A SHORT COURSE IN PETROLEUM GEOLOGY
WITH EXAMPLES FROM UTAH'S PETROLEUM PROVINCES

by

CAROL N. TRIPP

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INTRODUCTION

Persons utilizing this course will gain an understanding of many basic geologic principles, and how they relate to the field of petroleum geology. Additionally, the reader will be given a brief exposure to Utah's oil and gas provinces through the use of field examples. These examples are designed to show how the principles of petroleum geology apply to actual productive fields.

The course is designed to appeal to many groups, including: potential, and actual lease holders; persons interested in oil and gas investment opportunities; support personnel from exploration companies; scientists from other specialties desiring or needing a basic understanding of petroleum geology; lawyers, accountants, and other professionals who work closely with oil and gas companies; and the lay person who desires to understand more about geologic principles, petroleum geology, and Utah's petroleum provinces.

The simulation game "WILDCAT," is a supplement for this course, and has been developed to integrate the concepts presented. This game is fun, exciting, and challenging. It very closely approximates the operation of a company as it explores for oil and gas. It is playable by any number of people, and those persons completing the game will undoubtedly learn a great deal about the expense, intrigue, and risks of oil and gas exploration.

CHAPTER 1

STRATIGRAPHIC PRINCIPLES

1.1 Introduction

As one explores the mountains and roadsides, it becomes apparent that there are many different kinds of rock layers, or geologic strata. The understanding of the origin and composition of these layers is encompassed under the geologic specialty of **stratigraphy.**

1.2 Geologic Time Scale

Hundreds of years ago, geologists realized the earth had a rich historic record. Fossils were preserved in many sediments. These fossils were often very different from any animals or plants that were presently alive. Geologists came to realize that many species of animals and plants are now extinct, and that many of the species we have now, did not always exist. The most famous example of this is the dinosaur. It was soon decided that some sort of geologic time scale needed to be established to separate all of these fossils into time periods during which the plants or animals lived. Thus, the **Geologic Time Scale** was devised to classify fossils and the rock layers in which they are found.

The Geologic Time Scale, shown in the Appendix, lists the approximate age and duration of each period, and important biological events associated with the period. By assigning time periods to the various rock layers and fossils, geologists can distinguish older rocks from younger rocks. If, for example, dinosaur bones were found in a rock layer, you could be almost certain that the age of the rock was Mesozoic. If, in a second layer, horse footprints were found, then one could conclude that this second unit was from the Cenozoic era, and that the first layer is older than the second layer.

1.3 Law of Superposition

A very important concept in geology is the **Law of Superposition.** Very simply, this law states that the oldest rock units, or the layers that were deposited first, will be on the bottom, and that younger rock units will be on top. It is helpful to imagine a stack of pancakes when thinking about this principle. As the pancakes are cooked, they are stacked on a plate. The first pancake cooked is on the bottom of the stack, and the last pancake cooked is on the top of the stack; so it is with geologic strata.

The first rock layers laid down are the oldest, with the ones on top being the youngest.

This concept sometimes becomes confused when dealing with overturned beds. But, if using fossil evidence in conjunction with this principle, it can often be determined which units are oldest and youngest.

Once the relative ages and rock types of the units are determined by examining the fossils within them, names are assigned to the layers. A **stratigraphic chart** is then composed using these names. Some layers are very extensive and cover hundreds of square miles. Other units are very limited and may exist for only a few square miles. The individually named units are extensively described in the geologic literature, so that other geologists working in the area can **correlate** the rock units they are working on with rock units that have already been described.

Each area has its own geologic names for the various rock layers. Figure 1-1 is a portion of a stratigraphic chart for the Wasatch mountains east of Salt Lake City. The chart includes the names of the era and period, and the **formation** or rock layer names, thicknesses, and rock types or **lithologies.**

ERA	PERIOD	FORMATION	THICKNESS	LITHOLOGY
MESOZOIC	TRIASSIC	Ankareh	700'	Red to purple shale and sandstone
			75'	White, gritty quartzite
			800'	Red to purple shale and sandstone
		Thaynes	1000'	Gray limestone, sandstone, greenish shale
		Woodside	1000'	Red shale and sandstone

Fig. I-I: A portion of the stratigraphic column for the foothills east of Salt Lake City. (Modified from Granger and Sharp, 1952.)

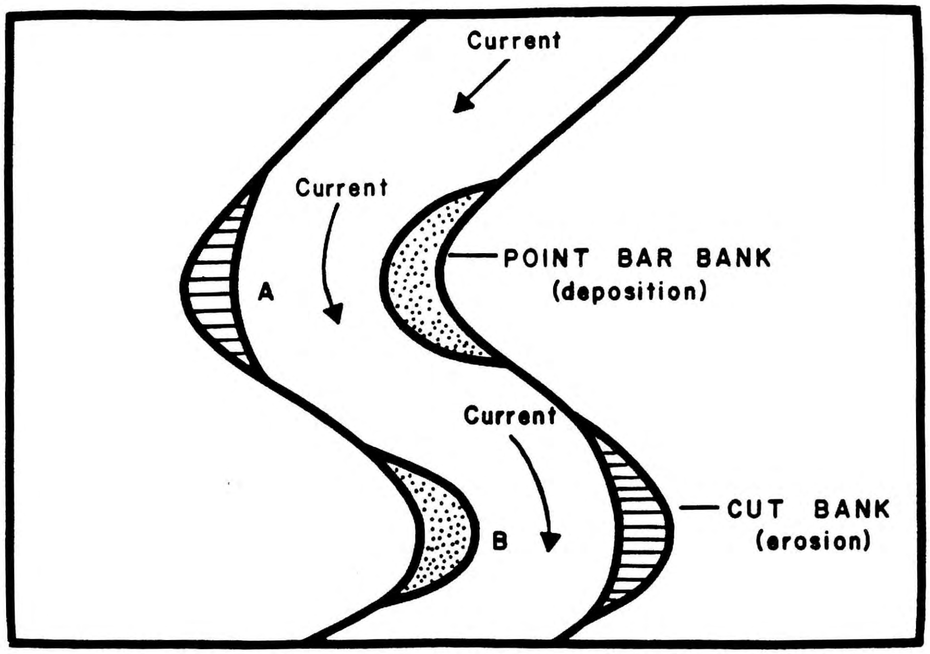
1.4 Depositional Environments

As can be seen from the stratigraphic chart in figure 1-1, the formations or rock layers vary greatly in thickness, and lithology or rock type. The lithology of the rocks in figure 1-1 varies between sandstone, shale, and limestone. The differences in the thickness and lithology of the units can be attributed to differing **depositional environments.**

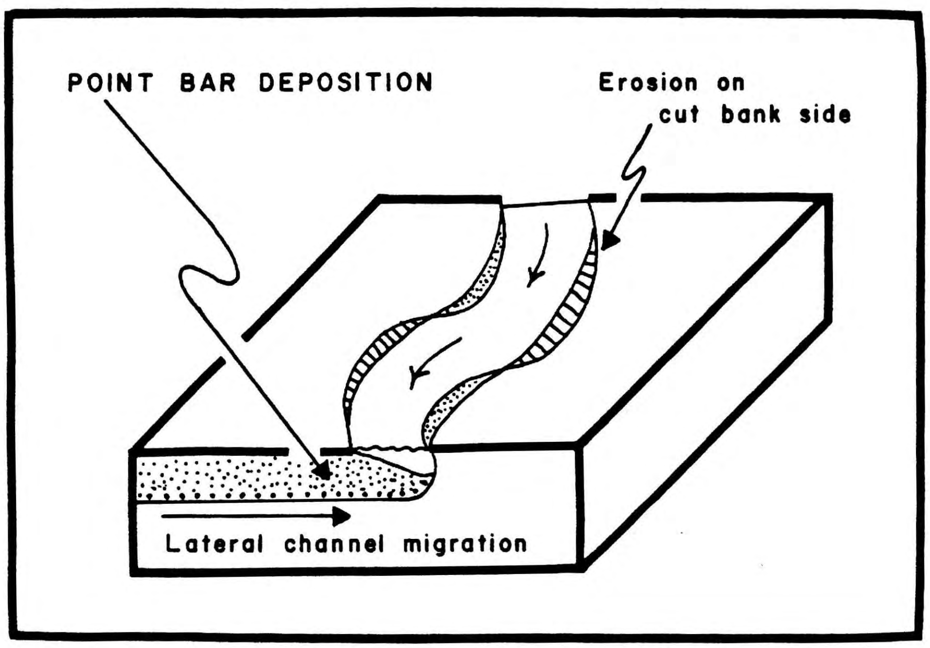
A depositional environment is the environment in which the sediments forming the rock units are deposited. There are numerous environments that allow for sediment deposition: **rivers, oceans, wind and lakes.** Certain lithologies and characteristics are common to each environment. An example of this is shale. Shale is always deposited by water, and never by wind. Some of the most common types of depositonal environments are discussed below.

Rivers- Geologists refer to deposition that occurs by rivers as fluvial. There are two major types of rivers: **meandering, and braided.**

Meandering rivers typically have one channel, which forms an "s" shaped river bed. Figure 1-2 shows deposition within a meandering river system. As the river flows downstream, sediment is removed from the cut bank



A. Meandering river showing erosion of cut bank side, and deposition of sands on point bar side. Material is stripped away from bank A. The sands are deposited downstream at bank B; the silt and clay from bank A is carried downstream. (Adapted from Dickey, 1986.)



B. Cross-section of a meandering river showing point bar deposition, and lateral migration of meanders. (Adapted from Selley, 1973.)

Fig. 1-2: Deposition in a meandering river system.

side of the channel, and deposited downstream at the point bars. As the river cuts deeper, and more and more sands are deposited, the point bar sandstones can become very thick; sometimes up to several tens of feet thick. These point bar sandstones are very important hydrocarbon reservoirs. (The terms petroleum, hydrocarbon, and oil and gas are used synonymously throughout this course.)

Within each environment, are sedimentary **facies.** A facies is the product of a depositional environment; it is a special environment within the general depositional environment, and is distinguished by such things as its geometry, lithology, and fossil types. Point bars are a facies within the meandering fluvial depositional environment.

Braided rivers are the second major type of river, and usually form when a river descends a steep surface, such as a mountainside. These rivers are generally interconnected with each other, and have few curves. Large amounts of sediment are moved, and often the rivers are active only after rainstorms or during spring runoff.

Because braided rivers carry so much sediment, channels quickly become choked. As the river carries its load downstream, the speed of the water slows because the gradient or steepness of the ground generally decreases.

Figure 1-3 shows that as the water slows, the river is unable to carry all of its load, and dumps some of it in the center of the channel. This clogs the original channel and two new channels are cut. The unloaded sediment is usually composed of heavier material such as gravel and sandstone. The depositional feature formed when the stream load is dumped is called a **bar**. These bars are a facies of the braided river depositional environment, and are important hydrocarbon reservoirs.

<u>Oceans</u>- The depositional environment of the ocean is very complex, with numerous subenvironments, or facies. One way to distinguish between the types of marine sedimentation, is by the amount of sediment being brought into the ocean from the land.

Deltas form when the sediment input from the land is large, and the ocean cannot effectively distribute all of it. Figure 1-4 shows the lobes of a delta as it enters the sea, and the accompanying barrier islands that form as the delta sands are redistributed by ocean currents.

Shorelines form when the ocean currents are able to disperse he incoming sediment load. Figure 1-5 shows the linear bar and barrier coasts that develop under these conditions.

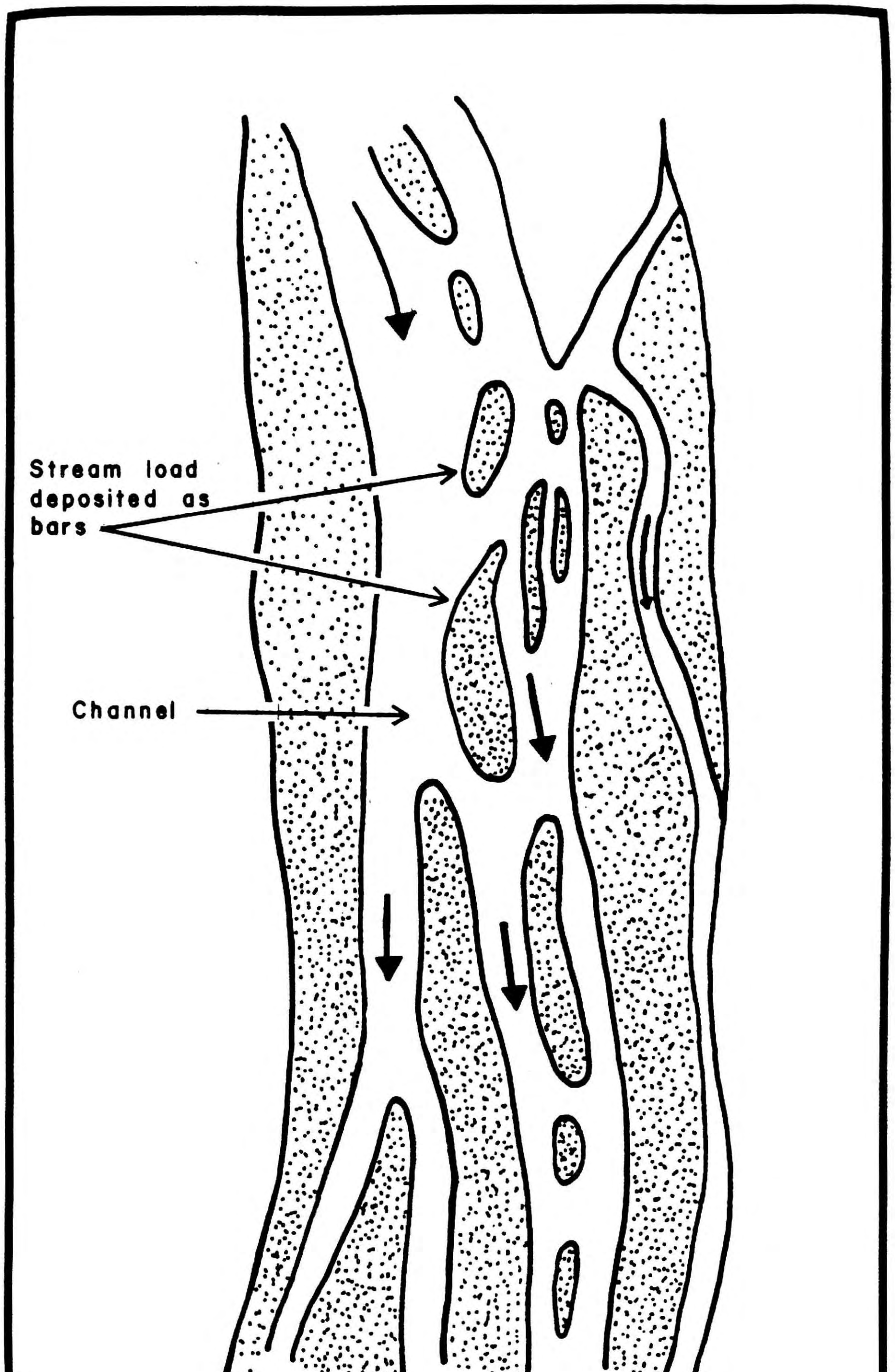


Fig. 1-3: Braided river system showing deposition of stream load in the form of bars. Channel switching occurs when bars are deposited. As slope steepness decreases, the stream loses velocity, and deposits more of its load. (Modified from Ethridge, 1983.)

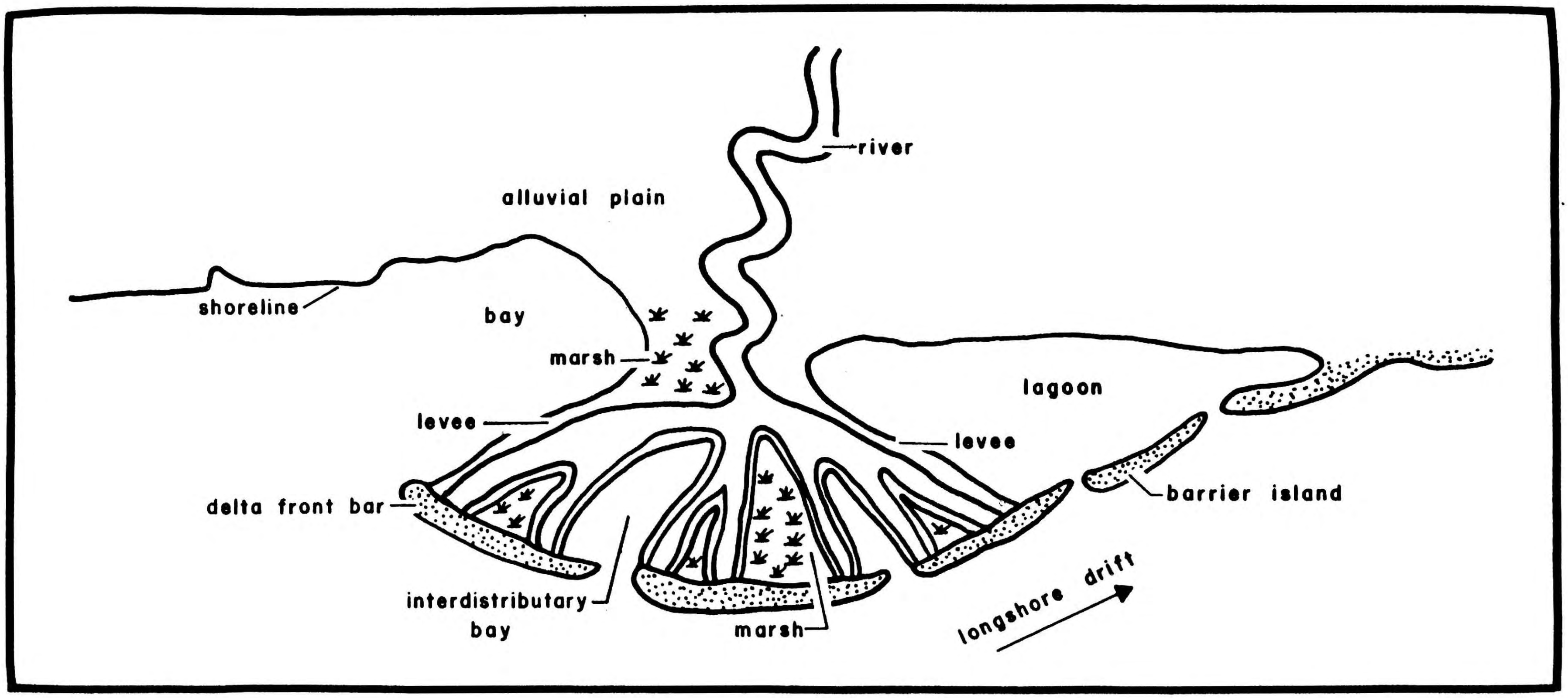


Fig. I-4: Diagram of a deltaic system. Deltas form when the ocean is unable to effectively redistribute all of the incoming land-derived sediment. (Adapted from Hyne, 1984 and Selley, 1973.)

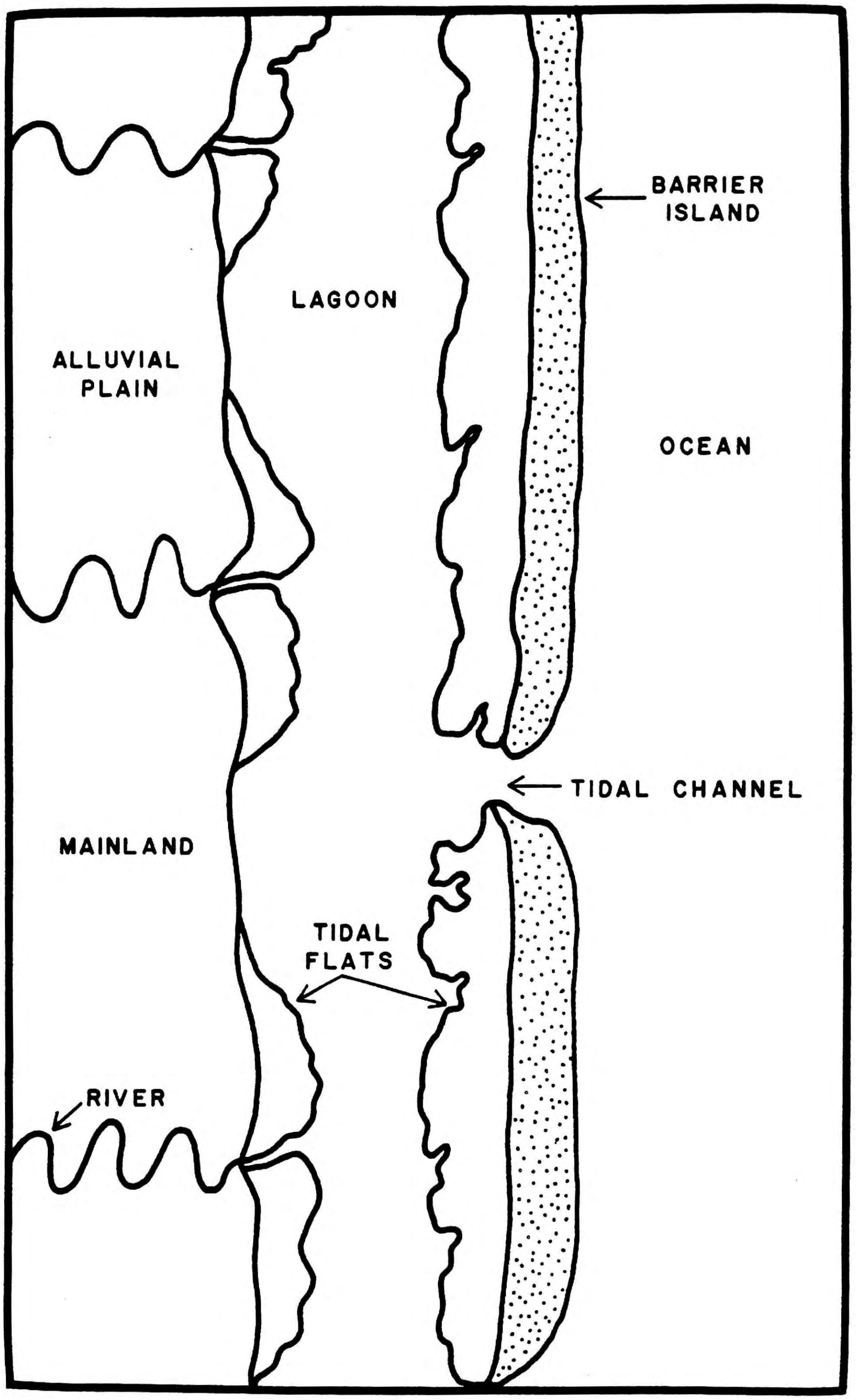


Fig. I-5: Diagram of a clastic shoreline. Linear bar and barrier coasts develop when the ocean currents are able to completely rework the incoming land-derived sediment. (Modified from Selley, 1973.)

