Major reading assignment.
For the second session... Earth Science Outside -- Geologic History of the Wasatch Front.

I hesitate to make this pdf available to you before class because I think you need to learn some principles of Earth science before you read this and I will cover those in the first session of the workshop. I don't want to scare folks off... but teachers from prior year's workshops have asked for this... so... I make it available.

second section of....

Utah's Geology

written for curious non-geologists who want to understand Utah's big bold beautiful geology

by
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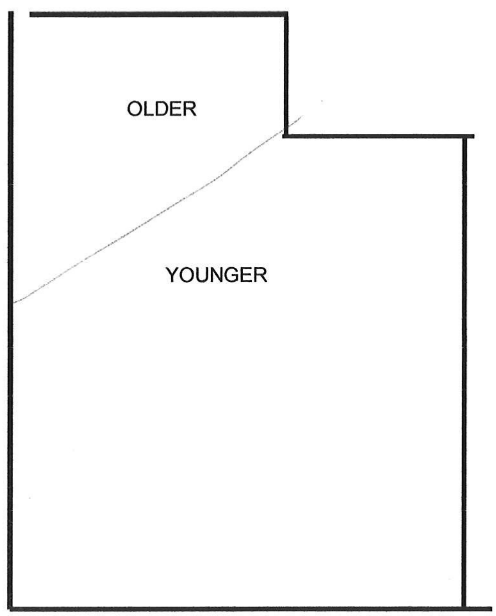
UTAH GEOLOGY
CHAPTER ONE

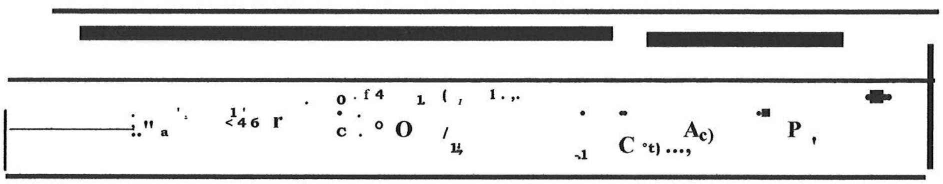
BENEATH IT ALL... THE BASEMENT
Hintze's "A Basement of Metamorphic Rocks"
Atwood's "Metamorphic Basement"
3.0 to 1.1 billion years ago
January 1 to August 20



Although layered rocks tell most of Utah's geologic story, before we study these layers of sedimentary rocks we will consider the very old rocks that they were deposited across. These very old rocks that underlie the sedimentary rocks are called basement rocks. Although these old rocks occur almost everywhere in Utah, in most places layer upon layer of younger sedimentary rocks deeply bury and hide them. We see basement rocks only in a few places such as: 1) in some mountain ranges where they have been lifted up and exposed by erosion, or 2) in deep canyons where rivers have cut through all the overlying sedimentary rocks, or 3) as samples obtained from deep drill holes. These oldest of Utah's rocks tell the story of Chapter One of Utah's Geologic History.

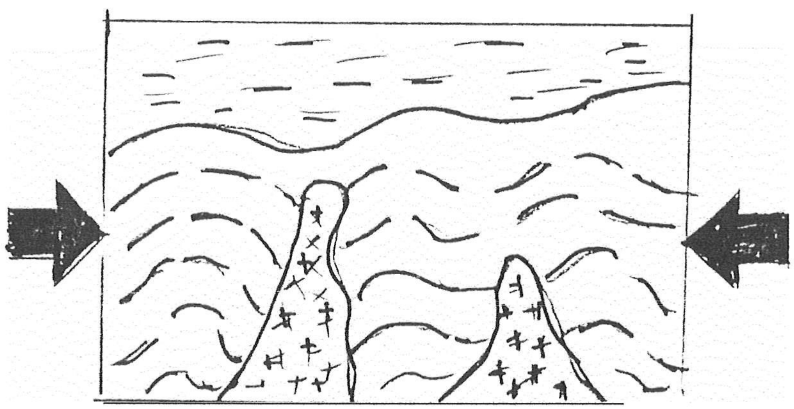
The basement story covers almost two thirds of the chronology that Utah rocks record. The history these rocks tell has few details because tectonic forces have deformed the rocks so severely. We do know that by the end of this time a complex of metamorphic rock had been formed upon which the layered sedimentary rocks of Utah were deposited. These metamorphic basement rocks fall into two age groups apparently representing two periods of development of the western part of the North American Continent. The oldest of these basement rocks are in northern Utah and are 2.3 to 3.0 billion years old. These rocks appear to have been originally layered sedimentary rocks deposited on oceanic crust and later intruded by igneous rocks, metamorphosed and attached to the North American Continent. These rocks are exposed in the Wasatch Range in a small area near Little Cottonwood Canyon, and in a large area extending from Bountiful to Brigham City, on Antelope Island in Great Salt Lake, in the Raft River Mountains and in the eastern Uinta Mountains. Younger metamorphic rocks that have had a much different history are found in a few deep drill holes in southern Utah and are exposed in the Grand Canyon and in western Colorado.

BEFORE 3.0 BILLION YEARS AGO



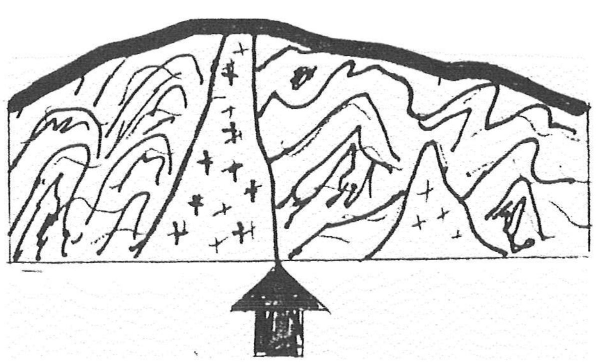
DEPOSITED AS LAYERED ROCKS

2.3 TO 3.0 BILLION YEARS AGO



DEEPLY BURIED, HEATED AND COMPRESSED, INTRUDERD BY IGNEOUS ROCKS, AND METAMORPHOSED

BEFORE 1.1 BILLION YEARS AGO



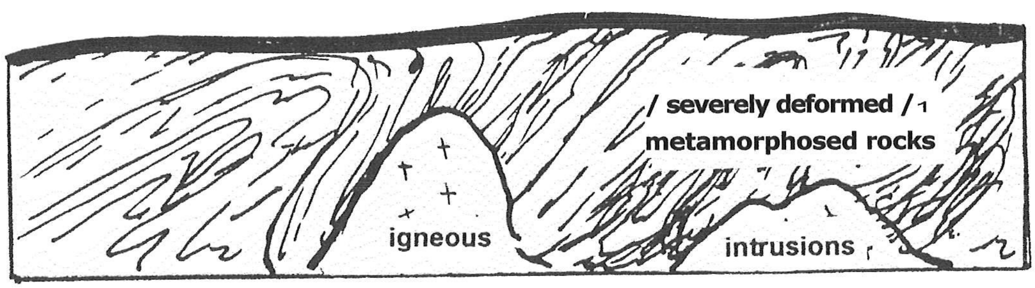
UPLIFTED AND ERODED

There are only a few ways that rocks can become as intensely metamorphosed as these basement rocks. When continents collide, when tectonic forces build mountain belts such as the Rocky Mountains or the Andes or the Himalayas rocks in the crust, deep in the Earth's crust are under such intense pressure and heat that minerals change their form and chemistry and rock acts almost like toothpaste. All of Utah's basement rocks were deeply buried, compressed, and subjected to intense heat and pressure and metamorphosed to an extent that their history that can only be partly unraveled. We can surmise that tectonic forces from mountain building or continental collisions metamorphosed these rocks at least once and probably twice before Utah's layered-rock story even began.

Through much of the latter part of this chapter the metamorphosed rock was exposed and being eroded. Erosion and deposition are a couplet. Bedrock erodes one place and becomes a sedimentary deposit somewhere else. But there is no sedimentary rock record left in Utah to tell us about this long period of erosion.

UTAH AT THE CLOSE OF CHAPTER 1

CROSS-SECTION



Resources from Chapter One:

Because of their great age we do not expect to find fossils in these rocks. Even if some primitive life forms that may have existed in the seas at that time had been fossilized, the metamorphism these rocks have experienced would have destroyed the fossils. These rocks are not valued commercially. They have not produced oil and gas. Only minor amounts of minerals have ever been mined from them.

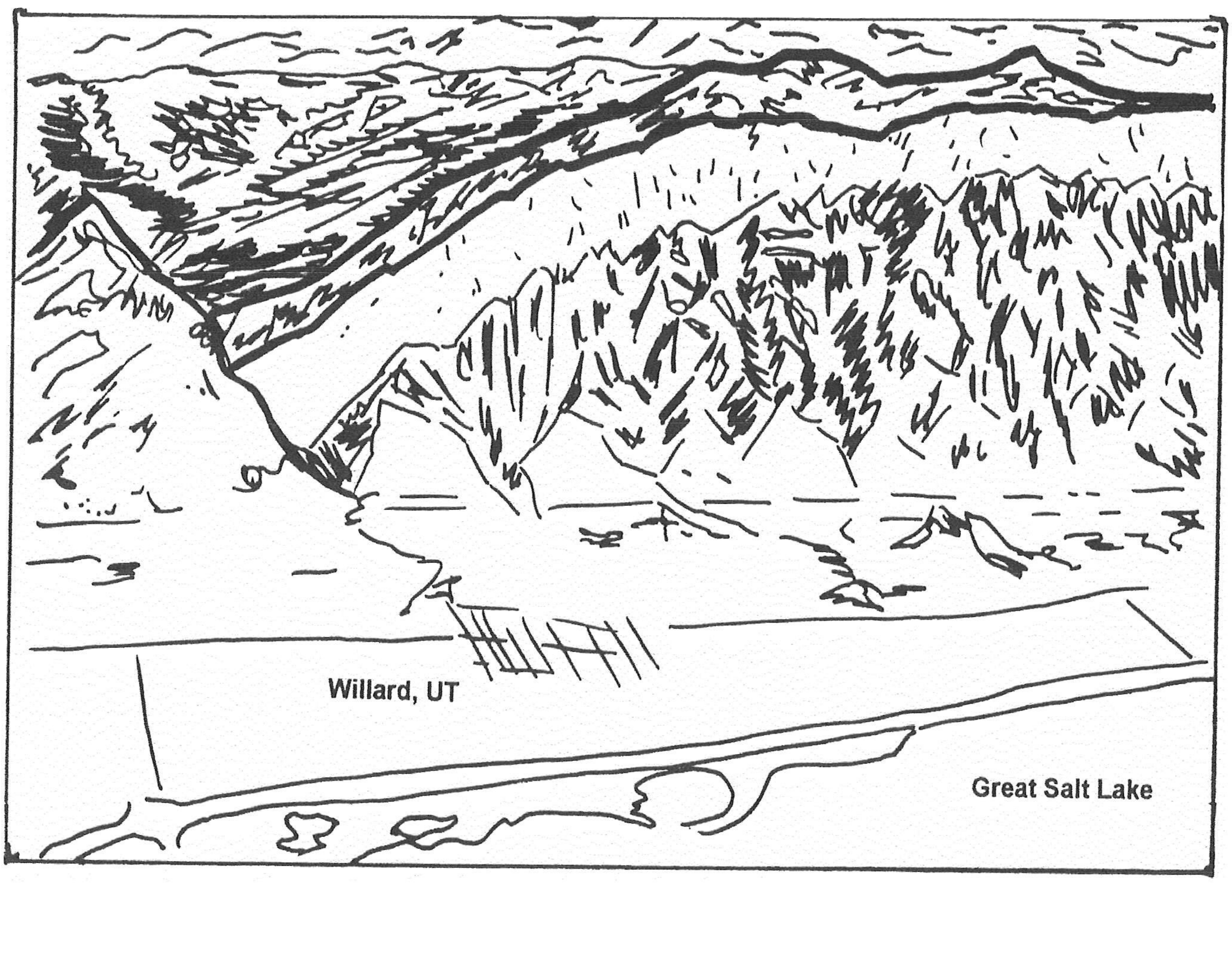
Scenery... what Chapter One rocks look like today:

Several ranges of the Basin and Range and along the Wasatch Front consist of these complex rocks. When you look at a mountain front of these rocks, they look a little mangled, as if they've had difficult lives and been badly stressed. Instead of neat rock layering of sedimentary rocks, or the bold homogeneity of intrusive igneous rocks, or the confused layering of volcanic (extrusive igneous) rocks, they usually have vestiges of layering, indistinct patterns.

