SECTION 4

Erosion and Deposition

Processes that sculpt landforms

* weathering and soils
* mass-wasting
* streams and drainage systems
* erosion by running water
* depositional features of streams
* deserts and wind features
* glaciers and glaciation
* coastal processes -- the ocean margins

CHAPTER 7

Weathering and Soils

Surface Processes
Weathering
Processes of Weathering
Mechanical Weathering
Chemical Weathering
Factors That Influence Weathering
Soils
Origin
Soil Profile
Soil-Forming Factors
Soils of Extreme Climates
Rate of Soil Formation
Paleosols
Essay: Cavernous Weathering in Antarctica
Summary
Important Words and Terms to Remember
Questions for Review

Chapter Heading from:
Skinner, B.J. and S.C. Porter, 1989. *The Dynamic Earth,* (John Wiley and Sons, New York)

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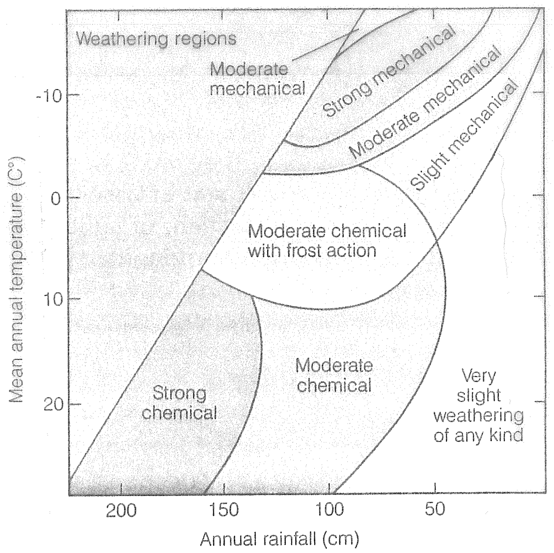

FIGURE 7.12 Climatic control of weathering process. Mechanical weathering is dominant where rainfall and temperature are both low. High temperature and precipitation favor chemical weathering. (*Source:* After L. C. Peltier, 1950.)

SUMMARY

1. The zone of weathering extends to whatever depth air and water penetrate. Water solutions, which enter the bedrock along joints and other openings, attack the rock chemically and physically causing breakdown and decay.
3. Mechanical and chemical weathering, although involving very different processes, generally work together.
3. Subdivision of large blocks into smaller particles increases surface area and thereby accelerates chemical weathering.
4. Growth of crystals, especially ice and salt, along fractures and other openings in bedrock is a major process of mechanical weathering.
5. Daily heating of rocks by the sun followed by nocturnal cooling may cause little or no breakdown, but intense fires can lead to spalling of rock surfaces.
6. The wedging action of plant roots and the churning of rock debris by burrowing animals can have large cumulative effects over time.
7. Carbonic acid is the prime agent of chemical weathering; heat and moisture speed chemical reactions.
8. Chemical weathering converts feldspars into clay minerals. Quartz is resistant to chemical decay and commonly remains as sand grains.
9. The effectiveness of weathering depends on such factors as rock type and structure, surface slope, local climate, biologic activity, and the time over which weathering processes operate.
10. Soils consist of weathered regolith capable of supporting plants. Soil profiles display distinctive horizons, the character of which depends on such factors as climate, vegetation cover and soil organisms, composition of parent material, topography, and time.
11. The A horizon is rich in organic matter and has lost soluble minerals through leaching. Clay accumulates in the B horizon together with substances leached from the A horizon. Both overlie the C horizon, which is slightly weathered parent material.
12. Soils of the polar deserts generally lack an A horizon. In tundra environments soils tend to be saturated and rich in organic matter.
13. Caliche is a common component of many arid-region soils and forms in the upper part of the C horizion.
14. Laterites are typical of tropical climates, display extreme weathering, and have concentrations of iron and aluminum oxides.
15. Paleosols are buried soils that can provide clues about former topography, plant cover, and climate.

Teacher feedback:

Teaching concepts of "Weathering and Soils" in Salt Lake County:

Distinguish between weathering and soils.
Weathering is a destructive process... bedrock is reduced to its components.
Soils result from contributions of a range of chemicals and chemical processes.

Weathered materials are the product of the rock being weathered. Some soils develop on weathered materials. Soils also develop on materials that have been transported. In Salt Lake County the soils in the valleys are far removed from the original bedrock and weathered material.

The development of a soil is an indication that the area is not an area of active erosion or active deposition. Soils take a long time to form. They don't have time to develop when erosion and / or deposition change the surface rapidly.

Soils take time to develop... and can easily be destroyed.

Salt Lake County examples of soils...

* lots of examples... natural and artificial
* discuss effects of climate
* what are the pre-irrigation soils of the area?
* discuss the human engineered soil processes of lawns --
    - irrigation has vastly changed and disturbed soil forming processes

Salt Lake County examples of weathering...

* lots of examples... on school grounds
    - disintegration of cement and asphalt
    - rust on vehicles
    - virtually every rock students find
* cemetery tombstones

Note how different areas of the county have different types and rates of weathering... effects of frost and freezing; organic material; salt along the Great Salt Lake; disturbed versus undisturbed areas.

CHAPTER 8

Mass-Wasting

Role of Mass-Wasting
Gravity
Downslope Movement of Debris
Mass-Wasting Processes
Basis of Classification
Slope Failures
Sediment Flows
Subaqueous Mass Movement
Triggering of Mass-Wasting Events
Shocks
Slope Modification
Undercutting
Exceptional Precipitation
Eruptions
Submarine Slope Failures
Mass-Wasting Hazards
Hazards Assessments
Hazards Mitigation
Essay: Collapsing Volcanoes
Summary
Important Words and Terms to Remember
Questions for Review

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Teacher feedback:

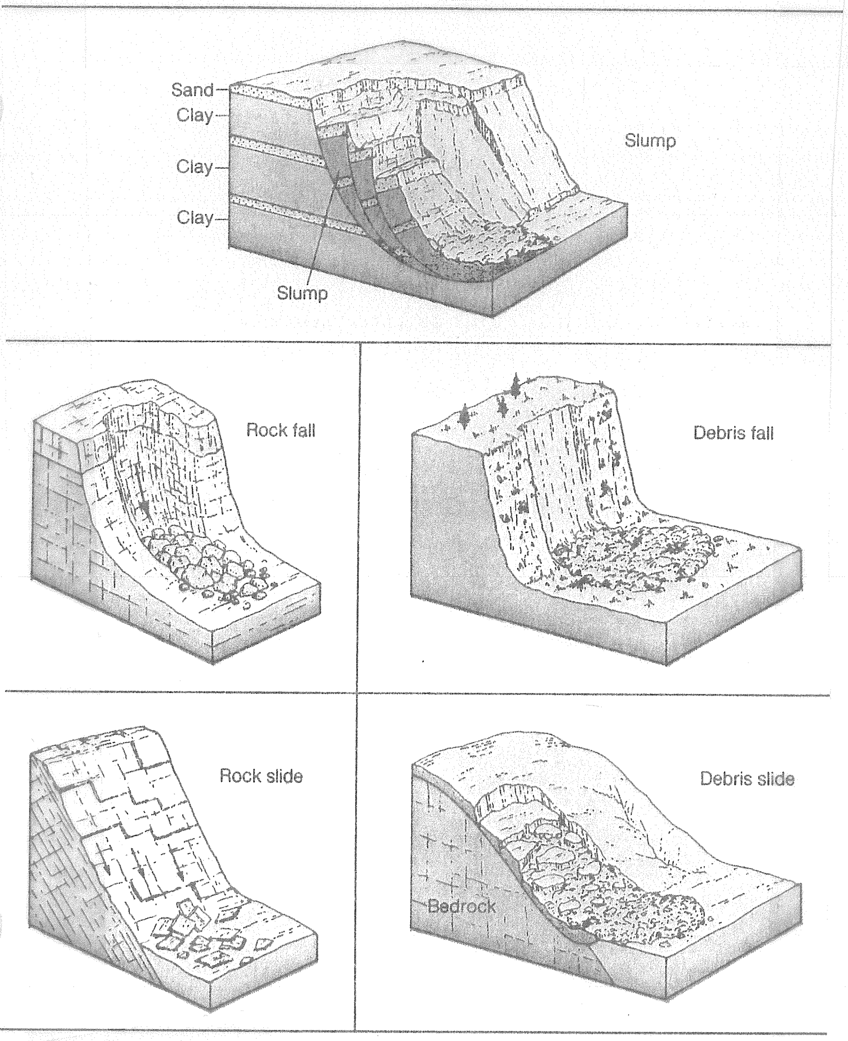

FIGURE 8.2 Examples of slope failures giving rise to slumps, falls, and slides.

SUMMARY

1. The pull of gravity causes rock debris to move downslope without a transporting medium. It affects rock debris both on land and beneath the sea.
2. The composition and texture of debris, the amount of air and water mixed with it, and the steepness of slope influence the type and velocity of slope movements.
3. Slumps involve a rotational movement along a concave-up slip surface. They commonly result in hummocky terrain having backward-tilted blocks of rock or regolith and concentrically aligned depressions.
4. Falling and sliding rock and debris masses are common in glaciated mountains where steep slopes abound.
5. Sliderock accumulates at the base of cliffs to produce taluses with slopes that stand at the angle of repose.
6. Slurry flows involve dense moving masses of saturated sediment that form nonsorted deposits when flow ceases. Flow velocities range from very slow (solifluction) to rapid (debris flows).
7. Eroding muddy streams can turn into mudflows that move rapidly down canyons and spread out as thin sheets of nonsorted sediment on fan surfaces at the foot of mountain slopes.
8. Highly mobile volcanic mudflows can travel many tens of kilometers from the slopes of volcanoes where they originate.
9. Although creep is imperceptibly slow, it is widespread and therefore quantitatively important in the downslope transfer of debris.
10. Large, rapidly moving debris avalanches are relatively infrequent but potentially hazardous to humans.
11. Mass-wasting events on hillslopes can be triggered by earthquakes, undercutting by streams, heavy or prolonged rains, or volcanic eruptions. Subaqueous slope failures may further be related to rapid deposition of sediments, oversteepening of slopes, and earthquake shocks.
12. Loss of life and property from mass-movement events can be prevented or mitigated by advanced assessment and planning based on geologic studies of previous occurrences.

Teacher feedback:

Teaching concepts of mass-wasting in Salt Lake County:

Distinguish between mass-wasting and weathering.

How much terminology needs to be learned?

- Rock-fall
- Landslide
- Debris flow

Concept of continuums...

- mass wasting features range in size... a few cubic meters to millions of cubic meters.
- mass wasting events range from short to prolonged... fast to imperceptibly slow.
- the proportion of rock, debris and water determines the nature of the mass wasting.

Examples in Salt Lake County:

- rock falls...
  - natural -- Mt Olympus Cove
  - human caused -- in the Bingham copper mine

- landslides...
  - natural --
    - Ensign Elementary School (SLDistrict)
    - Emigration Canyon
  - (Thistle landslide -- Utah County)
  - human caused --
    - along I-80 east to Park City

- debris flows...
  - Gun Club north of Big Cottonwood Canyon
  - flash floods from Butterfield Canyon
  - Emigration Canyon
  - (Rudd Canyon -- Davis County)

C H A P T E R 10

Streams and Drainage Systems

Streams in the Landscape
Erosion by Running Water
Geometry of Streams
Stream Channel
Velocity
Channel Patterns
Dynamics of Streamflow
Factors in Streamflow
Changes Downstream
Base Level
Artificial Dams
The Graded Stream
Large-Scale Changes in Equilibrium
Floods
The Stream's Load
Bed Load
Suspended Load
Dissolved Load
Competence and Capacity
Downstream Changes in Grain Size
Factors Influencing Sediment Yield
Depositional Features of Streams
Floodplains and Levees
Terraces
Alluvial Fans
Deltas
Drainage Systems
Drainage Basins and Divides
Stream Order
Evolution of Drainage
Stream History
Essay: Catastrophic Floods and the Channeled Scabland
Summary
Important Words and Terms to Remember
Questions for Review

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STREAMS IN THE LANDSCAPE

Almost anywhere we travel over the Earth's land surface we can see evidence of the work of running water. Even in places where no rivers flow today, we are likely to find deposits and landforms that tell us water has been instrumental in shaping the landscape. Most of these features can be related to the activity of streams that are part of complex drainage systems. A ***stream*** is a body of water that carries rock particles and dissolved substances, and flows down a slope along a clearly defined path. The path is the stream's ***channel,*** and the rock particles constitute the bulk of its ***load,*** the material that the stream moves or carries.

Streams play an important role in our lives. They are an important source of water for human and industrial consumption. Many rivers are avenues of transportation. They also have great scenic and recreational value. The floors of stream valleys are generally fertile, and building on them is easy because the terrain is gentle. As a result, they tend to invite large populations which then must face the danger of damage by floods as well as the necessity of controlling stream pollution from the discharge of wastes.

In addition to their immediate practical and esthetic importance, streams are vital geologic agents for the following reasons:

1. Streams carry most of the water that goes from land to sea, and so are an essential part of the hydrologic cycle.
2. Every year streams transport billions of tons of sediment to the oceans, where it is deposited and can ultimately become part of the rock record.
3. Streams shape the surface of the continental crust. Most of the Earth's landscapes consist of stream valleys separated by higher ground and are the result of weathering, mass-wasting, and stream erosion working in combination (Fig. 10.1).

Teacher feedback:

Teaching concepts of stream processes in Salt Lake County:

In general, surface water flows down-gradient.

Concept of base-level. What is the base-level in SLCounty?

The drainage patterns of streams tell us stories about the geologic past of areas of the valley... although the story can be difficult to decipher. (Potential lesson plan... define where drainage goes from the school... is the path what the students' would have expected... if not, why not?

* Trace the path of Little Cottonwood from the canyon mouth to the Jordan River. Why does the stream jog north the way it does?
* What affects the location of the Jordan River?
* Why is Bingham Creek so dry?
* Why are irrigation canals located where they are?

Compare the drainages of the east side of the valley and the west side:

Type of bedload of east side versus west side...

Quantity of material carried east side versus west side...

Timing of runoff east side versus west side...

Streams do an enormous amount of geomorphic work. They differentially erode less resistant units. Note where the east side canyons are located with respect to rock type and rock structure.

EROSION BY RUNNING WATER

Erosion by water begins even before a distinct stream has been formed. It occurs in two ways: by impact as raindrops hit the ground, and by sheets of water flowing over the ground during heavy rains. As raindrops strike bare ground they dislodge small particles of loose soil, spattering them in all directions. On a slope the result is net displacement downhill. One raindrop has little effect, but the number of raindrops is so great that together they can accomplish a large amount of erosion.

The average annual rainfall on the area of the United States is equivalent to a layer of water 76 cm thick covering the entire land surface. Of this layer, 45 cm returns to the atmosphere by evaporation and transpiration (Fig. 1.13), and 1 cm infiltrates the ground, recharging the groundwater; the remaining 30 cm forms runoff. We can subdivide the runoff into ***overland flow,*** the movement of runoff in broad sheets or groups of small, interconnecting rills, and ***streamflow,*** the flow of surface water in a well-defined channel. While streamflow is very obvious, overland flow is less so. Usually overland flow occurs only through short distances before it concentrates into channels and forms streams. Such flow takes place wherever rainfall is greater than the capacity of the ground to absorb it. The erosion performed by overland flow is called ***sheet erosion.***

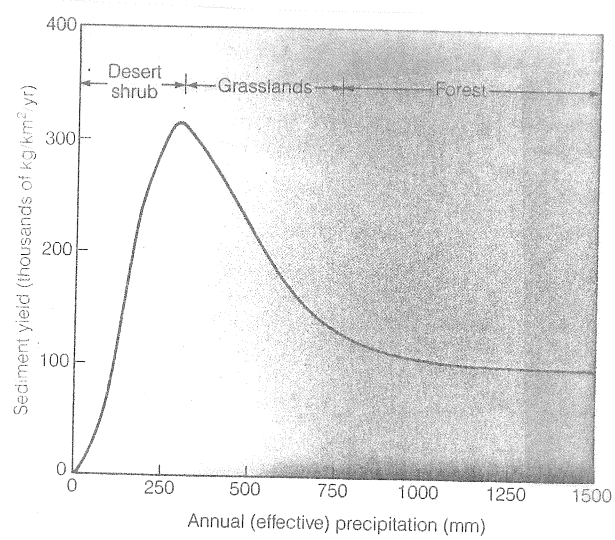

FIGURE 10.16 Relationship between sediment yield and precipitation. As precipitation increases, so does sediment yield, so long as vegetation cover remains restricted. Once the moisture level is sufficient to support continuous vegetation, erosion is reduced and sediment yield declines. (*Source:* After Langbein and Schumm, 1958.)

Teacher feedback:

Teaching concepts of erosion by flowing water in Salt Lake County:

Potential lesson plan...
identify areas of erosion on the school property,
what is the source of the water,
what is its destination,
how can erosion be reduced,
what would make it worse?
how does asphalt and paving affect runoff and erosion?

Teacher feedback:

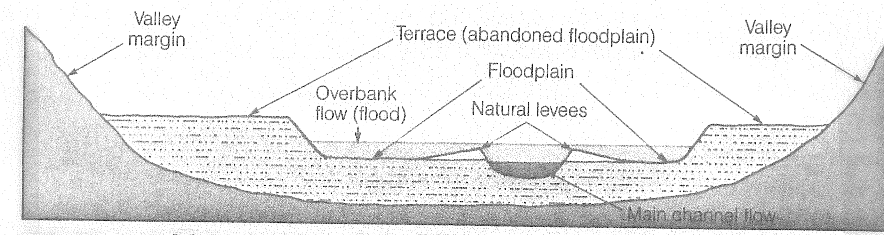

FIGURE 10.17 Main elements of an alluvial valley.

DEPOSITIONAL FEATURES OF STREAMS

Floodplains and Levees

When a stream rises in flood, it may overflow its banks and inundate the floodplain (Fig. 10.17). Many streams are bordered by natural levees—broad, low ridges of fine alluvium built along both sides of a stream channel by water that spreads out of the channel during floods. The alluvium of which levees are composed becomes still finer away from the river and grades into a thin cover of silt and clay over the rest of the floodplain.

Terraces

Most stream valleys contain ***terraces,*** which are abandoned floodplains formed when a stream flowed at a level above that of its present channel and floodplain (Fig. 10.17), Their presence indicates that a change in the equilibrium condition of the stream has occurred. Terraces form as a stream erodes downward through its deposits to a new level. A terrace may be underlain by sediments, by bedrock, or by both. In other words, a terrace is a landform and is distinct from the materials that compose it.

Teacher feedback:

Teaching concepts of deposition by flowing water in Salt Lake County:

Potential lesson plan... using the Jordan River as an educational laboratory

- Flood plain features
- Terraces
- Meanders
- Effects of channel dredging
- Effects of channel straightening
- Land use along the river
- Risk of flooding

Alluvial Fans

When a stream flowing through a steep highland valley comes out suddenly onto a nearly level valley floor or plain, it experiences an abrupt decrease of slope and a corresponding decrease in competence. Therefore, it deposits the part of its load that cannot be transported on the gentler slope.

As sediments are deposited, the stream channel shifts laterally toward lower ground. Through constant shifting of the channel, the deposit takes the form of an ***alluvial fan,*** defined as a fan-shaped body of alluvium typically built where a stream leaves a steep mountain valley

Teacher feedback:

Teaching concepts of alluvial fan formation in Salt Lake County:

Allluvial fans are built by debris flows.