Reefs, as shown in figure 1-6, develop when the amount of land-derived sediment is very small. They are composed of carbonates (limestones and dolomites); landward of these reefs, are lagoons.

Deposition also occurs beyond the deltaic, shoreline, and reef environments, very deep in the ocean. Typically, very fine-grained sediments, such as shales are deposited. These are thought to be the source rocks responsible for the generation of hydrocarbons.

Wind- Wind deposited sediments are termed **eolian** by geologists. Because of the potential thickness that eolian sediments may achieve (hundreds of feet), and their consistent nature, they are economically important as oil and gas reservoirs, and as ground water reservoirs. Figure 1-7 shows a cross section of a transverse dune. These types of dunes are thought to be responsible for most of the eolian sequences which are preserved in the geologic record.

Lakes- Lake deposited sediments are referred to as **lacustrine** by geologists. The Uinta Basin in eastern Utah was the site of ancient Lake Uinta. The Altamont-Bluebell trend produces from the lacustrine sediments of this ancient lake. Figure 1-8 shows the different facies associated with lacustrine deposition. It is the marginal lacustrine facies which contain the reservoir beds

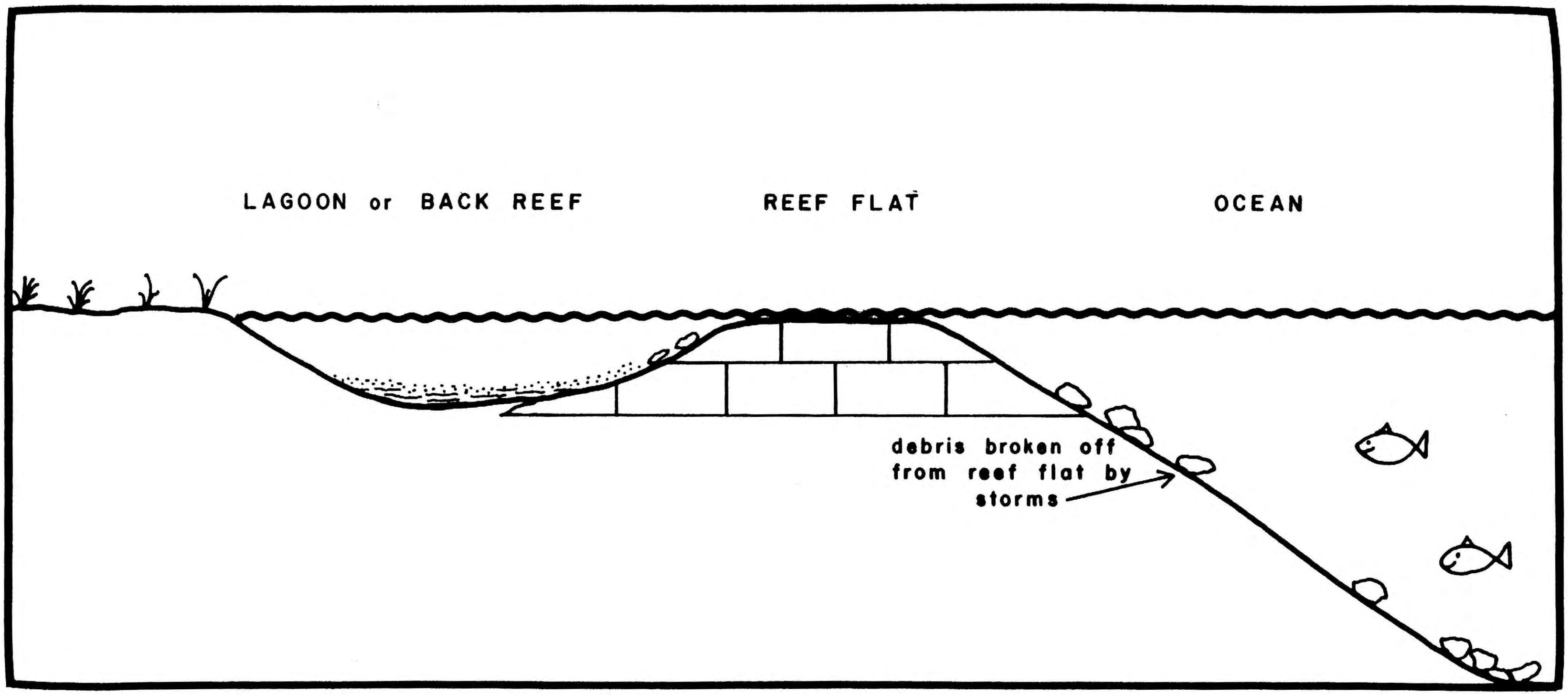


Fig. 1-6: Cross-section of a reef. (Adapted from Selley, 1973.)

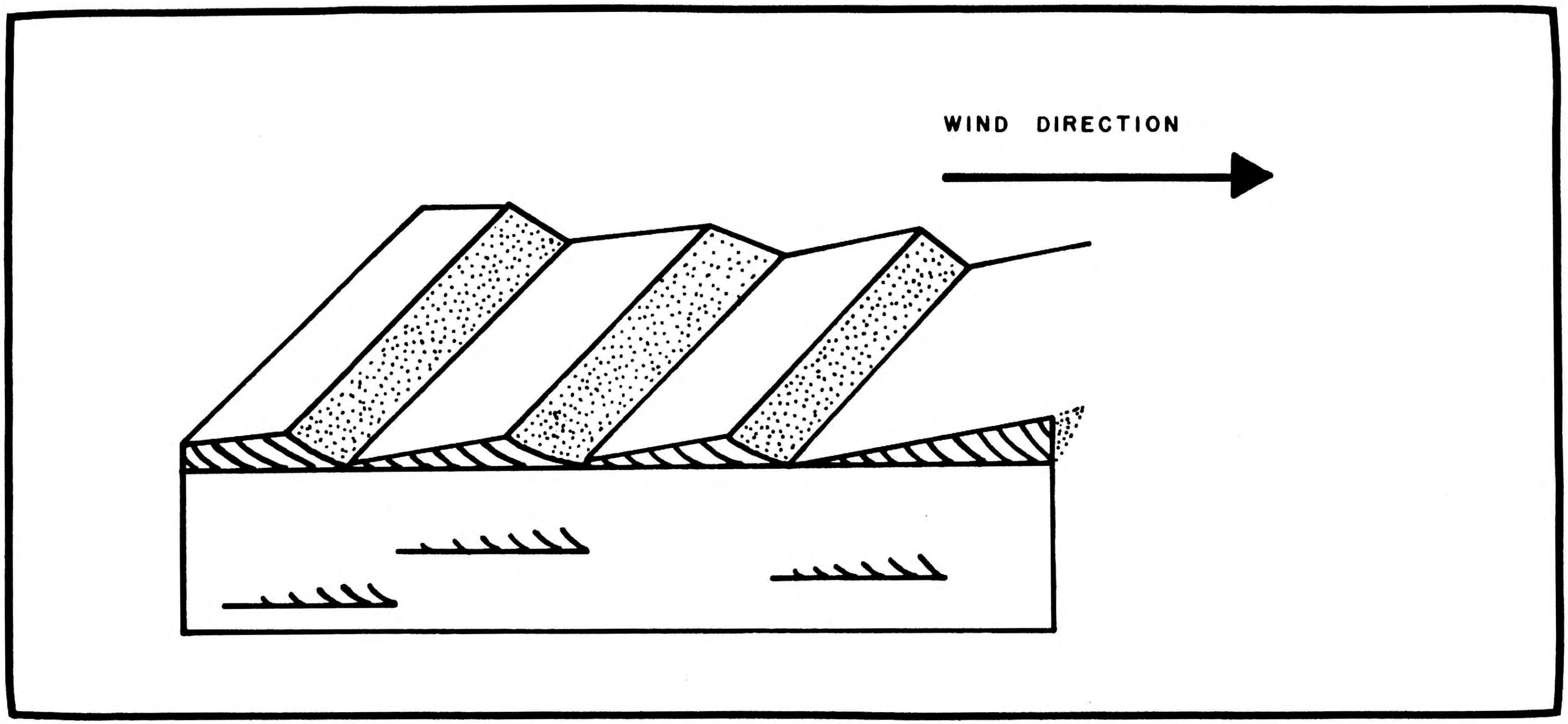


Fig. I-7: Cross-section of a transverse dune showing eolian deposition. (Modified from Selley, 1979.)

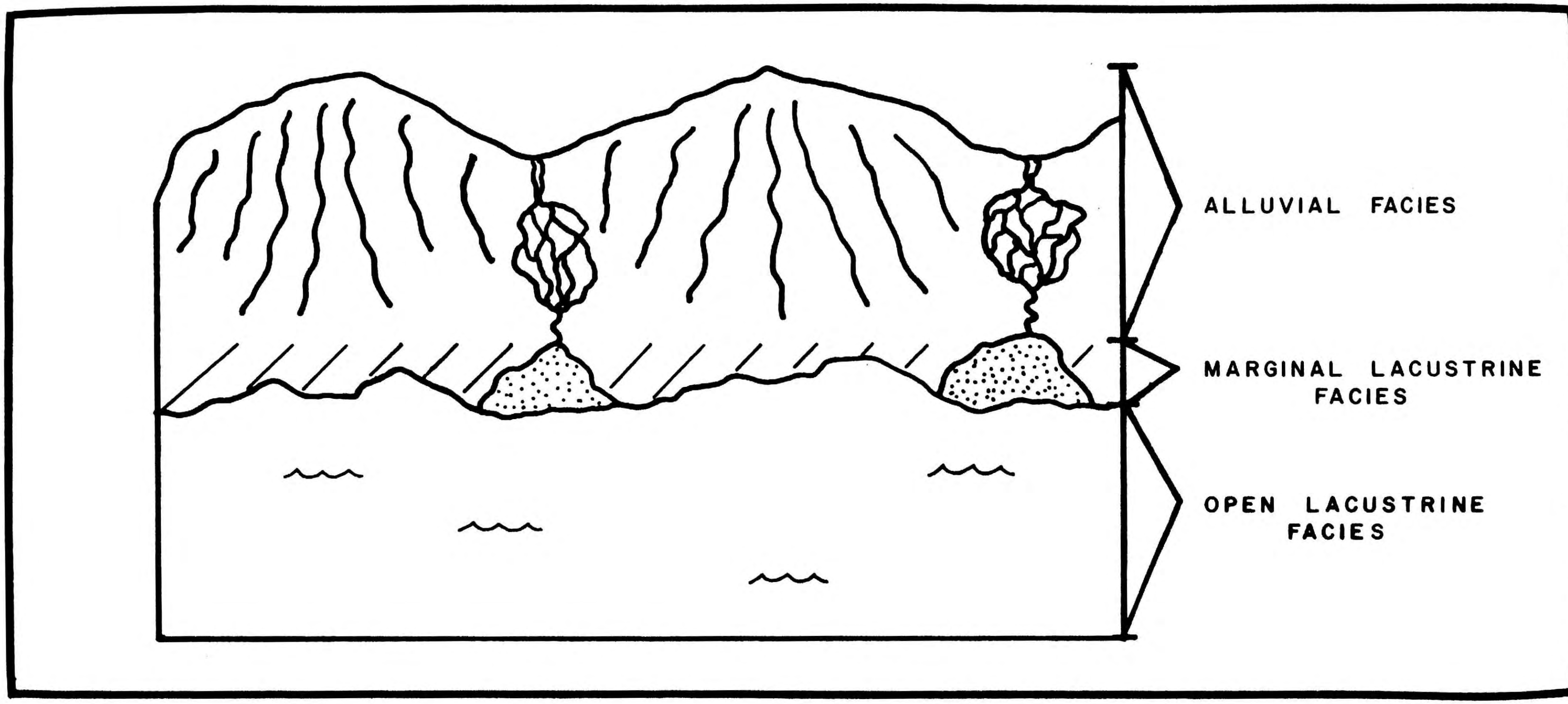


Fig. 1-8: Diagram showing lacustrine deposition. The mountains are drained by braided rivers within alluvial fans. Near the shore of the lake, deltas are formed. (Modified from Fouch, 1983.)

(hydrocarbon bearing). The source beds (where hydrocarbons form) for the hydrocarbons is the organic-rich open lacustrine facies.

When one thinks of depositional environments, there is a tendency to forget that a long time ago, things were very different. Today, for instance, the shoreline of the ocean is off the coast of California. In the Cretaceous period, the ocean shoreline ran through the state of Utah (Figure 1-9). Thus, it must be remembered that long ago, climates, mountains, valleys, oceans, rivers, lakes, etc., were all very different. That is why it is possible to find marine fossils in the foothills east of Salt Lake City.

Over the long period of time since the soft sediments were deposited, burial, compaction, and cementation have taken place. Temperature and pressure from these processes have caused these sediments to be solidified into rock.

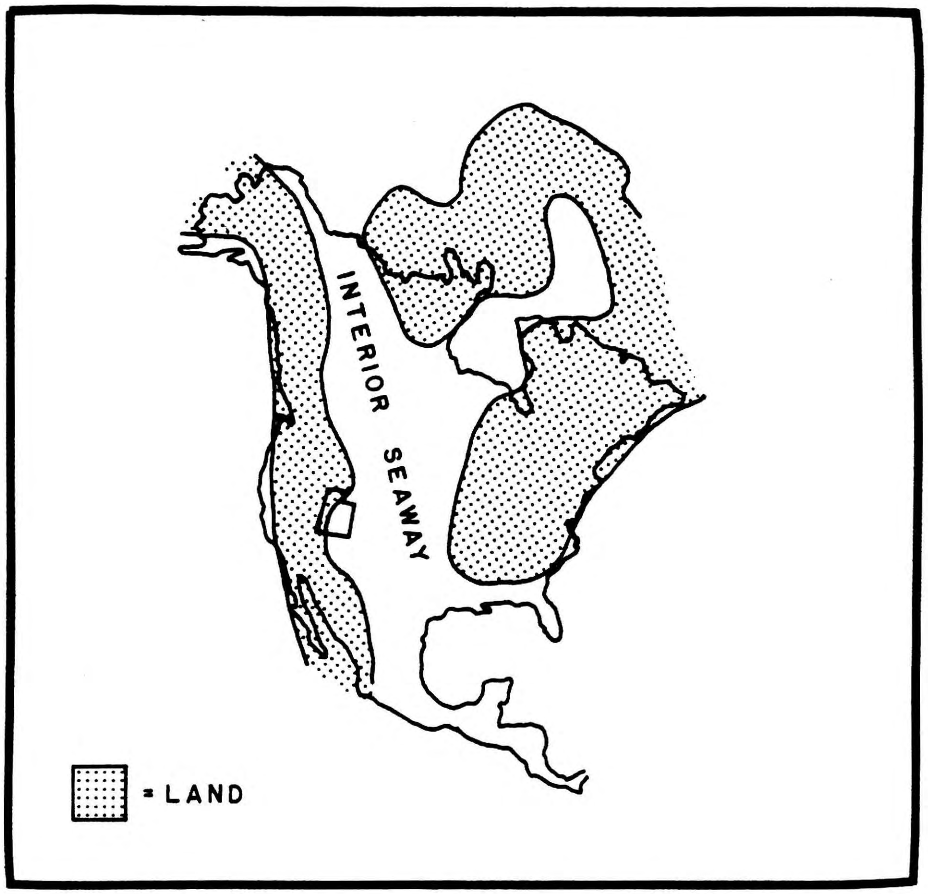


Fig. I-9: Geography of North America during the Cretaceous period. An interior seaway separated the continent; the western shoreline of the sea passed through Utah. (Modified from Ryer, 1983.)

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CHAPTER 2

STRUCTURAL PRINCIPLES

2.1 Introduction

After sediments are deposited, burial, compaction, and cementation begin to transform the loose sediments into rock. Additionally, an area may be **structurally** altered. This means that instead of the sediments remaining in the same position that they were deposited in , they are moved into new positions. There are three structural processes that are responsible for altering a rock layer's original position: **folding, faulting, and diapirism.** These will be discussed below. Additionally, unconformities will be explained; they are considered to be structural features, and are important in oil and gas exploration.

2.2 Folding

The two most common types of folds are **anticlines** and **synclines.** One way for folding to occur is by compression. Imagine that the crust of the earth is like a tablecloth. If one or both of the edges of the tablecloth are "compressed," or pushed toward the middle, wrinkles occur in the cloth that look like peaks and valleys. The peaks are the anticlines, and the valley-shaped folds are the synclines. Depending upon how much compression occurs, the folds in the tablecloth take on different positions; some have steep sides, and others lie on their sides.

Figure 2-1 is a diagram of an anticline showing the names used to describe the parts of the fold. The sides are referred to as the limbs. The axis or axial plane is the line or plane that could be drawn if the sides of the fold were separated. The axis is the highest point along the length of the anticline, and the lowest point along the length of the syncline. Usually, folds **plunge** or taper at the long ends. This can again be demonstrated by the folds in a tablecloth.

Although many variations are possible, figures 2-2 and 2-3 show four major types of anticlines and synclines. Symmetrical anticlines and synclines have vertical axial planes. Asymmetrical folds have inclined axial planes, and the limbs of the structure dip in different directions. Overturned folds also have inclined axial planes, but the limbs of the fold dip in the same direction. In a recumbent anticline or syncline, the axial plane is rotated 90 degrees or more from vertical. It is important to remember that **anticlines are formed with the oldest beds toward the center of the fold, while synclines are formed with the**

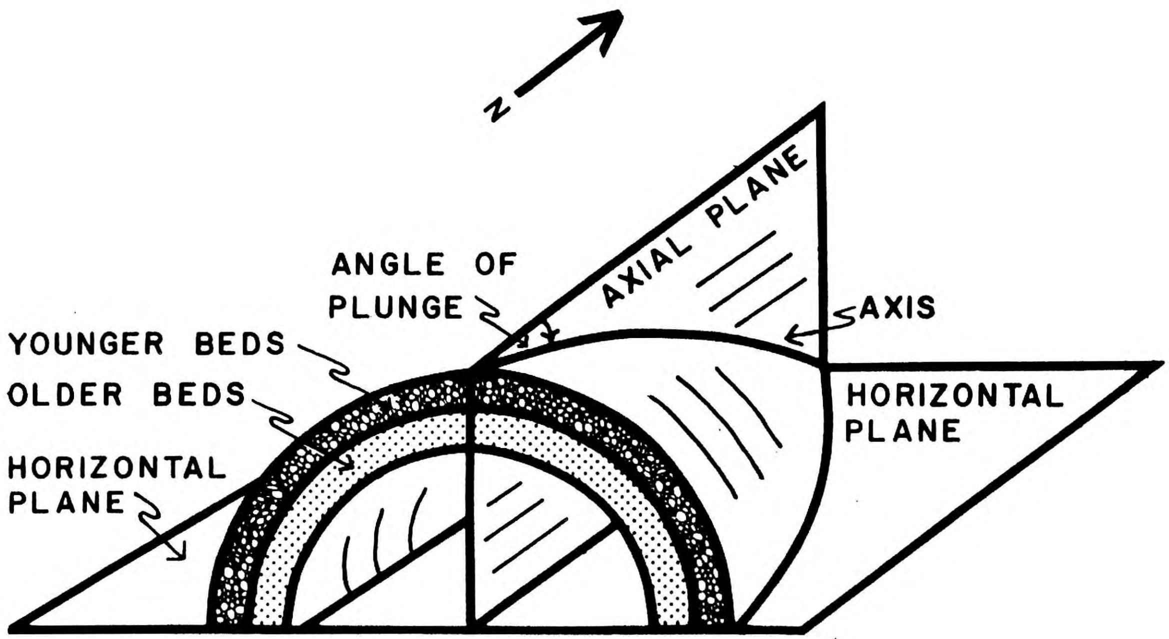
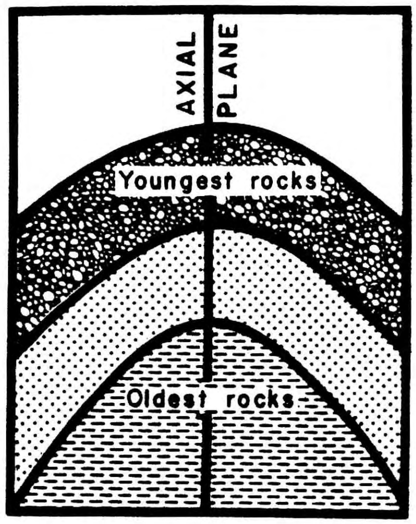
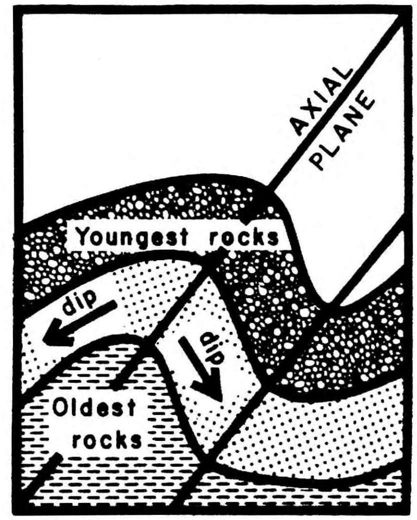


Fig. 2-1: Schematic of an anticline showing axial plane, axis, and example of northward plunge. Oldest beds are towards the center. (Modified from Semken and Tuttle, 1971.)