Some homeowners admire these unusual looking rocks and use them for landscaping

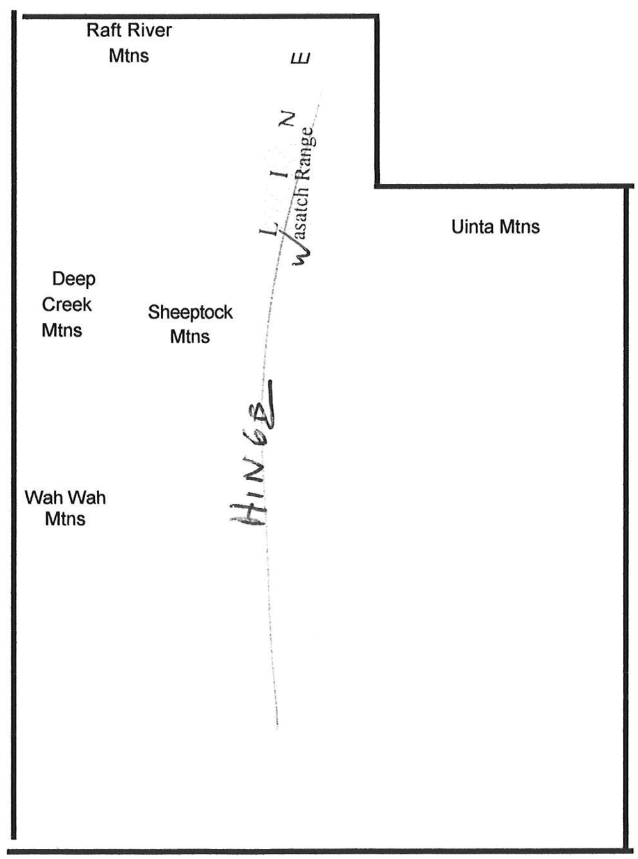
x

Chapter One bedrock, Farmington Complex, Brigham City, Adapted from Stokes (1986, p. 40)



UTAH GEOLOGY
CHAPTER TWO

OLD LAYERED ROCKS
Hintze's "An Aulacogen and Icehouse Earth"
Atwood's "Metamorphism Lite"
1.1 billion to 570 million years ago
August 21 to October 22



WHERE CHAPTER TWO ROCKS ARE EXPOSED TODAY

Beginning somewhat before one billion years ago, large areas of the basement complex of much of what would become North America subsided below sea level to form basins called aulacogens and in these basins thousands of feet of sediments were deposited. Geologists have not been able to map the extent of these sedimentary basins. Rocks from Utah's Chapter Two are exposed in several areas of northern and western Utah and in the Grand Canyon south of Utah. Geologists believe they are at depth across much of the state, buried by younger bedrock. During the active subsidence or rifting of these basins, the sedimentary debris deposited in the basin was mostly sand and mud eroded from surrounding metamorphic basement complex, mostly Chapter One rocks, and, in some areas, volcanic rock. These sediments became sandstone and shale, sedimentary bedrock. When overlying sediments deeply buried these rocks they were exposed to heat and pressure. The sandstone metamorphosed into quartzite and some of the shale into slate.

Today, erosion has exposed Chapter Two rocks beautifully in the Uinta Mountains where they form the central part of the mountains and are known as the Uinta Mountain Group and in the Big Cottonwood Canyon area of the Wasatch Range where they are known as the Big Cottonwood Formation, the Mineral Fork Tillite, and the Mutual Formation. An interesting feature of the Mineral Fork Tillite is that it contains evidence of glaciers in the area over 800 million years ago. Although the Chapter Two rocks in the Wasatch Range and Uinta Mountains experienced metamorphism it is minor compared to the metamorphism of Chapter One basement rocks. Chapter Two rocks still have some of their original layering. They look more like the sedimentary rocks that overlie them than the basement complex that the they lie upon. (Exception: the Chapter Two rocks of the Raft River Range were intensely metamorphosed, and resemble the underlying Chapter One basement complex.)

After these Chapter Two sedimentary rocks had been metamorphosed, once again the region experienced uplift. Erosion cut away overlying layers and eroded the Chapter Two rocks into a relatively smooth land surface slightly above sea level. By the end of Chapter Two, a major flexure, meaning a bend or wrinkle, in Earth's crust developed across Utah. This flexure known as "the hingeline" has divided Utah into two geologic regions for the remainder of geological time. In today's Utah it runs approximately north - south dividing the Basin and Range from the Rocky Mountain and Colorado Plateau physiographic provinces. When dinosaurs roamed the area (Chapter Five time) the area west of the hingeline was higher than the area east of the hingeline. At the end of Chapter Two time, the western side was below sea level and the eastern side above, but nearly at, sea level. The cause of the hingeline is not known for certain but it may relate to an ancient (Chapter One) rift in the North American continental plate west of Utah where part of the continent split away.

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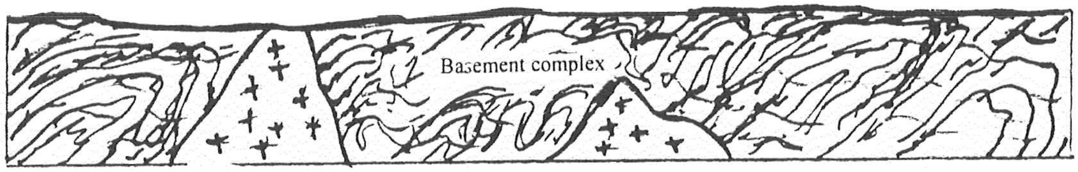
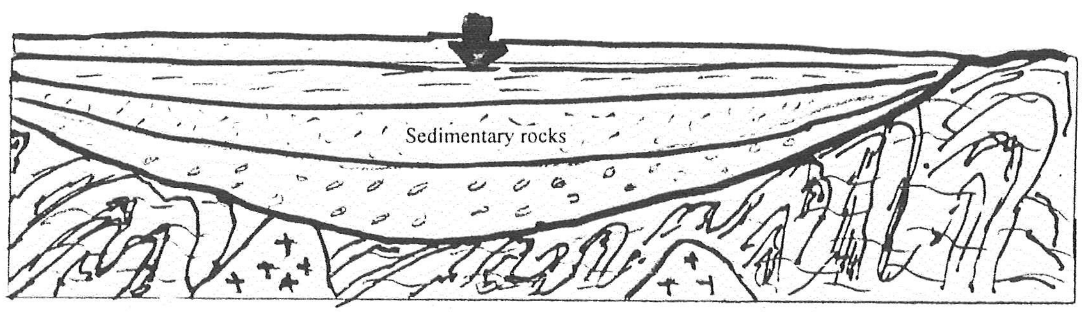
The end of Chapter Two marks the end of the Precambrian Era, the first and longest of the four internationally-recognized major divisions of geologic time.

Beginning



EXPOSED AND ERODED BASEMENT COMPLEX



SUBSIDENCE OF LARGE BASINS AND DEPOSITION OF THICK SEQUENCE OF LAYERED SEDIMENTARY ROCKS

AND LOW GRADE METAMORPHISM

UPLIFT AND EROSION

End of Chapter Two

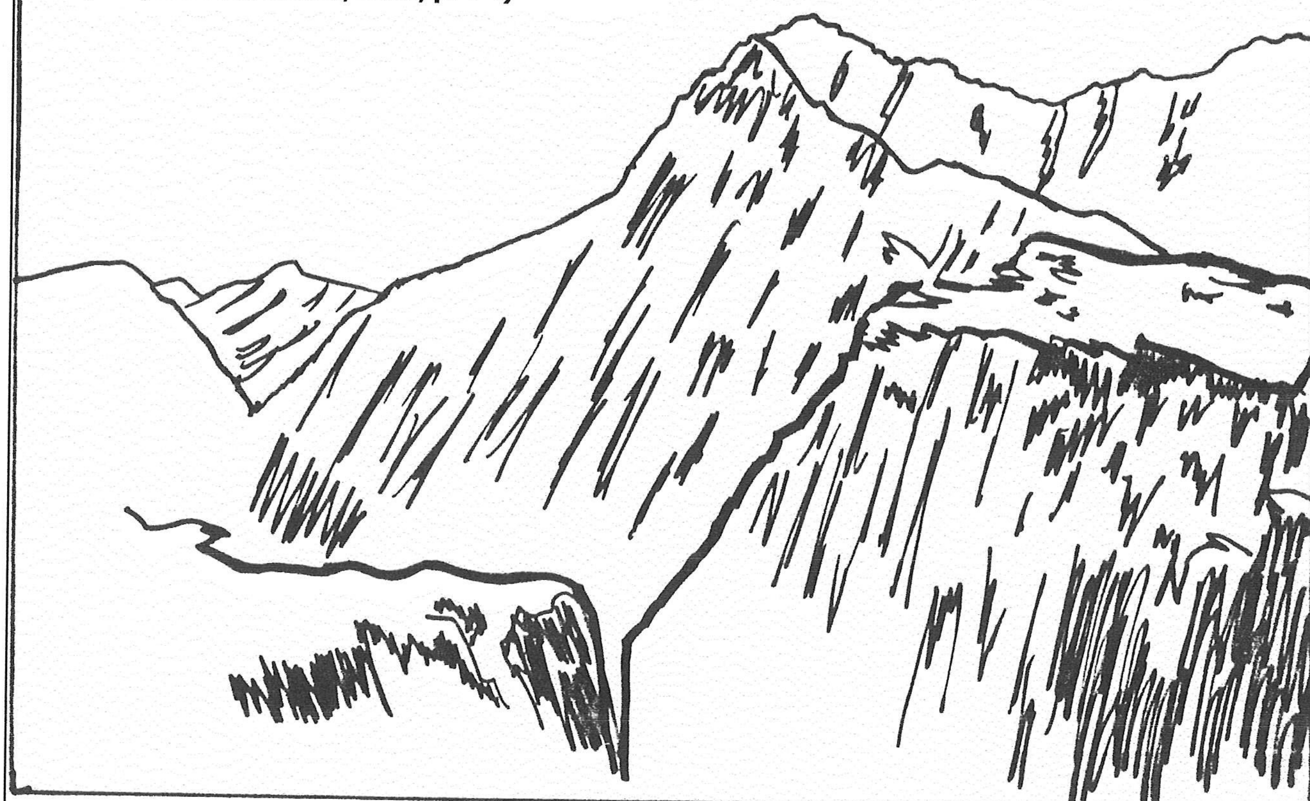
Resources from Chapter Two:

Although a few simple forms of life existed in the sea of this era they did not have the hard-body parts that form good fossils. Do not expect to find fossils in these rocks. Chapter Two rocks have not produced important amounts of minerals or petroleum.

Scenery... what Chapter Two rocks look like today:

The resistant, castle-like, reddish, quartzite, mountains that make up the Uinta Mountains present these rocks at their inscrutable best. They are also some of the most impressive rocks in Big and Little Cottonwood Canyons.

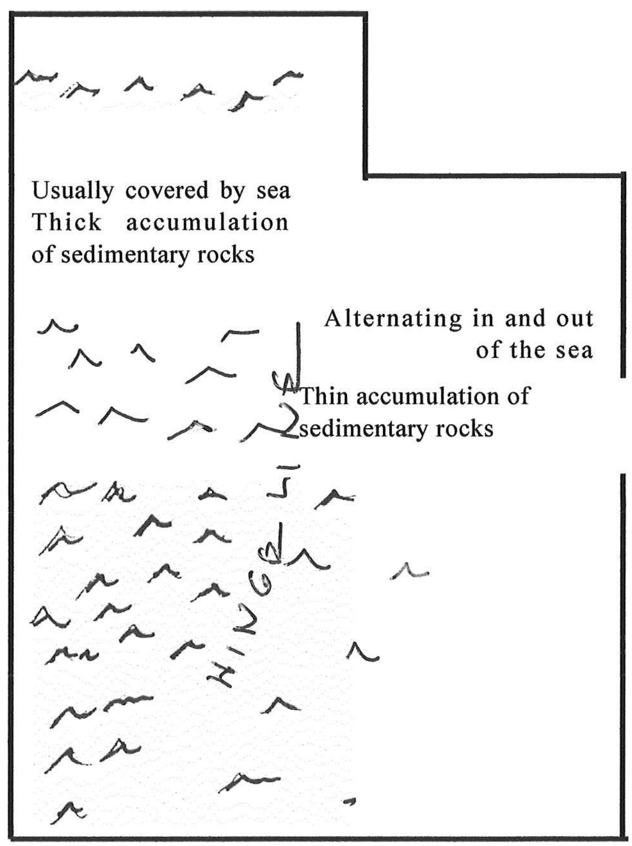
CHAPTER ONE. LAYERED. LOW-GRADE METAMORPHIC ROCKS
STORM MOUNTAIN, Big Cottonwood Canyon
(Adapted from Stokes, 1986, p. 4-4)



UTAH GEOLOGY
CHAPTER THREE

MORE SEA THAN LAND
Hintze's "A Warm Coastal Shelf"
Atwood's "Shallow Seas"
570 to 360 million years ago

October 23 to November 1 7

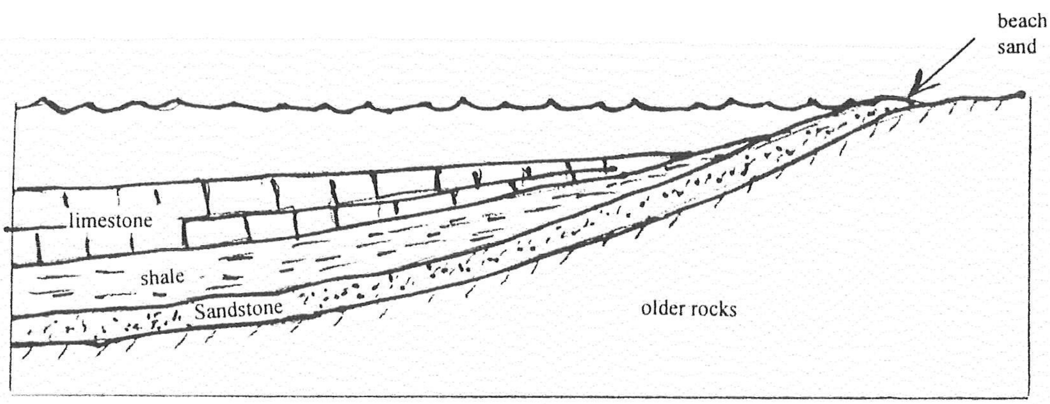


Chapter Three begins at the second world-wide internationally recognized division of geologic time - the start of the Paleozoic Era. Geologists established this major division of geologic time because, world-wide, many rocks of this age show abundant fossils. Utah's Chapter Three rocks are no exception. Most of the sediments deposited during this chapter were deposited in shallow seas somewhat similar to today's shallow seas such as east of Florida, the Caribbean Sea and the Bahamas. At times during Chapter Three of Utah's geologic history the sea covered all of the area that was to become Utah and at other times the sea covered only the area west of the hingeline.