What is an alluvial fan?

Discuss why alluvial fans are less common in SL County than in Tooele County.

Examples... west side of Salt Lake Valley

Emigration Canyon

west side of Oquirrh Mountains

Antelope Island

SUMMARY

1. Streams are part of the hydrologic cycle and the chief means by which water returns from the land to the sea. They shape the continental crust and transport sediment to the oceans.
2. Raindrop impact and sheet erosion are effective in dislodging and moving regolith on bare, unprotected slopes.
3. The average gradients of streams decrease from head to mouth, and their long profiles tend to be smooth concave-upward curves.
4. Straight channels are rare. Meandering channels form on gentle slopes and where sediment load is small to moderate. Braided patterns develop on steeper slopes and where bed load is large.
5. Discharge, velocity, and cross-sectional area of a channel are interrelated such that when discharge changes, the product of the other two factors also changes to restore equilibrium.
6. As discharge increases downstream, channel width and depth increase, and velocity increases slightly.
7. World sea level constitutes the base level for most streams. A local base level, such as a lake, may temporarily halt downward erosion upstream.
8. Streams tend toward a graded condition in which slope is adjusted so that the available sediment load can just be transported. Changes continually occur that upset a stream's balance, requiring adjustments to be made in the channel factors.
9. Streams experiencing large floods have increased competence and capacity, and so are capable of transporting great loads of sediment as well as very large boulders. Exceptional floods, however, have a low recurrence interval.
10. Although bed load in some streams may amount to as much as 50 percent of the total load, it is very difficult to measure accurately. Most suspended load is derived from erosion of fine-grained regolith or from stream banks. Streams that receive large contributions of groundwater commonly have higher dissolved loads than those deriving their discharge principally from surface runoff.
11. Sediment yield is influenced by lithology, structure, climate, and topography. The greatest sediment yields are recorded in small basins that are transitional from desert to grassland conditions, and in mountainous terrain with steep slopes and high relief. Under moist climates vegetation anchors the surface, thereby reducing erosion.
12. During floods, streams overflow their banks and construct natural levees that grade laterally into silt and clay deposited on the floodplain. Terraces are due to the abandonment of a floodplain as a stream erodes downward.
13. Alluvial fans are constructed where a stream experiences a sudden decrease in gradient, as where it leaves a steep mountain valley. It thereby loses competence and deposits the coarser fraction of its load. The area of a fan is closely related to the size of the drainage basin upstream from which its sediments originated.
14. A delta forms where a stream enters a body of standing water and loses its ability to transport sediment. The shape of a delta reflects the balance between sedimentation and erosion along the shore.
15. A drainage basin encompasses the area supplying water to the stream system that drains it. Its area is closely related to the stream's length and annual discharge.
16. Stream systems possess an inherent orderliness, with the number of stream segments increasing with decreasing stream order.

Teacher feedback:

CHAPTER 12

Glaciers and Glaciation

Glaciers
Glaciers as Part of the Cryosphere
Forms of Glaciers
Temperatures in Glaciers
Snowline
Conversion of Snow to Glacier Ice
Changes in Glacier Mass
Movement of Glaciers
Glaciation
Glacial Erosion and Sculpture
Glacial Transport
Glacial Deposits
The Glacial Ages
History of the Concept
The Last Glaciation
Earlier Glaciations
The Little Ice Age
What Causes Glacial Ages?
Glacial Eras and Shifting Continents
Ice Ages and the Astronomical Theory
Solar Variations, Volcanic Activity, and Little Ice Ages
Essay: The Earth's Future Climates
Summary
Important Words and Terms To Remember
Questions For Review

Chapter Headings from:
Skinner, B.J. and S.C. Porter, 1989. *The Dynamic Earth*, (John Wiley and Sons, New York)

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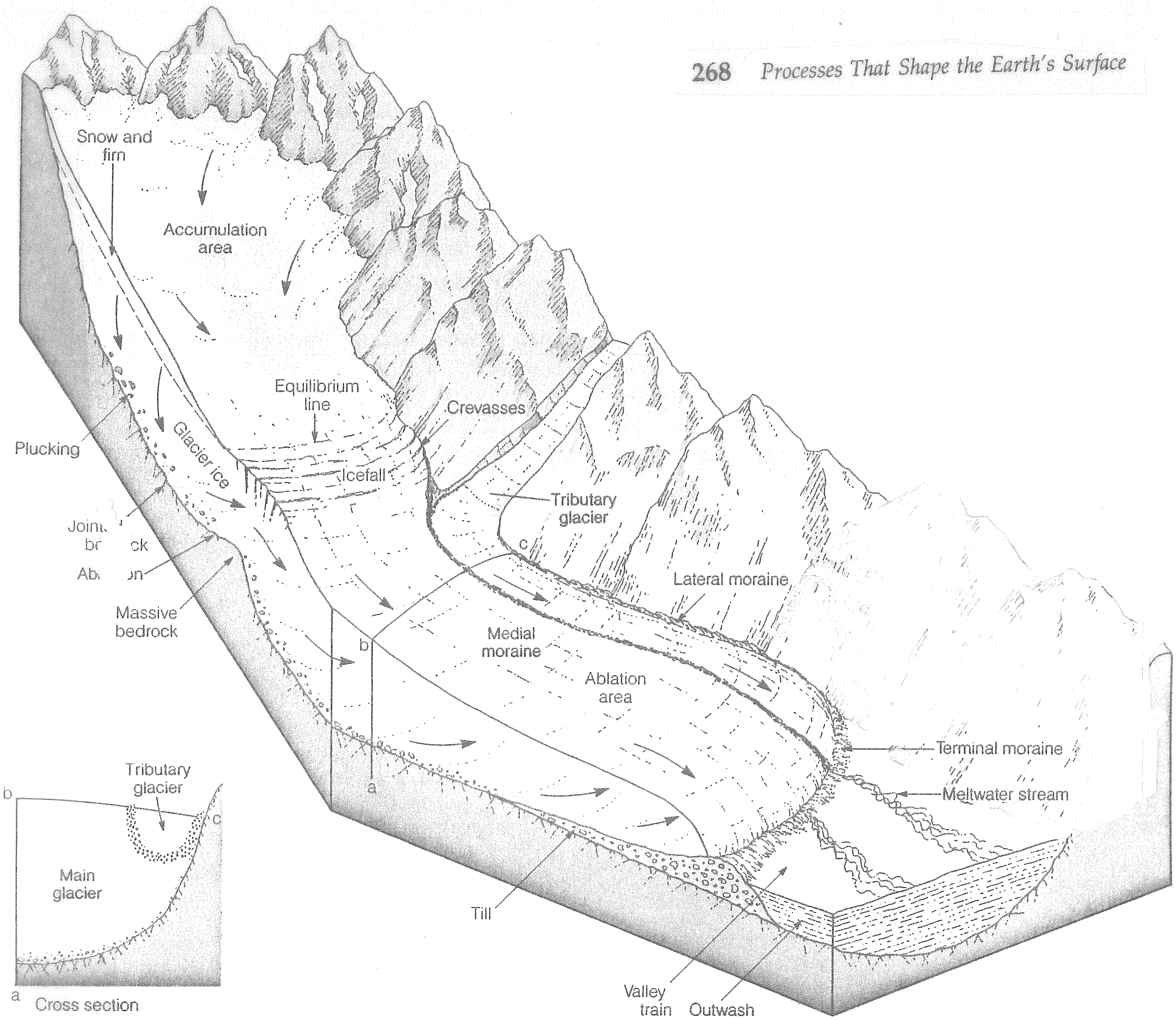

FIGURE 12.6 Main features of a valley glacier and its deposits. The glacier has been cut away along its center line; only half is shown. Crevasses form where the glacier passes over a steeper slope at its bed. Arrows show directions of ice flow.

Teacher feedback:

Teaching concepts of glaciers as a landform processes in Salt Lake County:

Teachers have an almost unique opportunity in Salt Lake County to see evidence of glaciers...and so near an urban center.

Salt Lake County's evidence of glaciers can be seen from most of the valley.
- Little Cottonwood Canyon
- upper portions of Big Cottonwood Canyon.

What are the glacial features?

The glaciers were not calving into Lake Bonneville... the ice had begun to retreat before Lake Bonneville reached its highest levels.

It takes a while for glaciers to form... and glaciers will not threaten today's school children. Even so, school children should realize how much our Earth's climate has changed in the last 20,000 years... which is a very short period of geologic time. What is different today is that human beings are altering the chemistry of the air we breathe and changes in air chemistry affect global as well as local conditions.

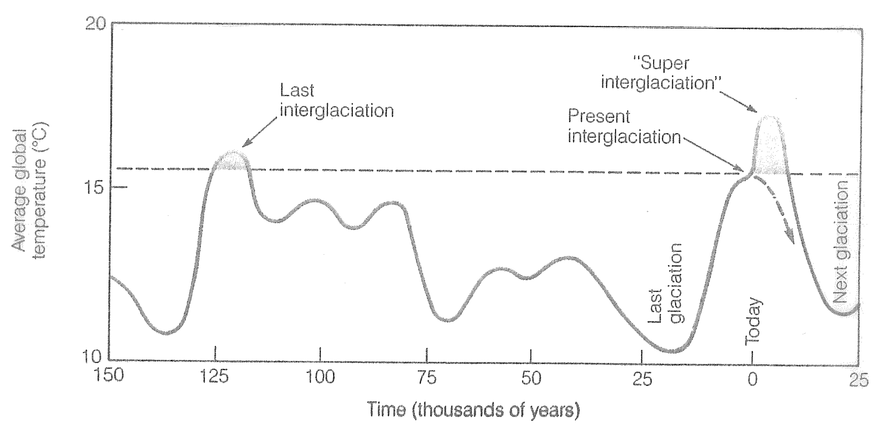

FIGURE B12.1 Course of climate during the last 150,000 years and 25,000 years into the future. The natural course of future climate (dashed line) would be one of declining temperatures until the next glacial maximum, about 23,000 years from now. With the CO_2-induced greenhouse effect, continued warming may lead to a super interglaciation within the next several hundred years. During such an interval, temperature may rise above that of the last interglaciation. The decline toward the next glaciation would thereby be delayed by several millennia. (*Source*: After Imbrie and Imbrie, 1979.)

Teacher feedback:

CHAPTER 13

and

Coastal Processes... including landforms associated with Lake Bonneville

The Ocean Margins

Currents, Tides, and Waves
Surface Ocean Currents
Tides
Waves
Transport of Sediment
The Shaping of Coasts
The Shore Profile
Depositional Features Along Coasts
Constructional Features Along Coasts
Coastal Evolution
Protection Against Shoreline Erosion
Essay: How to Modify An Estuary
Summary
Important Words and Terms to Remember
Questions for Review
Questions for Review of Part 2

Chapter Headings from:
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Steady State Along a Coast

Water meets land in a zone of dynamic activity marked by erosion and the creation, transport, and deposition of sediment. Through these activities, the form of the land slowly changes, and the water in motion moves and shapes the sediment derived from the land. The forces that fashion the shore profile—cliff, bench, and beach—tend to reach and maintain a condition of equilibrium or *steady state*, a compromise in the water–land conflict.

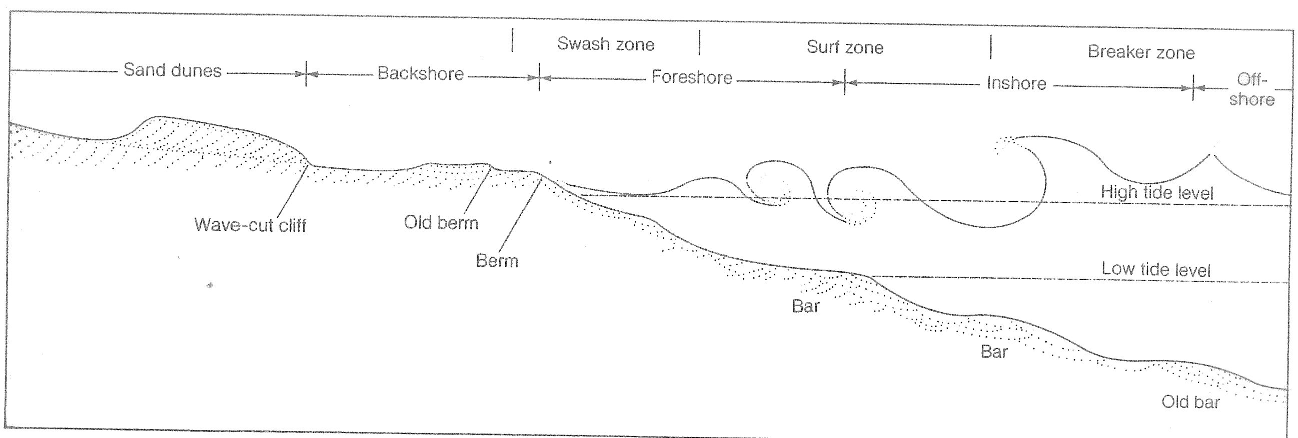

FIGURE 13.13 Typical profile across a beach showing foreshore, berm, and backshore elements. Length of profile about 100 m. Vertical scale exaggerated about twice.

Teacher feedback:

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Teacher feedback:

Deltas

As the water of a stream enters the standing water of the sea or a lake, its speed drops rapidly, it loses both competence and capacity, and it deposits its load. The sedimentary deposit that results may develop a crudely triangular shape like the Greek letter delta (Δ), from which the deposit derives its name

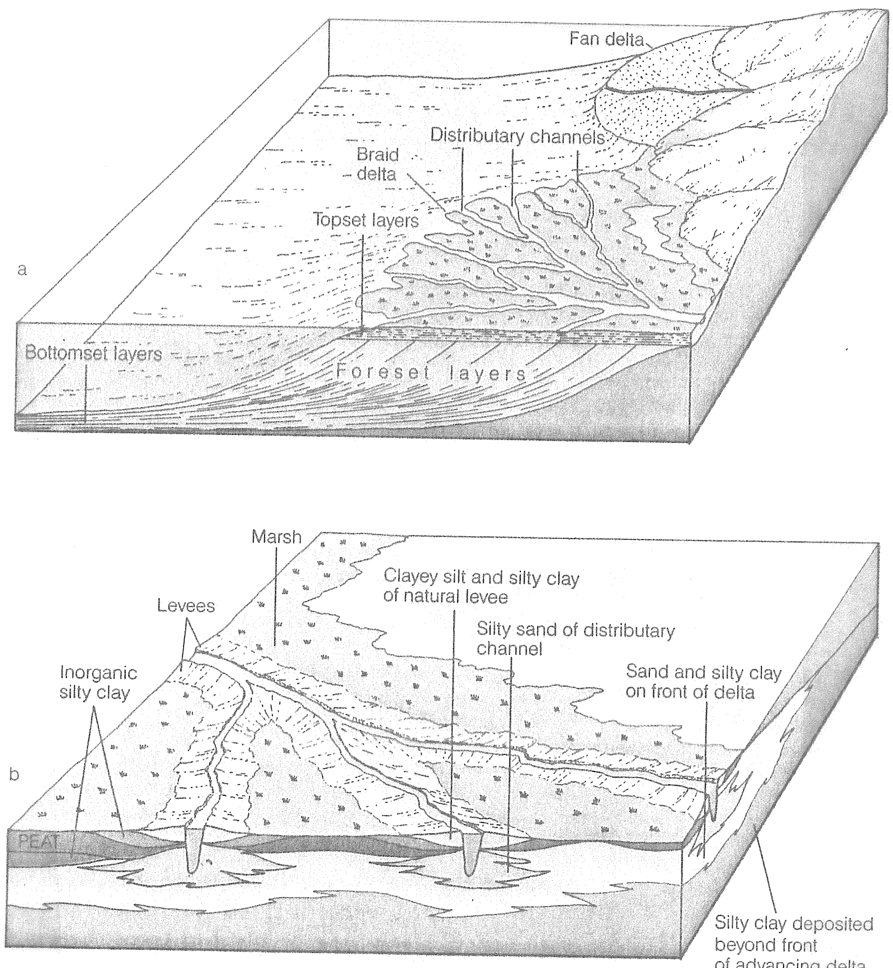


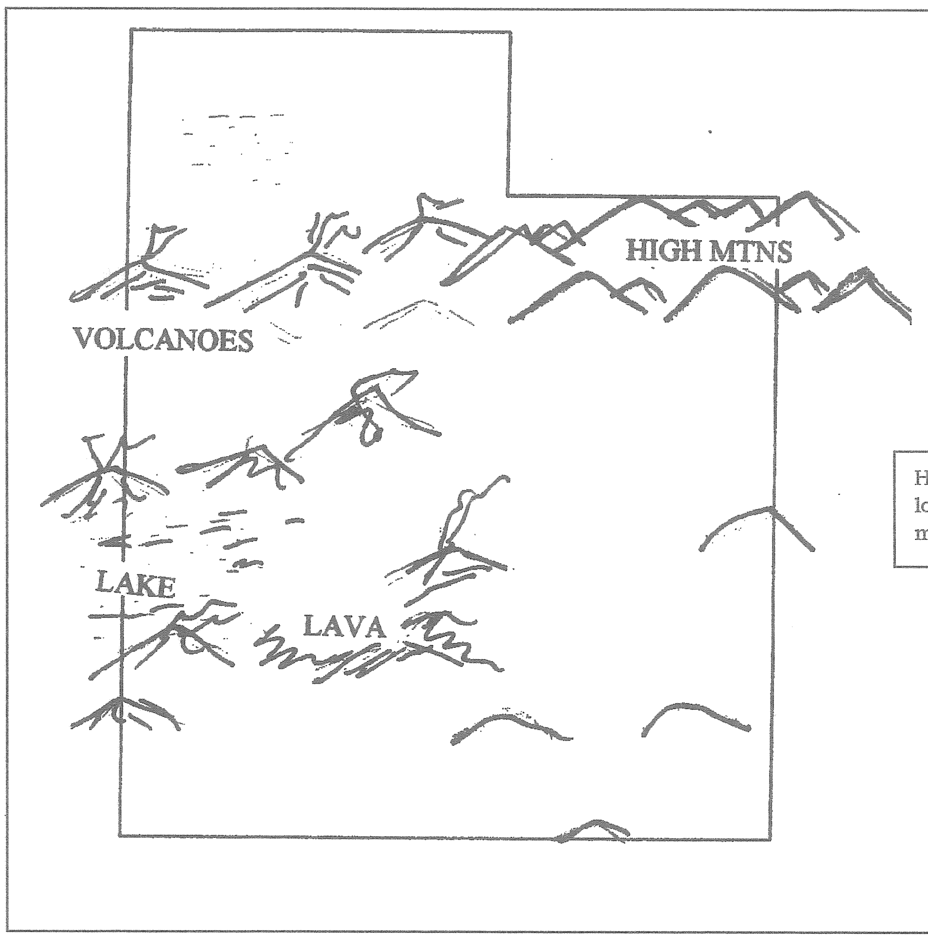
FIGURE 10.21 Main features of deltas. (a) A braid delta built into a lake displays topset, foreset, and bottomset layers. A nearby fan delta is an alluvial fan that is building out into the body of water. (b) Part of a large fine-grained delta built into the sea shows the intertonguing relationship of coarse channel deposits and finer sediments deposited on the delta front and beyond. (*Source:* Partly after Pettijohn et al., 1972.)

Story of Salt Lake County's most impressive landform: Salt Lake Valley

The setting twenty million years ago

Twenty million years ago none of the features that make up the surface of Salt Lake County today had been formed. Neither Salt Lake Valley nor the enclosing mountains existed. The evidence of what the details of surface of the land looked like at that time has been obliterated by millions of years of erosion and deposition. However, we can generalize about conditions at that time.