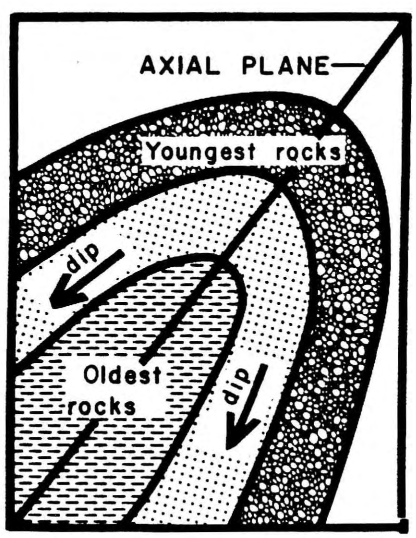
A

SYMMETRICAL: axial plane is vertical.



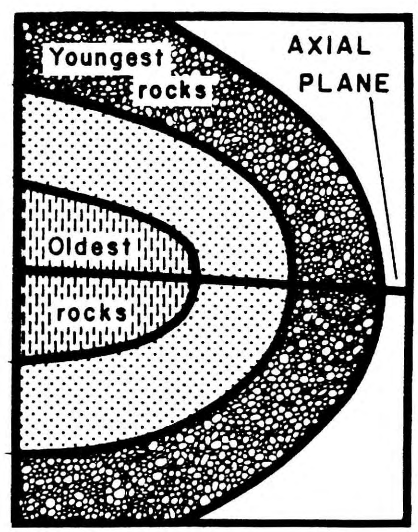
B

ASYMMETRICAL: axial plane is inclined. Limbs of anticline dip in different directions.



C

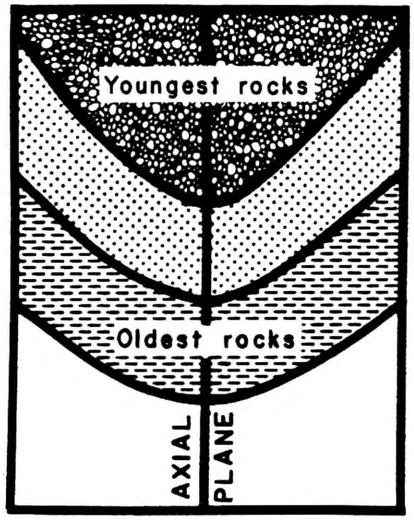
OVERTURNED: axial plane is inclined. Limbs of anticline dip in similar direction.



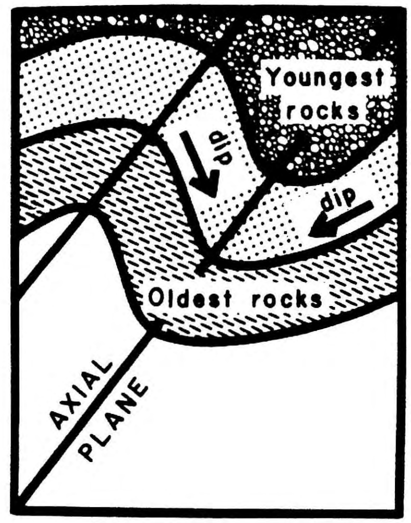
D

RECUMBENT: axial plane is rotated 90° or more from vertical.

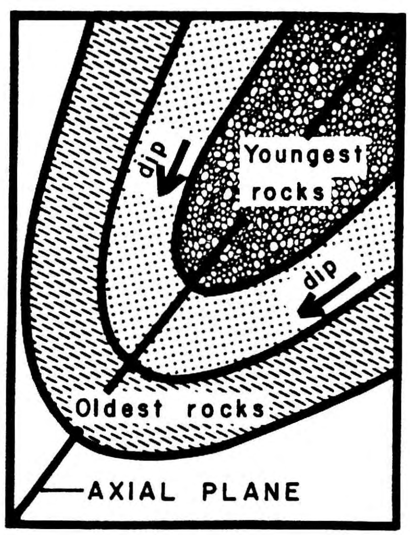
Fig. 2-2: Some varieties of anticlines. (Adapted from Billings, 1972.)



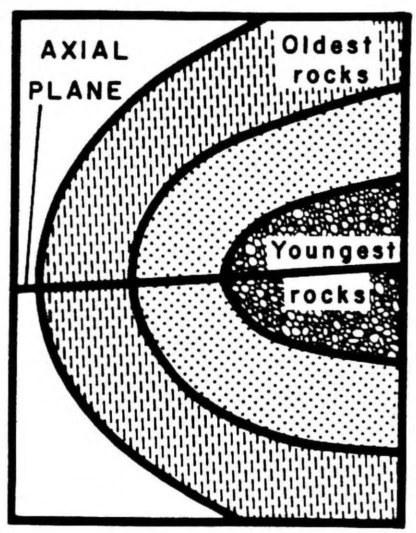
A
SYMMETRICAL: axial plane is vertical.



B
ASYMMETRICAL: axial plane is inclined. Limbs of syncline dip in different directions.



C
OVERTURNED: axial plane is inclined. Limbs of syncline dip in similar direction.



D
RECUMBENT: axial plane is rotated 90° or more from vertical.

Fig. 2-3: Some varieties of synclines. Synclinal folds have the youngest beds in the center of the fold. (Adapted from Billings, 1972.)

youngest beds toward the center of the fold.**

In the Wasatch mountains above Salt Lake City, Emigration Canyon lies in a syncline, as does Parley's Canyon. In between these two synclines is the Spring Canyon anticline. It should be noted that not all mountains and valleys are anticlines and synclines. The slope or dip of the individual rock layers must be examined to determine if an anticline or syncline exists.

Perhaps the most famous Utah anticline is the San Rafael Swell in Emery County. Located in east-central Utah, this kidney-shaped **uplift,** or anticline, rises approximately 2000', and is about 75 miles long and 30 miles wide.

Although the San Rafael Swell does not have economically producible hydrocarbon resources, **the vast majority of the world's petroleum reserves are found in anticlinal structures.** This is because oil and gas migrates to the top of the structure near the axis, and becomes trapped.

2.3 Faulting

Faults are breaks in the rock layers along which movement has occurred. The fault separates the layer into two parts as shown in figure 2-4. The separation or offset between the two layers is the **displacement.** The block above the fault is the **hanging wall.** The **footwall** is the block below the fault plane.

The description of the vertical, horizontal, and sideways movement of the fault blocks is complex, and not within the scope of this course to fully discuss. How the blocks move relative to each other is what determines the type of fault. There are literally dozens of ways for the blocks to move, and therefore numerous types of faulting. The three most common types are **normal, thrust, and strike-slip.**

Normal- A normal fault is a fault along which the hanging wall, or the wall above the fault plane, has moved downward. Figure 2-5 shows two examples of normal faulting. The direction in which the fault plane dips differs in the two examples; thus creating very different looking situations.

Thrust- Thrust faulting occurs then the hanging wall has moved upwards in relation to the footwall. Figure 2-6 shows two examples of thrust faulting. As in figure 2-5, the angle of dip on the fault planes differs between the two examples.

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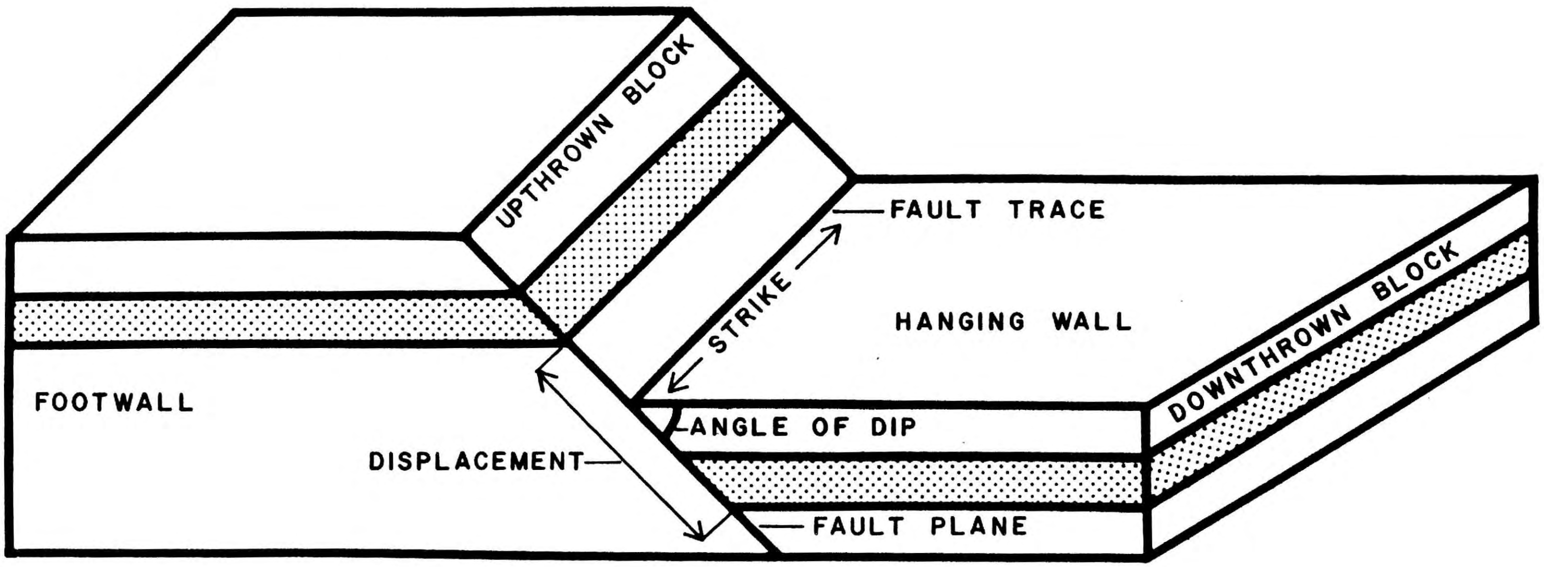

Fig. 2-4: Diagram showing fault terminology. Hanging wall is the block above the fault plane. Footwall is the block below the fault plane. Example shows a normal fault. In normal faulting, the hanging wall is downthrown in comparison to the footwall. (Modified from Semken and Tuttle, 1971.)

CNT-34

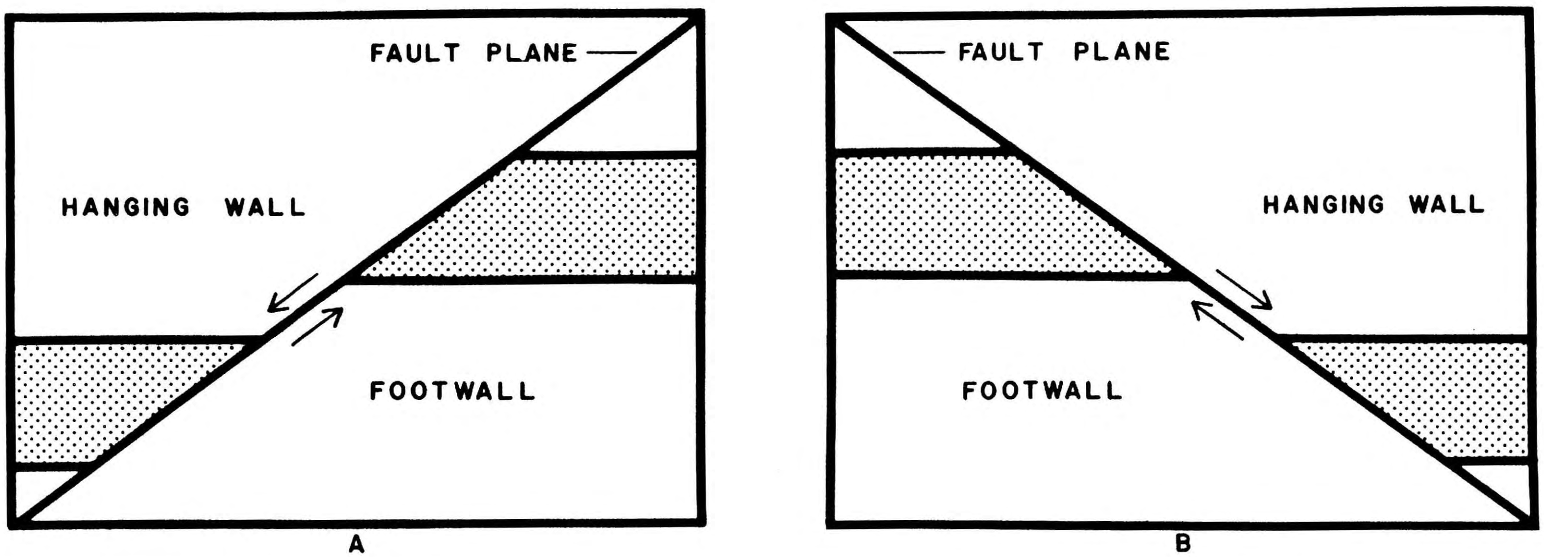

Fig. 2-5: Cross-sections showing normal faulting. Fault planes dip in different directions. Note that hanging wall is always above the fault plane, and footwall is always below the fault plane. In normal faulting, the hanging wall is downthrown with respect to the footwall.

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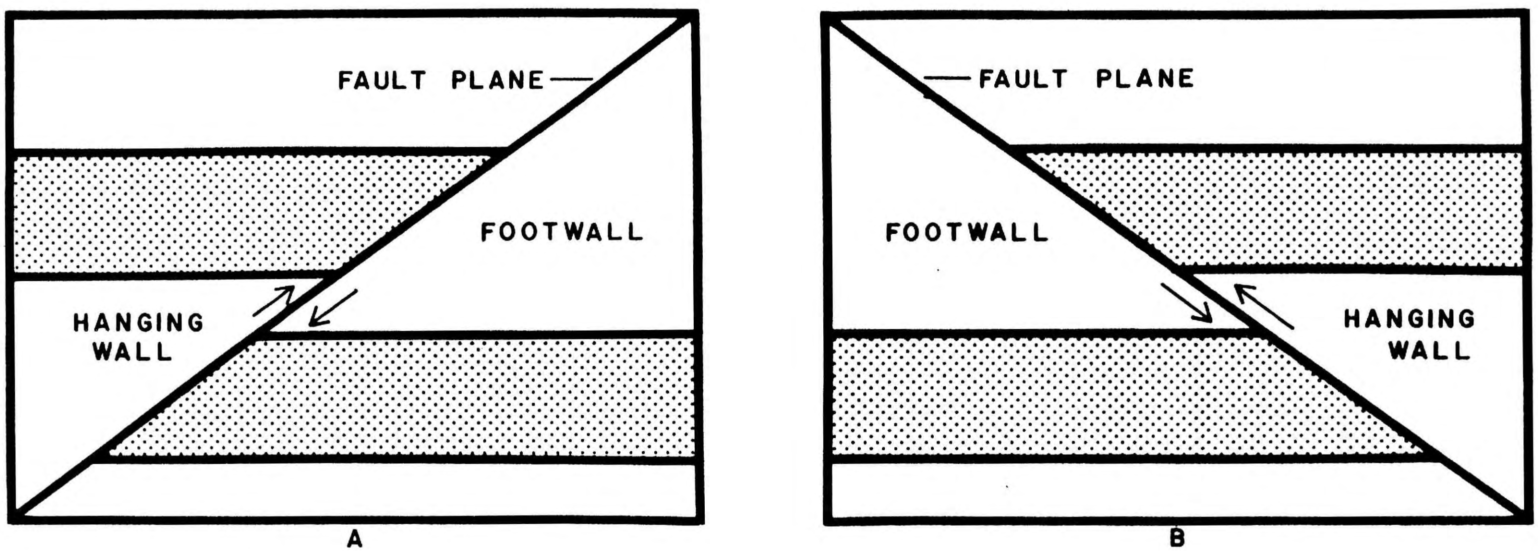


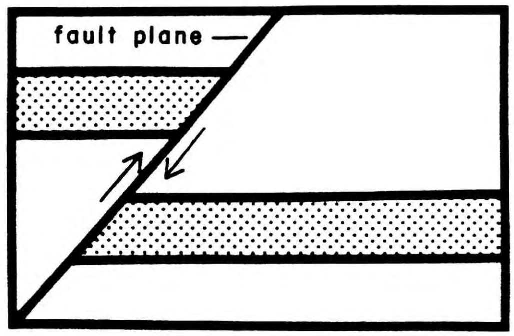
Fig. 2-6: Cross-sections showing thrust faulting. Fault planes dip in different directions. Note that hanging wall is always above the fault plane, and footwall is always below the fault plane. In thrust faulting, the hanging wall is upthrown with respect to the footwall.

There are three major categories of thrust faulting: **reverse, thrust, and overthrust.** As can be seen in figure 2-7, the criteria for deciding which type of thrust faulting has occurred, is based upon the dip angle of the fault plane. In reverse faulting, the fault plane dips at an angle greater than 45 degrees. If the fault plane dips at an angle less than 45 degrees, then a thrust fault is present. The term overthrust faulting is used in very special circumstances when the fault plane dips less than 10 degrees, and has a large net slip. Net slip is the amount that the hanging wall bed has slid over the top of the footwall bed.

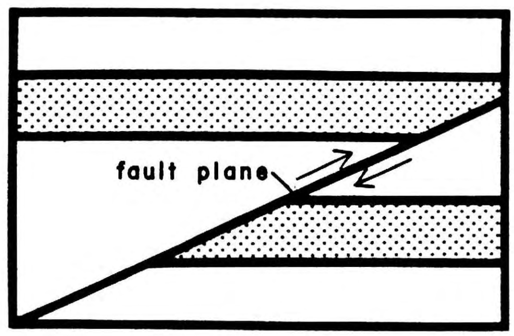
Thrust faulting is very important in petroleum exploration. When encountered in a well, thrust faulting causes the rock layers to repeat. If rock layers repeat that have hydrocarbon potential, then two reservoirs are encountered, instead of just one. This increases the hydrocarbon potential for the well tremendously.

When normal faulting is encountered in a well, beds are absent. In some cases, a normal fault could cause the target reservoir bed to be missing completely, or the well may only encountered a very thin section of the reservoir.

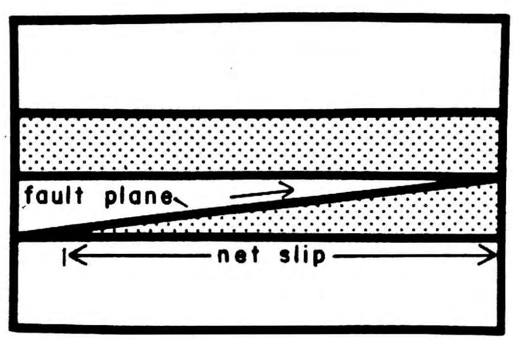
To help understand these principles, imagine some well locations in figures 2-5 and 2-6. Pretend the top edge of



A. REVERSE FAULTING: fault plane dips at an angle greater than 45°.



B. THRUST FAULTING: fault plane dips less than 45°.



C. OVERTHRUST: Fault plane dips less than 10°, and has a large net slip.

Fig. 2-7: Cross-sections showing different types of thrust faulting.

the cross sections is the surface of the earth. Project wells into the subsurface of the earth by drawing vertical lines down through the cross sections.

Strike-slip- In strike-slip faulting, the displacement occurs in a horizontal direction along the strike of the fault without any vertical displacement. Figure 2-8 shows an example of strike-slip faulting. Depending upon which direction movement has occurred, the fault is classified as either right or lefthand strike-slip.

2.4 Diapirs

The term **diapir** is derived from Greek and means "to pierce." Diapirs are formed when underlying rock pierces into overlying sediments. The most common type of rocks that act as diapirs are evaporites (salt, gypsum,and anhydrite), shale, and serpentine.

Figure 2-9 shows how diapirs greatly deform the surrounding rock layers. In so doing, they produce valuable hydrocarbon traps. These structures are not always evident from the surface, and must be discovered by geophysical methods (section 3.3), or by drilling.

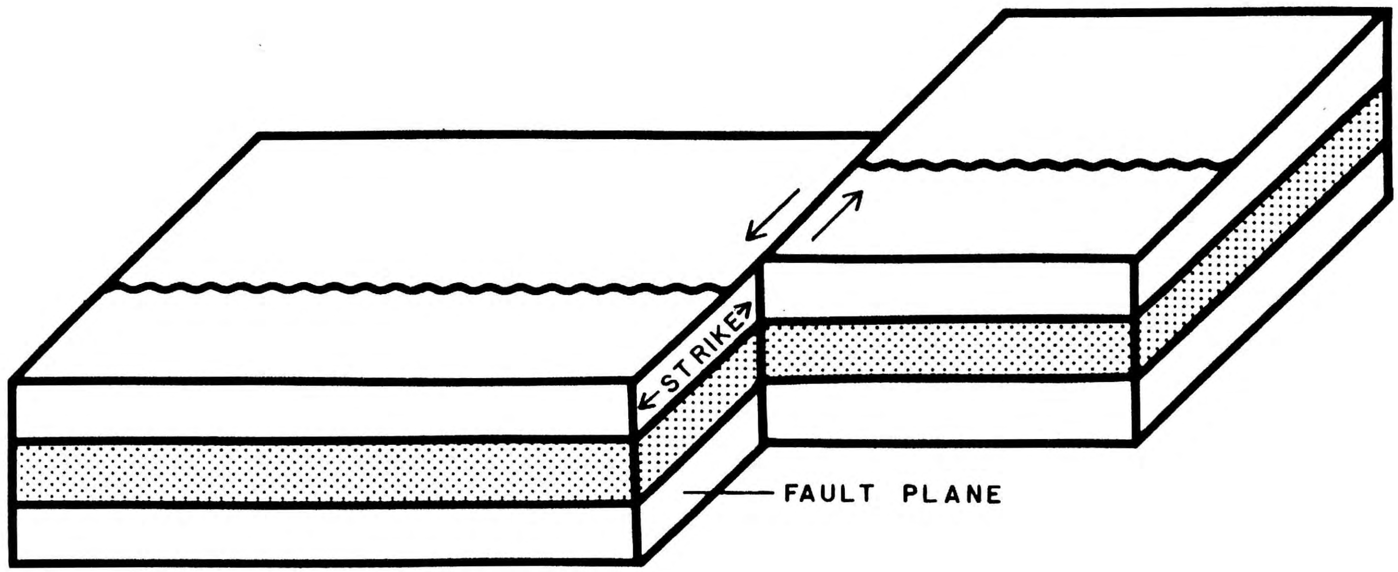


Fig. 2-8: Cross-section showing strike-slip faulting. Displacement has been in the horizontal direction along the strike of the fault. Depending upon which direction the relative displacement has occurred, the fault is classified as either right- or left-hand strike-slip. (Modified from Semken and Tuttle, 1971.)