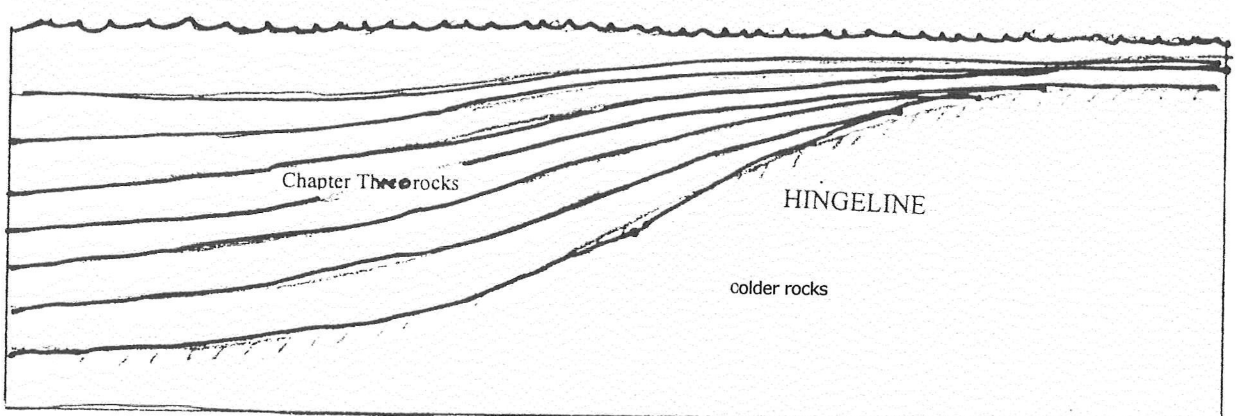
A variety of sediments record the history of the fluctuating seas. Along the land - sea margin, waves form beaches. When the sea *transgresses* inland, it builds beaches along the new shoreline and it leaves behind, on the sea floor, the sand from the beach it built before. That drowned sandy beach is buried by muddy sediments deposited in the open sea or by limy sediments such as those associated with coral reefs. The sand eventually becomes sandstone, and, if it is deeply buried and partially metamorphosed, quartzite. The muddy layers become shale. The limy layers become limestone. As the seas retreat from the land, the sequence will reverse as the beach sands are deposited across the muds that buried the transgressive beach deposits.

The beach sand that marked the coming of the first Paleozoic seas into and across Utah is seen now as a prominent tan or whitish band across mountain fronts of hard quartzite. This Tintic Quartzite was deposited across the dreary gray and black Chapter One metamorphic basement rocks or tan metamorphosed rocks of Chapter Two. This former beach complex can be recognized in the mountain fronts of several ranges of western Utah. This former beach was inundated by an ancient sea with sediments of finer material deposited in the sea that became shale. Because organisms had developed that used calcium carbonate from the sea water to grow shells or other hard parts to protect their soft body parts when they died their hard parts collected on the sea floor and combined with other calcium carbonate to produce *limestone* and sometimes *dolomite.* Because the seas of this chapter of Utah's geologic history deposited muds and lime with the carcasses of many life forms, the shales and limestones of this chapter make great fossil hunting. Areas of western Utah such as the Confusion Range and the House Range have world class reputations for the diverse, well-preserved, big and small, rare and common fossils of this geologic time. The easiest hunting for these fossils is in rock shops and motel lobbies of Delta.

As sediments accumulated on the sea floor west of the hingeline, the crust under the sea floor subsided and therefore the sea continued to accommodate and accumulate thousands of feet of sediments. East of the hingeline the crust did not subside, or did not subside nearly as much. Most of Chapter Three time, when the land was above sea level, erosion worked to level it. When shallow seas transgressed across the land, waves eroded the landscape, and deposited sandy beaches and muddy shallow water deposits. When land is exposed to erosion, a portion of the rock record is destroyed. During Chapter Three, parts of Utah east of the hingeline erosion obliterated some of the rock record or did not allow it to accumulate. So some time intervals of this chapter are not represented in the rock record.



SEQUENCE OF ROCKS DEPOSITED SEA MARGIN



AT END OF CHAPTER THREE

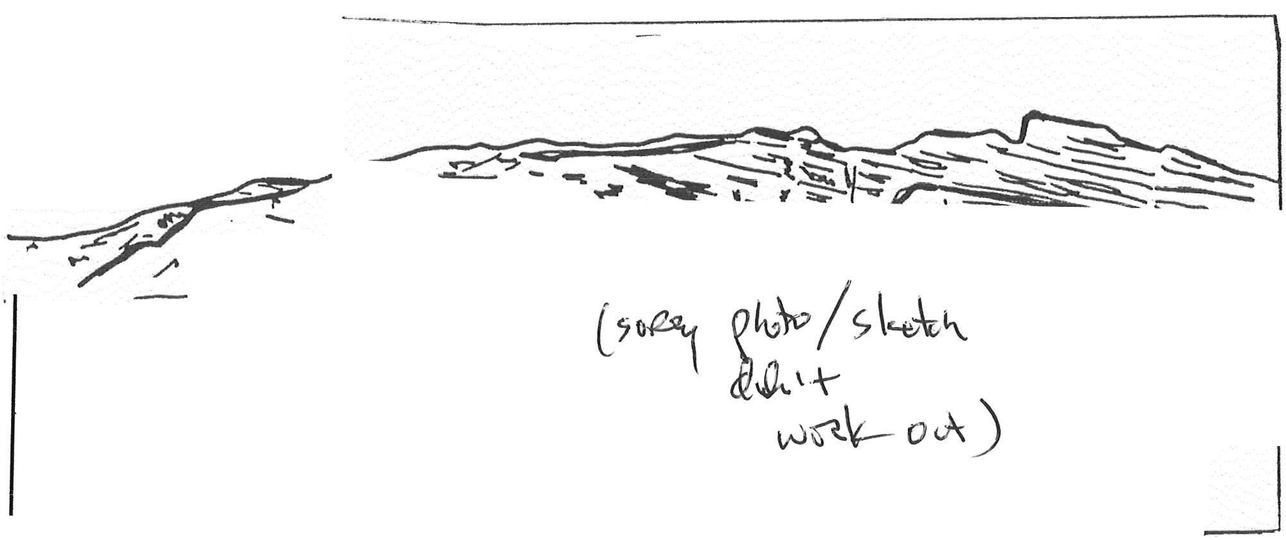
Resources from Chapter Three:

Chapter Three rocks are source rocks and reservoir rocks for some oil and natural gas in some areas of Utah, particularly southeastern Utah.

The fossil record of Utah's Chapter Three rocks are the best evidence of life of this time, anywhere, globally.

Scenery... what Chapter Three rocks look like today:

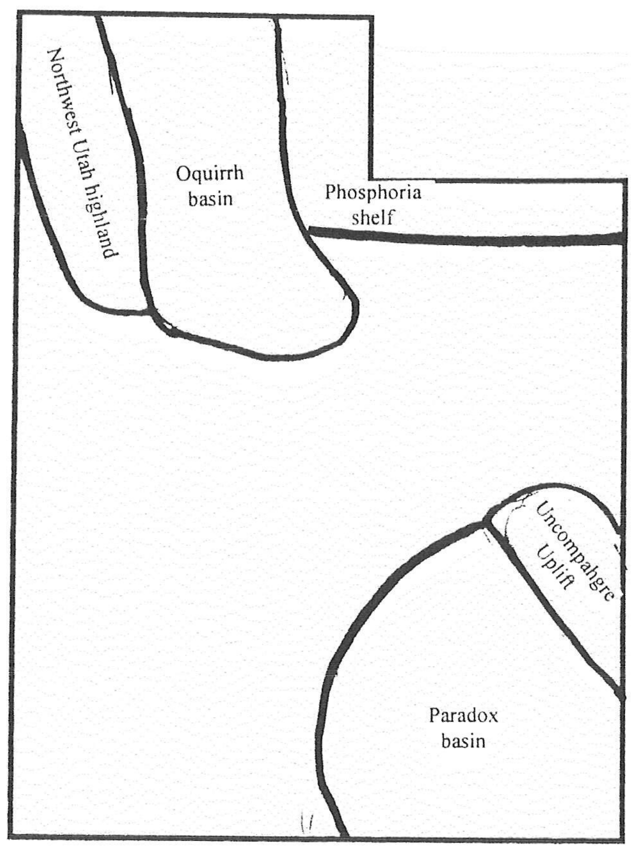
Chapter Three rocks dominate many of the ranges of western Utah. From a few miles away, the scenery can seem just nuances of gray with occasional bold white units (the beach deposits). Close up you can see layers of former sediments, fossils, and evidence of changing water depths and subtle changes of environmental conditions associated with tropical, shallow seas. This was a good time to be a *trilobite* in western Utah.



WEST FACE OF HOUSE RANGE from US Highway 6 - 50
(Adapted from Hintze, 1988, p. 165)

UTAH GEOLOGY
CHAPTER FOUR

LAND, SEAS, AND BASINS
Hintze's "The Oquirrh and Paradox Basins"
Atwood's "Broad Basins"
360 to 240 million years ago
November 18 to December 2



The relatively simple geography of Utah in Chapter Three (shallow seas like the Bahamas) persisted for millions of years from the beginning of the Paleozoic Era about 600 million years ago until about 360 million years ago. The shallow ocean environments west of the hingeline deposited thick sequences of sands, muds, and carbonates on an ever-subsiding ocean floor while the land east of the hingeline subsided much less and accumulated only a tenth the deposits when the shallow ocean transgressed across the terrain. In Chapter Four, major changes in Utah's geography resulted in major changes in patterns of sedimentation. Utah, still located in the tropics, still with little land relief, still with land surfaces mostly within a few hundred feet above or below sea level, developed two major subsiding basins somewhat similar to today's Gulf of Mexico.

The Oquirrh Basin of northwestern Utah:

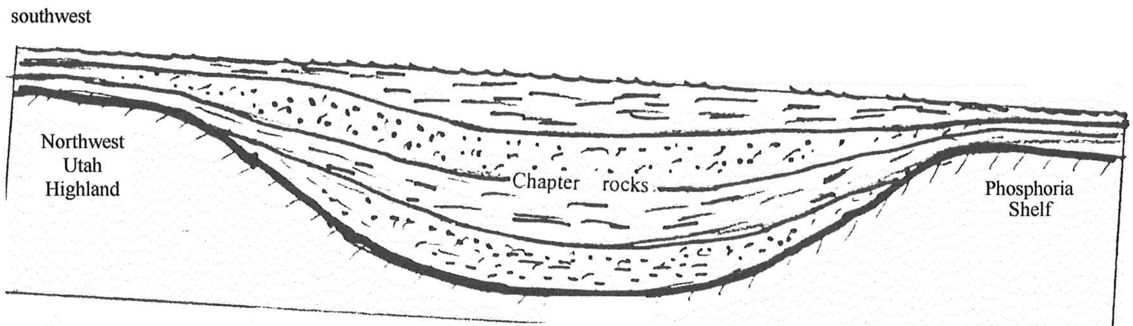
Where ocean waters cover the land, erosion from the land and life in the sea results in some deposition of sediments. The rate of accumulation depends on how much sediment is contributed and how conducive the underwater topography is for the accumulation of sediments. Chapter Four conditions were outstanding for sediment accumulation in northwestern Utah.

Phenomenally thick sections of sediments accumulated in northwestern Utah in the Oquirrh basin. Even after compaction these limestones and sandstones measure more than three miles thick. Today, millions of years later, these rocks now make up most of the Oquirrh Mountains and some of the other ranges of western Utah. The geography of northern Utah during Chapter Four had more topographic relief than in Chapter Three. Part of the time the northwest-Utah highland rose above the sea west of the Oquirrh basin. An area north and east of the main Oquirrh basin known as the Phosphoria Shelf developed near the end of Chapter Four. Here sea water unusually rich in marine life deposited sediments rich in phosphate. Today these sedimentary rocks are mined for fertilizer.