- To the south: Layers of volcanic rock and associated sediments covered the surface of what was to become the southern part of Salt Lake County.
- To the east: An extension of the Uinta arch may have continued as a high area across what is now eastern and southern Salt Lake County.
- The general area: The elevation the land surface was well above sea level with moderate local relief on the land. Streams carried the eroded sediment from the surface away from the area.

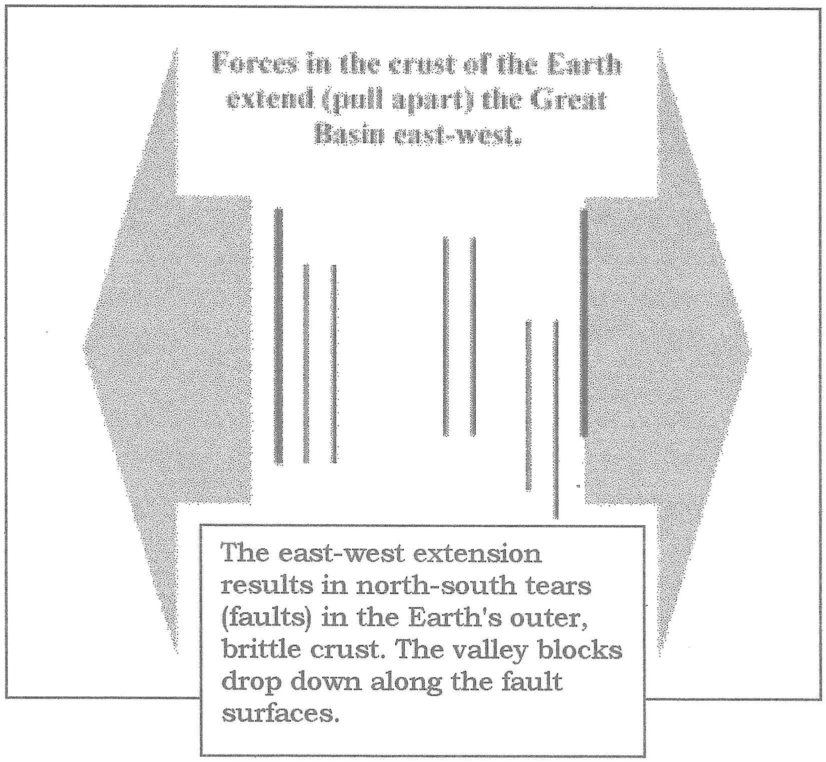


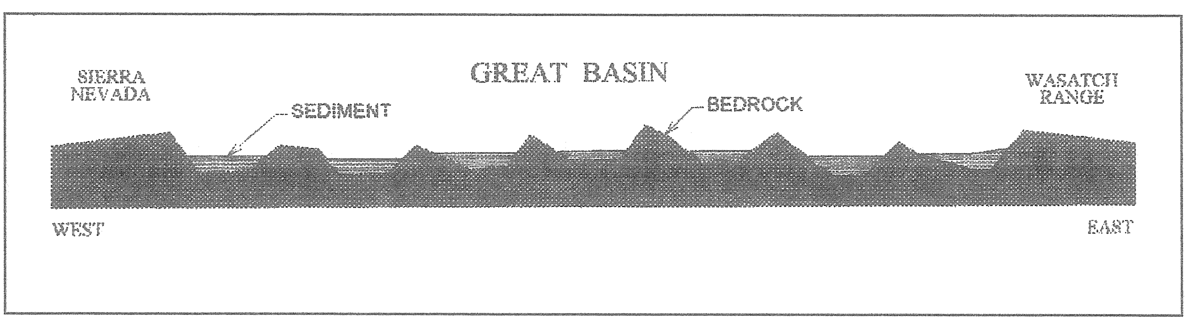
How what-is-now-Utah looked approximately 20 million years ago.

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

Tectonic extension... down-dropping results in Salt Lake Valley

Sometime after 20 million years ago, probably about 17 million years ago, the western part of the North American continent begin to change. Tectonic forces began to stretch the Earth's crust in the area that is now the northern Basin and Range province in a generally east-west direction. The upper brittle layer of the Earth's crust broke into north-south blocks along faults (fractures). Alternating blocks dropped down or rotated one side up and one side down. In these ways the land surface accommodated the extension. Salt Lake Valley became one of the down-dropped areas and the Oquirrh Mountains remained high. As tectonic forces pulled the region apart, the Earth's crust also thinned. The general level of surface of the northeast part of the Basin and Range Province subsided.





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

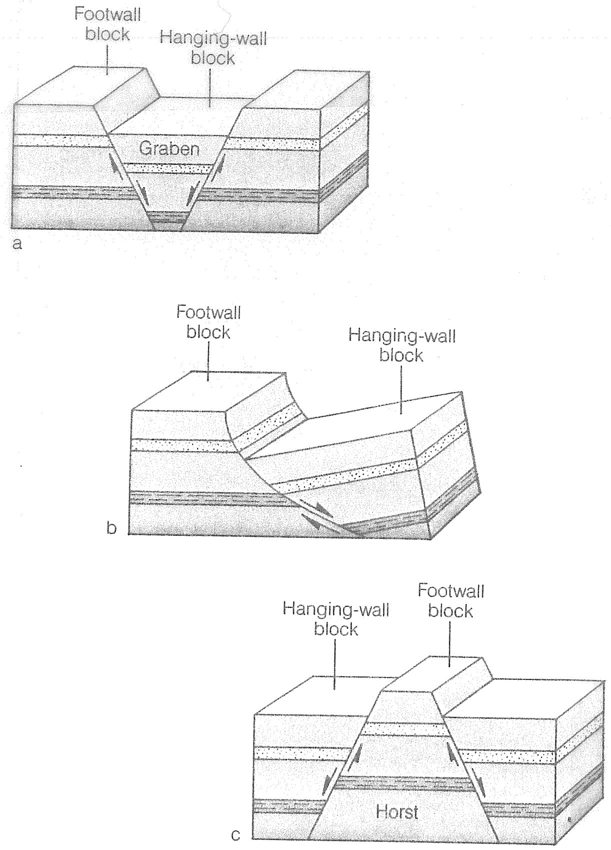


FIGURE 15.9 Horsts and grabens formed when tensional forces produce normal faults. (a) Graben. (b) Half-graben. (c) Horst.

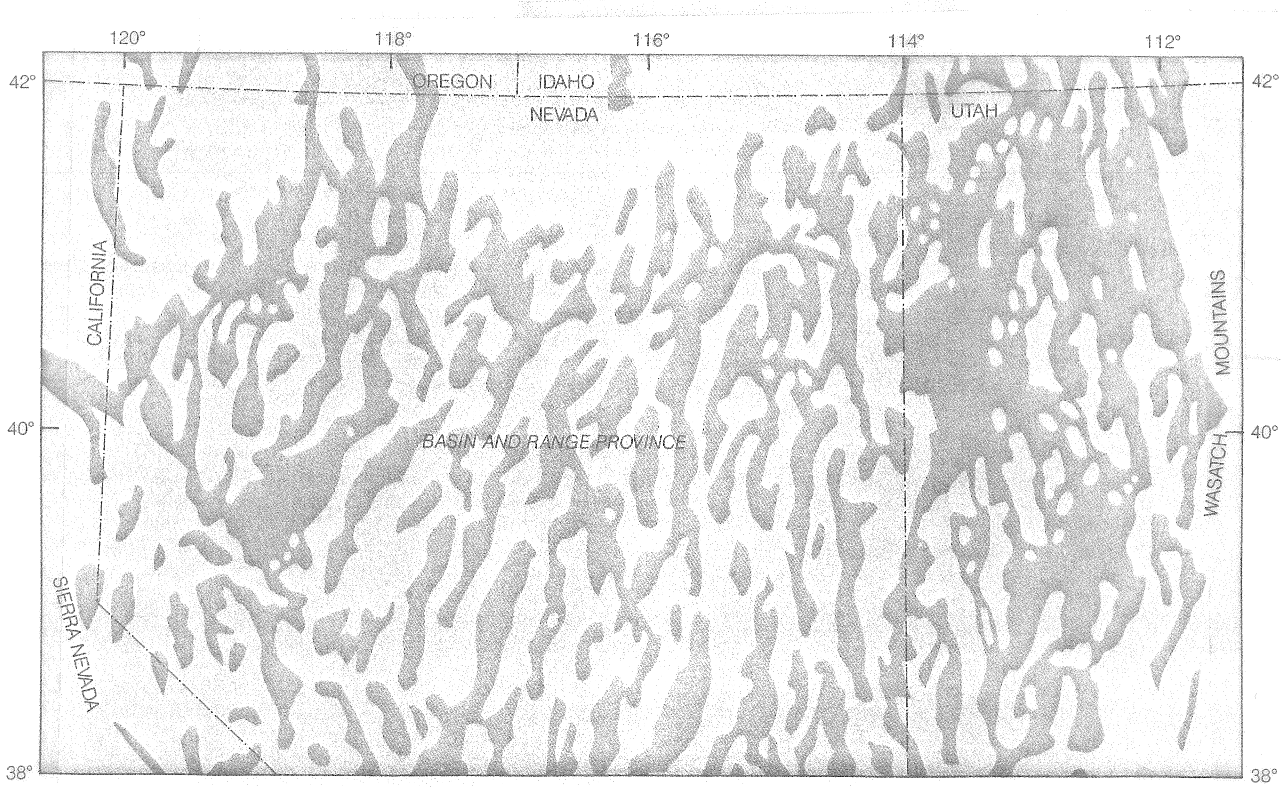
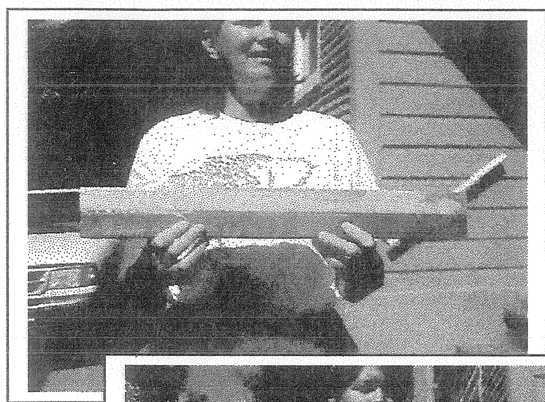


FIGURE 15.11 Map of the Basin and Range Province in Nevada and Utah. The Wasatch Mountains form the eastern border, the Sierra Nevada the western border. Green areas are mountains (horsts), brown areas basins (grabens). Boundaries of basins are normal faults. (Simplified from Geologic Map of the United States, U.S. Geological Survey, 1974.)

TEACHING MOMENT: The trigonometry of faults.
Show how the Earth can "add crust" in other words, become more distance between two points by dropping down pieces of crust along angled faults.
Activity one: draw the relationships on the blackboard.
Activity two: use wooden blocks, cut at an angle.



Blocks showing Salt Lake County topography, simplified, 20 million years ago before basin and range extension.

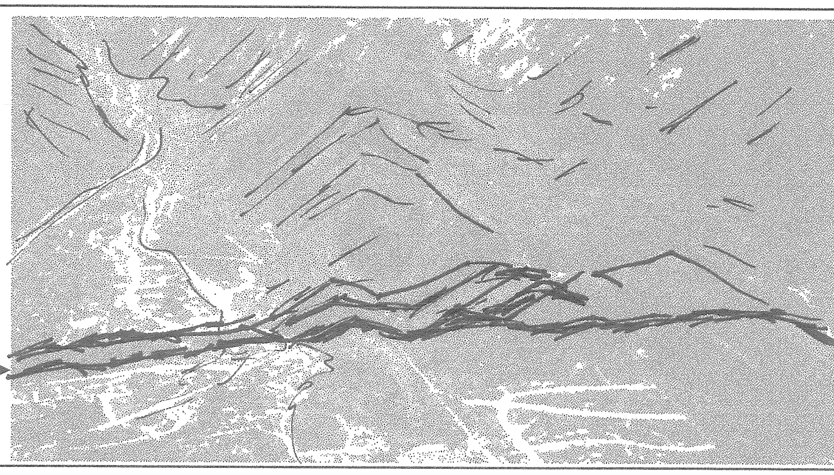
Basin and range topography:
How ranges are formed.
The distance between the ends of the blocks has increased.Valleys have dropped down on both sides of the middle block. The middle block, representing a mountain range, such as the Oquirrh Mountains or Antelope Island remains high. NOTE: the mountain was not pushed up, the valleys dropped down.

Story of Salt Lake Valley.
Forces in the Earth's crust pull east-west across the Great Basin. North-south faults that tilt at angles provide surfaces along which blocks of crust can drop down. This creates valleys. NOTE: the valley drops. The mountains don't have to rise up if the valley drops down.

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

The Wasatch fault

A major fault developed on the east side of the what was to become Salt Lake Valley. This fault is now known as the Salt Lake segment of the Wasatch fault. The location and form of the fault was determined by older faults and zones of strength and zones of weakness that existed before the crustal extension began. Down-dropping of the valley resulted from many events not just a single or even several events. Over the life of the Wasatch fault the average vertical displacement across the fault has been about two inches per one hundred years. The movement has not been constant or continuous but in drops of several feet causing large earthquakes and then hundreds of years of no change.



Photograph taken looking to the east at the mouth of Little Cottonwood Canyon. Note how the Wasatch fault slices like a knife wound south to north across the photo. Shadows highlight the multiple scarps of the fault zone.
Utah Geological Survey, Earthquake Hazards Slide Kit, #18.

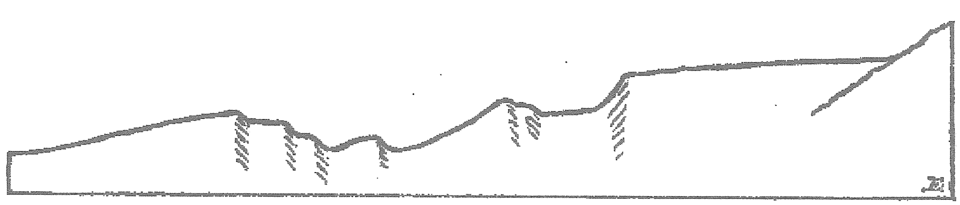


Fig. 44.—Profile of the South Moraine at the mouth of Little Cottonwood Canyon, showing the effect of Faulting.

Multiple scarps of the Wasatch fault zone, Little Cottonwood Canyon.
Same area as the photograph but looking north.
Sketch, G.K. Gilbert, 1890. Lake Bonneville, US Geological Survey Monograph 1 p. 347.

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

Erosion

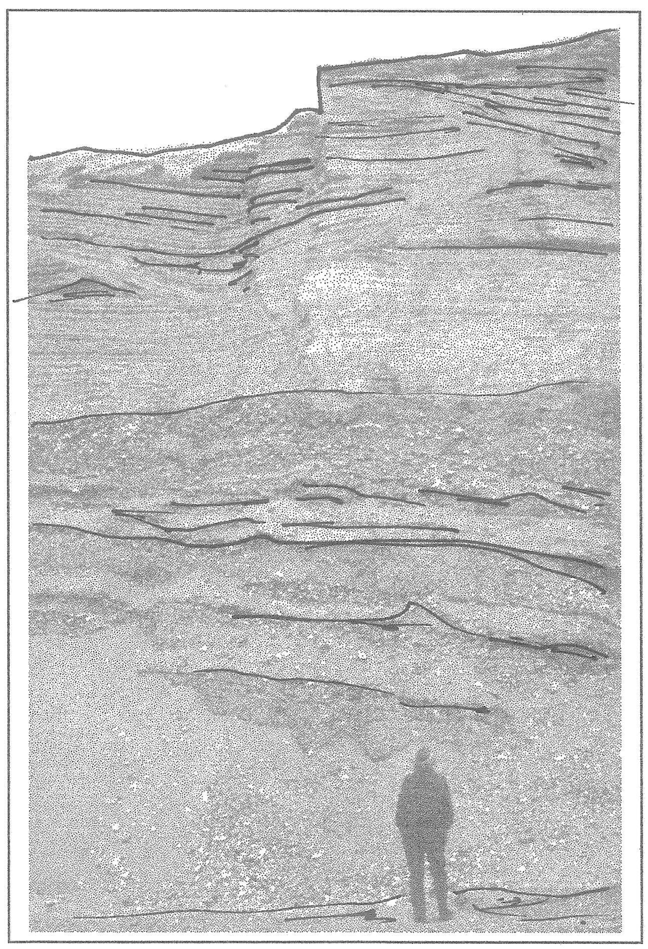
Regional relief (the difference between the areas of highest elevation and those of lowest elevation) greatly affects the rate of erosion. Relatively flat areas, even when they are topographically high, will not erode rapidly unless the streams of the area are trying to downcut to a baselevel (such as an ocean or a lake) that is considerably lower. When Salt Lake Valley began to drop (due to the extension of the crust discussed earlier) it disrupted the flow of streams. Streams flow down gradient. Therefore the stream began to flow into the areas that had downdropped the most.

The increase of surface relief (the elevation difference) from the valley to the adjoining mountains increased the rate of erosion and the volume of material being eroded from the mountains and carried by streams into the valley.

For a long time the streams struggled to maintain the old drainage patterns carrying sediment away from the region. But eventually the down-dropping of the valley and much of the rest of the northeastern portion of the Basin and Range province to elevations generally below the surrounding regions caused streams to flow into, not away from, the area.

Deposition

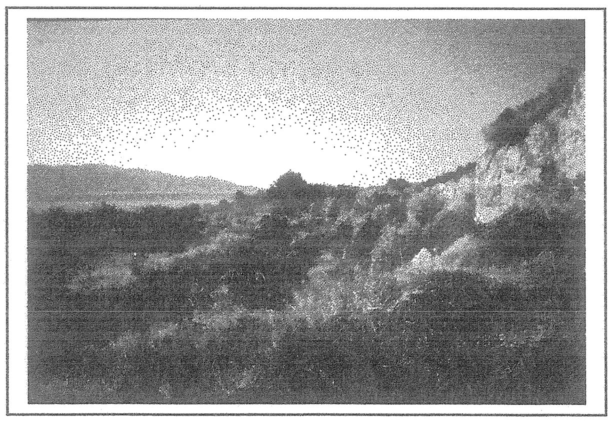
Erosion and deposition are a couplet. Increased erosion requires increased deposition. When the valley had captured the drainages, it captured the sediments carried by the streams. Great thicknesses of sediments accumulated in the valley. About a foot of sediment has accumulated for every two feet the valley subsided. Where the valley subsided more rapidly, more sediments accumulated; where it subsided less rapidly, less sediment accumulated.



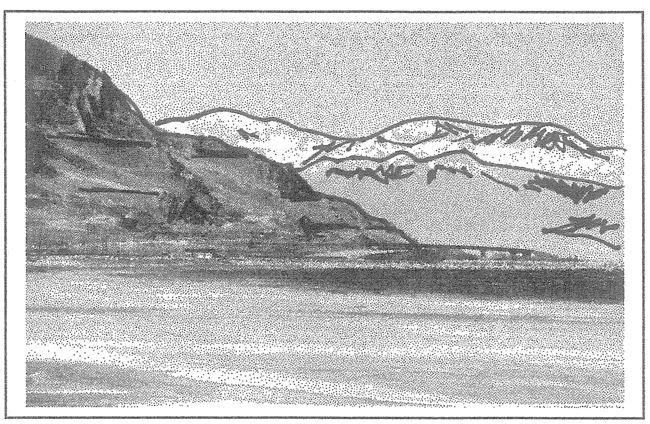
Lakes formed in the low areas of the basin that were the most down-dropped. The lakes expanded and contracted as the climate of the region fluctuated. During very dry cycles the surface area of the lakes shrank and streams deposited aprons of coarse material along the edges of the valley extending toward the lake. These features, called alluvial fans, are common in semi-arid environments where streams may not flow year-round. During very wet cycles the surface area of the lakes expanded and fine material was deposited across the bottom of the lakes.