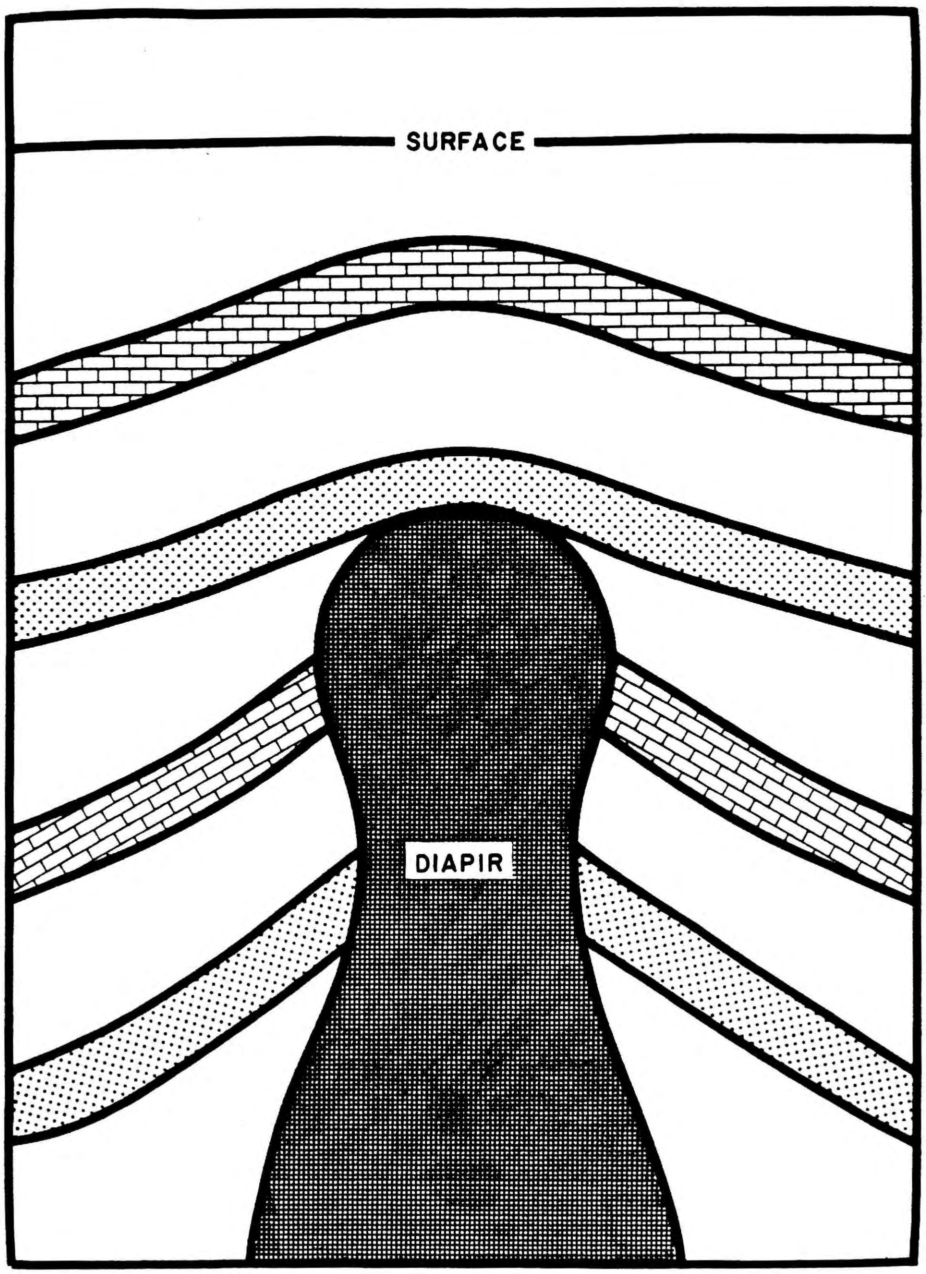


Fig. 2-9: Diagram showing a diapir, and the effect the piercing movement has on surrounding rock layers. Note that the surface may not show any deformation.

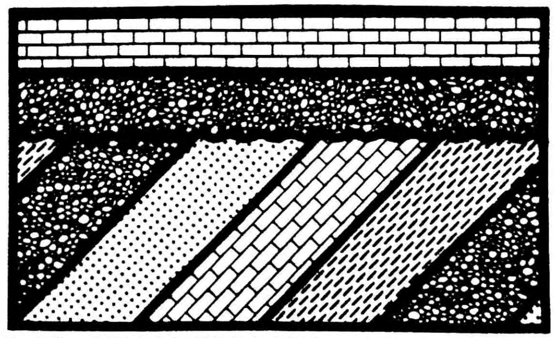
2.5 Unconformities

An **unconformity** is a break in the depositional history of the rock. Unconformities are considered to be structural features, even though stratigraphic events are necessary for their origin. However, the hydrocarbon traps formed by unconformities are considered to be stratigraphic, not structural. Valuable petroleum and mineral deposits are often associated with unconformities.

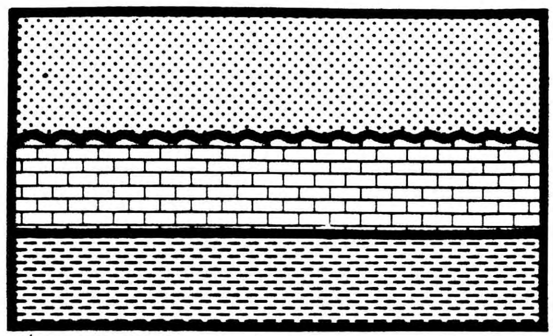
Unconformities are most commonly formed when the underlying rock is either uplifted or eroded. Following this, younger sediments are deposited. The break between the older and younger sediments is marked by an unconformity. The four most important types of unconformities are: **angular unconformity, disconformity, local unconformity, and nonconformity.** Figure 2-10 diagrams the four different unconformities.

Angular Unconformity- Angular unconformities occur when the older rock sequence is folded or tilted. The rocks are then eroded, either by streams or oceans. After erosion, more deposition occurs. The younger sediments are flat-lying.

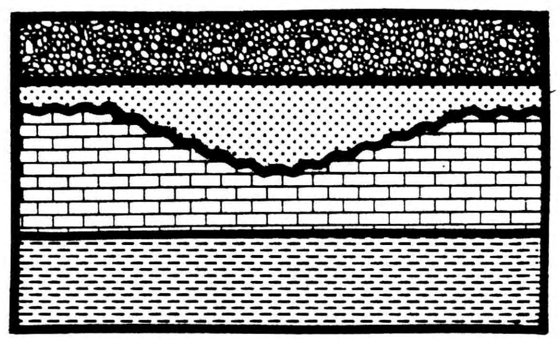
Disconformity- A disconformity occurs when the sediments on either side of the unconformity are parallel to



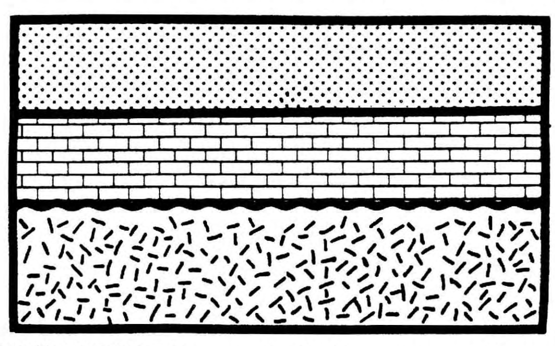
A: ANGULAR UNCONFORMITY: rocks on opposite sides of unconformity are not parallel.



B: DISCONFORMITY: rocks on opposite sides of unconformity are parallel. Scale is large.



C: LOCAL UNCONFORMITY: similar to disconformity, but on a smaller scale, such as channel in-filling.



D. NONCONFORMITY: rock below unconformity is of plutonic (intrusive volcanic) origin.

Fig. 2-10: Types of unconformities. 〰 = Unconformity. Older rocks are below unconformity, younger are above.

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each other. Erosion or nondeposition occurred to produce the unconformity. The scale of disconformities is large; often covering several hundred square miles.

Local Unconformity- Local unconformities are the same as disconformities, but on a much smaller scale. They include events such as the in-filling of fluvial channels.

Nonconformity- A nonconformity is most often described as a disconformity in which the older rock is of plutonic (intrusive volcanic) origin.

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CHAPTER 3

TOOLS OF THE GEOLOGIST

3.1 Introduction

Geologists use surface and subsurface information to form their conclusions. It is desirable to obtain as much information as possible before interpretations are made and conclusions are drawn. Given the same information, it is not unlikely that two geologists may develop different interpretations, and thus, different conclusions.

In the world of petroleum exploration, where a well may cost millions of dollars to drill, it is imperative that the geologist gain as much information as possible and interpret that information to the best of his or her ability. Because of the huge sums of money at stake, the interpretation and skill of the geologist creates the opportunity for fortunes to be made and lost. It is this intrigue that attracts many investors to the high risk world of oil and gas exploration.

This chapter will address the following topics: sources of surface information, sources of subsurface information (geophysical and geological), and the utilization and interpretation of surface and subsurface information.

3.2 Sources of Surface Information

Surface information is obtained from **land plats, topographic maps, geologic maps, and aerial photographs.**

Land Plats- It is very important to be able to accurately describe the location of a particular point on the earth's surface. An accurate description enables others to find the same location. The reader is undoubtedly familiar with the latitude and longitude system that is used for navigation. Geologists also use a type of meridian system to detail specific locations. The **Township and Range** system is used to accurately describe the location of such things as landslides, mines, and oil and gas well locations.

Principal meridians are the starting points for the township and range system of land description. The Salt Lake principal meridian begins on the southeast corner of Temple Square in Salt Lake City; a small monument marks the exact point. All of the townships and ranges for Utah are measured from this point, with the exception of a small amount of land in the Uinta Basin that has a separate meridian system called the **Uinta Special Meridian.**

Figure 3-1 shows a map of Utah with the meridian systems marked. Townships run north and south. Ranges are measured from east to west. Each township and range describes and area measuring approximately 36 square miles (6 miles by 6 miles). In Utah, there are 14 north townships, 43 south townships, 26 east ranges, and 20 west ranges, measured from the Salt Lake principal meridian.

The standard township is described as a 36 square mile block of land that can be described by a township number and a range number. Example: Township 14 South, Range 3 North. This is often abbreviated as T. 14 S., R. 3 N.. Occcasionally, these blocks of land deviate slightly because of the curvature of the earth. Slight offsets or corrections in the size of an individual township may occur.

Figure 3-2 shows how a particular location can be described using the township and range system. Each township is divided into thirty-six 1-square mile **sections.** These sections are numbered as shown in figure 3-2. Each section is one mile by one mile square, and contains 640 acres. A section may be divided into halves:

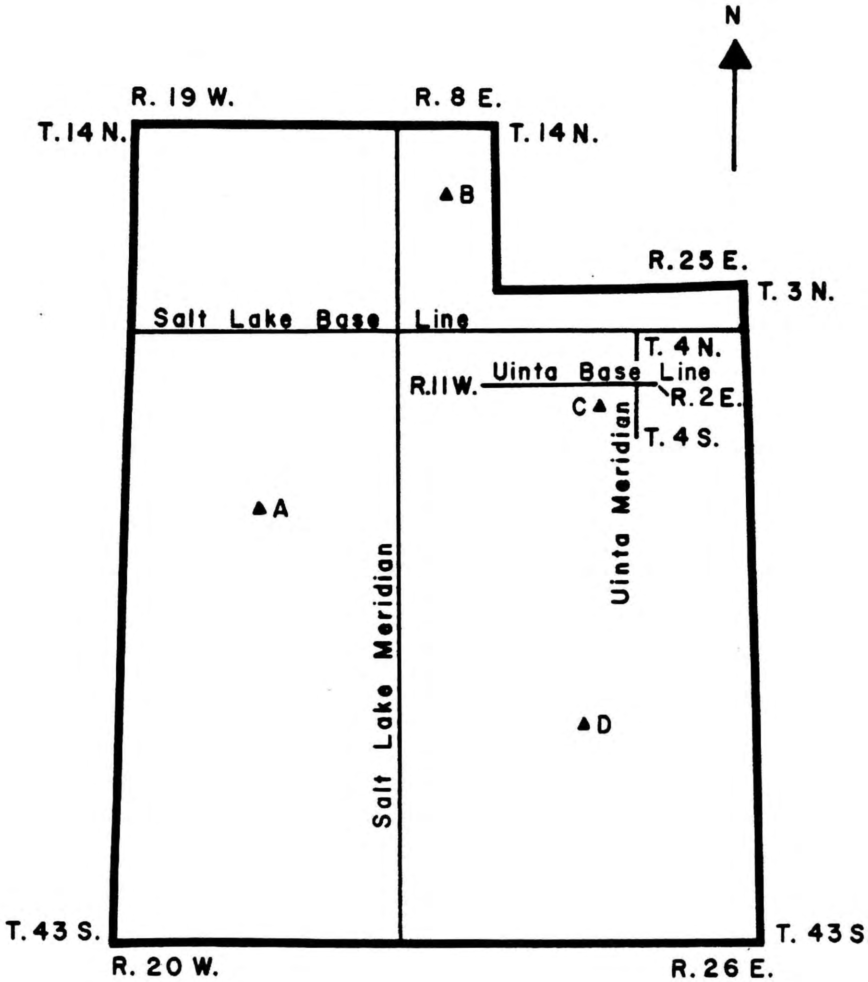

Fig. 3-1: Map of Utah showing the Salt Lake base line and meridian, and the Uinta Special base line and meridian. Each township and range measures an area of approximately 36 square miles, or 6 miles by 6 miles. The Salt Lake meridian system originates on the southeast corner of Temple Square in downtown Salt Lake City. Example locations on map: Point A is located in Township 13 South, Range 10 West, or T. 13 S., R. 10 W.; Point B is located in T. 10 N., R. 4 E.; Point C is located in T. 2 S., R. 3 W., Uinta meridian; Point D is located in T. 28 S., R. 14 E.

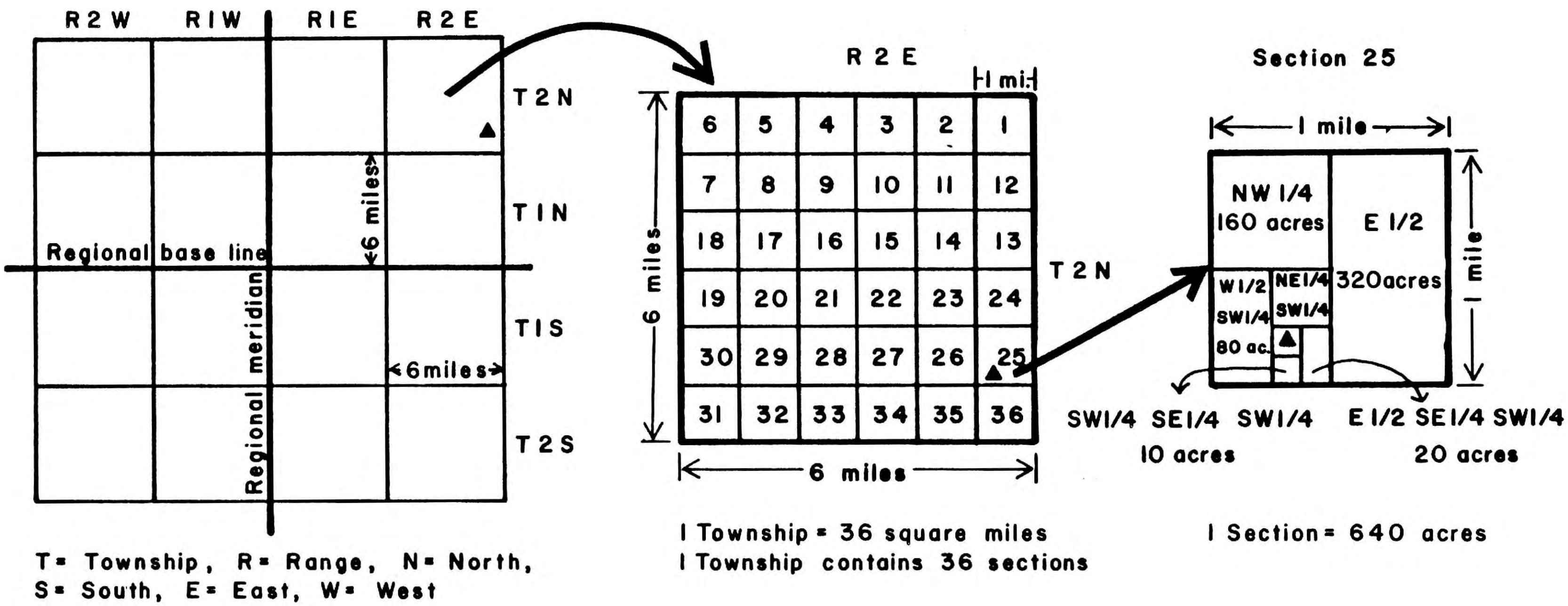

Fig. 3-2: Bureau of Land Management system for numbering townships, ranges, sections, and parts of sections. Point ▲ is located in the NW1/4 SE1/4 SW1/4 of Section 25, Township 2 North, Range 2 East.

north, south, east and west. Or, the section is divided into quarters, or fourths: the northeast quarter, the northwest quarter, the southwest quarter , and the southeast quarter. These are abbreviated by NE 1/4, NW 1/4, SW 1/4, and SE 1/4. Each quarter section is then divided into quarters again. Each of these quarter-quarters may then be divided into quarters again, forming quarter-quarter-quarters. When a section is divided like this, a very accurate description can be given very quickly.

When plotting a well location from a description, it is best to start at the extreme right hand side of the description first. For example, in figure 3-2, the plotted location is described as: NW 1/4, SE 1/4, SW 1/4 Section 25, Township 2 North, Range 2 East. First, find Range 2 East, and then Township 2 North. After that, section 25 should be located. Then the SW 1/4 should be determined. The southwest quarter should then be divided into quarters, and the SE 1/4 should be plotted. After this, the SE 1/4 of the SW 1/4 should be further divided into quarters, and the NW 1/4 should be plotted. This describes an area of approximately 10 acres. Sometimes, even more accuracy is necessary, and footages are given from the section lines to describe a location, along with the quarter-quarter-quarters. In our example above, the well location would be 920' from the south line of section 25 (fsl), and 1625' from the west line of section 25 (fwl). (1 mile = 5280'; thus, each section is 5280' by 5280'.)

Topographic Maps- Geologists use special maps called **topographic maps** to show them what the surface of the earth looks like. These maps are available from the United States Geological Survey, located in the Federal Building in downtown Salt Lake City. Additionally, many camping and hiking stores sell them. Most people are familiar with relief maps that are constructed from molded plastic and show mountains and valleys in three dimensions. Topographic maps are only two dimensional, but also show relief, by using **contour** lines. Each contour line represents the elevation above sea level for all of the points along that line. Figure 3-3 shows a topographic contour map of two hillsides separated by a river, which flows into the ocean. There are several points which can be made about this map:

1. Sea level is always shown as the 0' contour line.

2. Contour lines represent the elevation above sea level for all of the points on that contour line.

3. Topographic maps use a set **contour** interval for each map.

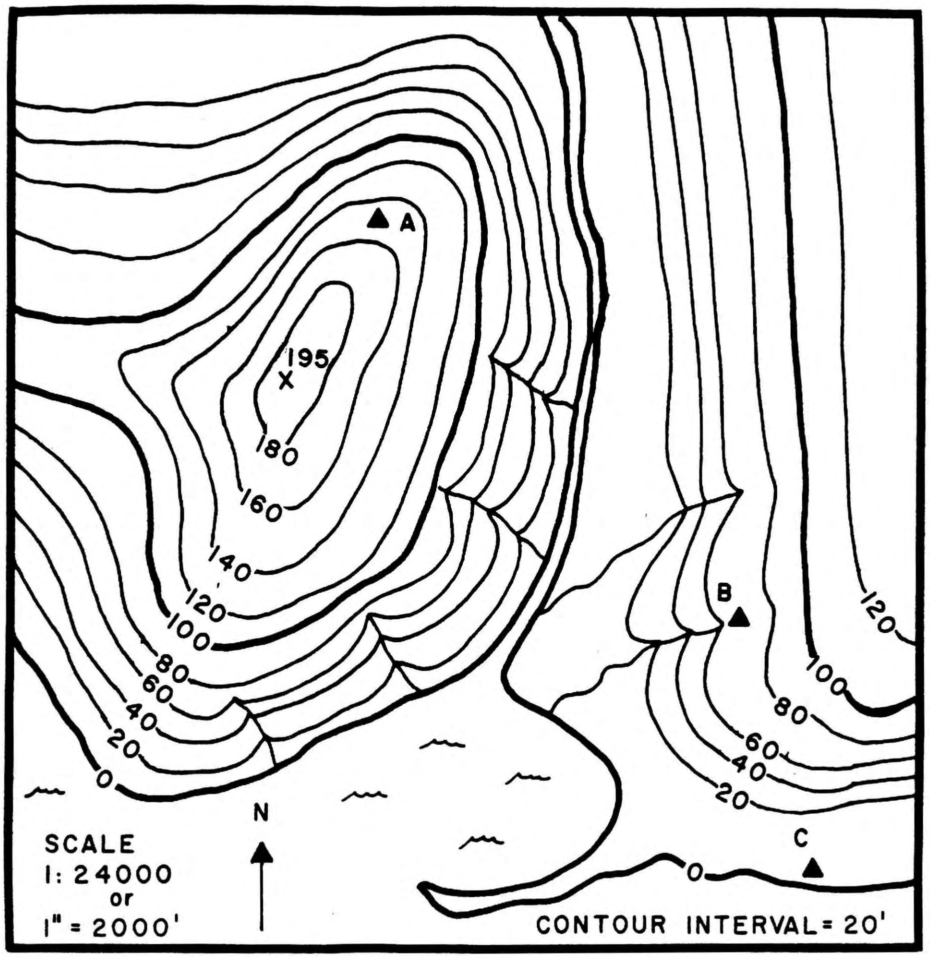

Fig. 3-3: An example of a topographic map. Contour lines show the shape and elevation of the land surface, and range from 0' to 180'. The contour interval is 20'. The above example shows two hillsides separated by a river, which flows into the ocean. The hillside on the right side of the river climbs to an elevation of 120'. A sand spit juts out into the ocean, forming a bay. On the left side of the river, is a hill with an elevation of 195' at its peak. Small rivers flow from each hillside into the main river and ocean. Elevation of points on map: A = 148', B = 67', C = 5'. (Adap- from Steger, 1986.)