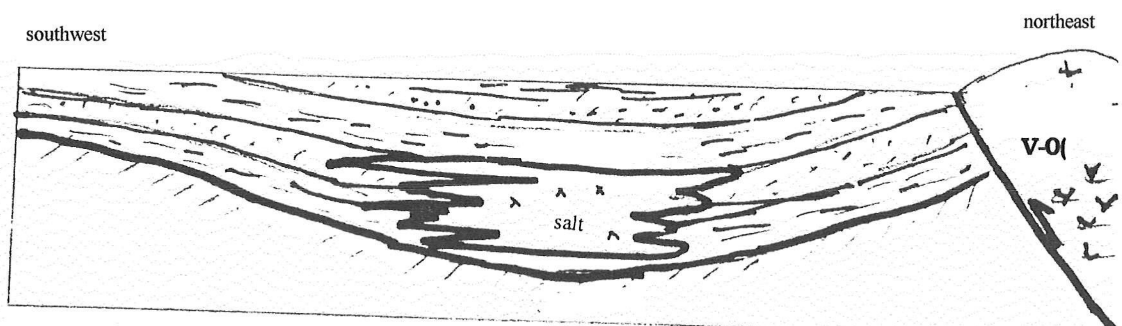
The Paradox Basin of southeastern Utah:

Utah's other Chapter Four basin developed east of the hingeline in southeastern Utah and extended into adjacent parts of Colorado, New Mexico, and Arizona. This was the Paradox basin, which received considerable sediment from the northeast from the Uncompahgre Uplift, a large mountain range. Unlike the Oquirrh Basin, a shallow sea with ongoing access to the ocean, the Paradox basin was periodically isolated from the ocean allowing its waters to evaporate and salt to accumulate. Thousands of feet of salt accumulated in the sediments of the basin. Salt has several features that make it an unusual rock. It is much less dense than most rocks, i.e. it weighs less per unit volume. Salt under pressure flows somewhat like silly putty. Because salt can flow and is less dense than the enclosing rock, some of the salt in the Paradox basin originally deeply buried by other sedimentary rocks has formed large elongate bubbles of salt rising toward the surface pushing through or doming up the overlying rocks. The resulting elongate domes are called salt anticlines. Today, potash is mined from the salt of these Paradox basin rocks. Rocks of Chapter Four are now exposed over large areas of southeastern Utah. The upper part of these Paradox basin rocks includes some of the colorful rocks of Monument Valley and other areas of southeastern Utah.

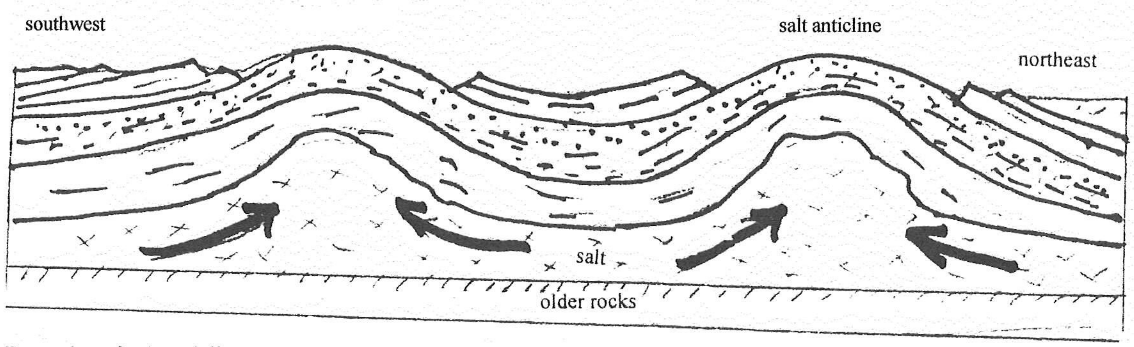
Toward the end of Chapter Four the Oquirrh and Paradox basins stopped subsiding, and shallow seas again covered most of Utah. The end of Chapter Four marks the end of the Paleozoic Era, the second of the great world-wide breaks of geologic time.



Oquirrh basin in northwest Utah at the end of Chapter Four



Paradox basin in southwest Utah



Formation of salt anticlines –
The salt was laid down in Chapter Four and arched into salt anticlines during Chapters Four through Nine.

Resources from Chapter Four:

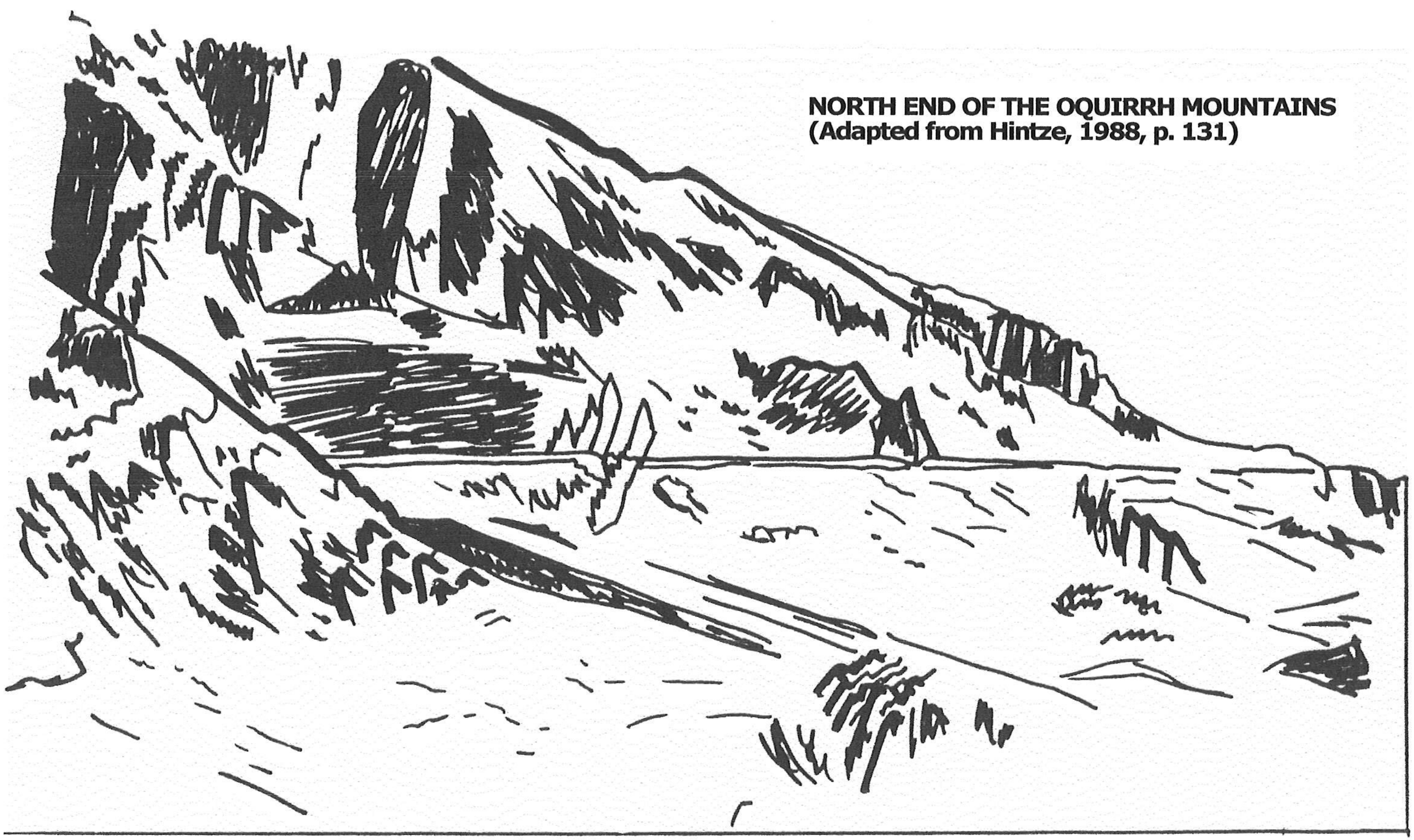
Chapter Four rocks have high potential as source rocks for petroleum because of the high organic component of many of the shallow marine sediments.

Many Chapter Four rocks contain fossils.

Some Chapter Four rocks were good host rocks for mineralization that occurred later, specifically, during Chapter Eight, such as what would become the Bingham Copper Mine.

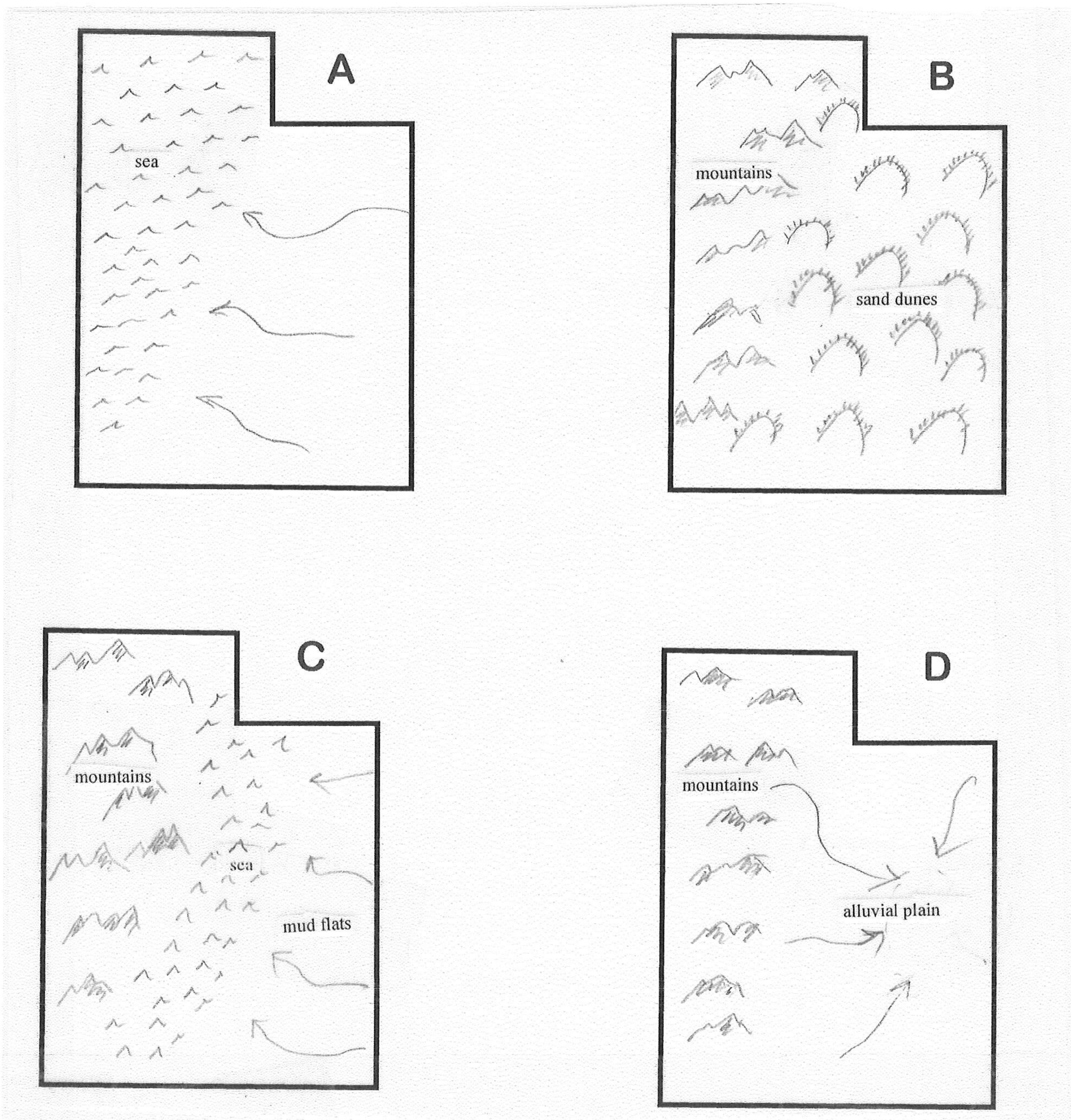
Scenery... what Chapter Four rocks look like today:

Sedimentary bedrock originally laid down as sediments by water in water tend to be gray. Many of the Chapter Four bedrock is tan or gray and, therefore, mountains made of Chapter Four rock are generally gray or tan. Fluctuations of sea level during Chapter Four changed coastal environments and their deposits. In some areas sandstones and shales were deposited above sea level, and some of these shales and sandstones in southeastern Utah are brightly colored. Many of the red rocks of the Colorado Plateau were floodplain and coastal plain rock laid down during Chapter Four.