Great Salt Lake

An area north of Salt Lake Valley subsided more than Salt Lake Valley. That area, now occupied by Great Salt Lake, is the lowest part of a large drainage basin that developed over the last twenty-million-year history of the Basin and Range province. Water now flows from great distances to reach Great Salt Lake. One of the rivers carrying water to the lake, the Jordan River, flows through Salt Lake Valley. This river does considerable geomorphic work, eroding sediments from some areas and depositing them elsewhere.



Jordan River, southern Salt Lake County. Note shorelines of Lake Bonneville in the background, sediments of Lake Bonneville in the right foreground.



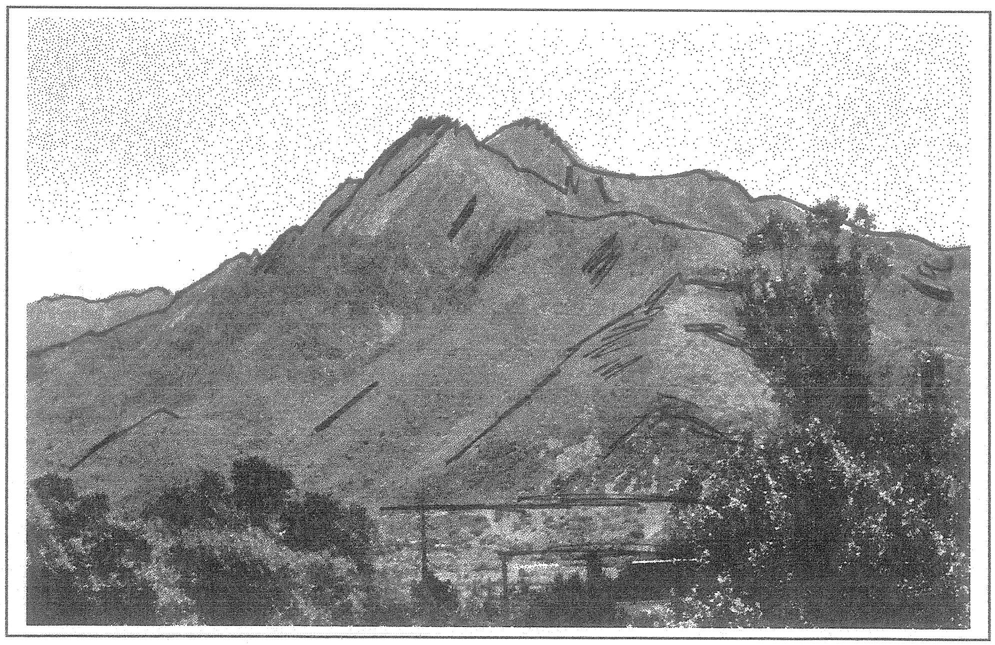
Great Salt Lake, northern Salt Lake County. Note shorelines of Lake Bonneville in the background (left). Note the fine sediments (muds) of Great Salt Lake and the virtually flat lake bottom.

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

Today's tectonic environment

The processes that formed Salt Lake Valley some 17 million years ago are continuing today and will likely continue for a very long time into the future. Crustal forces continue to stretch the Great Basin east-west. Salt Lake Valley will continue to drop down to accommodate much of this extension.

However, details of the story will change. The Salt Lake segment of the Wasatch fault is a complex geologic feature. It has shifted position within the valley and will shift again. The rate of displacement on the fault has varied. Some millennia the fault will move dozens of feet. Other times may be considerably more or less. Over a million or so years, the effect will be impressive. New faults related to the Wasatch fault zone, but generally considered to be separate faults, have developed. New faults will develop in the future.

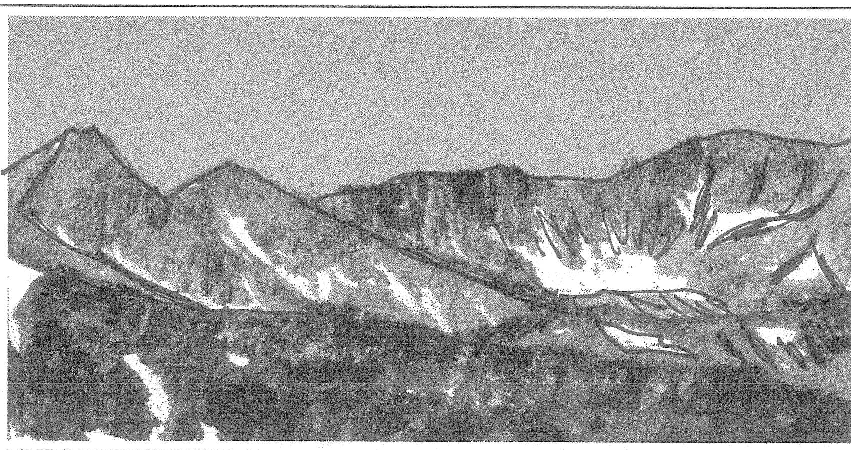


Looking east from the Salt Lake Valley side of the Wasatch fault to the Wasatch Range side of the fault and Mt. Olympus. This scene will have changed dramatically in a couple million years.

Today's erosional (and depositional) environment

The aggressive rate of erosion and depostion of the last few million years in Salt Lake County will persist into at least the next few million years because of the great relief (differences in elevation) of the mountains and valley. Climate changes will dramatically change lakes such as Great Salt Lake. Huge lakes rivalling Lake Bonneville and its predecessors will blanketing the area with sediments. Climate also may shrink the lake dramatically exposing areas near the lake to erosion. Climate changes caused the glaciation of the mountains and will cause glaciation in the future. Erosion from the next set of glaciers will resemble such erosion in the past.

Landforms of the future will evolve from those of today, just as today's evolved from those of the past. When you tell the story of today's landforms, you are teaching earth science.

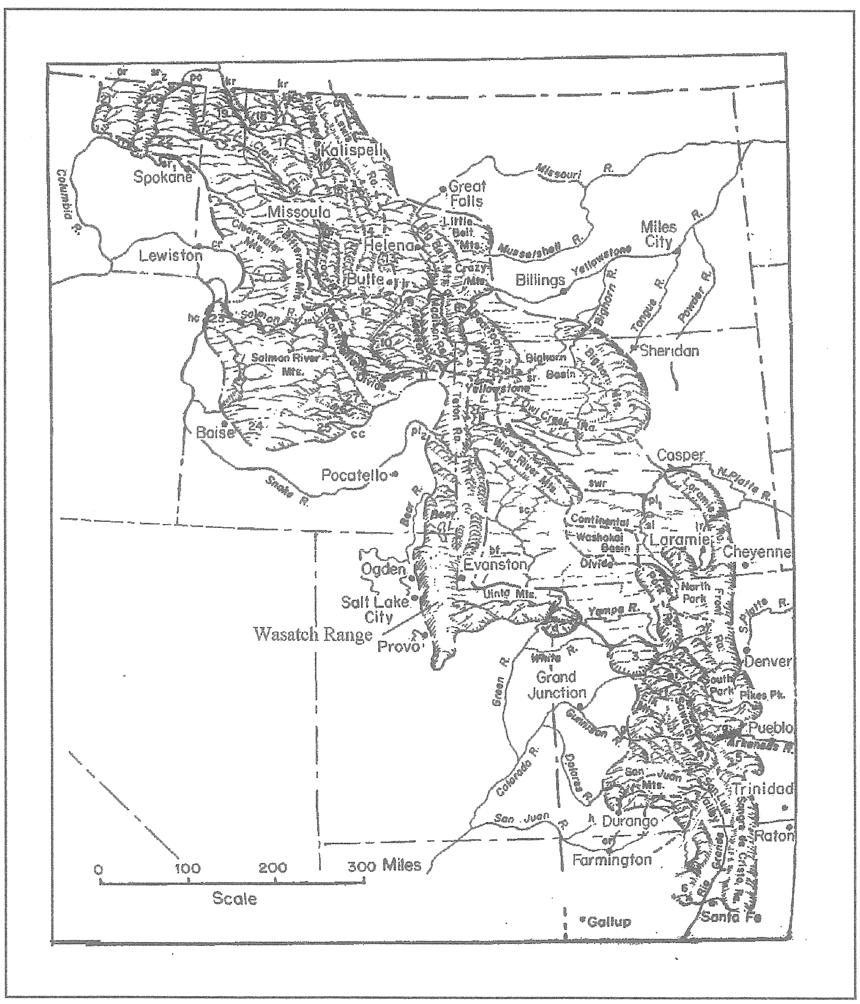


Glaciated areas tell stories of past climate changes and the probablility that climate ice ages will come again bringing glaciers to the Wasatch Range and huge lakes to the Salt Lake Valley.

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

Story of Salt Lake County's most admired landform: the Wasatch Range

Introduction:
The western edge of the Wasatch Range forms the western boundary of a portion of the middle Rocky Mountain physiographic province. It is an unusual range having some characteristics of the mountain ranges of both the Rocky Mountain province and the Basin and Range physiographic province, which borders it on the west. The Salt Lake County part of the Wasatch Range is more complex than other parts of the range both in the variety of rock types and its geologic structures.



Adapted from: C.B. Hunt, 1967. *Physiography of the United States,* W.H. Freeman and Company, San Francisco, p. 246, Figure 13.1 Physiographic map of the Rocky Mountains and Wyoming Basin.

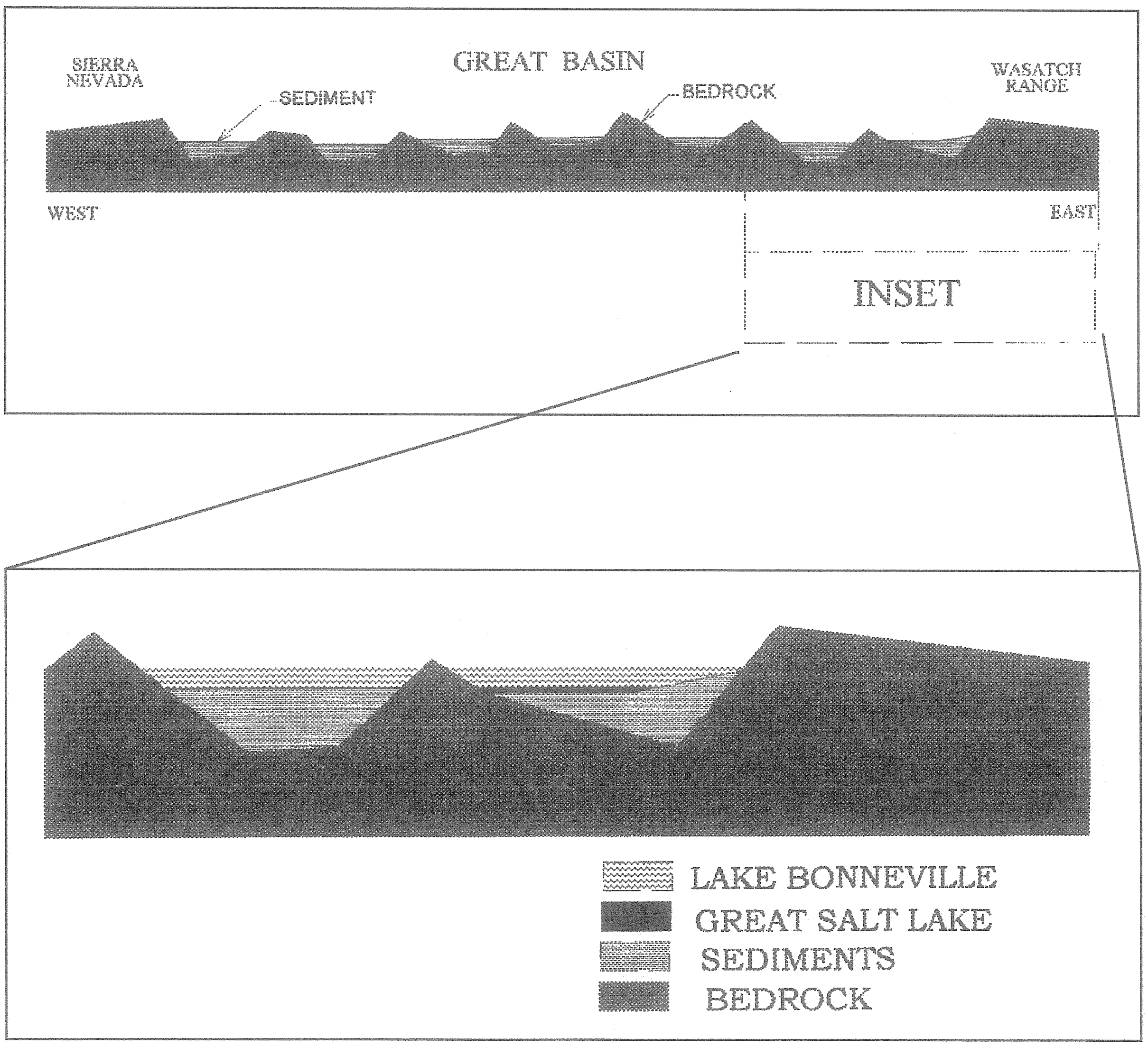
Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

The setting twenty million years ago:

Twenty million years ago none of the features that make up the surface of Salt Lake County had been formed. (See Section 5, the Story of Salt Lake Valley.) Basin and Range extension created both the Salt Lake Valley and the Wasatch Range. The bedrock units that make up the range today were buried under thousands of feet of bedrock and sediment.