4. An area between contours has an elevation somewhere between the two contour intervals by which it is bounded.

5. Each map has a set **scale.** The map in figure 3-3 has a scale of 1:24,000. This means that one unit on the map equals 24,000 units on the ground. Thus, one inch on the map equals 24,000 inches or 2,000 feet on the ground.

Topographic maps become very important when oil and gas well locations are decided upon. It is virtually impossible to drill on very steep mountainsides. Thus, even though all of the geological and geophysical data indicates good hydrocarbon potential, if the topography of the area is unacceptable, a different location will have to be found. Sometimes, the topography of the location is fine, but the access is very poor due to deep canyons, or high mountains. If drilling equipment must be trucked in from a roundabout way, or even flown in, drilling becomes even more expensive. It is important that the geologist be aware of these topographic considerations, as there may not be enough potentially recoverable hydrocarbons at the location to justify the additional expenses that would be incurred.

Surface Geologic Maps- Surface geologic maps usually show either the aerial distribution of rock types such as sandstones or granites, or they show the ages and formation names of the rocks in the mapped area. Other types of geologic maps involve subsurface data, and will be discussed in section 3.3.

Figure 3-4 shows a surface geological map of an anticline divided by a strike-slip fault. Surface geologic maps may contain any or all of the following information:

1. Topographic contours to allow land forms to be correlated with the geology.

2. Cultural and physiographic features such as towns, roads, lakes, rivers, and mountain peaks.

3. Longitude and latitude lines, as well as township and range designations.

4. Contacts between the various rock layers are drawn.

5. Faults are drawn, along with notations as to which way displacement has occurred.

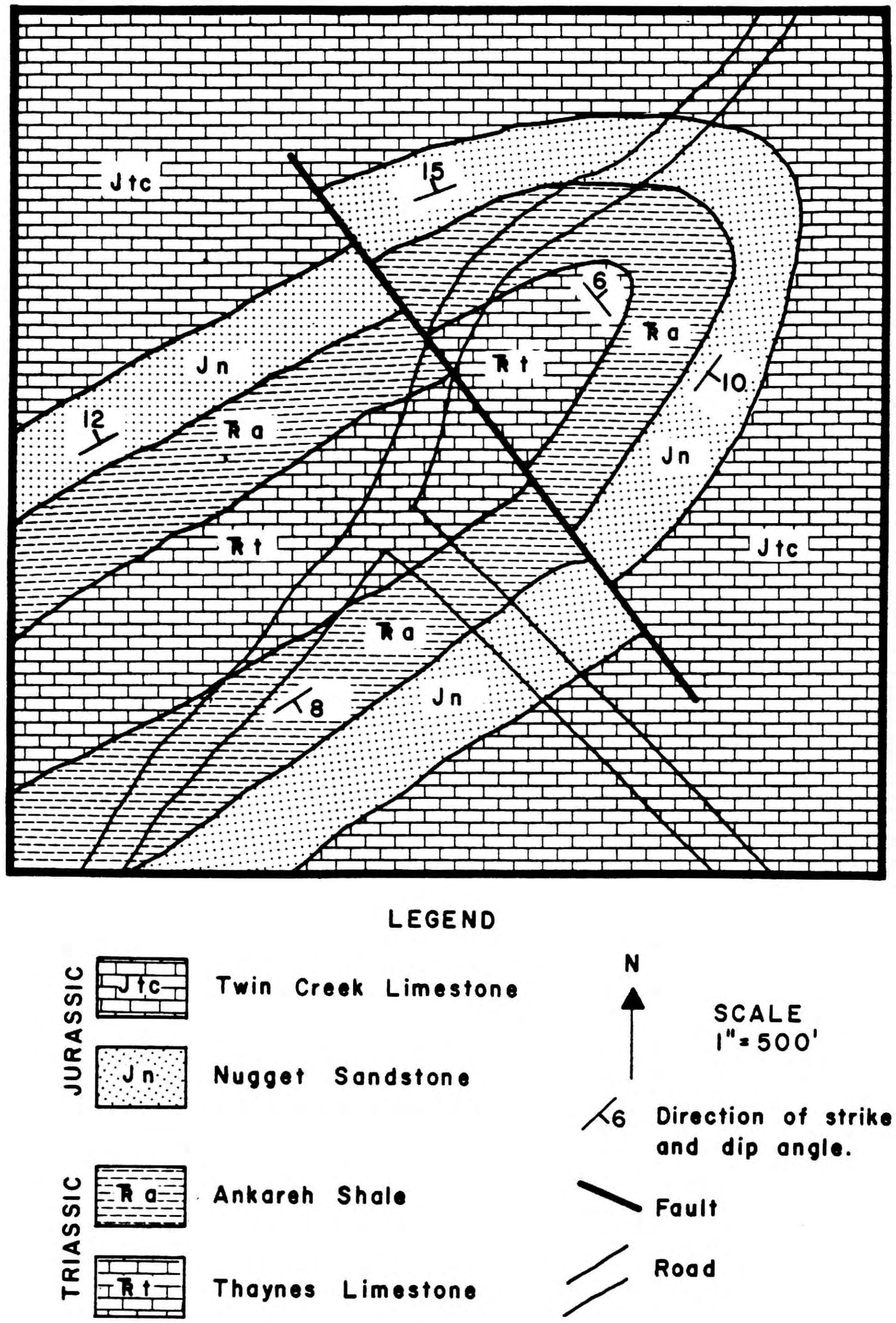

Fig. 3-4: An example of a surface geologic map, showing an anticline divided by a strike-slip fault. Two roads trend through the map area.

6. Strike and dip observations are noted. These measurements describe which way a rock layer is oriented in space. They are made with a special type of pocket transit called a Brunton compass. The **strike** of a bed is the direction in which an imaginary horizontal line would intersect the bedding plane of a rock unit. It is often stated as north or south and how many degrees east or west. Example: north, 30 degrees east. This means that the strike is 30 degrees east of north. **Dip** is the maximum slope of the bedding plane. Figure 3-5 demonstrates the concepts of strike and dip. These measurements are shown on a geologic map by a T-shaped symbol. The longer line (the top of the "T"), is representative of the strike, and is drawn with a protractor to match the actual strike measurement. The bottom of the symbol is drawn perpendicular to the strike line, and is a relatively short line, which represents the dip angle. The actual dip, as measured with the Brunton, is then written by the short line. Another way of thinking about strike and dip is to imagine a sloping roof. The strike of the roof would be parallel to to the ridge pole, and the dip would point down the slope of the roof in the direction water would drain.

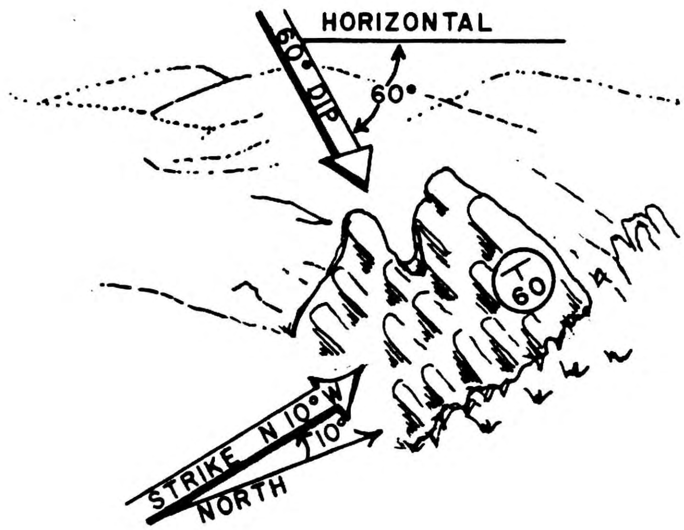

Fig. 3-5: Measurement of strike and dip. The T-shaped symbol shown on the rock outcrop above, gives the trend and amount of slope for the rock layers. (Modified from White, 1982.)

By including strike and dip measurements on geologic maps, geologists are able to very accurately describe the trend of geologic features that may have economic importance, such as anticlines.

7. A map legend will be shown explaining the map symbols used, and the age, name, and symbol or color assigned to each rock unit. The scale is also included.

Aerial Photographs- Geologists are able to obtain much information from aerial photographs. These photographs are generally taken from a plane equipped with sophisticated camera systems that keep track of the altitude of the plane, the direction of flight, and the speed the photographs must be taken at to ensure complete coverage. For wide-scale, regional mapping, satellite images may be utilized.

By using two photographs covering the same area, and a special viewing scope, called a stereoscope, geologists are able to view a photographed area 3-dimensionally. Measurements can then be taken and the geology of the area interpreted. Some of the information available from aerial photos includes:

1. Calculation of strike and dip of structural features such as anticlines.

2. Displacement along faults can be monitored.

3. Vegetative patterns aid engineering geologists in analyzing the permeability of the surface layers.

4. Movement of landslides and mud flows can be quickly and safely monitored.

3.3 Sources of Subsurface Geophysical Information

Both geophysical and geological methods of obtaining subsurface information are employed in petroleum exploration. While we are most concerned with geological methods within the scope of this project, a brief summary of geophysical methods seems necessary. The petroleum geologist is like an untiring detective; he or she is always searching for more clues as to where oil and gas potential may exist. Because of this, it is important that an understanding be gained of related fields, and the information which they can offer in the search for petroleum.

Geophysics is the study of the earth using physical measurements at the surface. While geology involves the study of the earth through direct observation of its surface, or subsurface using boreholes, geophysics involves the study of parts of the earth hidden from direct view.

There are four types of geophysical techniques most often used for exploration: **seismic (reflection and refraction), gravity, magnetics, and electrical methods.**

Seismic Reflection Method- The seismic reflection method is the most commonly used geophysical technique in oil and gas exploration. Subsurface features, such as anticlines, faults, salt domes, and reefs, can be differentiated by measuring the time required for a seismic wave (or pulse) to return to the surface after the wave reflects from the boundaries between rock layers having different physical properties. As shown in figure 3-6, the seismic wave is generated by a near-surface explosion of dynamite, mechanical impact, or vibration. The point of explosion is called the **shot point.** The pulse reflections back to the surface are recorded by instruments responsive to ground motion. They are laid along the ground at varying distances from the shot point. Variations in the reflection times from recording point to recording point indicate structural features in the subsurface.

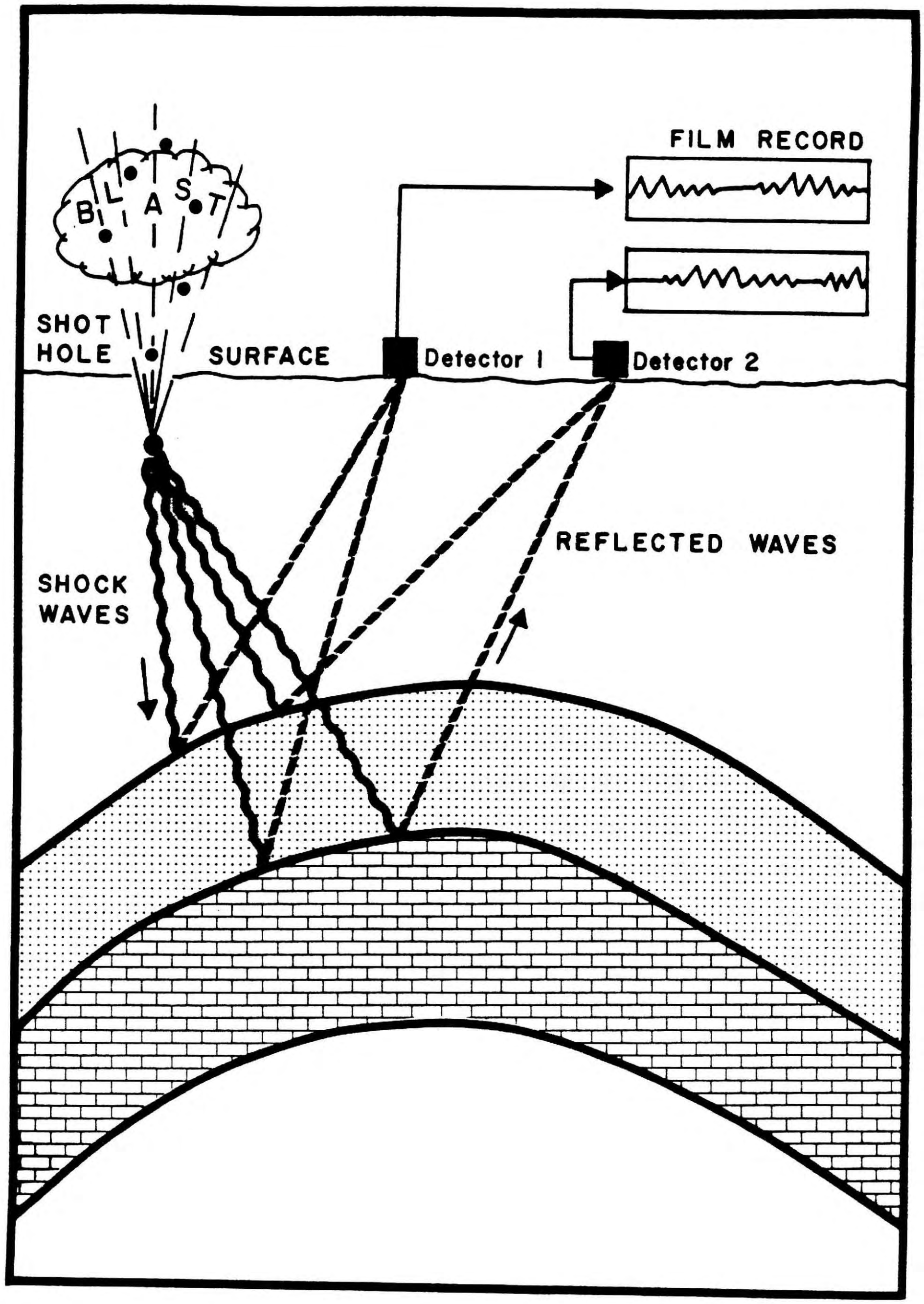

Fig. 3-6: Simplified sketch of the seismic reflection method. A near surface blast sends shock waves into the subsurface. The waves return to the surface after reflecting off of the boundaries between rock layers with different physical properties. Detectors at the surface record variations in the reflection times of the waves. (Modified from Wheeler and Whited, 1985.)

Reflections from depths 20,000 feet or more can be picked up at the surface, enabling the geophysicists to look at the structure of the entire sedimentary section. Structural relief can be determined to within 10 or 20 feet under ideal conditions.

The reflected data is extensively processed by computers to enable the structural features to be ascertained more clearly. Many of these subsurface structures are associated with hydrocarbon accumulations.

Seismic Refraction Method- Refraction seismic techniques differ from reflection methods in that the detecting instruments record the seismic pulse at a distance from the shot point that is large, compared with the depth of the mapped horizon. The waves thus travel long horizontal distances, making it possible to cover an area in shorter time and more economically.

In spite of its advantages, refraction techniques are less precise than reflection methods in obtaining accurate structural information. Additionally, a greater explosion is required, and the field operation is usually on a larger scale than that required by reflection methods.

Gravity Method- Gravity prospecting measures minute variations in the pull of gravity from subsurface rocks.

Different types of rocks have different densities; denser rocks have the greater gravitational pull. If higher density rocks are arched upward, as in the case of an anticline, then the earth's gravitational field will be greater along the axial plane of the structure.

The differences measured by gravity methods are extremely subtle, and often interpretation of the results is subject to ambiguity. Usually, additional geophysical techniques, such as reflection seismic are used to confirm gravity findings.

Magnetic Method- Magnetic surveys map variations in the magnetic field of the earth. The method is commonly used for direct location of ores containing magnetic minerals. Also, since igneous bodies can be differentiated from sedimentary rocks using this method, magnetic surveys are used for mapping the thickness of sedimentary basins.

Like gravity surveys, magnetic surveys are subject to ambiguity in interpretation, and require that additional geophysical or geological data be obtained prior to a prospect being drilled.

Electrical Methods- Electrical prospecting involves numerous testing techniques. Each of these measures a specific electrical property or characteristic of the earth. Applications include: the mapping of bedrock for engineering geology studies, the determination of ground water salinities, the search for geothermal resources, and the prospecting for certain minerals. Electrical methods are not widely used for hydrocarbon exploration. This is because there are few diagnostic contrasts in the electrical properties of sedimentary rocks.

3.4 Sources of Subsurface Geological Information

Subsurface geologic information is obtained exclusively from drilled and drilling wells. This information is combined with surface information and subsurface geophysical information to form a "picture" of the subsurface which integrates all available data.

There are three major sources of subsurface geologic information obtainable from wells:

1. **Samples:** includes mudlogs and core data. These are obtained as the well is being drilled.

2. **Wireline Logging:** sometimes referred to as "borehole geophysics," this is performed after the well has been drilled.

3. **Completion and Production Information:** includes drill stem testing, production testing, and cumulative production information.

Sample Information- As a well is drilled, the rock that occupied the well bore is brought to the surface. This not only allows the well to be drilled deeper, but also allows a record to be kept of the type of rocks the well is penetrating. Small chips (approximately one-fourth inch square) of rock, also known as cuttings, are carried up to the surface in the drilling mud which circulates in the well bore while the hole is being drilled. These chips are trapped by a mechanical mechanism called a shale shaker, and separated from the drilling mud. The cuttings are then collected and examined by the wellsite geologist, or by the **mudloggers**, who are hired to examine them. The term mudlogger is used, because the well is drilled with drilling mud. This mud is used to: lubricate the drill bit, prevent the hole from caving in, prevent blow outs, and bring the cuttings to the surface.

The wellsite geologist constructs a sample log, after examining the cuttings. An example of a sample log is shown in figure 3-7. It shows the well depth, the lithology of the rocks in graphic form (see the appendix for a chart showing the various rock symbols most commonly used), and a brief description about the rocks.

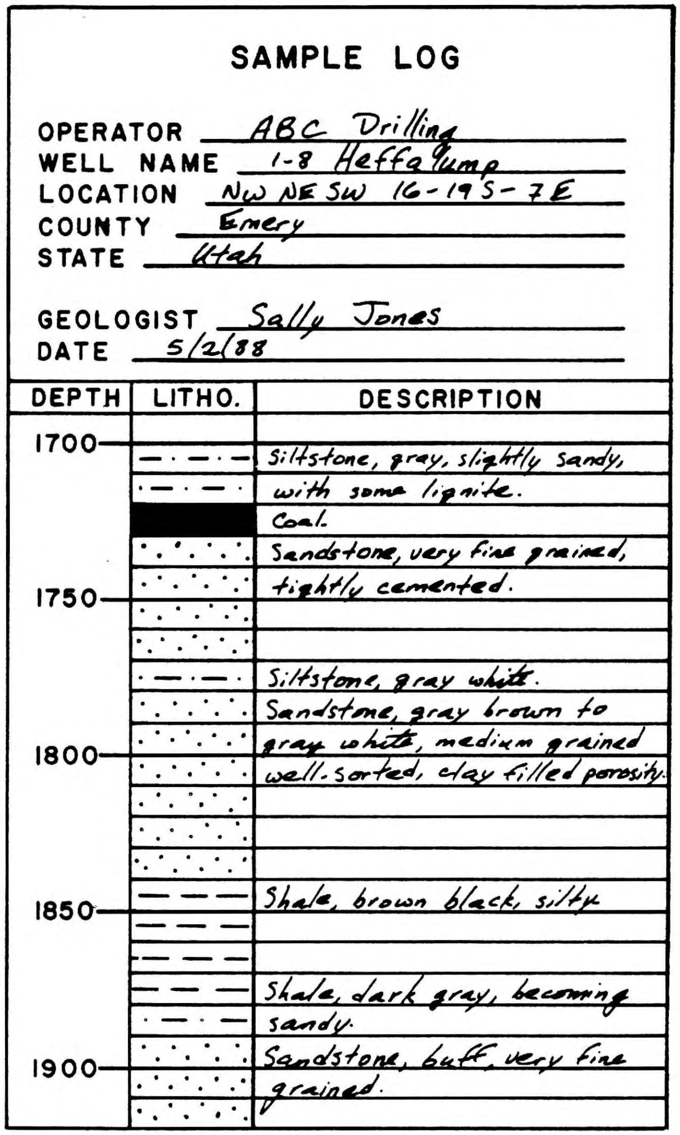

Fig. 3-7: An example of a sample log.