UTAH GEOLOGY
CHAPTER FIVE

MORE LAND THAN SEA
Hintze's "Dinosaurs and Deserts"
Atwood's "Land and Lizards"
245 to 144 million years ago
December 3 to December 13



We begin Chapter Five at the beginning of the Mesozoic Era, the third of the four great world-wide breaks of geologic time. Chapter Five's story has major geologic changes because the geography was changing from a Utah mostly under water to a Utah mostly above water. The geologic evidence of those environments contrasts dramatically so the rock record of Chapter Five juxtaposes contrasting rock types even though most of Utah was still within a thousand feet above and below sea level and still in the tropics.

During Chapter Four, water of shallow seas and broad basins dominated Utah's geography. Sea level fluctuated and the land rose. By the end of Chapter Five, land dominated the geography. The environments that existed during the transition from more sea to more land changed dramatically and left diverse rock types as its record.

1) Toward the end of Chapter Four, all of Utah was above sea level. For several million years the land eroded destroying some of the existing rock record and depositing few sediments that persist today as sedimentary rock.

2) But by the beginning of Chapter Five, once again shallow seas covered most of the area of Utah west of the hingeline while mudflats typified the near-sea-level, near-shore areas east of the hingeline. Sediments deposited in this latter environment are some of the colorful maroon red beds of the Colorado Plateau.

3) By the middle of Chapter Five, a Sahara-like desert covered most of the state with sand dunes that would become the beautiful tan and white sandstones that dominate the southeastern Utah landscapes today.

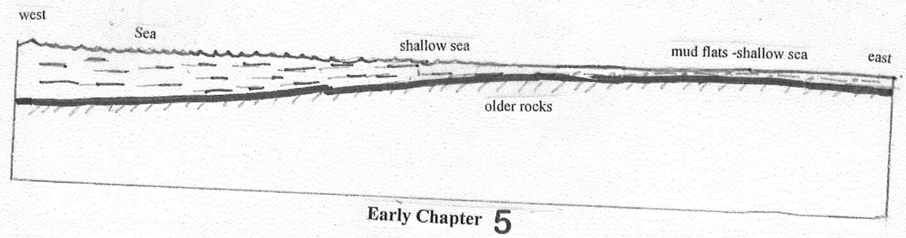
4) Later on in Chapter Five, an arm of the sea transgressed from the northeast across central Utah. Today, gypsum in the Salina area is mined from deposits of that sea.

5) Toward the end of Chapter Five, all of Utah was above sea level. The Morrison Formation, famous for the dinosaur fossils of Dinosaur National Monument and elsewhere in Utah, was being deposited as sands, muds, and conglomerates in streams and shallow lakes of a semi-arid, landlocked basin that extended over a large area of western North America including eastern Utah.

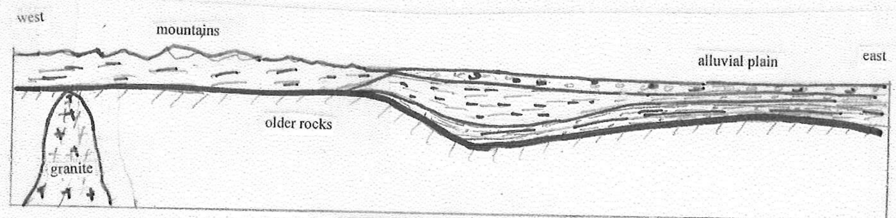
By the end of the Chapter Five, the sea that had persisted for so long on the west side of the hingeline would not flood western Utah again. Mountain building that had started farther west, initially in California and continuing into Nevada began to affect western Utah. The near sea-level, low relief topography, of a Utah located in the tropics was about to change dramatically in Chapter Six.

Resources from Chapter Five:

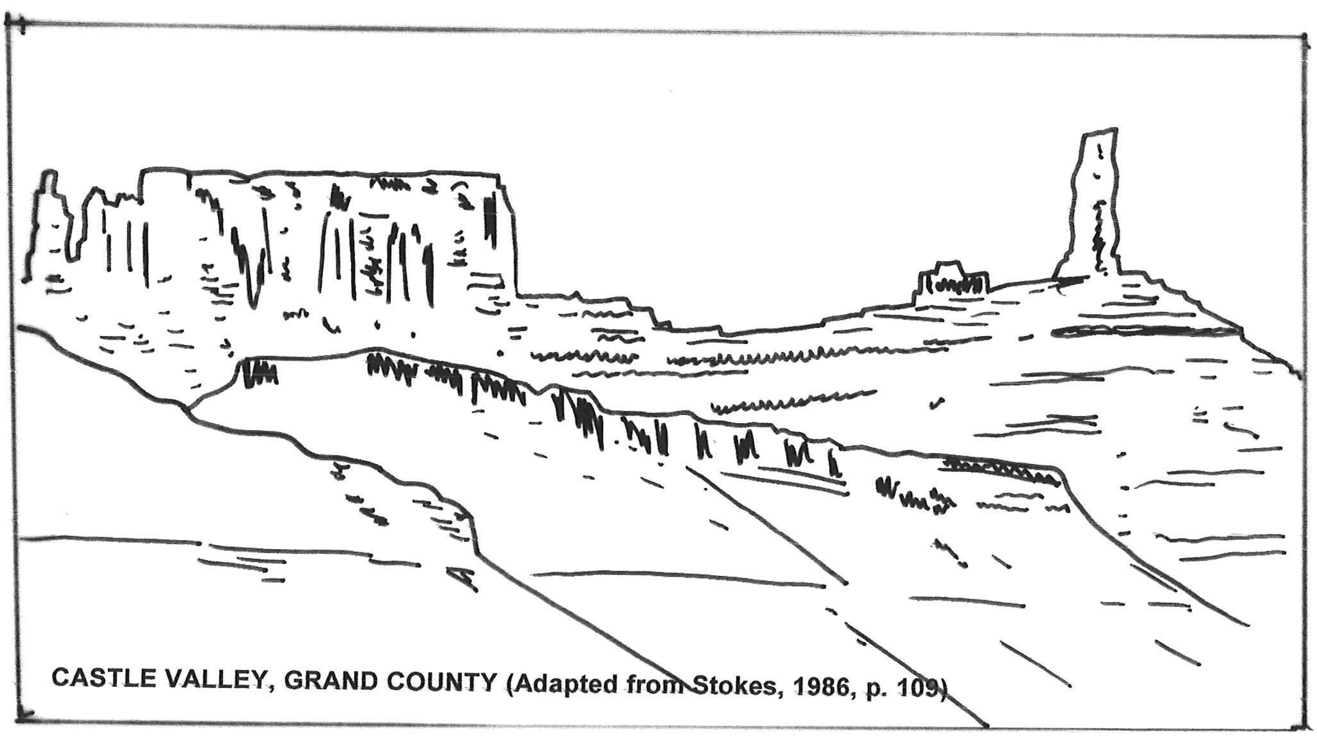
Most of the uranium mined in Utah has come from the Morrison Formation and other rocks of this chapter. Dinosaur bones also are resources of the Morrison Formation.



Early Chapter 5



End of Chapter 5

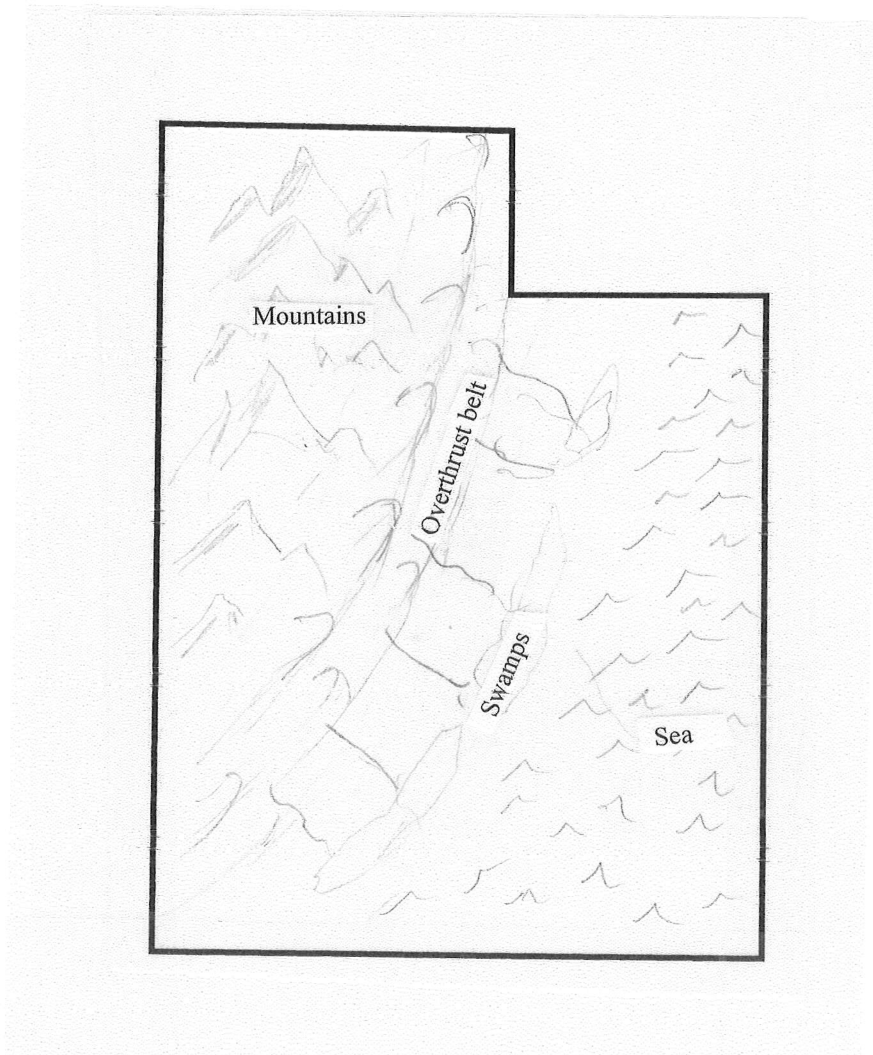


CASTLE VALLEY, GRAND COUNTY (Adapted from Stokes, 1986, p. 109)

Scenery... what Chapter Five rocks look like today: Utah's national parks are mostly Chapter Five bedrock parks. The vistas are spectacular: big bold red. Among the most spectacular are: Zion, Canyonlands, Arches, Capitol Reef, Glen Canyon, and Lake Powell.

UTAH GEOLOGY
CHAPTER SIX

MOUNTAINS AND SWAMPS
Hintze's "The Sevier Orogeny and Coal Swamps"
Atwood's "Scrunch and Swamps"
144 to 66 million years ago
December 14 to December 23



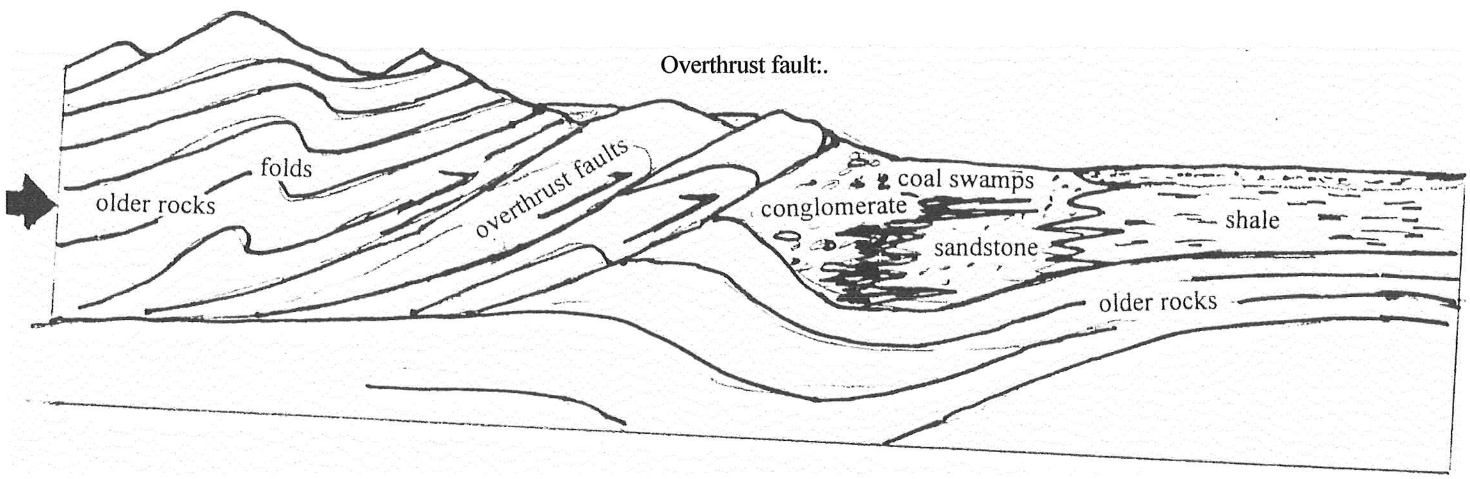
Tectonic forces, forces within Earth acting on the crust of Earth make big changes, slowly. The tectonic and igneous history of Utah during Chapters Three, Four and Five had been relatively uneventful. Little igneous activity had occurred. Relatively minor tectonic activity had moved most of the billion-year accumulation of layered sedimentary rocks up and down a few hundred feet or more and some of them a thousand feet or more. Some of the rock layers elevated above sea level eroded away. Those that remained had not been strongly tilted or folded. East of the hingeline Earth's crust was stronger than to the west of the hingeline.