Tectonic extension... down-dropping results in

- **the Salt Lake Valley**
- **AND the Wasatch Range**

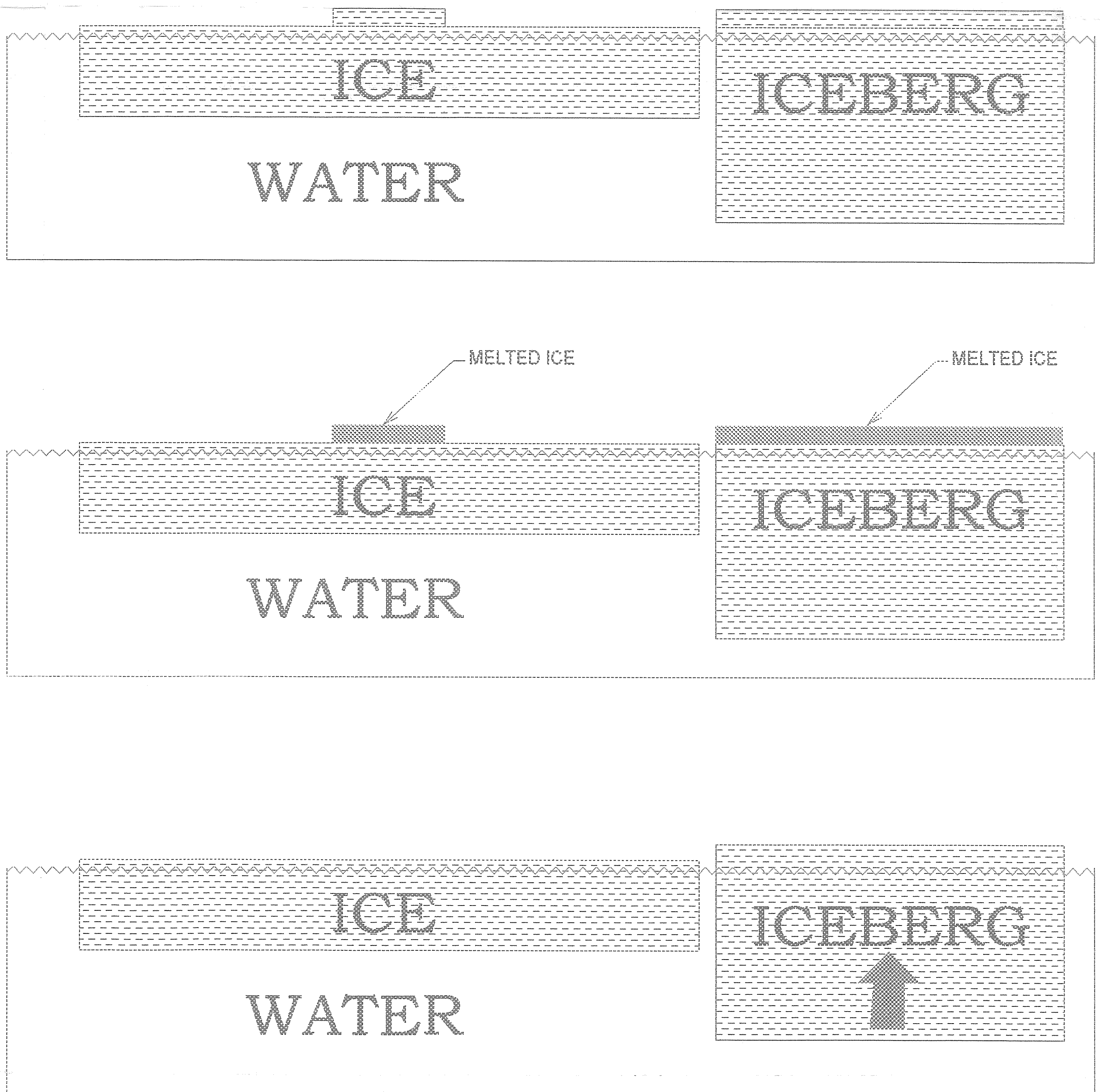


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

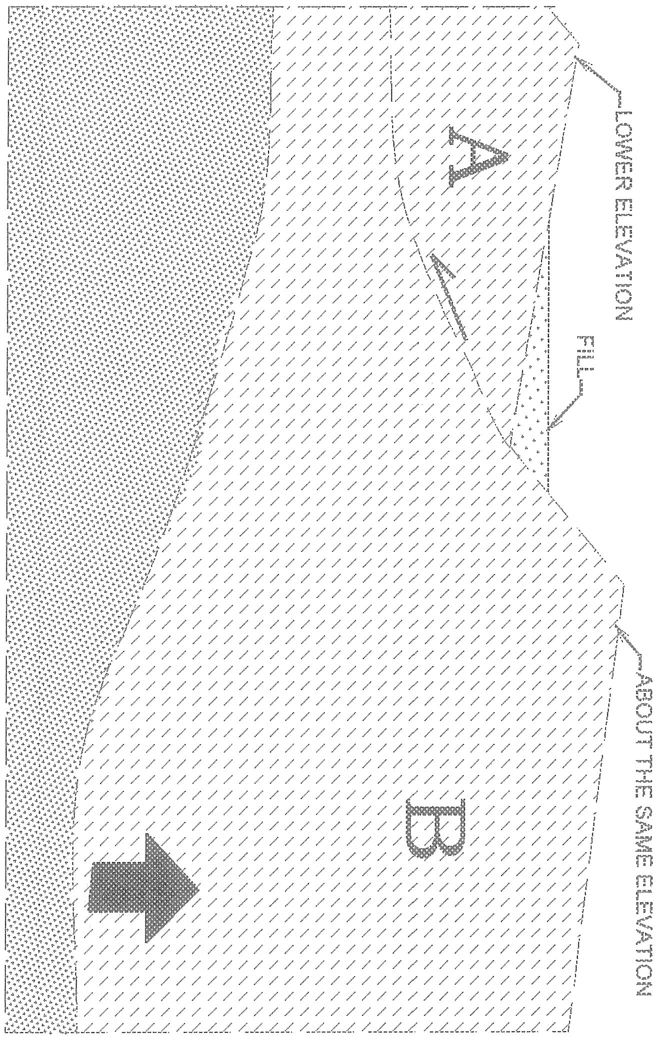
Role of Isostasy

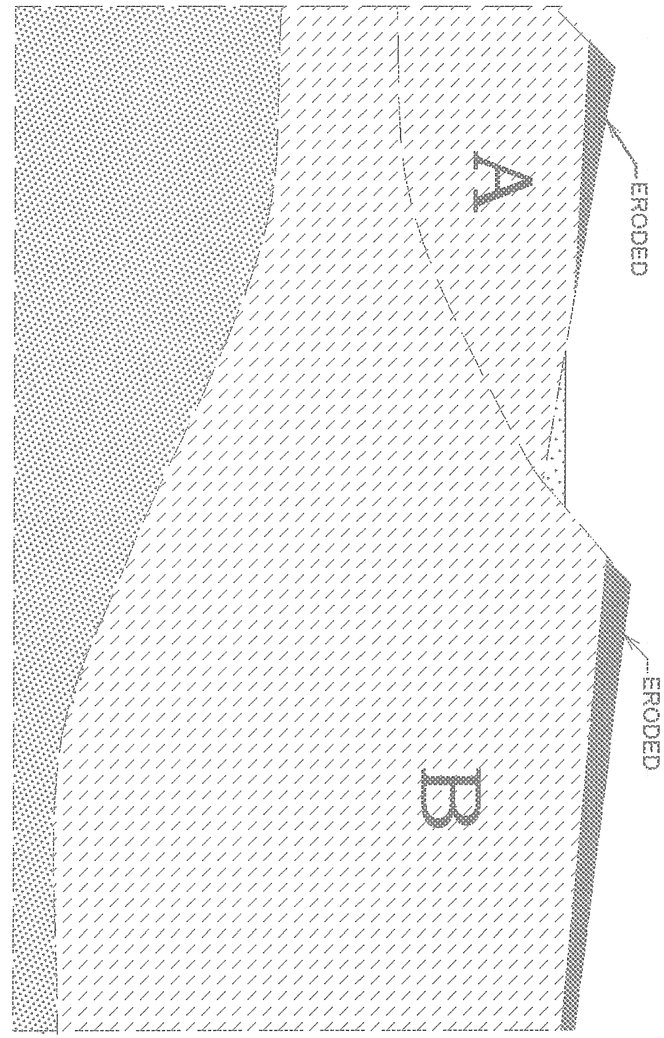
The dropping down of the valley areas caused by the pulling apart of the crust is sufficient to result in mountain ranges such as those of the Basin and Range. But that is only a portion of the story of the Wasatch Range. (REMINDER: The Wasatch Range is not in the Basin and Range province because it is more like the Rocky Mountains.) Some large mountain masses such as the Rocky Mountains in Colorado and the Sierra Nevada in California are blocks of less dense rigid material that float on the more fluid material that underlies them. (ANALOGY: Icebergs float.) When 100 feet of the top of an iceberg is removed by erosion or melting, the elevation of top of the iceberg is not 100 feet lower. The center of gravity of the iceberg rises in the water. In the same way, when rock is eroded from the Sierra Nevada or Rocky Mountain masses, the mountains rise. The process, isostasy, maintains some mountain masses at high elevations. Even though thousands of feet of rock have been eroded from the Wasatch Range and the mountainous area to the east, they remain high. (INTERESTING CONCEPT: The Basin and Range mountains such as the Qquirrh Mountains and Antelope Island are more like the ice on the ice sheet, left side of the diagram. When 100 feet of rock is eroded from Basin and Range ranges, most of the ranges will be virtually 100 lower in elevation.)

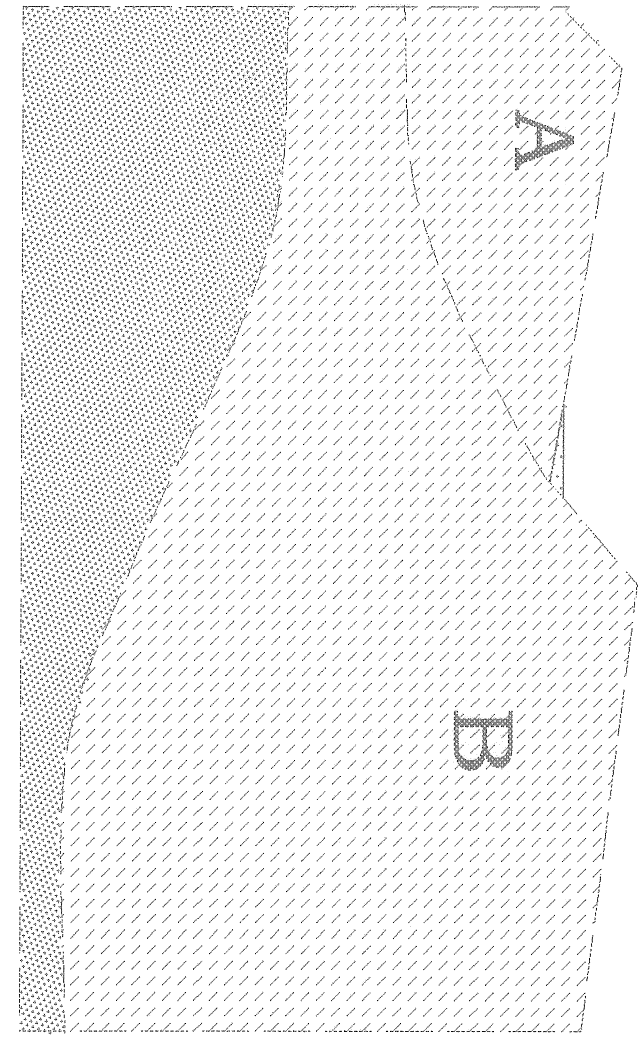
(See diagrams on the following two pages.)



Teacher feedback: ____ easily understood, ___ Okay, _____Needs improvement
Comments:



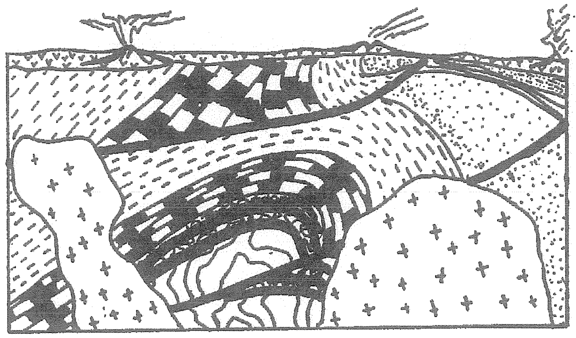




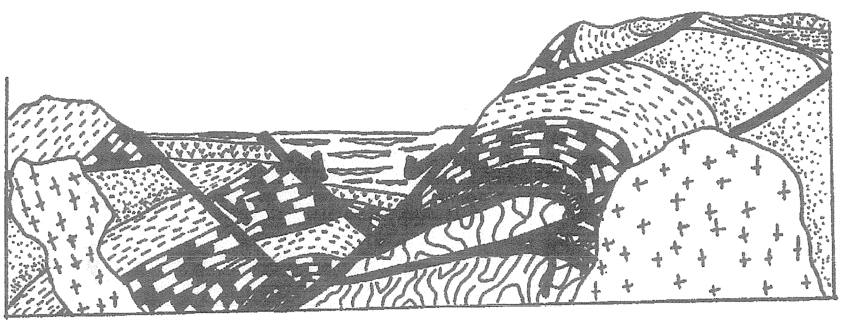
Teacher feedback: ____ easily understood, ___ Okay, _____Needs improvement
Comments:

Erosion

As the valley area west of the Wasatch Range dropped down and became a valley, erosion increased in the mountains and exposed rock units that had been buried under thousands of feet of bedrock and sediment. NOTE: bedrock is almost always older than the landform. The Wasatch Range is a relatively young geologic feature. The bedrock of the mountains is much older than the mountains.



Schematic of Salt Lake County before (above) and after (below) basin and range extension. Note the erosion of thousands of feet of material and its deposition in Salt Lake Valley.



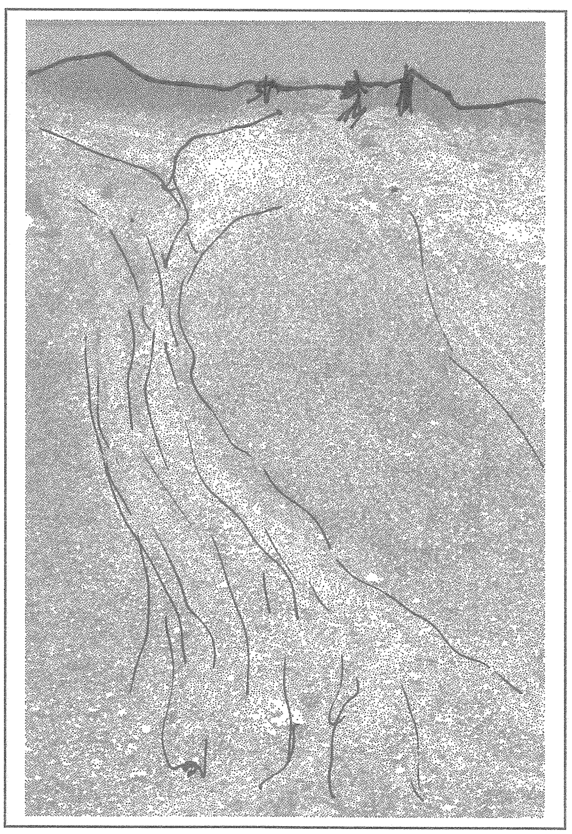
Alta,Utah. Older bedrock units exposed by erosion of the Wasatch Range.

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

Climate

The mountains also forced air flowing from the west to rise and cool, increasing the precipitation from storms moving through the area. Even today the height of the Wasatch Range is credited with Utah's "greatest snow on earth."

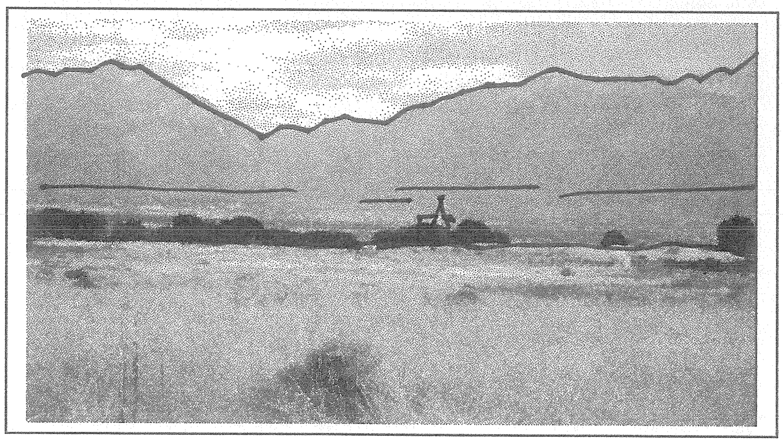
The climate of the area has undergone many significant changes. When the climate is cool and the winter snowfall large, the snow in some areas of the Wasatch Range in what is now southern Salt Lake County does not melt in the summer. When permanent snow packs accumulate year after year they can become thick enough that the snow, compacted into ice, flows slowly down gradient as glaciers. These glaciers like giant bulldozers and ice conveyor belts greatly accelerated the erosion of several canyons of the Wasatch Range. Landslides, debris flows, and rock falls also are and were important agents of erosion.

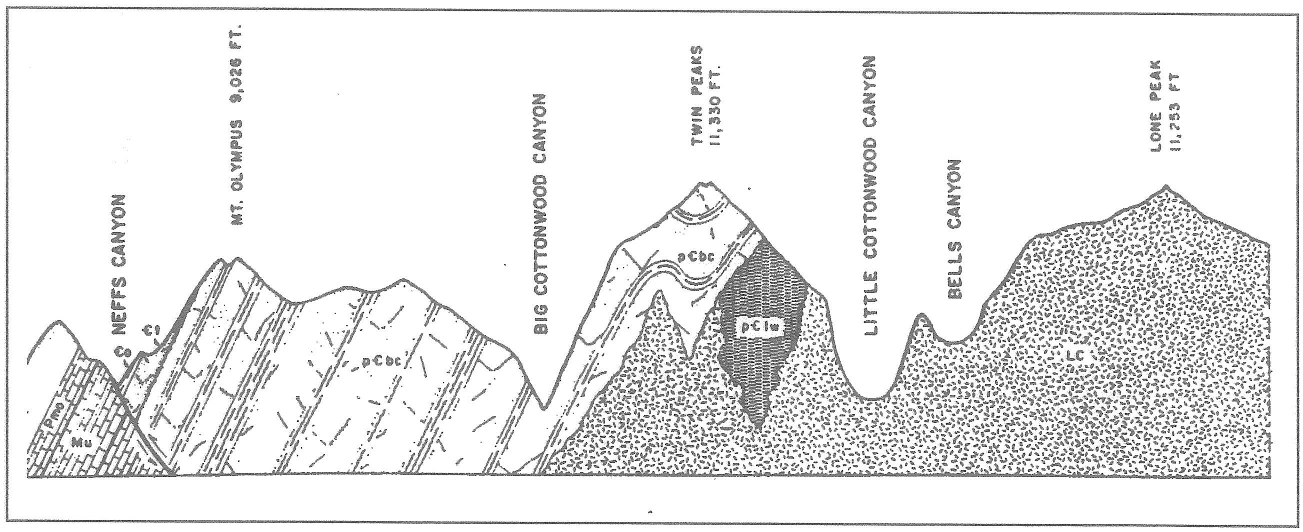


Erosion of the Wasatch Range: Debris flow of glaciated material, Mineral Basin near Snowbird, UT.

The future of the Wasatch Range

The Wasatch Range is a very special mountain range. Although only a very small part of the residents of Salt Lake County live in the Wasatch Range, the range enables Salt Lake Valley to support the large population that lives there. And because of the special nature of the range it will continue to exist after many other ranges to the west have eroded away or been drowned in sediments.





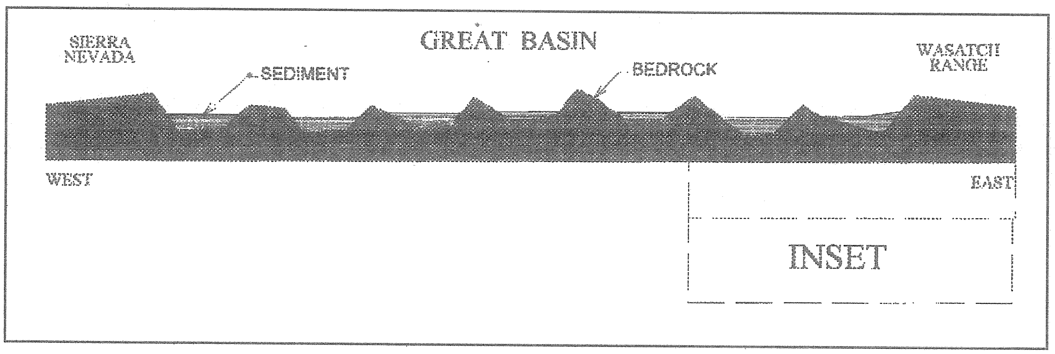
From: Diagrammatic Geologic Cross-Section, prepared by the Department of Geology, University of Utah, 1963.

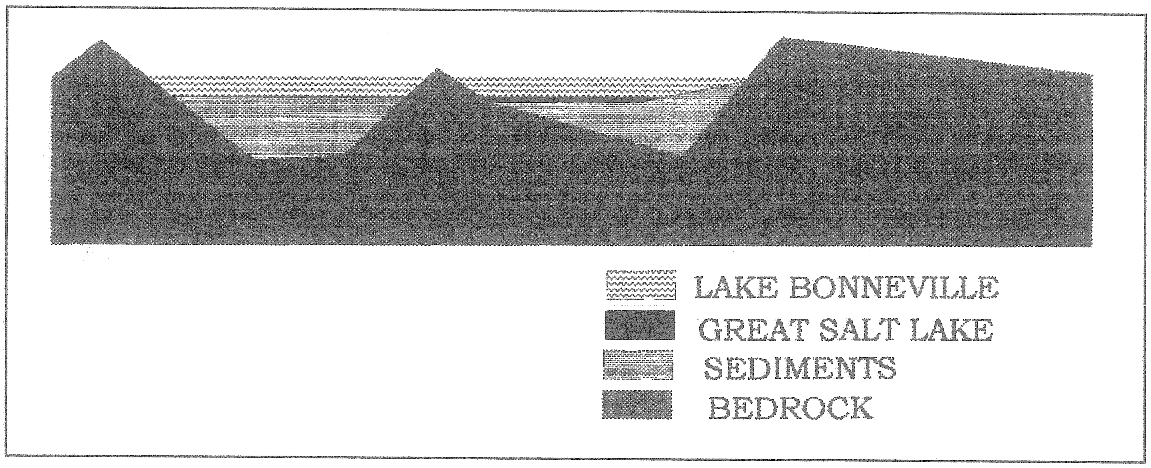
Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Story of Salt Lake County's most famous landform: Great Salt Lake

The Story:

Twenty million years ago the area that is now Salt Lake County was all relatively high and drained by rivers that flowed out of the region, probably to the Pacific Ocean. Then as the area that is now the Basin and Range Province began to stretch in an east – west direction areas and some area of the region began to subside – *basins* - while other areas remained high - *ranges*.

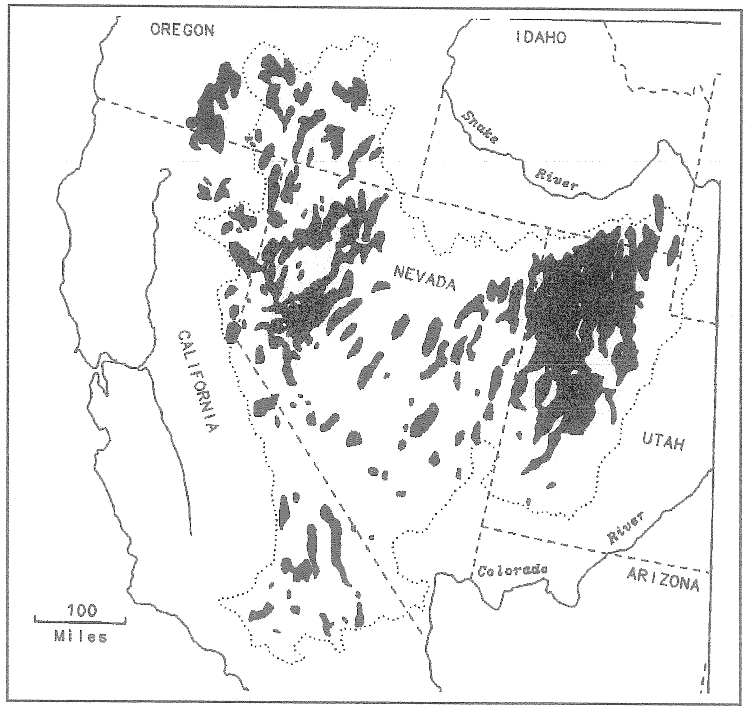




For awhile the rivers may have been able to maintain flow to the oceans carrying away the debris eroded from the ranges. Eventually the subsidence became too great and the rivers changed their courses and flowed into the basin and range valleys. Valleys also captured the sediments eroded from the ranges. Today we can identify thousands of feet of sediment deposited in these basins over the last fifteen or so million years. Much of it was deposited in lakes. Most of these sediments now lie buried beneath the valleys where they cannot be easily examined to determine the details of the distribution of lakes during this period.