Oftentimes, the geologist may include other information which is pertinent to that particular well.

If mudloggers are hired to examine the well, then a more complete sample log is made. This is called a **mudlog.** Numerous formats are used by the different mudlogging companies to present the sample information, but a mudlog almost always includes the following:

1. A description of the type of rock drilled. This is called a lithologic description. The mudlogger samples cuttings from whatever interval length the exploration company desires. A 10 foot interval is the most common. The mudloggers have instruments within their trailers that keep track of how many feet have been drilled. After the samples are brought in from the shale shaker, the drilling mud is washed off, and the chips are examined under a microscope.

2. The amount of hydrocarbons present in both the rock sample and in the drilling mud associated with the cuttings. The hydrocarbon content is determined by machines that detect and measure hydrocarbons, and by visual examination, ultra-violet light fluorescence, and mixing with solvents

3. The **penetration rate**, or rate of drilling, is recorded. This is important because different rock types drill at different speeds. An increased rate of penetration is called a drilling break, and may indicate increased porosity and permeability in the rock, thus indicating the potential for hydrocarbon production.

4. Miscellaneous data pertaining to the drill bit type, mud weight, and viscosity of the drilling mud.

5. Depth column showing the depth of the well.

6. A header with information about the well's name and location, and an explanation of the abbreviations used, and the symbols used in the graphic lithologic description section.

Sometimes, a very complete record of the rock being drilled is desired by the wellsite geologist. A **core** will then be requested, which removes the rock as a solid column. Usually, sixty feet of core can be cut at one time. Coring is a much slower, and therefore a much more expensive operation than drilling. For selected zones, the information gained is well worth the financial investment. Special laboratories perform sophisticated analyses; allowing more complete data to be obtained from coring than from mudlogging. Much of this data is necessary for accurate reserve calculations.

<u>**Wireline Logging**</u>- Wireline logs are run after the well has been drilled. Very sophisticated and technically advanced instruments are lowered to the bottom of the hole on a **wireline,** or a cable. The cable is wound onto a large spool in the logging truck. The cable acts as a very long extension cord, and connects the instrument to the truck not only physically, but electrically, as well. When the instrument reaches the bottom of the well, the logging engineer and his assistants begin to slowly reel in the cable to lift the instrument toward the surface. As the instrument is brought up, it records information about the rock layers in the well. This information is recorded on magnetic tape, and processed by a computer in the truck. Wireline logging is very complex and expensive, but is necessary in order to provide accurate information about the rock layers in the subsurface. Logging allows potential hydrocarbon reservoirs to be delineated, and provides information that is crucial in determining whether a well will be a producer, or a dry hole.

There are several types of logging instruments or **sondes,** that are lowered into the well. Each kind measures different parameters of the rocks. Some of the most common types of wireline logs are:

1. **Electric Logs-** There are several types of electric logs, including: Spontaneous Potential, Resistivity, Induction, Dual Induction, and Laterolog. All of these logs measure the electrical properties of the rock layers. Because oil and gas have high electrical resistivity, the resistivity measuring logs can delineate possible oil and gas bearing strata.

2. **Gamma Ray Logs-** The gamma ray device measures the natural radiation of the rocks. Shales are relatively radioactive, and thus can be easily distinguished from sandstones and carbonates (limestones and dolomites).

3. **Caliper Logs-** The instruments, or sondes, have arms on them to either press them against the side of the well, or keep the instrument centered in the hole. As the sonde is brought up to the surface, the diameter of the hole is recorded. Sometimes, even though the hole is drilled to a certain diameter, "washouts" occur. A washout is an area that has been enlarged because of the drilling process and the type of rock, and can

affect the accuracy of the logging instruments.

4. **Porosity Logs-** Neutron, Density, and Sonic logs are all used for measuring the porosity of the rock layers. Each porosity log assumes a certain rock matrix, such as limestone or sandstone. This matrix value is set by the logging engineer, and can be changed to match the lithology of the rocks being logged.

The **Neutron** log has a radioactive source that bombards the walls of the well with high speed atomic particles (neutrons).

The **Density** log bombards the well bore with gamma rays.

The **Sonic** log determines the velocity of sound through the rock layers.

Usually, all three porosity devices will record similar porosity over a rock layer. Sometimes, however, the results will be different. One example is when gas is present in a rock layer. When this happens, the neutron porosity will read low, and the density porosity will read high. This is called **gas effect,** and is used as a way of finding hydrocarbons. Care must be taken that the hole is **in gauge** or not washed out, as this will cause the density porosity to read high, and will create a false gas effect.

5. **Dipmeter Logs-** The dipmeter tool determines the orientation of the rock layers in a well, and is used for structural interpretation.

The science of log interpretation is very complex and there are literally hundreds of volumes written on the subject. It is not possible within the scope of this course to impart a complete understanding of wireline logging. Rather, a very brief, and somewhat oversimplified summary concerning the interpretation of wireline logs is given below.

Although there are numerous wireline logging companies, the format of a typical wireline log presentation is fairly consistent, and appears similar to the logs shown in figure 3-8. The logs have a header containing information about the well itself: its location, elevation, depth, elevation, drilling mud information, etc.. The actual log consists of three **tracks,** or sections. Each of these tracks has a scale at the top.

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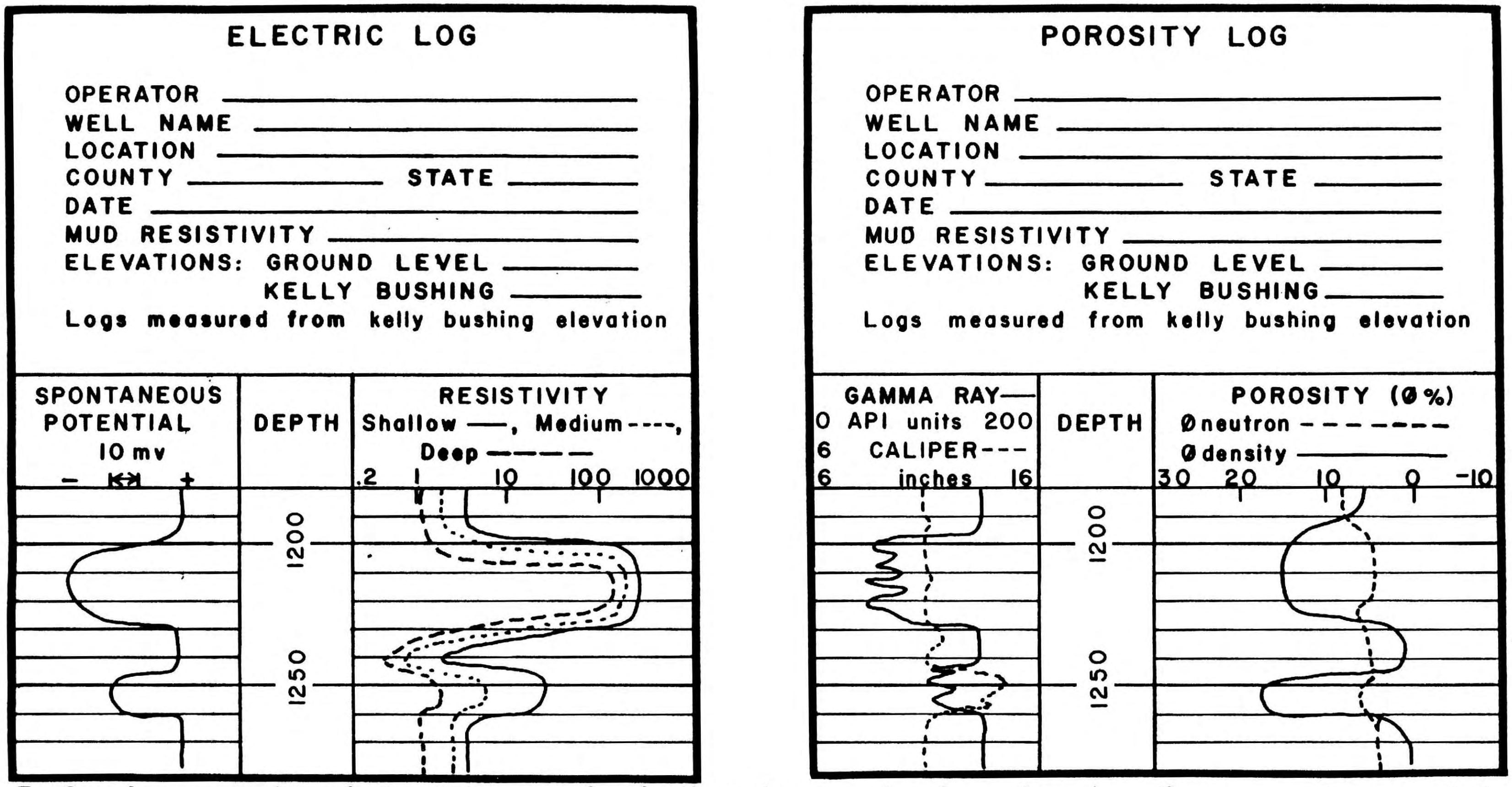

Fig. 3-8: An example of two types of wireline logs, showing log headings, scales, and log responses.

In track one, the Spontaneous Potential, Gamma Ray, and Caliper log results are recorded. Any, or all three, may be presented on a single log. Both the Spontaneous Potential and the Gamma Ray logs will deflect to the left if reservoir (potential hydrocarbon bearing) rocks are encountered.

In track two, the depth is listed. In the header, reference is made as to what part of the rig or ground is considered 0'elevation. Usually, all depths are relative to the kelly bushing (KB) elevation. This means that the kelly bushing is the point from which measurement of the well depth begins. The kelly bushing (figure 5-2), is slightly above the drilling floor of the rig, approximately 10'-25' above the ground, depending on the size of the drill rig.

In track three, the Resistivity, Induction, Laterolog, or Porosity information is recorded. The resistivity log identifies the fluid in the pore spaces of the rock and will kick to the right if oil and gas are encountered. The porosity logs are plotted with higher porosity on the left. A rock with good porosity will cause the curves to move to the left.

Figure 3-9 is a chart showing wireline responses to some common rock types and borehole conditions.

Wireline logs are combined with mudlog or sample information, core analyses, and drill stem test data to aid in correctly evaluating the well bore for hydrocarbon potential. Due to slight differences in measurement, the depth of the sample logs, mudlogs, cores, and drill stem tests may have to be adjusted slightly, so that all of the information is consistent. Usually, the depth on the wireline logs is considered to be the most correct.

Once all of the information for a given well is assembled, and analyzed, **correlations** between wells are made. Similar rock layers are compared for reservoir characteristics such as thickness and porosity. Figure 3-10 shows how wireline logs can be correlated between wells. It is important for the geologist to correlate correctly; the zones being correlated must be the same in each well. A newly drilled well may be correlated with an already productive well to compare the productive intervals. If the newly drilled well has a potentially productive interval with porosity, thickness, and structural position similar to the producing well, then the newly drilled well will probably also produce.

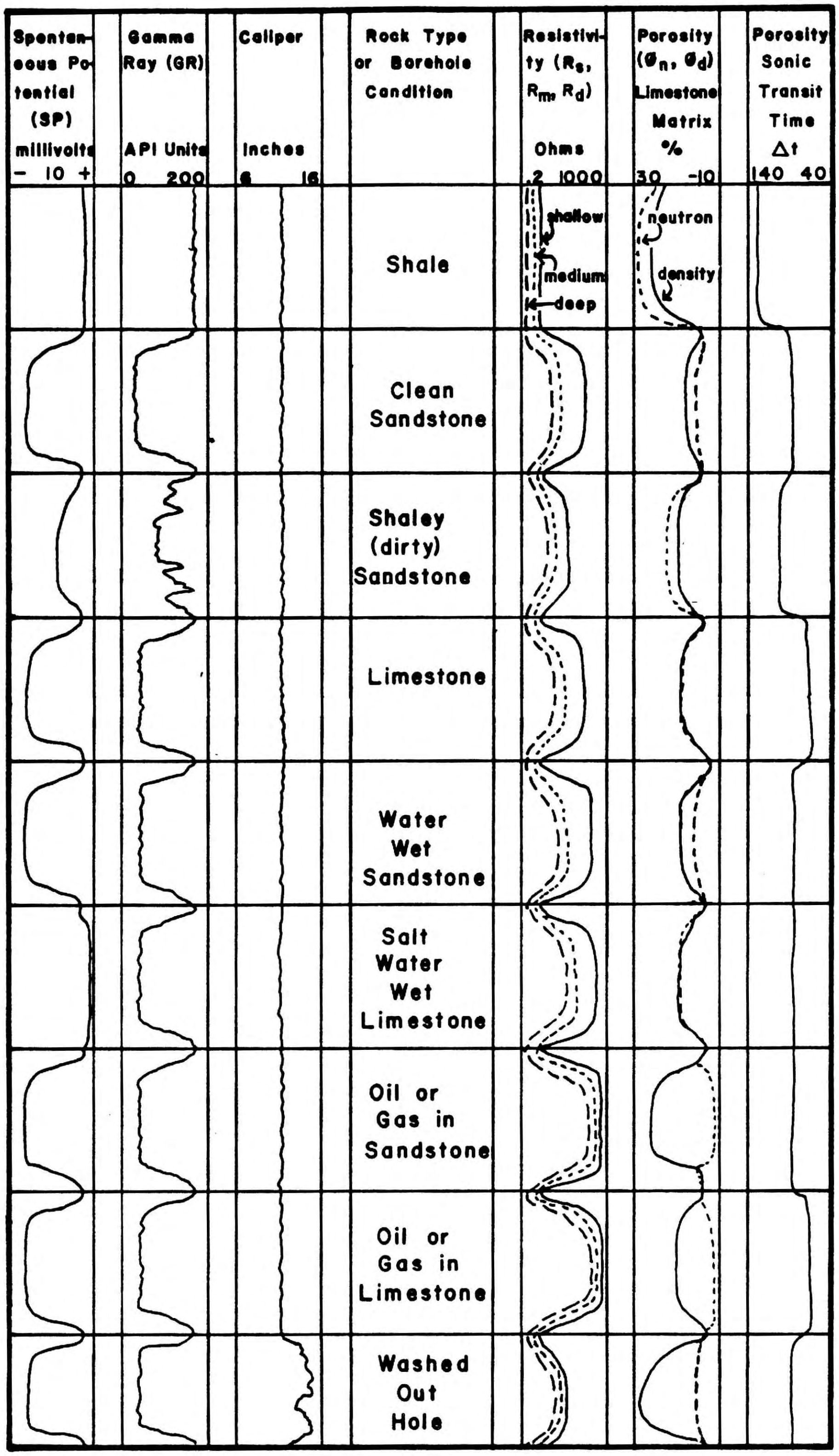

Fig. 3-9: Chart showing wireline log responses to various rock types or borehole conditions.

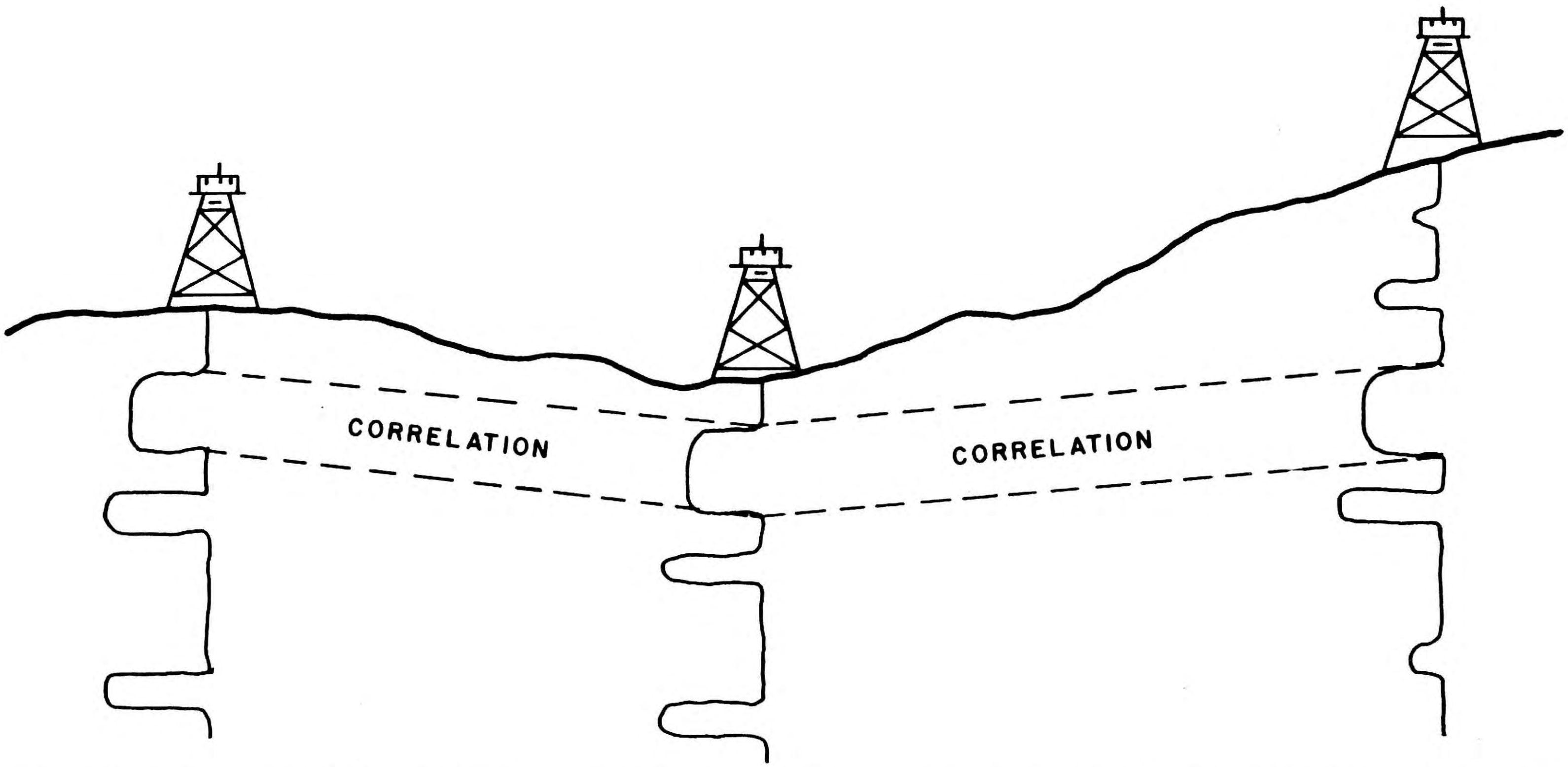

Fig. 3-10: Diagram showing correlation of a sandstone bed using the Spontaneous Potential (SP) log.

__Completion and Production Information__- The third major source of subsurface geological information is completion and production information. This includes **drill stem testing, production testing,** and cumulative production information.

Drill stem testing is a temporary completion of the well. It is performed soon after a zone has been drilled. If a good mudlog **show** of oil and gas is encountered, drilling is temporararily halted. All of the pipe is brought out of the hole and the drill stem test tools are attached and lowered into the well. All of the drilling mud is left in the hole, to keep the well under control, and prevent a blow out. The drill stem test is a means of removing the weight of the mud column, and allowing a particular zone to produce as it would in a cased hole. Pressure information is recorded about the tested zone, and the oil, gas, and/or water within the zone is sampled. From this information, calculations can be made, and conclusions drawn as to the productive capability of the zone. A well operator may decide to not run any drill stem tests, or numerous tests may run over several different zones while the well is drilling. The cost of running a drill stem test is very low compared to the cost of later running casing over the zone, perforating, and production testing the zone.

The actual interpretation of the drill stem test results is very complicated. A pressure chart (figure 3-11) records information about the zone being tested, and a record is made of the fluids recovered. If the recovery from a zone consists only of water, and no oil or gas, then the zone's ability to produce hydrocarbons is virtually nil.

Production Testing- After a well has been drilled, a decision must be made concerning the running of casing. Casing is steel pipe that is cemented into the wellbore and permanently holds the well open. Often, if the well is very deep, surface casing, and intermediate casing is run to ensure that the upper parts of the hole are stabi-lized, while the well is drilled deeper. In this case, wireline logs, and drill stem tests are conducted before the intermediate casing is run. Then, when the final depth is reached, the final logs are run over the last section of uncased hole. The two sets of logs may then be combined into a log suite of the entire hole.