During Chapter Five, tectonic forces had affected the western margin of the North American continent dramatically. We surmise that the North American continent shoved into a neighboring plate to the west and California et al eventually joined onto North America. California and Nevada experienced the brunt of the action during Utah's Chapter Five time. Western Utah felt the repercussions in Chapter Six. When the region compressed in an east-west direction, the layered sedimentary rocks to the west of the hingeline began to buckle into folds. The land surface pushed up. The compression and deformation extended over much of western Utah. As the folding became more intense, a major mountain belt formed much as the Himalayas form today. Nearly horizontal fault planes allowed sheets of rock to slide eastward tens of miles over younger less disturbed rocks. These faults are called thrust or overthrust faults. Today we call the eastern-most remaining zone of these complexly folded and overthrust rocks the Overthrust Belt.

High mountain ranges shed coarse rock debris as stream deposits and alluvial fans. The high mountains west of the hingeline shed their debris eastward as thick beds of conglomerate. Eastern Utah, still near or just below sea level, and toward the middle of the chapter was flooded by a very shallow sea way that separated the western North America from eastern North America. The under-appreciated "ugly" gray Mancos Shale in the Green River area typifies deposits of this time. Sharks cruised the shallow sea. Dinosaurs roamed the land. Wave action and alongshore currents created extensive sandy shore deposits. Extensive swamps thrived. The shallow sea responded to the rise and fall of sea level by invading and retreating across the shore. When the sea withdrew the sand and swamps moved eastward. When the sea advanced, the swamps and sand moved west. These alternating deposits can now be seen in the Book Cliffs. As the lush vegetation in these swamps was buried it became coal.

As Chapter Six and the Mesozoic Era came to a close, tectonic forces still accommodating the compression associated with collisions to the west were shifting east and the uplifted mountainous terrain west of the hingeline succumbed to erosion. The Mancos sea retreated from the mid-continent and Utah saw the last of transgressing ocean waters.

Mountains



Overthrust fault:.
folds
older rocks
overthrust faults
coal swamps
conglomerate
sandstone
shale
older rocks

Resources from Chapter Six:

Utah's richest coal deposits originated in Chapter Six swamps. Much of Utah's richest oil and gas are produced from Chapter Six sandstone. Fossils, including sharks' teeth, are abundant in some layers of the gray rocks. Plants and evidence of dinosaurs are common in the sandstones and coal layers.

Scenery... what Chapter Six rocks look like today:

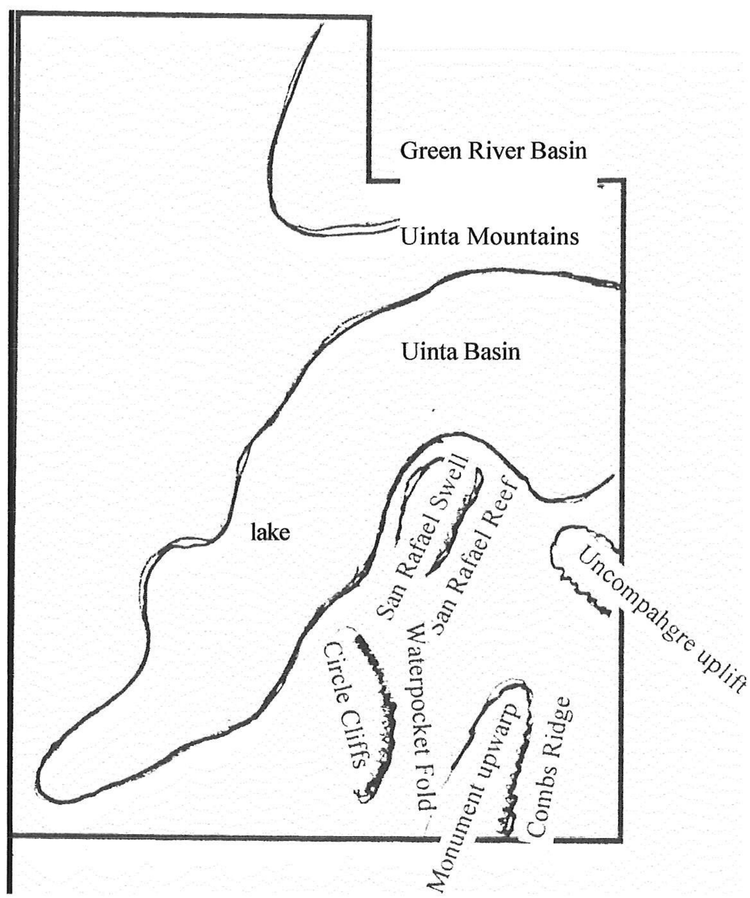
The gray scenery along Interstate 80 east to the Colorado crosses the "drab" Mancos Shale. Charlie Hunt, a renowned Utah geologist wrote that "even the lizards don't like the Mancos." Perhaps for that reason, this desert terrain attracts companies that dispose municipal and nuclear waste; military installations for testing missiles where they can do little harm; and transportation corridors. Some of the sandstones Chapter Six form dramatic cliffs. If you appreciate badlands topography and the nuances of the subtle interplay of tan and gray, you will find the Book Cliffs spectacular and the Mancos badlands country photogenic.

Much of the folding and tilting of the rocks now visible in western Utah occurred in Chapter Six. So, although there are few Chapter Six rocks in Salt Lake County, the effects of the mountain building (NOT THE WASATCH RANGE) of Chapter Six bring us the folds of Grandeur Peak and the tilting of the rock layers of Mount Olympus.

MANCOS SHALE west side of the San Rafael Swell looking north from I - 70
(Adapted from Hintze, 1988, p. 178)

UTAH GEOLOGY
CHAPTER SEVEN

THE UINTAS, PLUS SOME STRAY FOLDS
Hintze's "The Uinta Mountains"
Atwood's "Uintas and Uplifts"
66 to 37 million years ago
December 24 to December 26

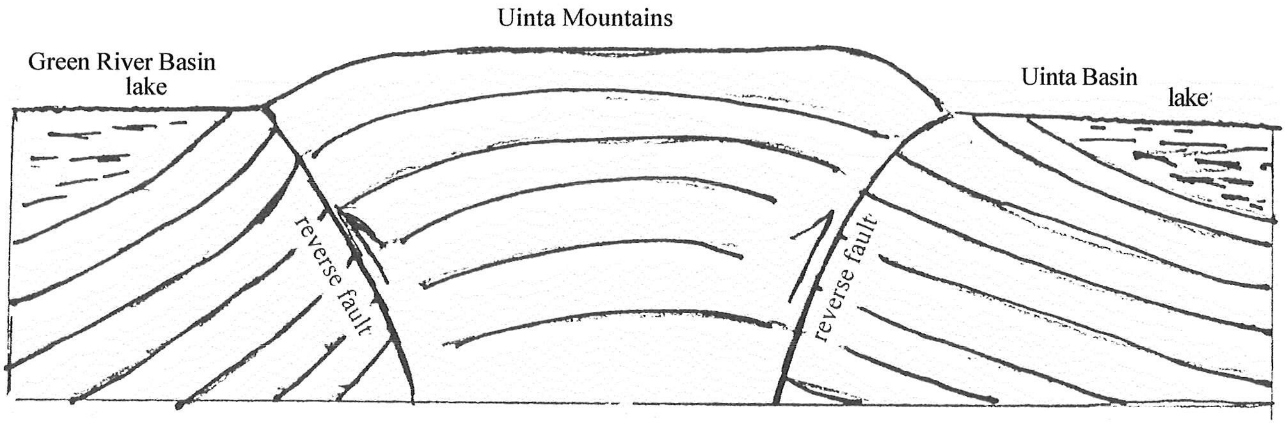


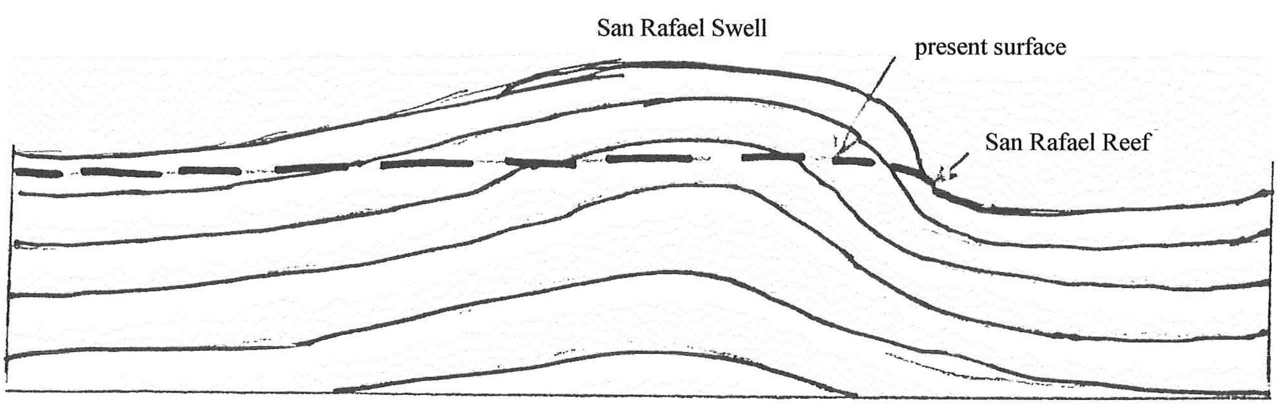
Chapter Seven begins at the beginning of the most recent of the four internationally recognized world-wide geologic divisions, the Cenozoic Era. The movement of the North American continent that caused dramatic compression west and across the hingeline had not caused much deformation in the more stable areas to the east. But in Chapter Seven as the western highlands of Utah eroded, the east experienced deformation, but of a different form.

As tectonic forces shortened the crust and rotated continental blocks, large mountain ranges, including the Rocky Mountains in Colorado, the Wind River Mountains of Wyoming, and the Uinta Mountains in Utah rose. Concurrently, several large basins adjacent to mountain masses became depressed topographically. In Utah, the Uinta Mountains rose between the Uinta basin on the south and the Green River basin on the north. Stream flowed into the basins. Extensive lakes developed north and south of the Uinta Mountains. The streams carried sediments and deposited them in the Uinta and Green River basins. As much as 10,000 feet of sediments accumulated in the deepest of these basins. Lakes extended from the Uinta Basin southwest across central Utah, but much less sediment accumulated in lake areas far from the Uinta Mountains.

Erosion planed down much of western Utah. Some sediments, mostly conglomerates were deposited in areas west of the rising Uinta Mountains. Salt Lake County has some of these conglomerates, evidence that the pre-Wasatch fault terrain of Salt Lake County was vast river high-elevation plains stretching from the Uinta Mountains.

At the end of Chapter Seven, all of Utah had been elevated well above sea level. The mountainous areas west of the hingeline continued to erode. The Uinta Mountains rose and also eroded. Sediments of the Uinta Mountains were deposited in major basin lakes that extended into central Utah. Portions of southeastern Utah had responded to compressional forces by folding. Erosion attacked the higher areas. Utah's geologic record had changed dramatically from continuous wide-spread marine deposits to continental deposits of lakes, streams, and alluvial fans.


Uinta Mountains
Green River Basin
lake
Uinta Basin
lake
reverse fault
reverse fault


San Rafael Swell
present surface
San Rafael Reef

Resources from Chapter Seven:

Chapter Seven lakes preserved abundant algae and other organic matter that make good source rock not only for oil and gas but also oil shale and tar sand.

Scenery... what Chapter Seven rocks look like today:

The Uinta Mountains formed Chapter Seven. They have been greatly modified by erosion in the millions of years since they were formed, but they still exist and are among the oldest landforms in Utah

The tectonic forces of Chapter Seven that uplifted and bent Chapter Five rock layers of southeastern Utah created the unusual folds we see today in Chapter Nine as the San Rafael Reef, the Waterpocket Fold, and Comb Ridge.