Lake Bonneville and its predecessors.

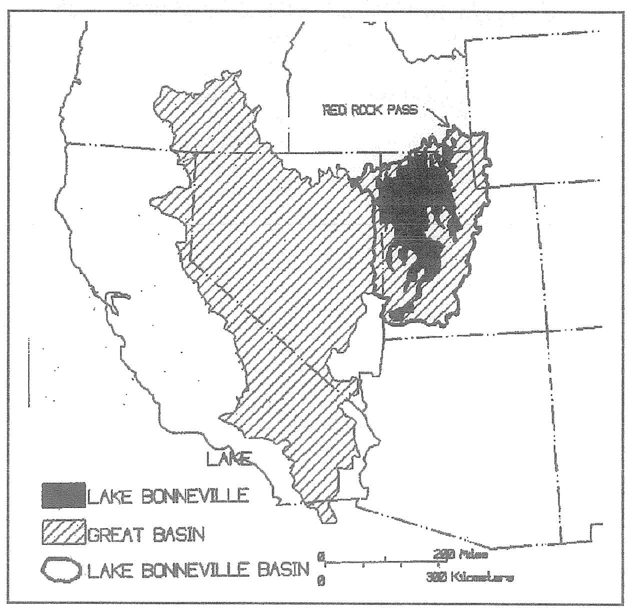
By one million years ago the Great Basin had achieved approximately its present form. Valley areas formed small closed basins that linked into larger and larger basin areas. Large and small lakes occupied the Salt Lake Valley responding to climate changes. The Lake Bonneville deep lake cycle began about 30,000 years ago. Several lakes occupied basins of the Great Basin during the last Ice Age.



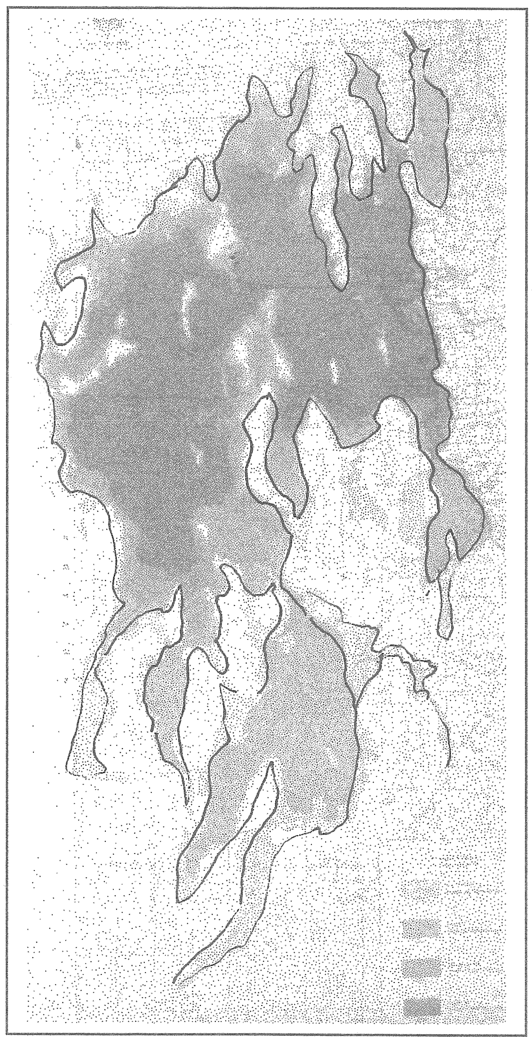
From: D.K. Grayson, *The Desert's Past, a natural pre-history of the Great Basin.* 1993. The Smithsonian Institution Press, Washington D.C., p. 86.

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

Lake Bonneville's rise began about 30,000 years ago. By about 15,000 years ago the lake had risen so high its waters flowed over the rim of the Great Basin and eventually to the Pacific Ocean. The overflow pass was east of present day Red Rock Pass in southeastern Idaho. The flow from the lake varied considerable including some years when the lake did not overflow at all.. The prominent shoreline formed at this level is called the Bonneville shoreline of Lake Bonneville.



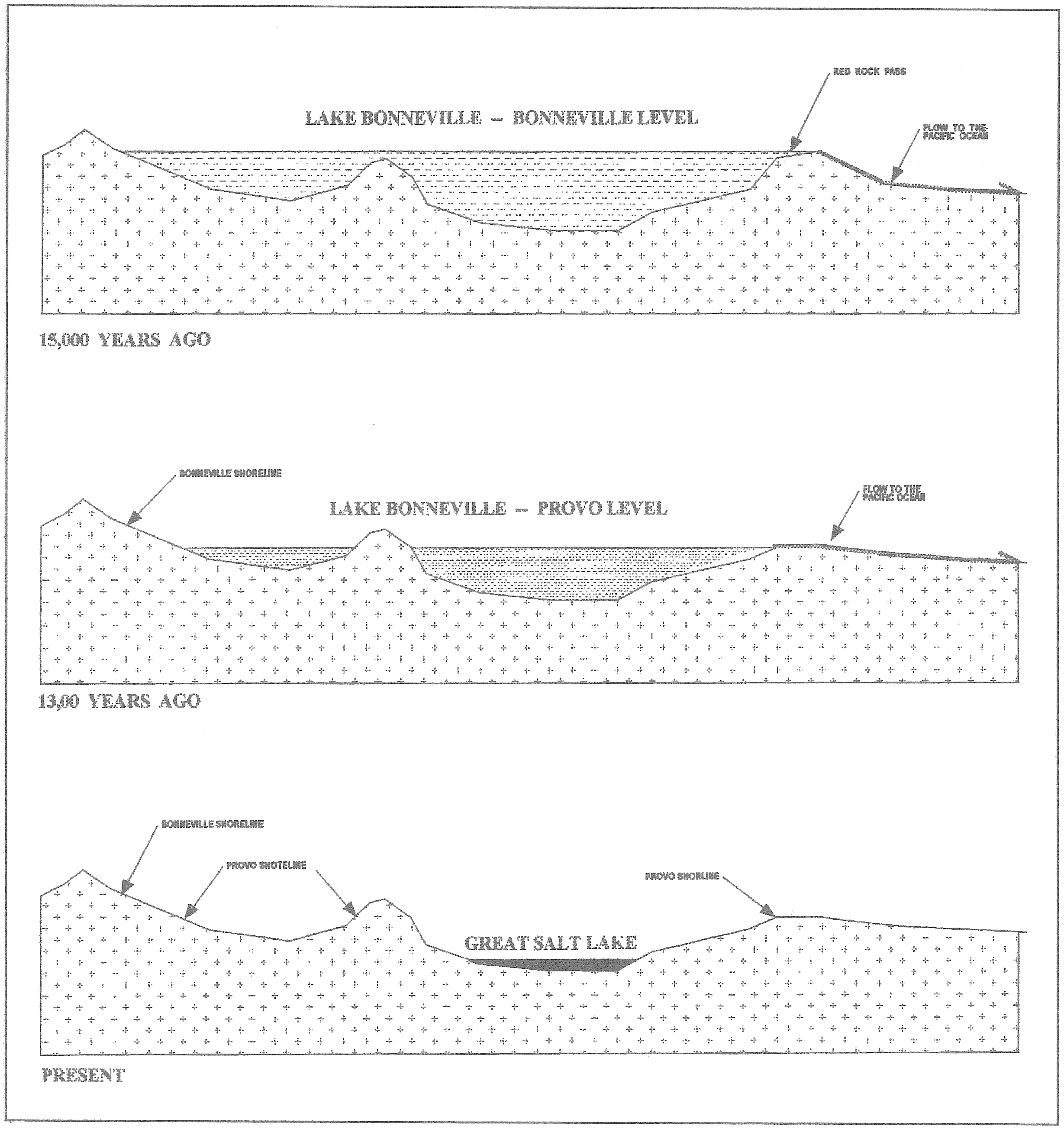
Adapted from D. R. Currey in *Great Salt Lake, a scientific, historical, and economic overview*, 1980. Utah Geological Survey Bulletin 116.



From: D.R. Currey, G. Atwood, and D.R. Mabey, Major Levels of Great Salt Lake and Lake Bonneville, 1984, Map 73, Utah Geological Survey.

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

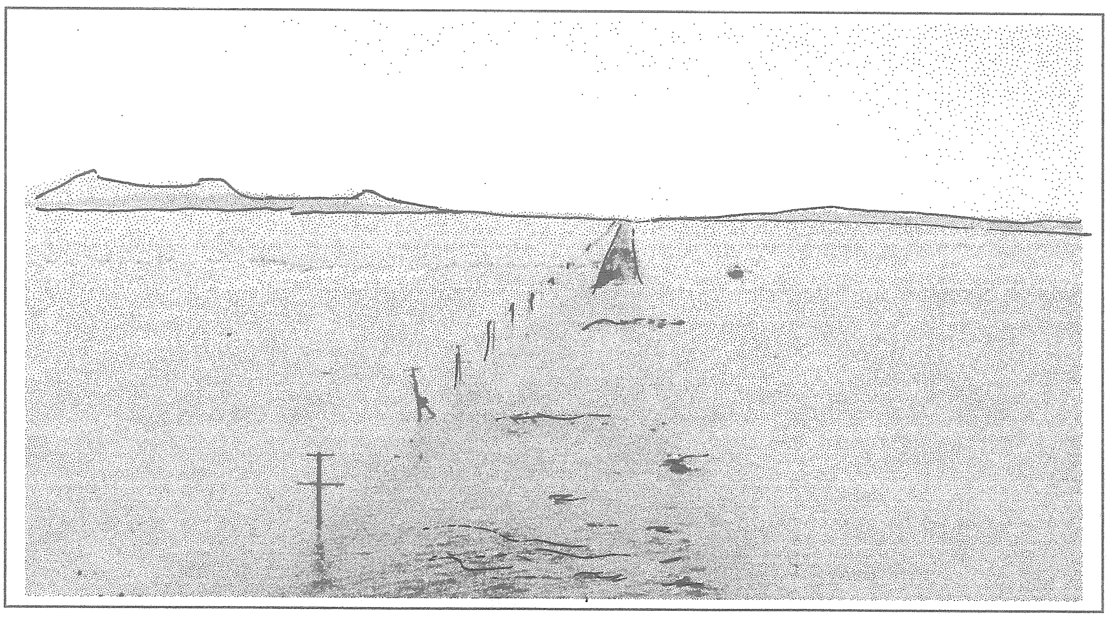
About 13000 years ago the outlet failed catastrophically releasing a flood of water through Marsh Valley to the Portneuf River and on into the Snake River. Eventually the lake stabilized for perhaps a thousand years at a new, lower overflow, controlled by Red Rock Pass, Idaho, and called the Provo level of Lake Bonneville. The shorelines built at this level are the most prominent of all. The lake still covered much of Salt Lake Valley with a maximum depth of about 600 feet. A global climate change about 12,000 years ago to a warmer and drier climate shriveled the lake to about its present size. It fluctuated perhaps 50 feet and stabilized as what we call Great Salt Lake.



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

Recent History of Great Salt Lake

When the Mormon pioneers arrived in Utah, Great Salt Lake was at about the same level it is today. They knew from reading earlier explorers' reports that the lines visible around the valley that looked almost like bath-tub rings were ancient shorelines. They found that salt could be harvested from the lake and that level of the lake fluctuated during the year and from year to year. After the pioneers had lived in Salt Lake Valley about twenty years, Great Salt Lake rose dramatically flooding land around the lake and alarming Salt Lake City residents who had no way of knowing how high the water might reach. Brigham Young sent a party around the lake to see if some way could be found to divert water from the lake to the west onto the Great Salt Lake Desert. The State of Utah implemented that diversion over one hundred years later. The lake crested in the early 1870s without causing much damage and began a general retreat that lasted about ninety years. Roads, Railroads, power lines and other structures were built on the lakebed that had been flooded in the 1870s. When another series of wet years came in the 1980s the lake rose to the previous high causing hundreds of millions of dollars in damage.



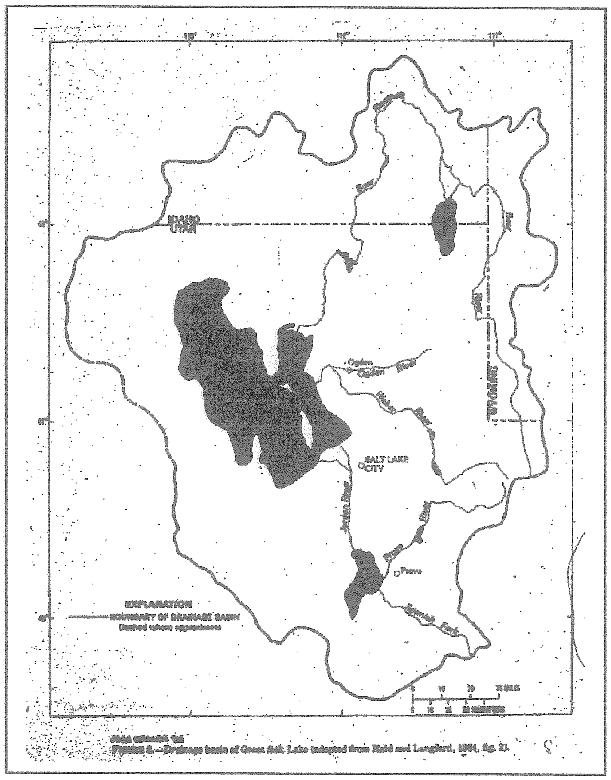
1980s flooding of transcontinental rail route.

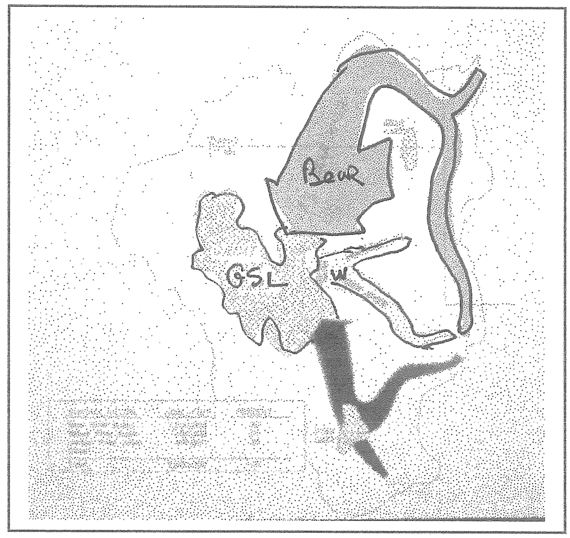
Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Lake Processes

Inflow to Great Salt Lake

Great Salt Lake is the largest lake in the Great Basin. The largest rivers supplying water to Great Salt Lake are the Bear, Weber, and Provo Rivers (through the Jordan River). All three originate in the Uinta Mountains. Great Salt Lake also receives water from several streams draining the Wasatch Range including Bells, Little Cottonwood, Big Cottonwood, Mill, Parleys, Emigration, Red Butte and City Creek. Rivers and streams flowing into Great Salt Lake account for 66 percent of the water entering the lake. Precipitation falling directly on the lake adds another 31 percent, and springs discharging directly into the lake provide the remaining 3 percent.





From: T. Arnow and D. Stephens, 1990. *Hydrologic Characteristics of the Great Salt Lake, Utah: 1847 - 1986,* U.S. Geological Survey Water-Supply Paper 2332.

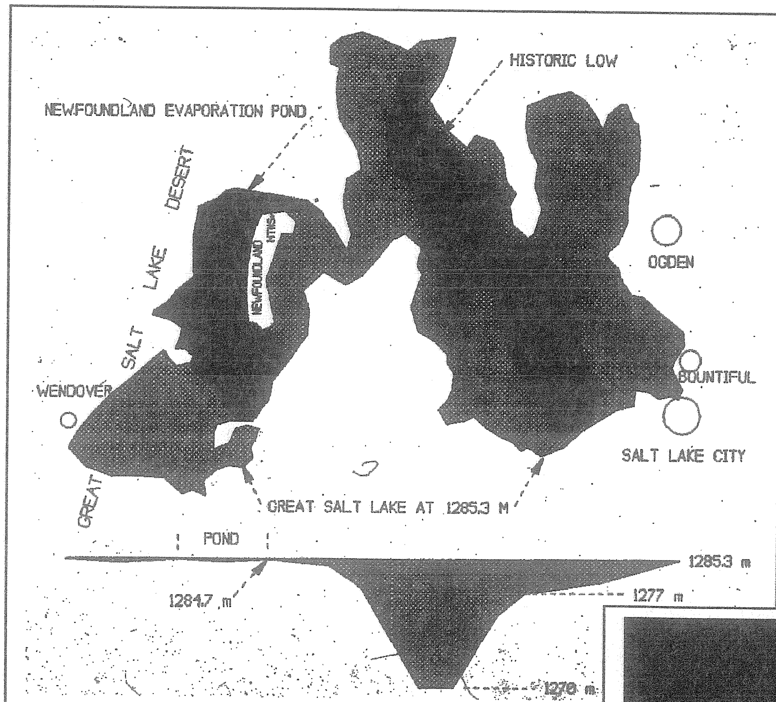
Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Outgo from the lake

Great Salt Lake occupies the lowest area of the northeastern part of the Great Basin. Water leaves the lake by evaporation into the atmosphere. Several factors determine the rate of evaporation from the lake:

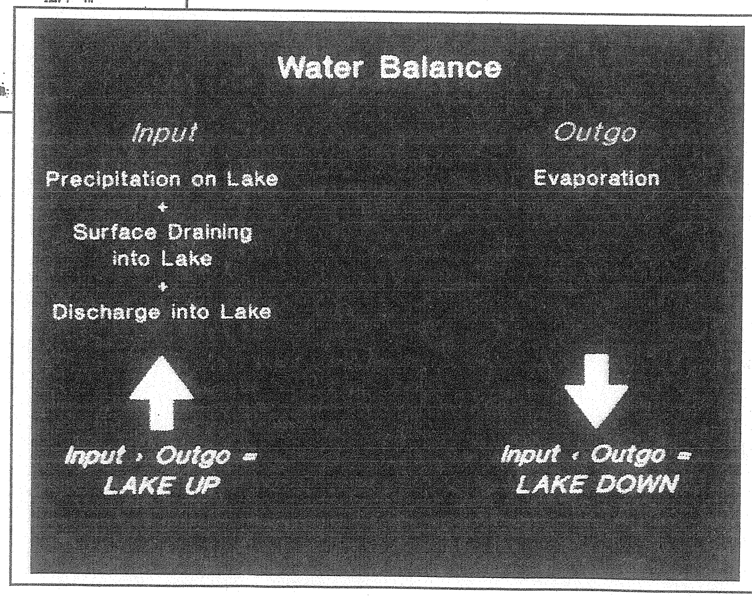
- surface area of the lake,
- weather over the lake,
- temperature of the lake, and
- salinity of the lake.

The shape of Great Salt Lake, much like a fry pan, causes increases in the lake's volume to raise the lake level by a few feet and increase the surface area by hundreds of square miles. This rapidly increases evaporation off the lake substantially.



Water balance of the lake.

If water is added to the lake faster than evaporation removes it, the volume of the lake increases, the surface of the lake rises, the lake spreads out, and evaporation of water from the lake increases. The lake rises until evaporation equals inflow. When evaporation exceeds inflow, the level of the lake and the surface area diminish until evaporation again equals inflow.

