mabey, and we drew extensively on contributions he had made to a never-completed manuscript "*The Earthquake Threat and Challenge of Utah*" by Walter J. Arabasz and Don R. Mabey. There is still a need for a scientifically up-to-date, well-written, well-illustrated, book written for the intelligent and curious non-geologist reader that attempts to answer just about any question about Utah's earthquake hazard.

Last, and not least... the **US Geological Survey**, beleaguered by the Contract for America, needs your recognition and appreciation for over a century of work that has contributed the most to the understanding of the earthquake hazard in Salt Lake County,,, through its own work and the work of others it has funded. The nature of Salt Lake County's earthquake hazard is such that very long periods of time pass without any earthquakes to attract the attention of the public and public officials. Sustained funding for essential continuing programs such as for the US Geological Survey and the University of Utah's Seismograph Stations has proven difficult. It would be a tragedy to lose support for these important programs.