The decision to run the final **string** of casing is based on the mudlog, wireline logs, drill stem tests, core analyses, and correlations with offsetting, or nearby wells. It is very expensive to run casing, and the best decision may be to fill the well with cement, and abandon

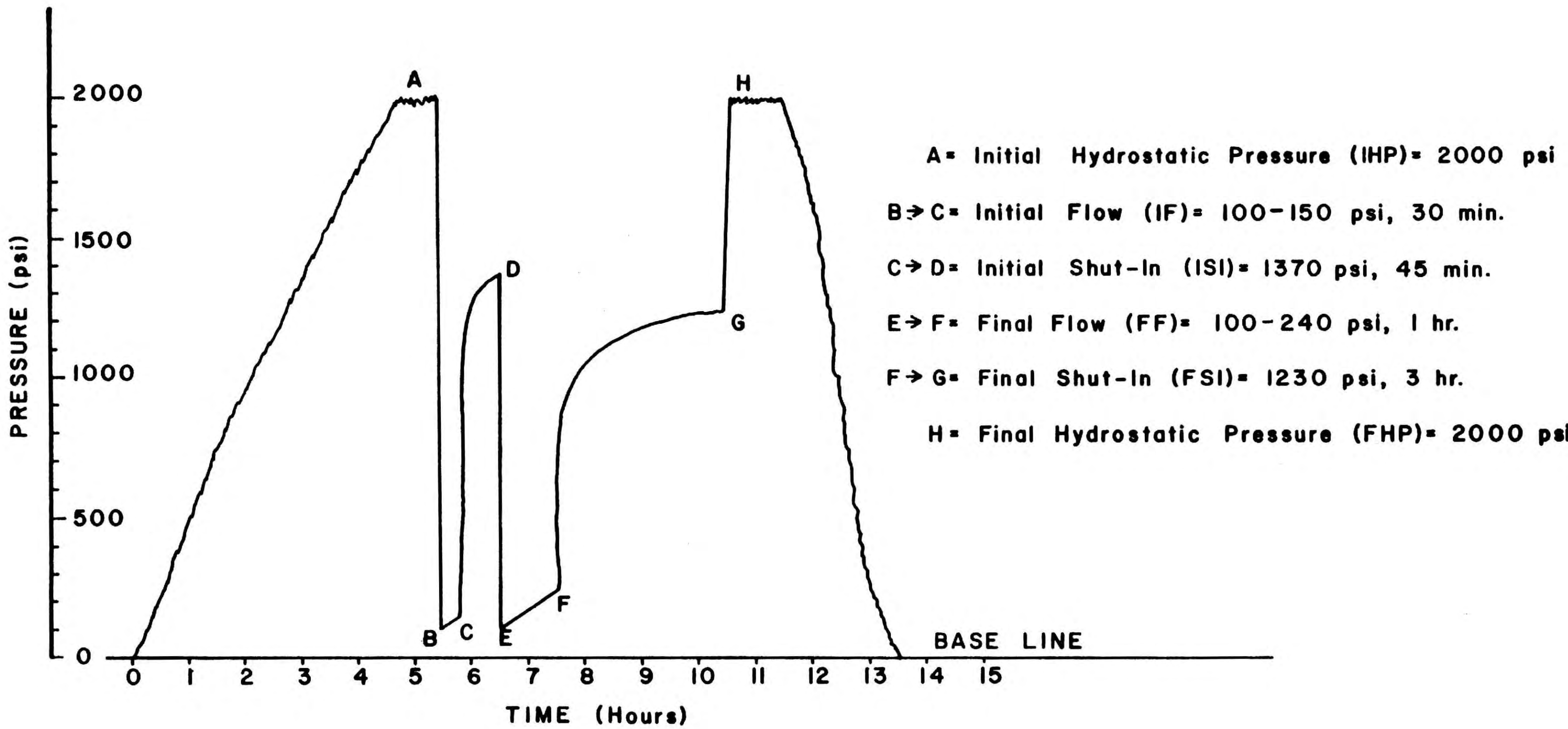

Fig. 3-11: Example of a drillstem test pressure chart.

the it. If this is done, the well is considered **dry and abandoned**, or D and A.

If casing is run, then the wellbore is **perforated** in selected zones which are believed to have hydrocarbon potential. Perforating punches holes through the casing, allowing the reservoir fluids of a zone to flow into the wellbore. After perforating, a **production test** is performed, which is very similar to a drill stem test, but lasts longer, is more sensitive, and yields more information. After it has been perforated, the zone is often **stimulated.** This usually entails fracturing and/or acidizing. The formation is fractured by creating very high pressure within the zone. Pressure is built up by pumping fluid into a sealed off interval of the well. The fractures are then acidized to further enlarge them. The acid dissolves some of the rock matrix, and enhances the permeability. The cracks, or fractures, are then propped open by pumping granular material, such as walnut shells, or glass balls into them.

After a well has been perforated and **treated** by fracturing and/or acidizing, production equipment is hooked up, and the **Initial Potential,** or IP of the well is tested by allowing the well to produce. The IP of a well is an indication of the type of daily production that can be expected. Production is reported in barrels of oil per day

(BOPD), barrels of water per day (BWPD), and thousands of cubic feet of gas per day (mcfd). One barrel holds 42 gallons. The "m" in mcfd, stands for milli, meaning 1000. 5 mcfd is actually 5000 cubic feet of gas per day.

This initial potential information is crucial in helping an oil company decide whether to immediately drill another well in the area. Sometimes, the company will decide to wait and see what kind of **cumulative production** the well is capable of over a period of months or even years. Additionally, the IP and cumulative production of surrounding wells, completed in the same zone, are analyzed to determine if a newly drilled well might be an economic success.

3.4 Utilization and Interpretation of Surface and Subsurface Information to Create the Prospect

There are two primary ways that the petroleum geologist utilizes surface and subsurface data: **cross sections, and maps.** There are numerous types of cross sections and maps; the most common ones are discussed below.

Surface Cross_Sections- One of the most common means of utilizing topographic and surface geologic maps (section 3.2), entails the construction of a surface topographic profile and geologic cross section. A cross section is a two dimensional view of what you would see on and below the surface if you cut and parted the land surface. An example of this is a road cut, which gives the motorist a cross sectional view of the strata that used to lie on top of the road surface.

Figure 3-12 shows how a simple topographic profile and geologic cross section can be made. First, the cross section line is drawn on a geologic map. This geologic map also has topographic contours. The cross section line is labelled X-X' in our example. In figure 3-12 b, a piece of paper is placed along the cross section line. The topographic contours and geologic contacts are transferred to the piece of paper at the point where they intersect the cross section line. On another piece of paper, a vertical scale is marked off along one edge. The vertical scale usually matches the horizontal scale given on the map. This is true in our example. In 3-12 c, the piece of paper with

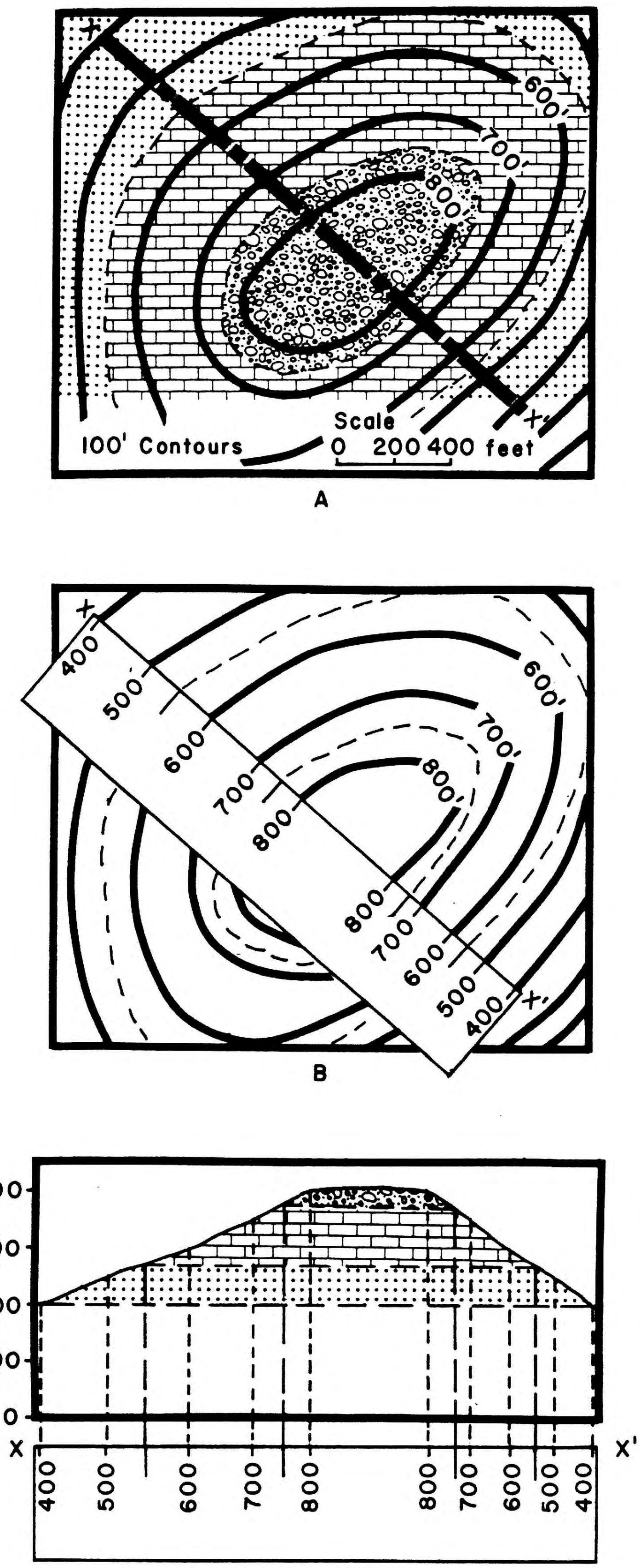

Fig. 3-12: Preparation of a topographic profile and geologic section. See text for details.

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the topographic contours and geologic contacts ticked off, is placed at the bottom of the piece of paper with the vertical scale. The topographic contour values are then projected upwards to their correct position on the vertical scale, and a dot is marked on the paper. The dots are then connected to form a topographic profile. The geologic contacts are then projected upwards to the topographic profile line. The like contacts are then connected together with horizontal lines. Our example assumes that all of the geologic strata are flat lying. When the strata are not flat lying, then strike and dip symbols are included and projected into the cross section. This procedure is rather complicated, and is not within the scope of this course.

Subsurface Geologic Cross Sections- The geologist often incorporates subsurface information into the surface geologic cross sections that he or she makes. The subsurface information is gathered from wells that have been drilled in the area. More commonly, no surface geologic cross-section is constructed, only a subsurface one.

The subsurface geologic cross section is invaluable to the petroleum geologist, and is one of the most frequently used means of presenting information when a prospect is being formulated. The following summarizes the general procedure for the construction of a subsurface geological cross section:

1. Determine what the cross section is to represent. What formations or reservoir intervals will be shown?.

2. Determine what type of datum will be used: structural (tied to elevation), or stratigraphic (tied to a particular marker bed). Often, both types of cross sections are created for a prospect.

3. The line of cross section is chosen, and the wells to be used are picked.

4. Horizontal and vertical scales are chosen.

5. All available information is plotted.

6. Data is correlated, and conclusions are drawn.

Subsurface geologic cross sections are shown in figures 3-13 and 3-14. These cross sections are made using wireline logs from three wells. Instead of using electric logs, porosity logs, or mudlogs could have been used. The two cross sections in figures 3-13 and 3-14 utilize the same wells, and well logs, but they look very different. The reason for this is that they are different types of subsurface cross sections: structural in figure 3-13, and

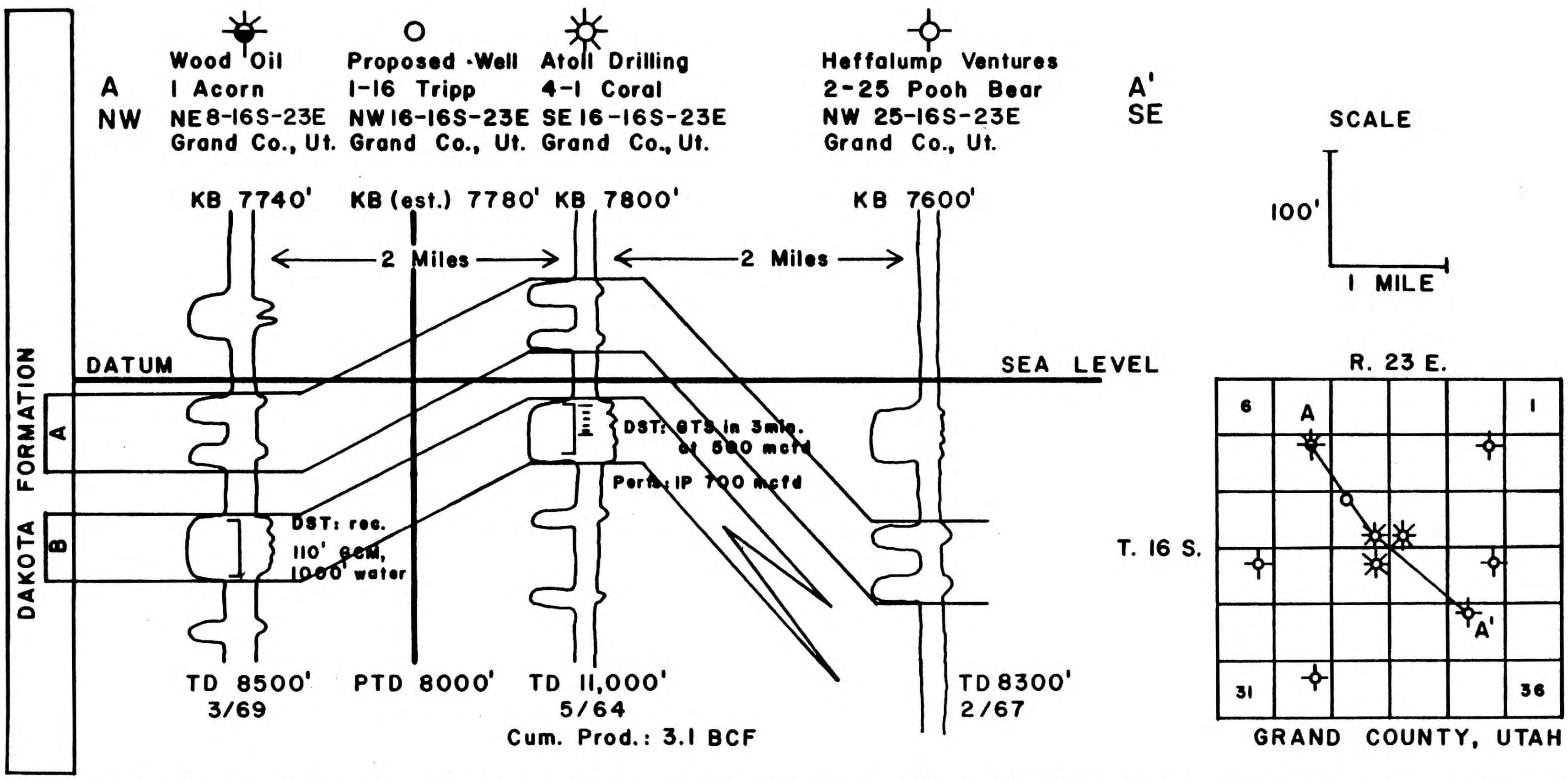


Fig. 3-13: Structural subsurface geologic cross-section using wireline logs. (Information is not factual.)

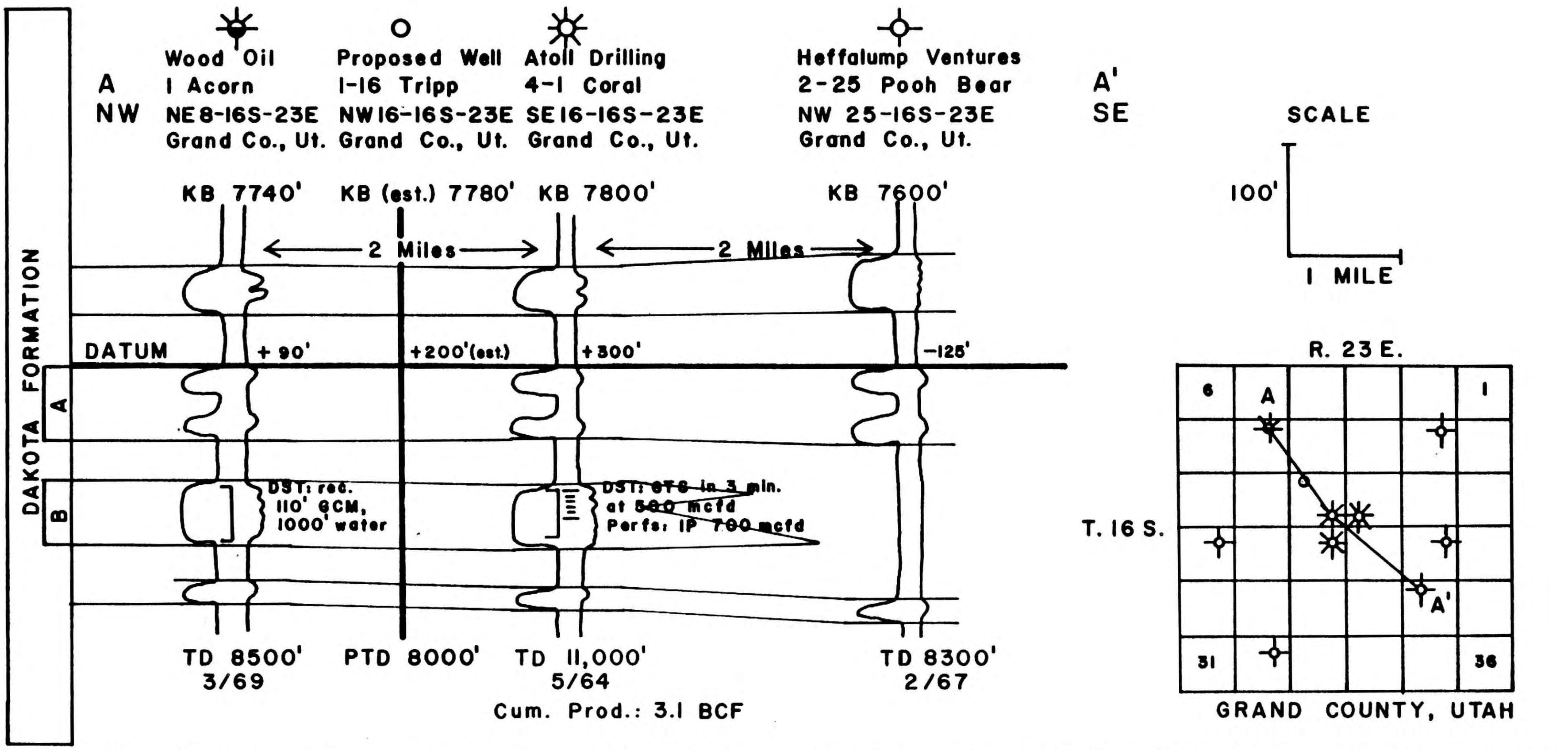


Fig. 3-14: Stratigraphic subsurface geologic cross-section using wireline logs. (Information is not factual.)

stratigraphic in figure 3-14. The only difference between the two types of cross sections is the **datum.** The datum is a continuous reference line in the area of the crosssection. It is a horizontal plane which is held constant; all other data is shown in reference to the datum. In the case of a topographic map, the datum is sea level, or 0'. All of the topographic contours are relative to sea level. A **structural** subsurface geologic cross section also uses elevation as a datum. In our example, sea level or 0' is the datum, although any elevation may be used. Thus, to create the datum in figure 3-13, the elevation of the well is subtracted to find where sea level or 0' would be. This is done by solving the formula: Elevation - ? = Datum elevation. In the 1 Acorn well shown in figure 3-13, the solution to the formula would be: 7740' - ? = 0', or 7740' - 7740' = 0'. Thus, our sea level datum would be found at the 7740' depth in the 1 Acorn well. If a datum of 2000' had been chosen for the structural cross section, instead of a datum of 0', the formula would be: 7740' - ? = 2000', or 7740' - 5740' = 2000'. In this case, a 2000' datum would be found at a depth of 5740' in the 1 Acorn well. Sea level is a convenient datum, because it enables the construction of a strutural cross section to be done very quickly: whatever elevation is given for the well, is also the depth in the well that 0' or sea level will be found at.

Figure 3-13 shows an anticline when the zones on the logs are correlated with each other. The well in the middle (4-1 Coral) is located near the **crest,** or highest point on the structure. It can also be shown by looking at this cross section, that the 1 Acorn well is lower than the 4-1 Coral well, but higher structurally, than the 2-25 Pooh Bear well. The proposed well, 1-16 Tripp, is higher structurally than the 1 Acorn well and the 2-25 Pooh Bear well, but lower structurally than the 4-1 Coral well. It can also be seen on this cross section that the zone which produces in the 4-1 Coral well (zone B), recovered gas cut mud, and water on a drill stem test of the same zone in the 1 Acorn well. Zone B is missing in the 2-25 Pooh Bear well. The proposed location, 1-16 Tripp, may be successful because it is updip from the 1 Acorn well, which was abandoned because the reservoir zone was wet. The proposed location should find the zone present; a proposed location between the 4-1 Coral and the 2-25 Pooh Bear well, may find that the zone is missing, as it is in the 2-25 Pooh Bear well.

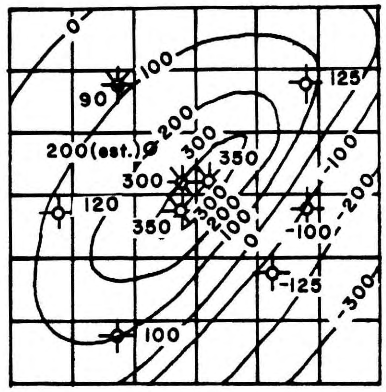
Also note that the cross section is labelled with all available information, a scale, a base map, elevations for each well (in our examples, the kelly bushing (KB) elevation is used), geologic formation names, and well symbols. These well symbols, shown at the top of each well log in the cross section, and on the base map, indicate the status of the well. A list of these symbols and their meanings is given in the Appendix, along with the symbols used on the logs for showing cored, drill stem tested, and perforated intervals.

Figure 3-14 is a stratigraphic cross section of the same wells in figure 3-13. In this case, a **stratigraphic** datum is used. This type of datum uses a specific geologic marker or rock layer as a reference line. Like all other datums, this datum must be continuous throughout the area. The cross section is constructed by placing the logs so that the datum is along a straight line, as in figure 3-14. In this example, the datum is the top of zone A. After the datum has been picked on all of the logs, the other beds or formations are correlated. On a stratigraphic cross section, it is very easy to note changes in bed thickness. Our example readily shows that zone B is missing in the 2-25 Pooh Bear well. Sometimes, it is difficult to correlate the beds on different logs. In this case, it is imperative that all available logs, mudlogs, core data, and drill stem test data be used in order to ensure the correlations are correct.