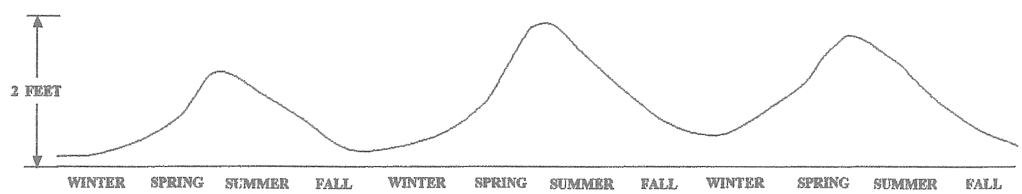


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

Fluctuations of Great Salt Lake and its predecessors.
- **Annual**
- **Historical**
- **Geological**

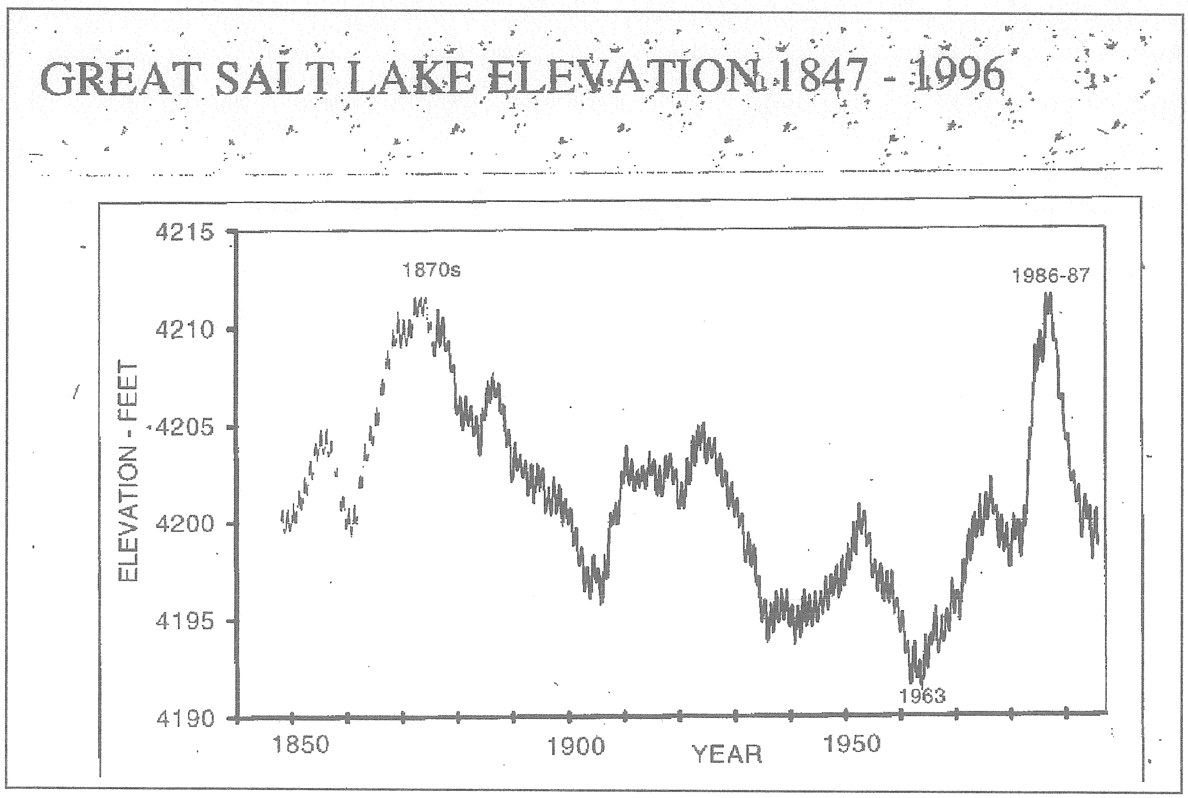
Great Salt Lake goes through an annual cycle.
- The lake rises in the late winter and spring when evaporation is low and the inflow of streams and direct precipitation onto the lake is high.
- As evaporation increases in the summer and the inflow and precipitation decrease, the lake level declines and continues to decline through the fall..

The average annual fluctuation of the lake elevation is about two feet.



TYPICAL ANNUAL FLUCTUATIONS OF GREAT SALT LAKE

Historic fluctuations of Great Salt Lake

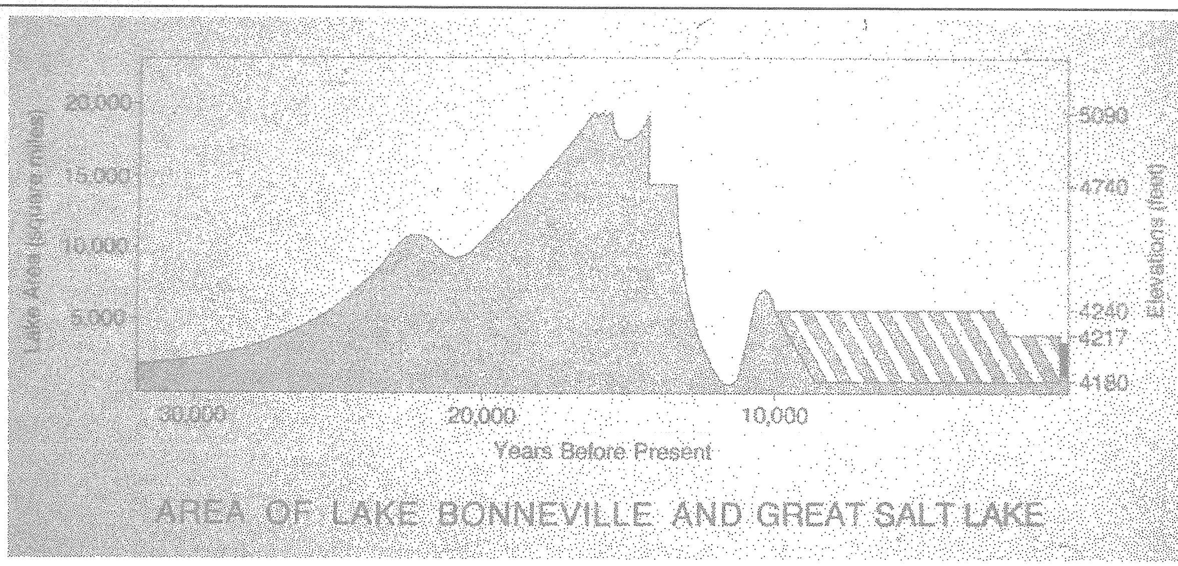


Data from U.S. Geological Survey.

In addition to the annual cycle the lake goes through cycles produced by longer-term variations in the weather over lake's drainage basin. In the 1980s a series of years of above-average precipitation caused the lake level to rise about twelve feet. Periods of drought cause the lake level to decline.

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

Geologic fluctuations of Great Salt Lake and its predecessor, Lake Bonneville



From: D.R. Currey, G. Atwood, and D.R. Mabey, 1984. Major Levels of Great Salt Lake and lake Bonneville, Map 73, Utah Geological Survey.

Lake sediments are the historians of climate change. By studying the geologic record of lake sediments, scientists learn about the climate over the region tens of thousands and even hundreds of thousand of years before historic records began in 1847. When the climate of the region was cooler and wetter, the lake was much deeper. The last of these deep lake cycles began about 30,000 years ago. About 15,000 years ago when the lake reached a depth of about 1000 feet only the tops of the higher mountains of northwestern Utah stood out as islands. Lake waters flowed over the rim of the Great Basin through the Snake and Columbia Rivers to the Pacific Ocean. This part of the rim of the Great Basin consisted of sand and gravel that was relatively easy to erode. Eventually this natural dam failed releasing a tremendous flood of water. The lake rapidly lowered about 400 feet. This was one of the greatest floods recorded in the geologic record. The Bonneville deep lake cycle ended when dry climates returned and the lake receded to about its current level.

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

Landforms of Great Salt Lake
Lake sediments.

Each annual cycle of the lake is marked by a line of debris on the lakeshore at the highest level reached by the lake waters and on the lake floor by distinct layer of sediments. Layers of sediments result from the annual influx of water and sediment in the spring and the annual variation in temperature of the water in the lake. Detailed examinations of the layer can provide information on the conditions of the lake the year the layer formed. The line of debris on the lake shore will be washed away the next time reaches or exceeds this level, but the layer on the floor will be preserved under the layer deposited the next year. This stack of layers provides an annual record of the lake and the weather that affects the lake much like the growth rings of a tree provide a record of the tree's growth and the weather that affects the tree.

Debris of 1980s

Photo (missing)

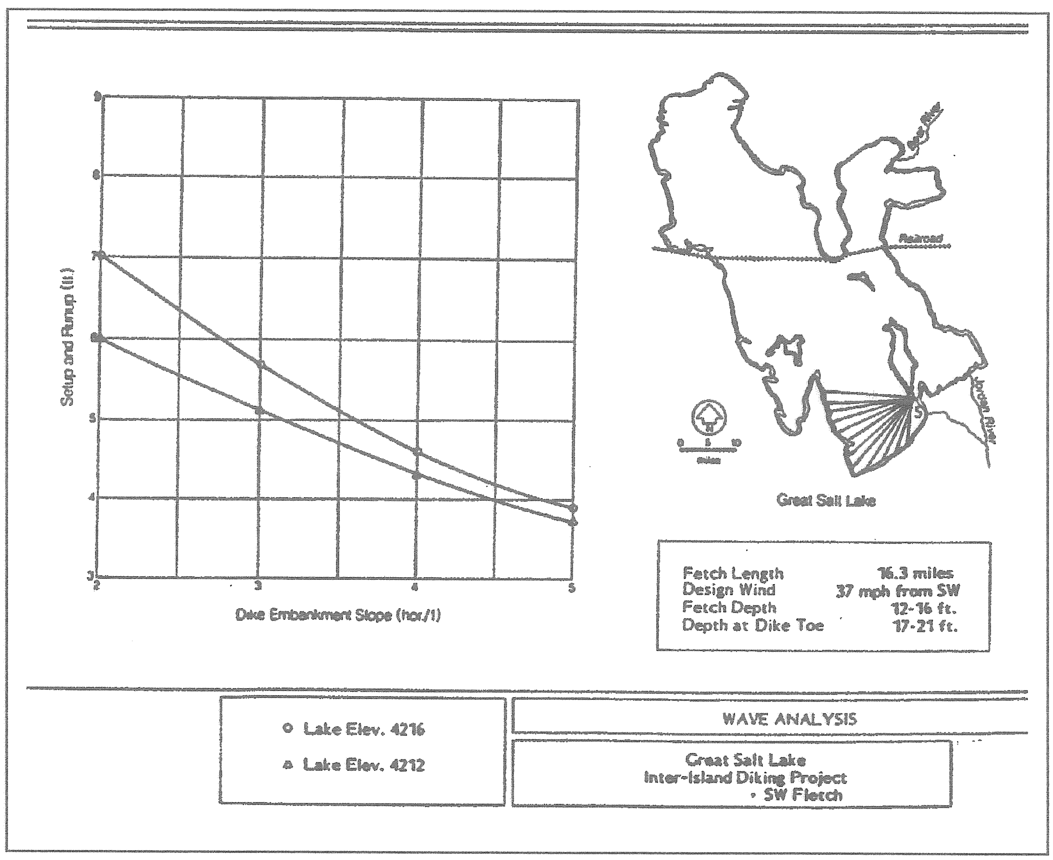
Layered sediments.

Photo missing

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

Landforms of Great Salt Lake
Beach deposits

Great Salt Lake is not large enough to have significant tides such as affect the oceans. However, winds caused by storm weather across the lake have a major impact on the lake surface. When a strong wind blows across the lake for several hours, water piles up on the down-wind shore, and wind generated waves carry water and debris to high levels. That is why the flooding along the lakeshore extends to elevations several feet above the still-water elevation of the lake. Once the wind stops blowing the lake level oscillates: water rises on the upwind shore as it falls on the downwind shore. Each oscillation takes about six hours. Oscillations continue with diminishing amplitude for several cycles.

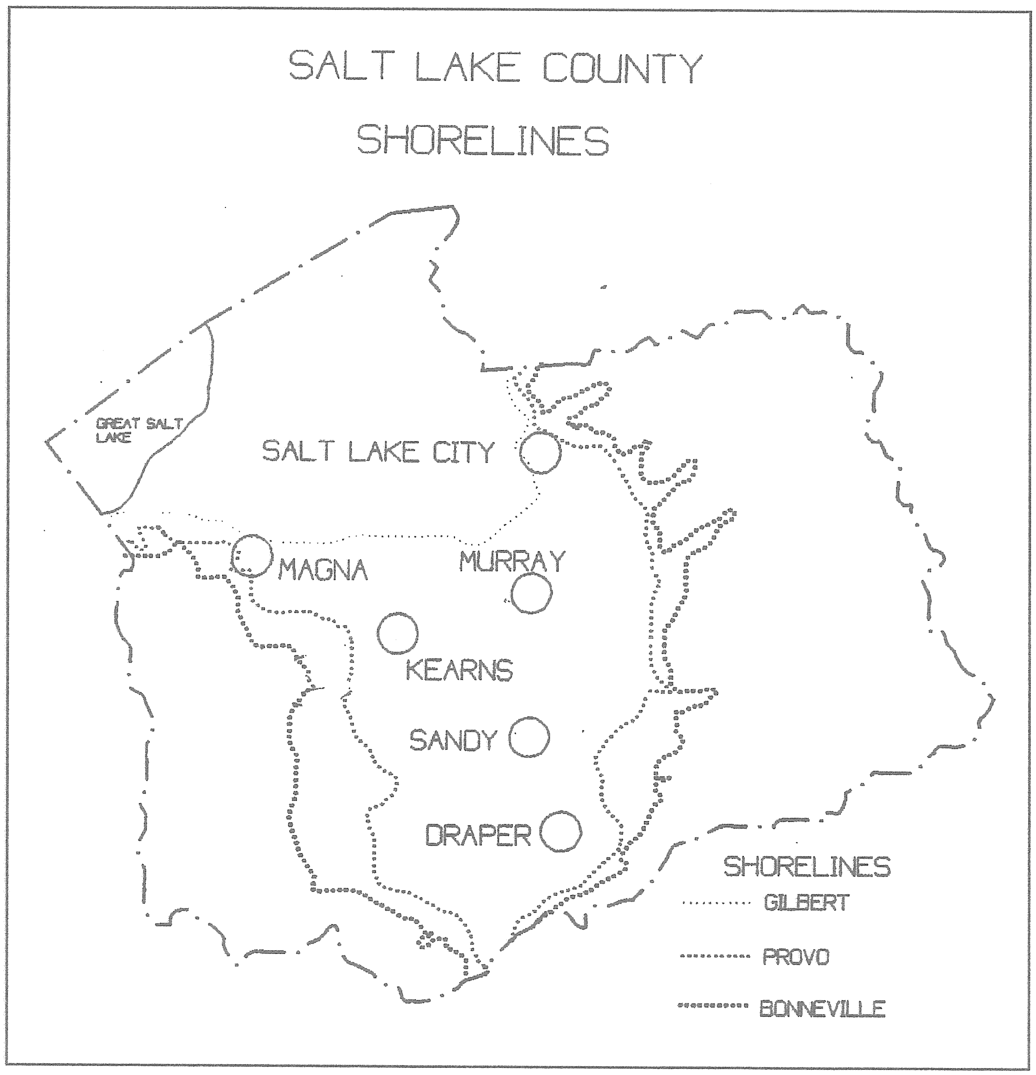


From: Inter-island Diking Feasibility Study, 1986. Prepared for the Utah Department of Natural Resources.

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

Landforms of Lake Bonneville
Lake Bonneville covered most of Salt Lake Valley with water in some areas 1000 feet deep. Evidence of this great lake can be found all over the valley floor below the 5200-ft contour. Below that level, nearly all of the local landforms were formed, or modified, by the lake. The shorelines are the most widely recognized features. Construction companies mine the sand and gravel of various Bonneville shorelines around the valley. The highest shoreline marks the level where water overflowed the rim of the Great Basin. The U on the hill slope just east of the University of Utah is immediately above the Bonneville level. The next lower shoreline marks the lake level after the great flood. The University of Utah is built on geologic features of the Provo level. Sandy, Utah is built on sands of the deltas that Little Cottonwood Creek built into the lake. Lake-bed clays of mid-valley are the well-known to local residents.

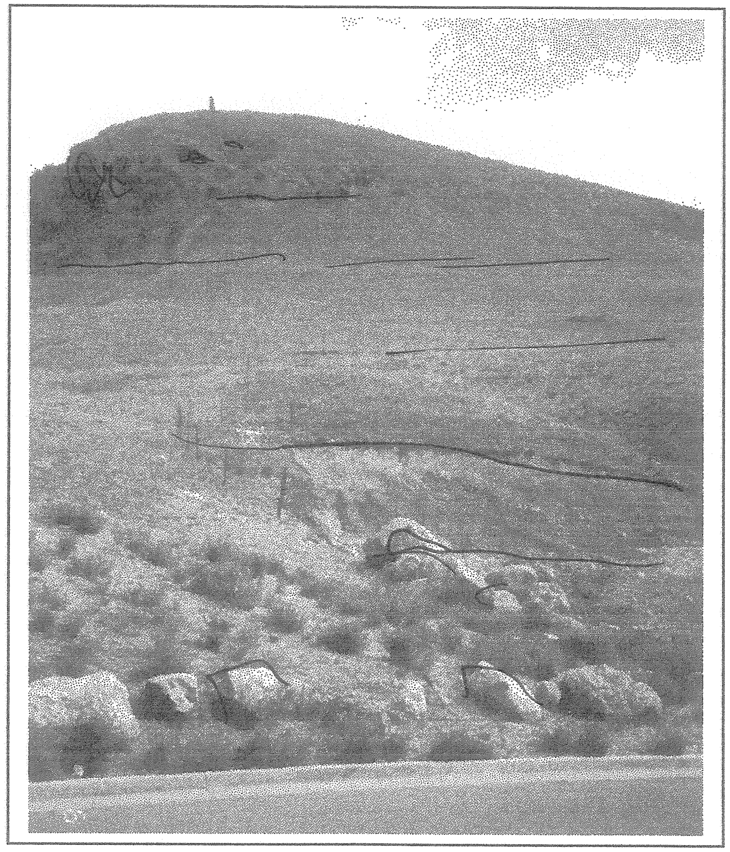
Locations of shorelines, Salt Lake County.