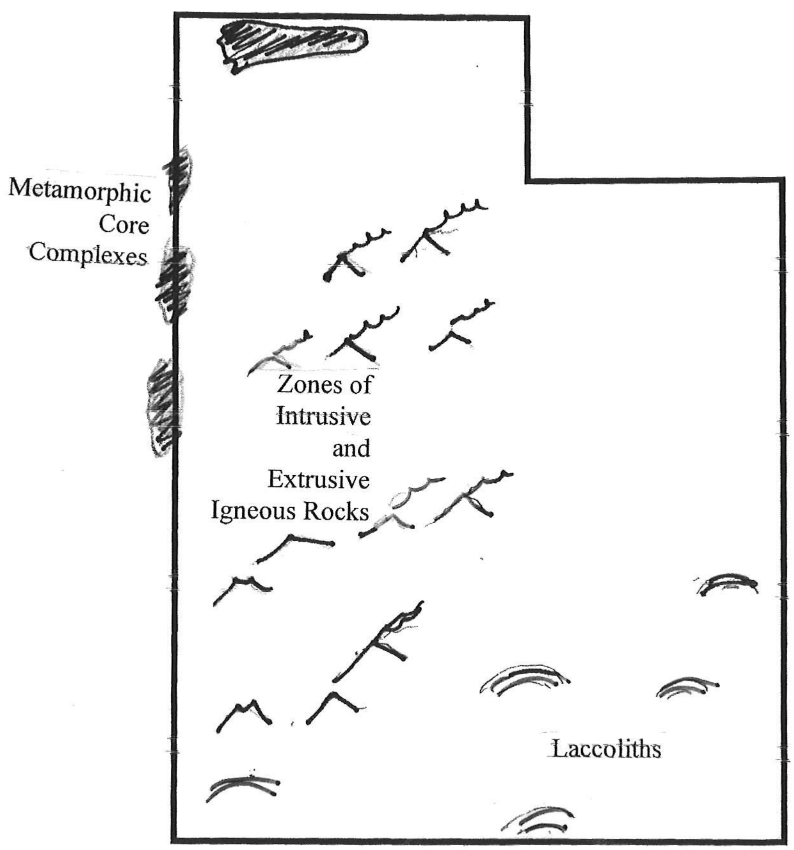
Exposures along US Highway 6 - 50 over Soldier Summit show off some basin deposits from the Green River lake. Lakes make some of the best historians of geologic time because lakes capture sediments in sequence. Utah's Chapter Seven sediments of the Uinta Basin tell stories of ash falls, fresh and brackish lake environments, and heavily vegetated terrain inhabited by alligators and monkeys.

Don't look for Chapter Seven rocks in western Utah. Erosion of the Chapter Seven mountains of western Utah washed away the local rock record. Some of the debris deposited to the east as sand and gravel can be seen as conglomerate along Interstate 80 in Echo Canyon.

CIRCLE CLIFFS ANTICLINE
(Adapted from Stokes, 1986, p. 239)

UTAH GEOLOGY
CHAPTER EIGHT

VOLCANOES AND ORE BODIES
Hintze's "Volcanoes galore"
Atwood's "Voluminous volcanics"
37 TO 24 MILLION YEARS AGO
December 27 to December 28



Tectonic forces drove the collision of the North American continent during Chapters Six and Seven and its repercussions dominated Utah's geologic scene during Chapters Six through Eight. As the western part of the North American Continent overrode Earth's crust to the west, the crust of the western part of the continent thickened and the overridden portion was deeply buried and heated to high temperatures. In Chapter Eight some of this heated rock melted and rose toward the surface.

The thickening of the crust and the heating of the deeply buried lower portion produced unstable conditions. When rock masses are heated they become less dense than the rocks that surround them and they tend to rise toward the surface of Earth the way hot-air balloons rise through cooler air. This phenomenon had diverse consequences:

1) All of southeastern Utah was uplifted during Chapter Eight along with the rest of the Colorado Plateau.

2) In southern and western Utah many individual molten masses of rock rose toward the surface.

3) Some of these masses reached the surface in western Utah and erupted from volcanoes.

3a) Lavas covered large portions of western Utah, flowed down channels to low places, and filled in local topography.

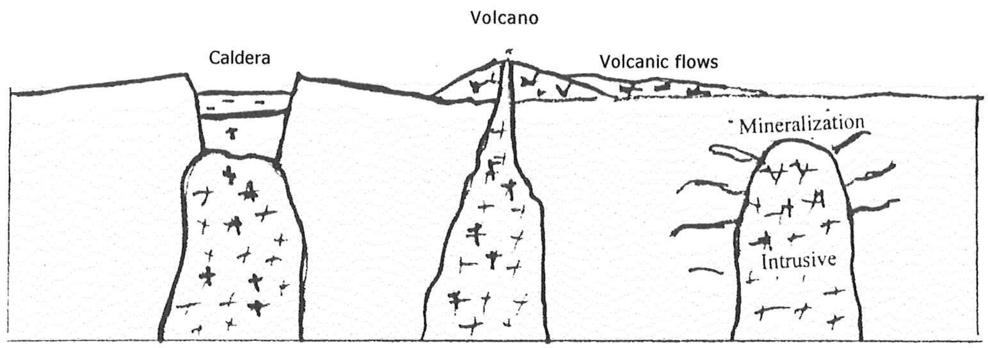
3b) Ash spewn out from volcanoes settled out across the entire state. Some ash deposits, now compacted into rock is several thousand feet thick.

3c) Some volcanoes exploded and collapsed forming calderas similar to today's Crater Lake in Oregon.

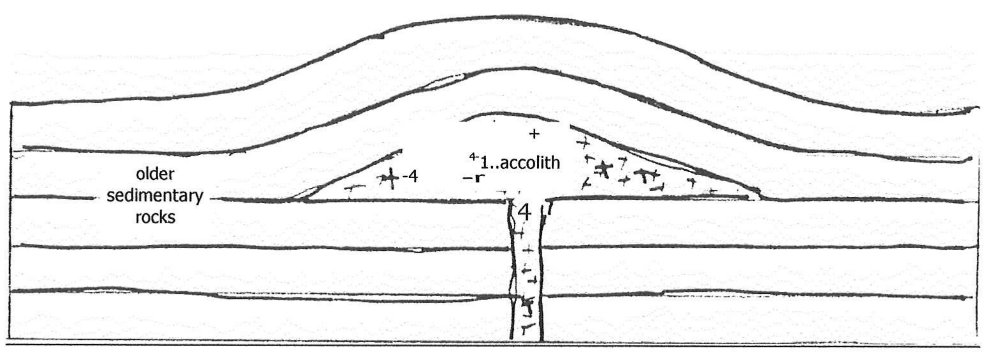
4) Not all the molten masses of igneous rock reached the earth's surface. When the molten rock cools and solidifies before reaching the surface it becomes intrusive igneous bedrock such as granite. Some Chapter Eight intrusive masses have been exposed by erosion during Chapter Nine.

4a) Example Little Cottonwood stock: Some rising masses of molten rock moved upward into the overlying country rock and incorporated the surrounding rock. Such rising masses could harden miles below the earth's surface as blobs of igneous rocks called plutons. Some have been exposed after erosion removed the miles of overlying bedrock.

4b) Example La Sal Mountains: Some rising masses of molten rock encountered nearly flat-lying sedimentary rocks near Earth's surface, squeezed between layers, and lifted up layers. These Christmas-tree-shaped bodies of igneous intrusive rock called laccoliths build domed mountain landforms by intruding the overlying layers.



WESTERN UTAH



SOUTHEASTERN UTAH

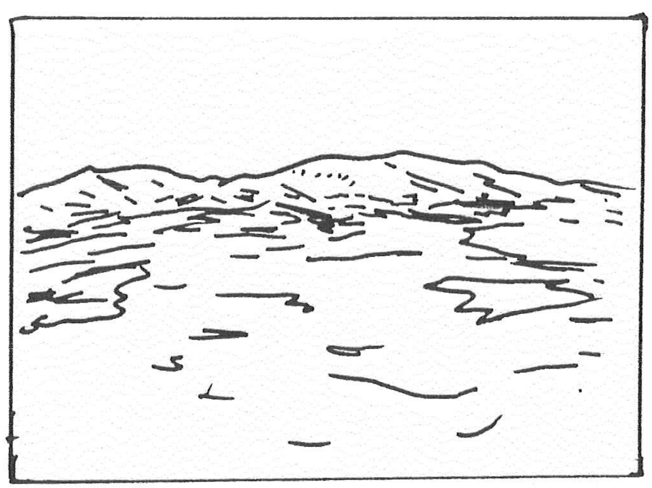
Resources from Chapter Eight:

Molten masses of igneous rock consist mostly of silica (quartz) but may include a small percentage of metallic elements. Hot fluids and gasses carry these minerals as they circulate in and around the cooling rock masses. As the fluids and gasses cool, minerals become trapped within the rocks surrounding the cooling igneous rock masses and some within the cooling igneous masses.

Deposits of copper, gold, silver, lead, zinc, and iron in western Utah formed as minerals precipitated while igneous bodies and their surroundings cooled. The igneous bodies of western Utah and associated ore deposits occur in three east - west trending zones. The northern-most extends through Bingham Canyon, Brighton, Alta and Park City. The central one trends through Eureka. The third extends from Marysvale to Pioche, Nevada and includes the iron deposits west of Cedar City. The southernmost trend is not as well defined as the two zones to the north.

Scenery... what Chapter Eight rocks look like today:

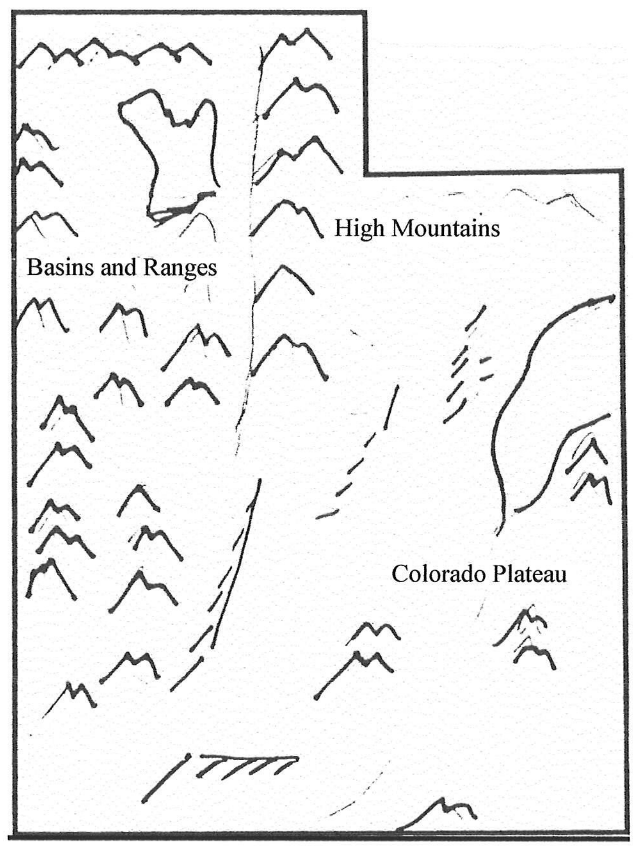
The Chapter Eight volcanic rocks of south-central Utah now appear as flat-topped terrain with light-colored jumbled looking mountain faces like Big Rock Candy Mountain of the Marysvale area. Large intrusions of granite make up the steep-walls of Little Cottonwood Canyon mined for the rock of the Salt Lake LDS Temple. In southern Utah laccolith mountains have looked like mountains since they were formed about 25 or 30 million years ago. Erosion has exposed the intrusive interior of the laccoliths of Pine Valley, La Sal, Abajo, and Henry Mountains. The laccolith of Navajo Mountain has not yet been exposed by erosion.



ABAJO MOUNTAINS looking west
(Adapted from Stokes, 1986, p. 186)

UTAH GEOLOGY
CHAPTER NINE

EXTENSION TO THE WEST
STABILITY AND EROSION TO THE EAST
Hintze's "The Great Basin"
Atwood's "Now – Stretch!"
24 million years ago to the present
December 29 to December 31



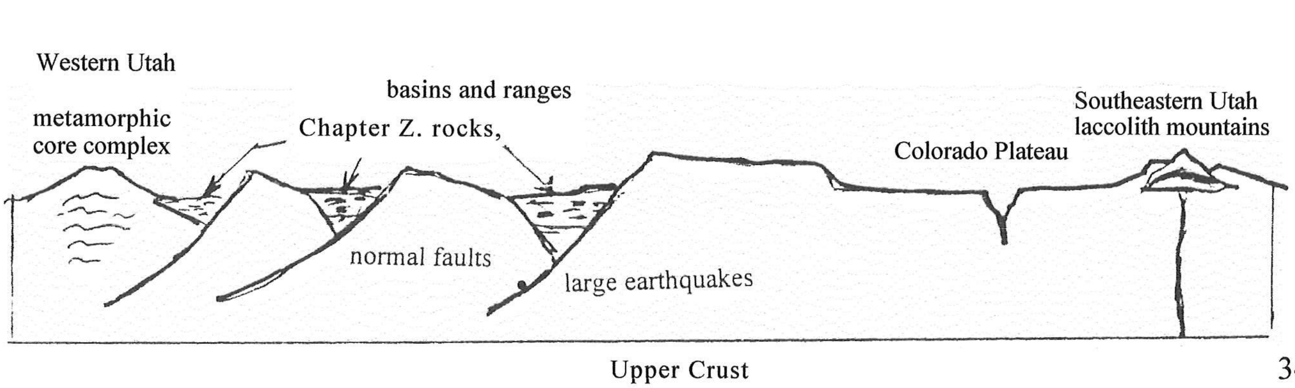
Tectonic forces, erosion, and deposition continue to write this most recent chapter of our story, Chapter Nine. The hingeline that has been a demarcation line of Utah geography for 600 million years continues to delineate Utah's contrasting geology. The earth's crust differs significantly on the two sides of the hingeline. East of the hingeline the thicker, more stable crust rides high. Erosion carves landscapes and over most of the area rivers carry the sediments eroded toward the Pacific Ocean. West of the hingeline, the thinner crust, stretched by tectonic action, broken into ranges and valleys by faults, captures sediments in basins with no drainage outlet to the ocean. Along the hingeline, some areas share characteristics of both. Although the Wasatch Range is bounded to the west by the Wasatch fault has some characteristics of the Basin and Range, it belongs geologically and geographically with the Rocky Mountain province.

East of the Hingeline:

Erosion dominates the scenery of the Colorado Plateau during Chapter Nine. Water, wind and gravity break up the mostly-layered bedrock. The Colorado River carries the debris toward the Pacific Ocean. Today impediments such as Glen Canyon dam trap the sediments. Left alone, the reservoir of Lake Powell will eventually fill with sediments and become mud flats. Erosion of southeastern Utah carves impressive landforms that each year attract millions of tourists from all over the world to gape at the geology and learn about the complex ecosystem that has adapted to it.

West of the Hingeline:

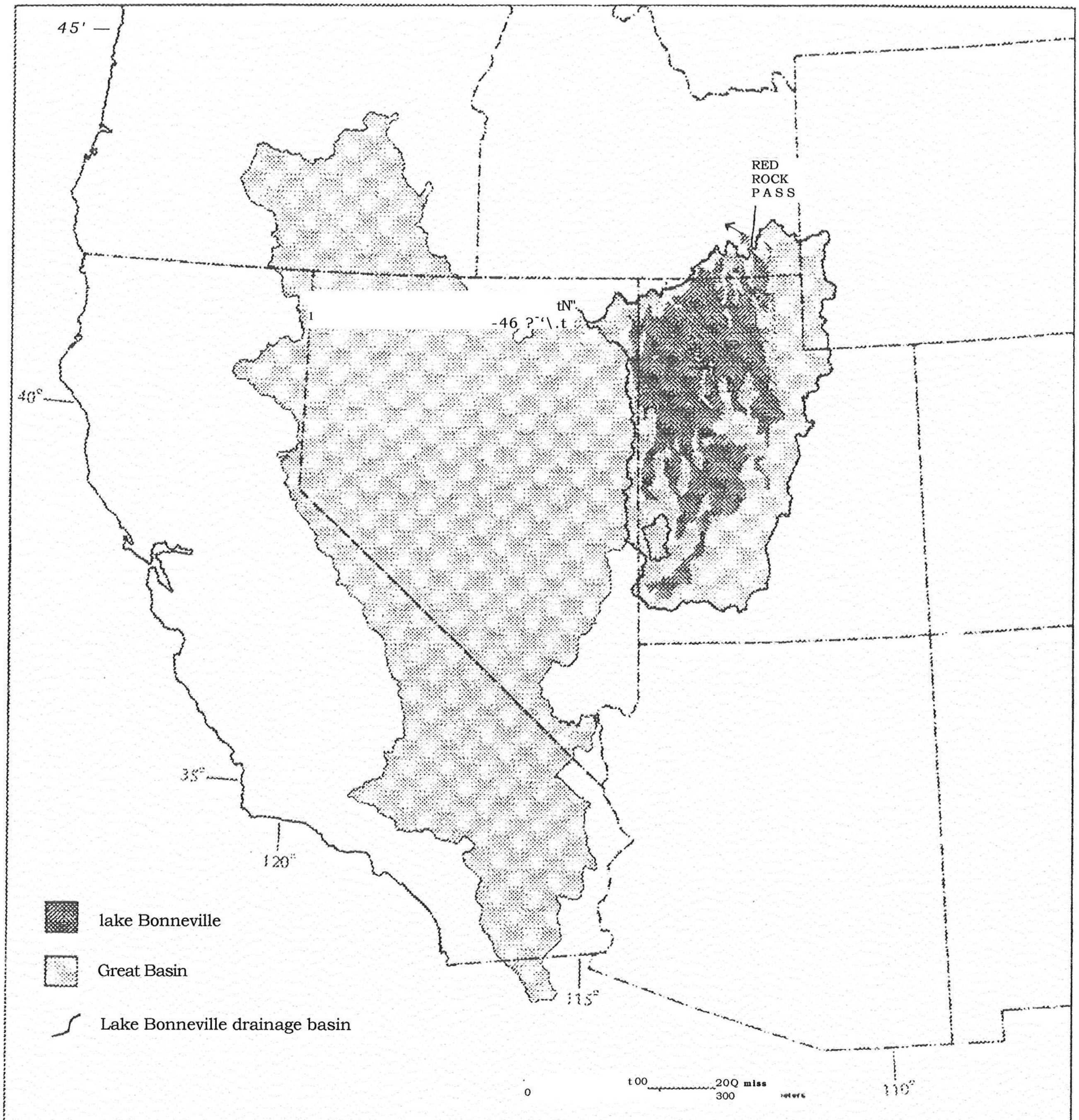
The area along the hingeline and to the west experiences dramatically more active tectonic forces during Chapter Nine. Deposition dominates the landscape. The part of Earh's crust that a few tens of millions of years ago was being shortened by compression is now being pulled apart by extension. The Basin and Range province from the Wasatch Range across western Utah and Nevada to the Sierra Nevada of California gets a little wider every year. As the crust stretches in an east-west direction, the upper, brittle upper ten-plus miles of the crust has broken into north-south pieces, separated by faults. Some pieces have dropped down and form valleys while adjoining blocks remain high and are the ranges of Basin and Range province. Streams and flash floods carry debris eroded from the ranges onto the valley floor. Some of these valley fill deposits of sand and gravel and clay exceed two miles in thickness and tens of cubic miles in volume. Stretching part the earth's crust takes time. At depth, the warmer, ductile crust can stretch like taffy. But at the surface, the solid rock crust, rigid and brittle, catches up in jerks. The down-dropping of the valleys along faults occurs abruptly producing large earthquakes. In some areas the crust's extension opens conduits that have allowed molten basalt to rise from great depths to flow out on the surface as basalt. One such flow near Fillmore is less than a thousand years old.



Chapter Nine includes effects of major climate changes of the last few million years. Climate change affects rates of erosion, deposition and local topography on both sides of the hingeline. The Wasatch Range, the Uinta Mountains, the Deep Creek Range, the La Sal Mountains, and some other of the higher mountains of Utah receive large amounts of snow in the winter. During periods when the climate of the region is colder and wetter than now, enough snow falls to remain through the summer, to accumulate in the winter, and produces glaciers. The evidence of past periods of glaciation can be seen as cirques, moraines, little mountain lakes, and striated bedrock where debris in the moving ice gouged scratches as the ice traveled over the bedrock.

Because most of the Utah portion of the basins of the Basin and Range province have no stream outlet to the ocean, lakes form in low places. Lake level of these closed-basin drainages respond to climate changes. The Great Basin is closed area with no drainage outlet to the ocean. Large and small lakes form in its many sub-basins and fluctuate in size as the climate over the region changes. Many contain water only for shoat times every decade or so. Great Salt Lake is the largest lake in the Great Basin. For thousands of years, water containing small amounts of salt and impressive amount of sediment has flowed into the lake, deposited the sediment, and then evaporated leaving behind the salt. Enough salt has been left behind to make present lake very salty, much saltier than the oceans.

Great Salt Lake, controlled by today's semi-arid climate, occupies only a small portion of the Great Basin. Fifteen thousand years ago, during the most recent major Ice Age, a very large lake, Lake Bonneville, covered most of northwestern Utah, and about a quarter of the Great Basin. On our year-long geologic time scale, that is only three minutes ago. The cool wetter climate at that time drove the lake higher and higher until it reached and flowed across the rim of the Great Basin into the Snake River, down the Columbia River, and into the Pacific Ocean. Both the glaciers of the mountains and the large lakes were effects of climate change. When the climate became drier again, more water evaporated from the lake's surface than the lake received and it shrank and shrank to about the size of the present Great Salt Lake, about one thousand feet lower than the highstand of Lake Bonneville. The sand and gravel deposits built at different stages of the lake now provide construction materials for the buildings and roads of western Utah and the Wasatch Front.



(Adapted from Currey)

A string of high mountains along the northwest borders of Utah known as metamorphic core complexes has a complicated geologic history. During Geologic Chapters Five and Six, parts of the earth's crust stayed significantly hotter for long periods of time than their surroundings. The heat and pressure re-metamorphosed some of the already-metamorphosed bedrock of Utah's Chapter One basement and metamorphosed some of the overlying layered sedimentary rock. Igneous rock intruded these metamorphic rocks making the entire complexes of rock hotter and less dense that their surrounding. With the extension of the Basin and Range in Chapter Nine, these complexes of igneous and metamorphic rock rose up like corks carrying sedimentary rocks above them some of which slid off the highlands and traveled miles away. The highlands with their igneous interiors form the high mountains of the northwest corner of Utah: the Raft River Mountains and the Pilot Range. Some ranges of the Basin and Range province, such as the Snake Range along the Utah Nevada border have characteristics of fault-bounded ranges and metamorphic core complexes.

Resources from Chapter Nine:

Erosion during Chapter Nine has exposed some of the resources created in Chapters One through Eight... stone, oil and gas, coal, potash, and metals. Three resources we mine today are the product of the geologic processes of Chapter Nine. The most obvious are the sand and gravel deposits of the lakes of the Basin and Range. Mining and chemical companies also harvest diverse salts from the lakes of the Basin and Range basins.

Another potential energy resource, geothermal energy, is a little more complicated. Because the crust of western Utah is thinner and warmer than the crust to the east of the hingeline, Most of Utah's hot springs occur along or west of the hingeline. Faults can act like plumbing systems. Colder water percolates into the earth along cracks and through rocks. The crust gets hotter at depth so the water heats up. Then, being warmer and less dense, the water rises along faults to the surface. Just the normal thermal gradient of the earth heats water sufficiently to drive the system. However, in a few areas such as at Roosevelt Hot Springs and Sulfurdale near Cove Fort still- cooling masses of igneous rock heat the circulating water. Two of these areas produce enough hot water and stream to generate electricity.

Scenery... what Chapter Nine rocks AND LANDFOMRS look like today:

Dr. William Lee Stokes calls Utah the "Bedrock State." We have the bold red cliffs of the Colorado Plateau, the subtle gray mountains of the Basin and Range, and the grand mountains of the Rocky Mountains. None of the bedrock of these features is Chapter Nine rock. Chapter Nine rocks are mostly sediments of the past 17 million years. Chapter Nine deposits carried by wind, water, glaciers, ground failures, and human beings can be found in the basins of the Basin and Range, the valleys of the Rocky Mountain physiographic province, and the canyons of the Colorado Plateau.

The scenery that you see across Utah today is Chapter Nine scenery and the landforms you see are Chapter Nine landforms. Don't confuse the age of landforms with the age of the rock they are made of. Virtually all of the Basin and Range landforms did not exist 20 million years ago. The Uinta Mountains and some of the features of the Colorado Plateau formed in Chapters Six and Eight, but the erosional landforms result from etching of rocks by the Colorado River system which has been hard at work only for about 20 million years, Chapter Nine.

UTAH GEOLOGY TOMORROW

Geology is cumulative. The landforms of tomorrow are built from the landforms of today. Areas exposed to the ravages of erosion will continue to erode and the sediment will travel to a destination and become layered sediments. Eventually, tectonic forces in the earth will change from their Chapter Nine mode and Chapter Ten will begin.

From the perspective of our lifetimes, we will live, and our children will live, and their children will live in Chapter Nine. An understanding of the geology tends to increase an appreciation of the scenery and science around us. Understanding the geology also has many practical applications. Geologists unravel geologic history with practical objectives to determine and understand current conditions and to foresee future. For example, a geologist involved in the search for oil and gas needs to understand where, and how the oil and gas was formed millions of years ago, and the rocks and structures where it can be trapped. An engineering geologist examining a site for a dam needs to know the history of the rocks, soil and landforms at the site to determine what needs to be considered in designing and building a dam that will be safe and function properly.

The present is the key to the past, the past is the key to the present and both the past and the present are the key to the future.

Resources from the future Chapter Ten:

To understand where new energy, mineral, and water resources will be developed and how to develop and manage them, we need to understand the geologic controls that determine the occurrence of these resources.

Hazards of Chapter Ten:

The landscape of Utah continually changes although most of the changes are so slow or so infrequent that many people are not aware of them. Hazards to life and property associated with some of these changes can be mitigated effectively if the geology is understood and respected. Every structure we build upon the earth relies on and reacts to its geologic conditions. Considering the geology of the site is an integral step of locating, designing, and building any structure. When it is skipped, it is as hazardous financially as not checking liens on a property.

Scenery... the joy factor Utah's spectacular geology, whenever:

Geology is a very practical science and it is also an entertaining science. As with most science, an understanding of it grows with time. The laboratory for geology is the out of doors. Every where you drive, hike, bicycle, or walk you see geology.

If you have suggestions on how this book can be more helpful transmitting the pure pleasure of understanding Utah's geology, please let us know. Actually, please let us know however we can improve this book. It is meant for readers like you.