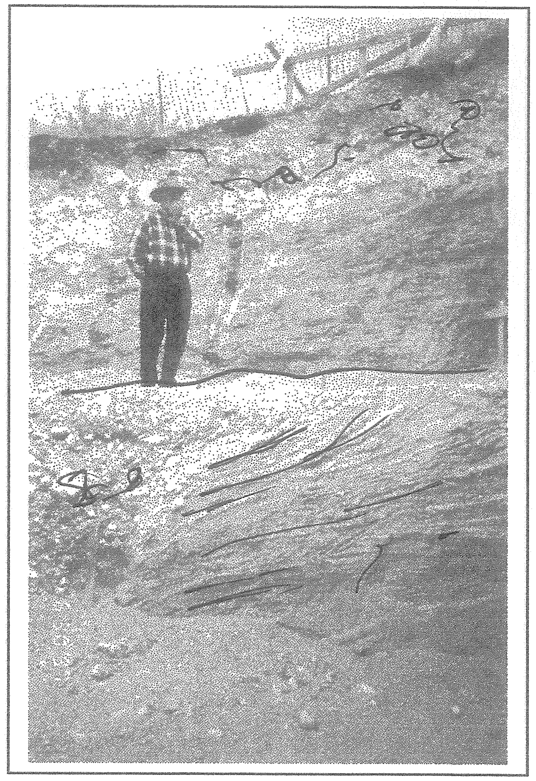


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

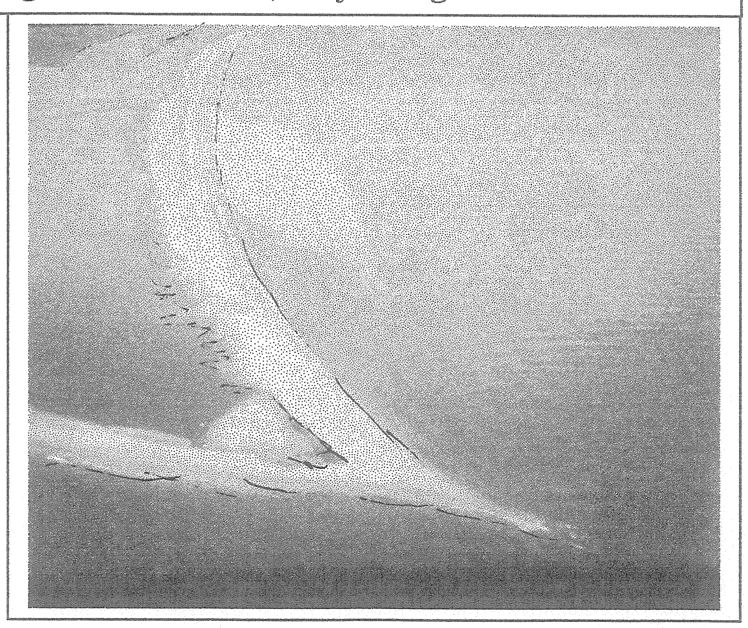
SCENE FROM LAKE BONNEVILLE

Ensign Peak area.





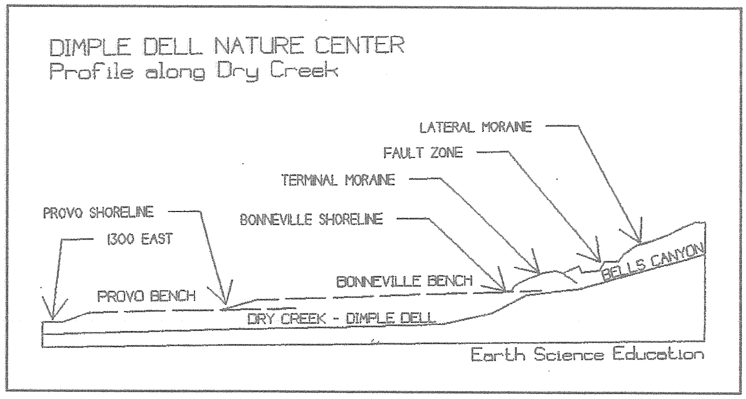
Lake features, (spits and lagoons) of Great Salt Lake developed by storm waves and currents of at least two directions. This is how the Ensign Peak subdivision might have looked 14,000 years ago.

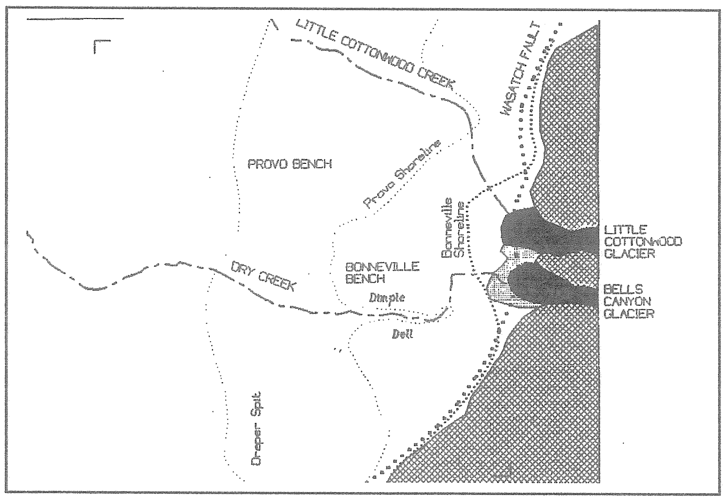


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

SCENE FROM LAKE BONNEVILLE

Little Cottonwood area.

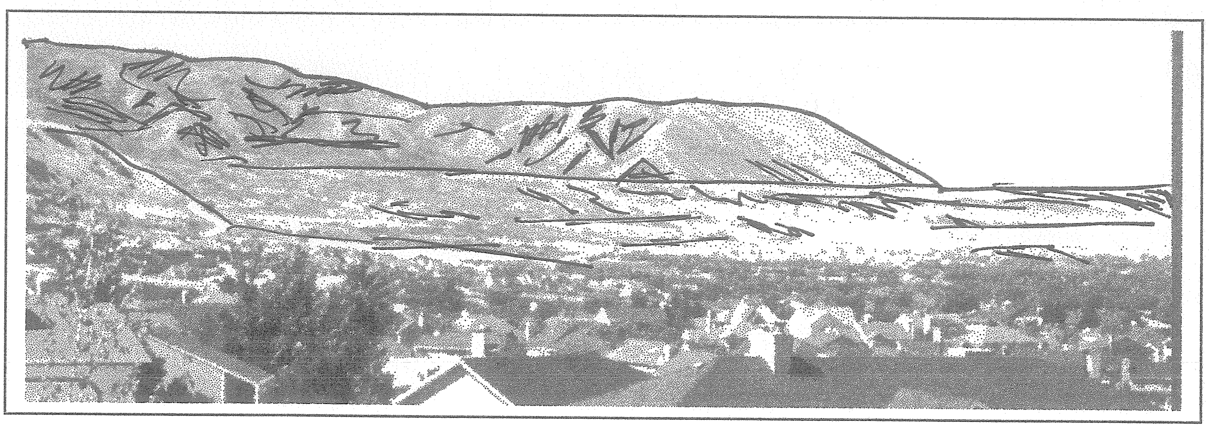


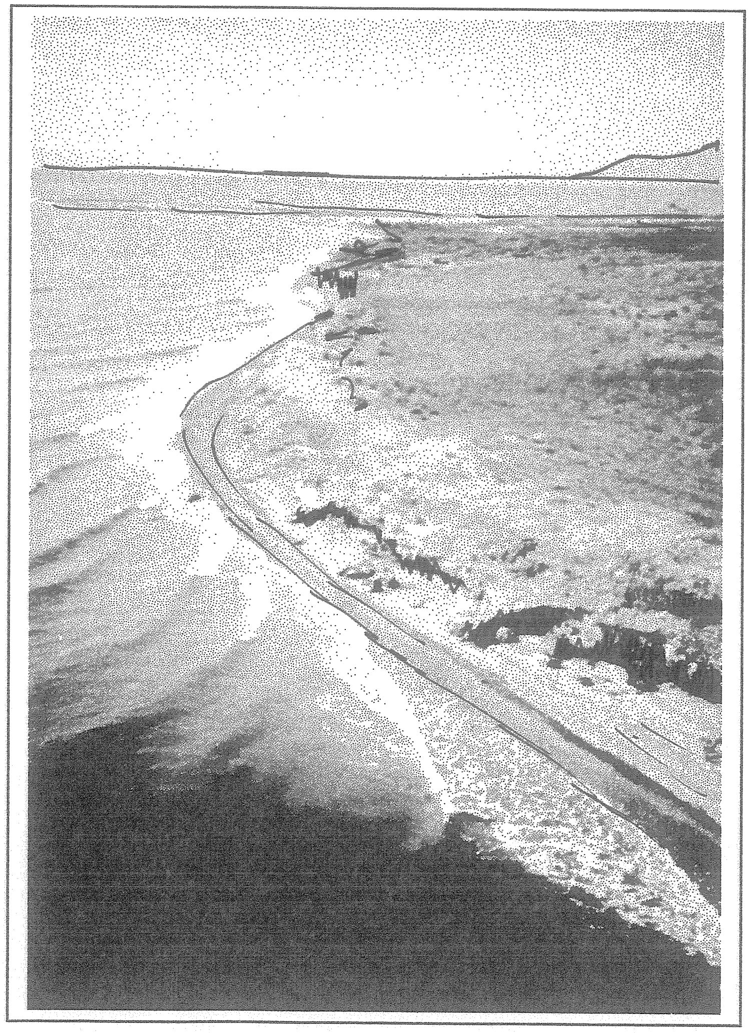


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

SCENE FROM LAKE BONNEVILLE

Draper.
Point of the Mountain.



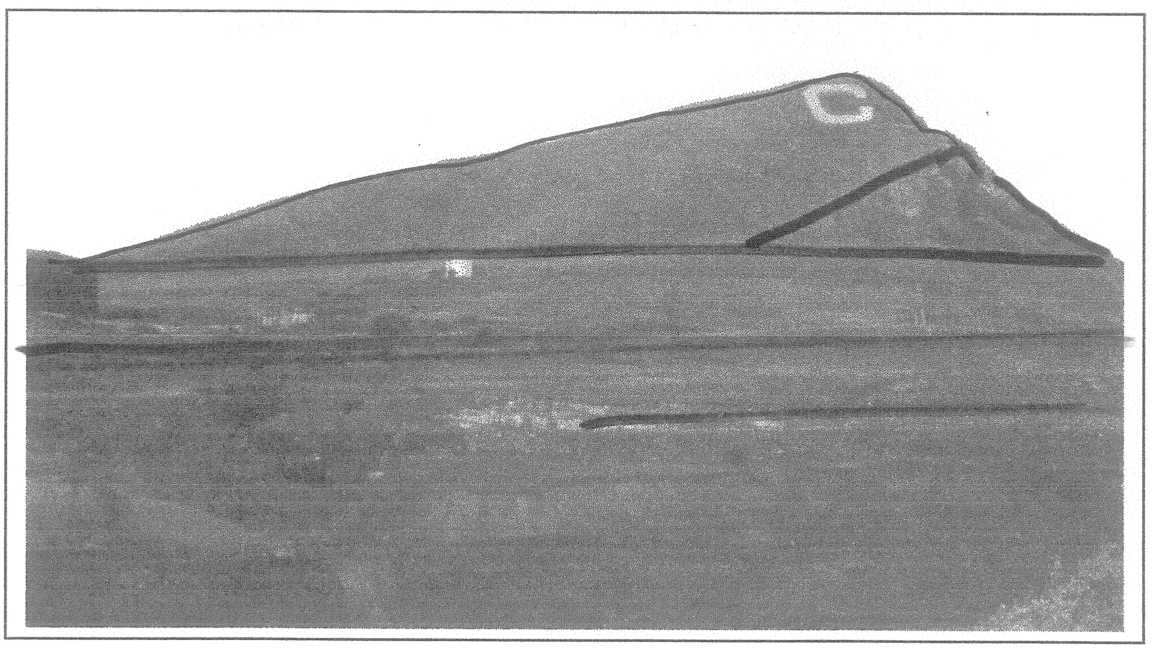


Longshore processes building beaches, Great Salt Lake, Antelope Island

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

SCENE FROM LAKE BONNEVILLE

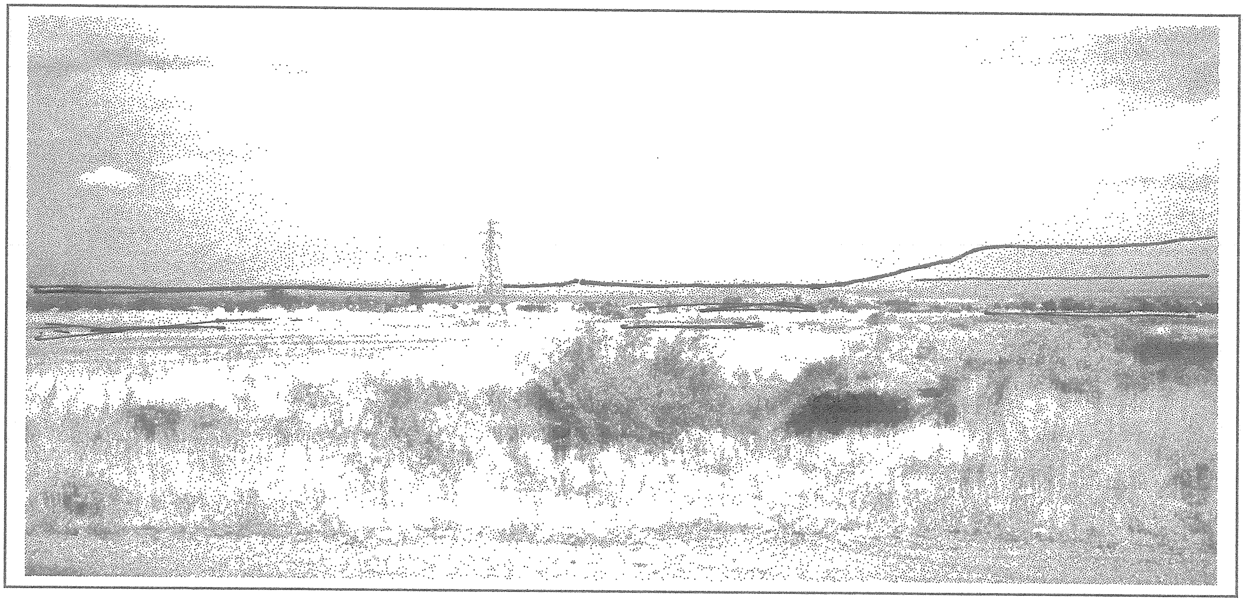
Magna area.

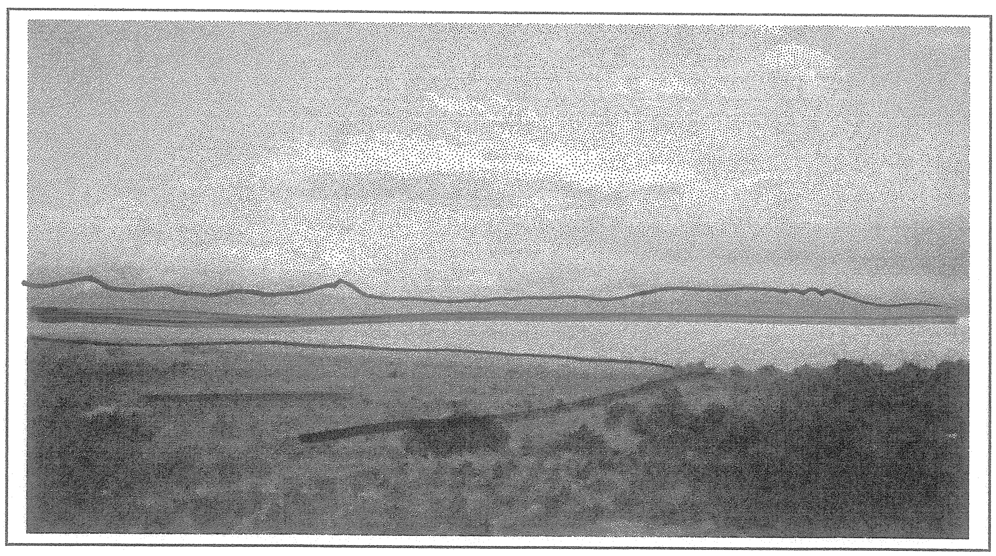


Teacher feedback: ____ Easily understood ____ Okay ____ Needs improvement.
Comments:

SCENE FROM LAKE BONNEVILLE

West Valley City area.



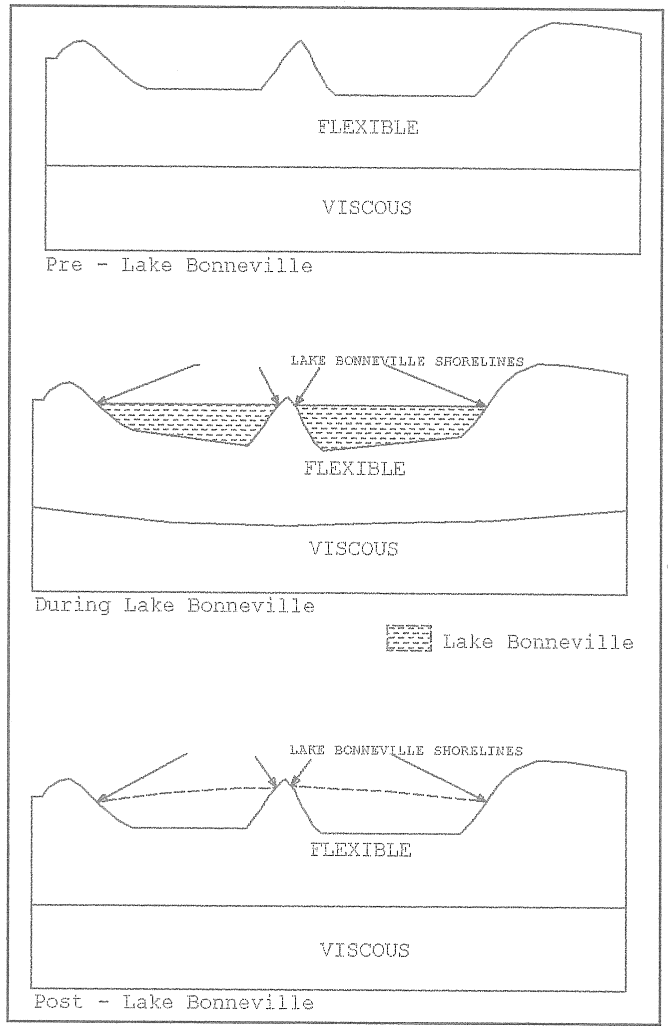


How the Bonneville beaches of the west side of Salt Lake County might have appeared during Lake Bonneville times.

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

Deformed shorelines of Lake Bonneville.

An interesting aspect of the Lake Bonneville story involves elevations of the highest shorelines formed by the lake. The crust of the earth under much of what is now the Great Basin was probably never as strong as the crust under the central part of the North American continent. Thinning and heating related to the extension of the Basin and Range province further weakened the crust. By Lake Bonneville time the crust was strong enough to support the weight of an average sized mountain range but not strong enough to support the weight of the water in Lake Bonneville. Under the load of the lake, the rigid crust displaced some of the viscous underlying material. The lake area sank and the immediately surrounding area rose. When Lake Bonneville was at its maximum depth the crust under the central part of the lake was depressed about 250 feet. When the load of water was removed as the lake declined, the crust rebounded as the viscous material flowed back under the lake. The highest shorelines of Lake Bonneville are now about 250 higher in what has once the center of Lake Bonneville (now the area west of Great Salt Lake) than they are around what was the margin of Lake Bonneville.



Answering the question "what is the elevation of the highest shoreline of Lake Bonneville?" isn't straightforward. "About 5200 ft above sea level" is a good approximation.

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

Living on the shores of Great Salt Lake

Great Salt Lake is a great natural treasure that is not fully appreciated by many of the residents who live alone its shores. The lake moderates the climate of the Wasatch Front. Its marshes support an abundance of wildlife. The lake offers a variety of recreational and tourist opportunities. Extracting minerals from the lake has been an important industry since pioneer times and in more recent years harvesting brine shrimp eggs has become an important industry. Great Salt Lake is a good neighbor for residents of Salt Lake County. It also is a great teacher... of geologic processes, landforms, and how to develop land wisely (or unwisely).