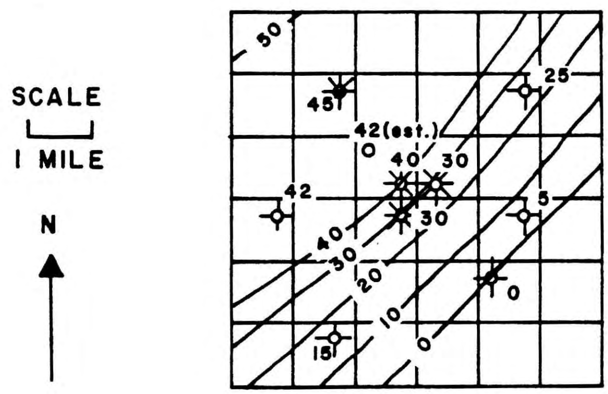
Stratigraphic datums are also useful in the construction of geologic structure maps, which will be discussed later. In figure 3-14, there is a number on the datum line for each well. This number is the structural elevation, in relation to sea level, of that datum. It is calculated by the following formula: Elevation - Datum depth in well = Structural elevation of datum. The datum, or the top of zone A in the 1 Acorn well is found at 7650'. Thus, in the 1 Acorn well, the formula's solution is: 7740' - 7650' = 90'.

<u>Surface Geologic Maps</u>- Much information can be gained about the subsurface through the use of surface geologic maps. An examination of the surface geologic map in an area would rule out hydrocarbon potential in locations that had intrusive volcanics on the surface, or surface exposures of very old rocks. These areas would be ruled out because of the lack of underlying sedimentary rocks that may contain hydrocarbon resources.

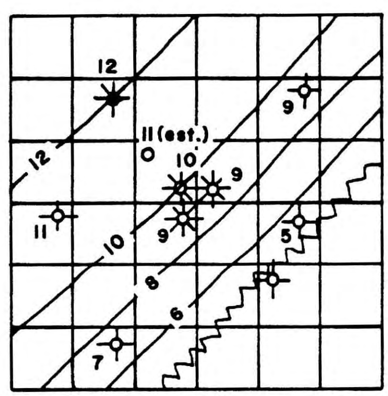
<u>Subsurface Geologic Maps</u>- There are numerous types of subsurface geologic maps, all showing a variety of information. The most common types of subsurface geologic maps are **contour** maps. These are similar to surface topographic maps in that they have contour lines. On a topographic map, the contours represent elevation. On subsurface geologic maps, the contours are also representative of a specific item. Some of the more common subsurface geologic maps represented by contour mapping are shown in figure 3-15, and include:



A. Structural contour map. Contours are based on top of zone A, shown on figures 3-13 and 3-14. 100' contour interval.



B. Isopach map of the productive sandstone (zone B) in figures 3-13 and 3-14. 10' contour interval.



C. Reservoir map showing porosity percent of zone B from figures 3-13 and 3-14. 2 % contour interval.

Fig. 3-15: Examples of subsurface geologic maps. Values are calculated from each well's wireline logs and posted by the well symbol; maps are then contoured.

1. **Structure Maps-** These maps show the subsurface elevation of a particular geologic marker. For instance, from figure 3-14, the **subsea** elevation, or elevation with respect to sea level of zone A, is 90' for the 1 Acorn well. This is calculated by solving the formula: Elevation - Datum Depth = Subsea or Structural Elevation of Zone. The top of zone A is found at a depth of 7650' in the 1 Acorn well. Thus, the formula's solution is: 7740' - 7650' = 90'. This calculation is made for all of the wells in the area that is to be mapped. A structure map can then be constructed, as shown in figure 3-15 a. This is a structural contour map based on the top of zone A as shown in figures 3-13 and 3-14. Subsea elevations have been posted by each well, and the data has been contoured. The structural contour map shows an anticline; this is consistent with what the cross sections in figures 3-13 and 3-14 show.

2. **Isopach Maps-** An isopach map shows the thickness of a particular interval. An example of an isopach map is shown in figure 3-15 b. Zone B, which is the productive interval shown on the cross sections in figures 3-13 and 3-14, is isopached in this example. The thickness of zone B

has been calculated for each well in the mapped area, and plotted beside the well symbol. The thicknesses are then contoured. As is shown in figure 3-15 b, zone B thins towards the southeast. This is consistent with what is shown on the cross sections in figures 3-13 and 3-14.

3. **Reservoir Maps-** This type of map includes contour maps with various reservoir characteristics such as porosity, permeability, and water saturation. Figure 3-15 c shows a porosity map for zone B from our example in cross sections 3-13 and 3-14. The porosity of the interval decreases towards the southeast. No porosity values are shown after the zig-zag line. This line indicates that the zone is missing; therefore no porosity values are available. The zig-zag line is consistent with the 0' isopach line shown in figure 3-15 b.

The same rules used for contouring topographic maps, hold for the contouring of subsurface geologic maps. Any contour interval may be used. A 10' contour interval in figure 3-15 a, would make the contours too close together, and would clutter the map. Conversely, a 100' contour interval in figure 3-15 b, would not show the thinning of zone B to the southeast; the only contour that would be shown on the map would be the 0' contour. It is important to remember that the values found within the bounds of two contour lines must fall numerically within the values of the contour lines. In other words, the contour point value of 15 must fall between the contour intervals of 10 and 20.

The combination of surface and subsurface geological and geophysical data, cross sections, and maps to integrate data into a correct interpretation of an area is what makes a **prospect.** In heavily drilled areas, a large amount of data is usually available, and the geologist can be more certain that his or her interpretation is valid. In sparsely drilled areas, data is scarce, and many inferences must be drawn. Because of this, it follows that the success rate for drilling productive wells in sparsely drilled or **wildcat** areas, is much lower than for drilling in **developed** or heavily drilled areas.

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CHAPTER 4

THE PETROLEUM PROSPECT

4.1 Introduction

In order for an area to have petroleum producing potential, four criteria must be met. If any of these four criteria are not present, oil and gas will not be found. They are: **a hydrocarbon source, a migration mechanism, a reservoir to hold the hydrocarbon, and a trap to prevent the hydrocarbon from leaving the reservoir.**

4.2 The Hydrocarbon Source

It is thought that oil and gas have been generated from organic matter buried in sedimentary rocks. The rocks believed to be responsible for the greatest amount of hydrocarbons are black shales found in marine settings. These shales are composed of very fine grained sediments such as mud and silt mixed with organic matter from plants and animals. These plants and animals forming this organic matter are very small. They include phytoplankton and zooplankton (very small marine plants and animals), and some terrestrial (land) plants. Over time, the fine-grained sediments and organic matter are decomposed by bacterial action, and buried at increasing depth by more sediment and organic matter. Burial causes pressure and temperature to increase within these black shales, and petroleum is then produced by means of very complex chemical and biological interactions.

4.3 The Migration Mechanism

The organic rich black shales do not allow the oil and gas to be readily released into a drilled well bore. Oil and gas must migrate into rocks with better reservoir qualities, (porosity and permeability). Exactly how the oil and gas migrates, remains somewhat of a mystery, but is is generally thought that as the organic- rich shales become more deeply buried, they are compressed. This compression causes a decrease in the size of the pore spaces, or holes between the rock grains. These spaces are filled with water and petroleum. When compressed, the water and petroleum are squeezed out into the overlying rocks. Additionally, the generation of oil and gas from the solid organic matter, causes an increase in volume. This creates fractures within the source rock, allowing the hydrocarbons to migrate upward and hopefully into a rock layer with good reservoir properties.

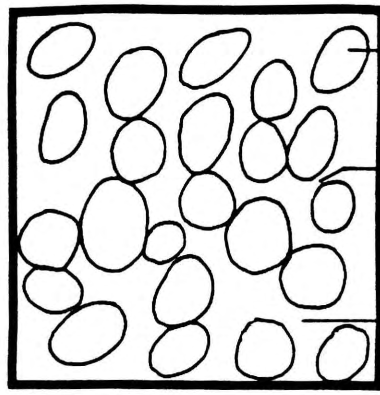
The migration of oil and gas from the source rock into the reservoir is called primary migration. Secondary migration occurs after the oil and gas are in the reservoir rock, and they migrate into the trap of the reservoir.

4.4 The Reservoir

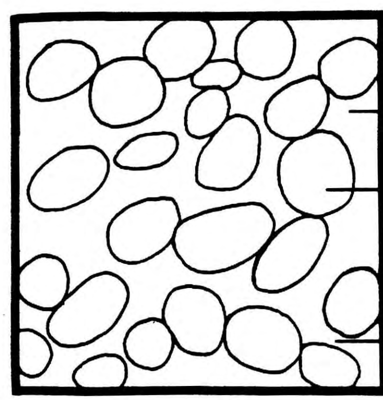
A good reservoir rock must contain both **porosity** and **permeability.** These concepts are illustrated in figure 4-1. Porosity is a measure of the volume of space between the grains of the rock, and is often referred to as "pore space." Porosity is represented by the Greek letter phi (**Ø**), and is measured in percent. Permeability is a value which demonstrates the degree to which the pore spaces interconnect. If none or very few of the pores connect, then the oil and gas in the pore spaces of the reservoir will be unable to flow into either the trap or into the wellbore. Permeability is usually referred to by the letter K, and is measured in millidarcies.

The two most common types of reservoir rocks are **sandstones** and **carbonates.** The successful search for oil and gas depends on geologists understanding how and where sandstones and carbonates are deposited.

Sandstone Reservoirs- Sandstones are deposited by **rivers, oceans, the wind, and lakes.** The geometry, or size



A. Close-up of a sandstone showing individual sand grains and the pore spaces between them. Porosity is a measure of the volume (in percent) of pore space in a rock sample.



B. Permeability measures the ease with which a fluid can flow through the pore spaces of the rock. For a better understanding of this principle, attempt to trace a route through the pore spaces and pore throats from one corner of the diagram to the opposite corner.

Fig. 4-1: Porosity and permeability.

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and shape of the sandstone body is dependent upon its depositional environment.

Rivers deposit sands as point-bar deposits in a meandering river, and as bars in a braided river (figures 1-2, and 1-3). Because of the constant channel switching and migration that occurs in both types of rivers, the sandstones become interconnected, and produce sizeable hydrocarbon reservoirs.

Oceans have sandstone deposition at the shoreline, and at the sites of deltas, where rivers meet the ocean (figures 1-4, and 1-5). Modern day shorelines are very laterally extensive, as are ancient, buried shorelines. Near shore deposits, such as barrier islands, are smaller, but nonetheless are signigicant reservoirs for hydrocarbons. **Deltaic deposits are responsible for most, if not all of the world's great oilfields.** When the river reaches the ocean, it drops its entire sediment load, because the ocean waters are much calmer than the river. There are numerous subenvironments, or facies, within the deltaic environment, and much time and study has been devoted by to the understanding deltaic processes. Perhaps the most well-known and widely studied delta in the world is the Mississippi delta system. By studying a modern day example, insight can be gained as to how reservoir quality sediments are deposited.

Eolian, or wind deposited sediments (figure 1-7), often cover hundreds of square miles, and are sometimes hundreds of feet thick. When oil and gas deposits do occur within them, they are economically very significant. The eolian Nugget Sandstone is the major reservoir rock for the Rocky Mountain Overthrust Belt.

Lakes have shoreline and deltaic environments (figure 1-8). The depositional processes are similar to oceans, but on a smaller scale. Ancient Lake Uinta filled the Uinta Basin and created significant hydrocarbon reserves that are being produced today from fields such as: the Altamont-Bluebell trend, Cedar Rim, Red Wash, and Natural Buttes.

Carbonate Reservoirs- Carbonates (limestones and dolomites), differ from sandstones in many ways. They are not transported and deposited like sandstones, but are found in very close proximity to where they originated. Carbonates are formed mostly from the remains of animals (shellfish, coral, and bryozoans) and plants (algae), predominantly in marine or ocean environments. Some carbonates are also formed in lacustrine or lake settings, but these are generally very thin, and not laterally extensive. Marine carbonates, however, are often quite thick and laterally extensive. Because of this, they form extensive hydrocarbon reservoirs.

Ancient marine carbonates were deposited in three environments: **shelf, slope, and basin.** It is the shelf environment which is responsible for the carbonate reservoirs of greatest economic significance.

The **shelf** deposited carbonates extend from the shoreline through the reef (figure 1-6). Due to fluctuations in the sea level, several carbonate sequences may occur. The reef is formed by very diverse organisms, such as coral, sponges, mollusks, bryozoans, and algae.

The **slope** subenvironment is often called the forereef, and consists of material that has been ripped or broken off the reef by waves and deposited as "reef talus." These deposits sometimes form excellent reservoirs.

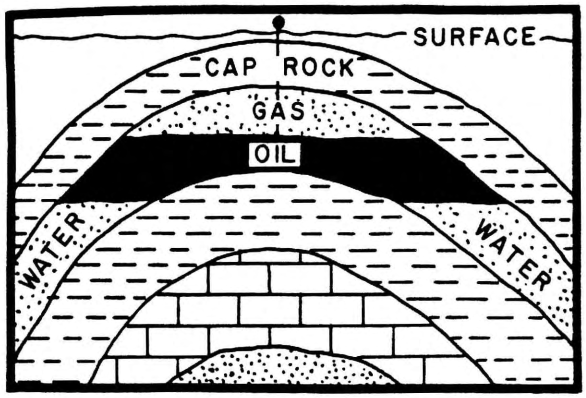
The **basin** subenvironment is usually composed of lime muds deposited in quiet, deep, waters. This environment normally lacks the permeability necessary to produce hydrocarbons, but is sometimes organic-rich enough to act as a source for the hydrocarbons.

4.5 The Trapping Mechanism

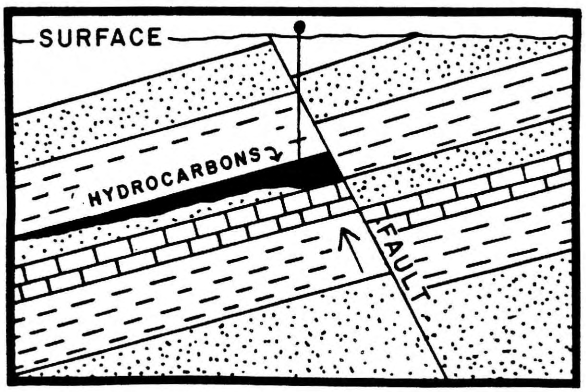
Once the hydrocarbons have migrated into the reservoir rock, there must be some mechanism present to **trap** and concentrate them in sufficient quantities for economic production. Secondary migration, or migration within the reservoir itself, is responsible for allowing the hydrocarbons to migrate into the trap.

There are two major types of traps which will be discussed in detail: **structural and stratigraphic traps. Structural traps form when the reservoir is deformed by folding or faulting.** Many depositional environments produce reservoirs that are both laterally and vertically extensive. In these cases it is imperative that a structural trap be present in order to effectively accumulate hydrocarbons. **Stratigraphic traps are formed by deposition of reservoir rock such as point bar deposition in rivers, or by the erosion of the reservoir rock to form an angular unconformity.**

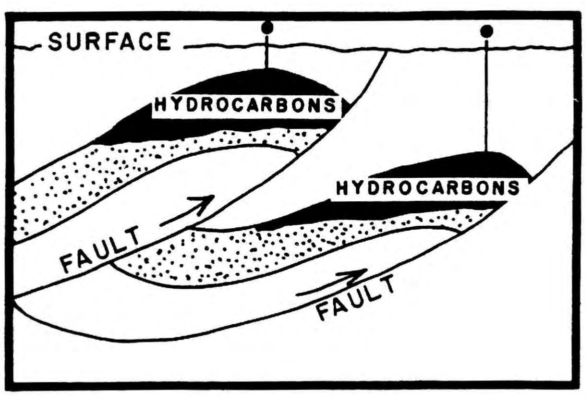
<u>Structural Traps</u>- **Anticlines account for the vast majority of traps which are producing hydrocarbons today (figure 4-2a).** Once the hydrocarbons have migrated into the reservoir rocks, they migrate up into the tops of anticlines. The gas, oil, and water separate into layers within the anticlinal structure, much the same way air, oil, and water separate when poured into a bottle. Depending upon how many reservoir beds are present, the anticline may have numerous productive horizons, at different depths in the well. Each of these reservoirs has its own gas-oil-water contact. Also, immediately above



A. Typical anticlinal trap. An anticline may have numerous reservoir beds. Each reservoir has its own gas, oil, and water contacts, and is sealed by an overlying impermeable cap rock.



B. A fault trap is formed when displacement causes a reservoir bed to be sealed by an impermeable bed on the other side of the fault.



C. Thrust faulting and drag folds form the types of hydrocarbon traps found in the Rocky Mountain overthrust belt.

Fig. 4-2: Common types of structural traps.

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each reservoir bed is an impermeable bed called a cap rock. This cap rock prevents the oil and gas from migrating out of the reservoir bed.

Faults also produce structural traps for hydrocarbons. The fault plane may act as a barrier to oil and gas, if the beds on the opposite side of the fault from the reservoir are impermeable (figure 4-2b). If the bed across fault from the reservoir bed is porous and permeable, then the oil and gas will flow across the fault, and into the other reservoir bed. Additionally, as in the case of the anticline, the reservoir bed must be overlain by an impermeable bed to effectively trap the hydrocarbons.

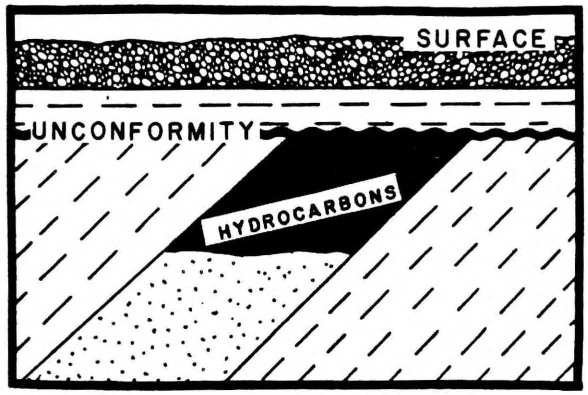
One of the most famous fault trapped hydrocarbon provinces is the Rocky Mountain Overthrust Belt, where a series of thrusts has produced **drag folds** (these look like anticlines) into which hydrocarbons have migrated (figure 4-2c).

<u>Stratigraphic</u> <u>Traps</u>- There are four major types of stratigraphic trapping: **angular unconformities, reefs, shoestring sandstones, and updip pinchouts.**

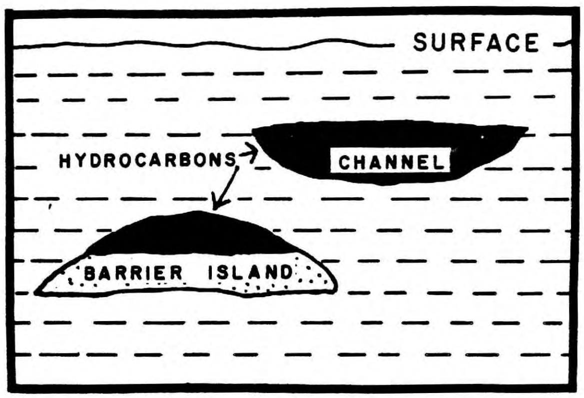
An **angular unconformity** is an ancient erosional surface. When a reservoir rock is terminated under an angular unconformity and overlain by a seal or a rock with poor reservoir qualities (lacking in porosity and permeability), such as a shale, large hydrocarbon traps can be formed. A diagram of an angular unconformity acting as a trap for a hydrocarbon bearing sandstone reservoir is shown in figure 4-3a.

The **reef flat,** or top of the reef, as shown in figure 1-6, usually possesses excellent reservoir qualities. When these reefs are overlain by shale (indicating an advance of the sea over the top of the reef), or by salt (indicating a retreat of the sea), a trap is formed, which isolates hydrocarbons migrating into the reef reservoir.

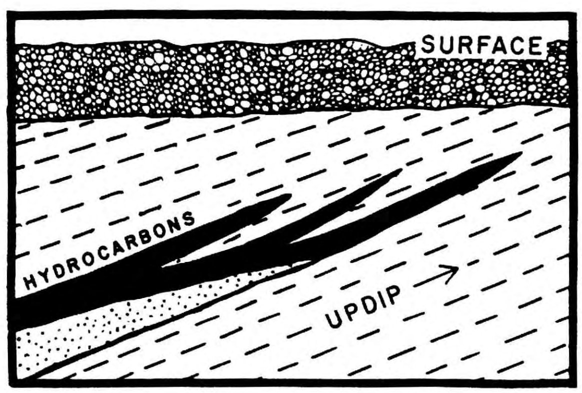
Production can occur not only from the reef, but from anticlinal structures on top of the reef as it is buried. These are similar to the compactional anticlines formed over the top of a diapir. Compactional anticlines form because the underlying reef or diapir is very resistant to compaction, and forms a high spot in the topography. As sediment accumulates in the area, a greater thickness is deposited on the sides of the diapir or reef. As more and more sediment is added, the loose sediments on the sides compact more than the sediments on the top, because the reef or diapir is so resistant to compaction. This results in anticlinal structures forming on top of the reef or diapir. Numerous potential reservoir beds may be deposited.



A. An angular unconformity becomes an effective hydrocarbon trap when the rock overlying the unconformity is impermeable.



B. Shoestring sandstones are typically encased in shales, which serve as the source rock and the trapping mechanism.



C. Another type of stratigraphic trap is an up-dip pinchout of reservoir sandstones into impermeable shales.

Fig. 4-3: Common types of stratigraphic traps.

Shoestring sandstones are long, narrow lenses of sandstone deposited as beaches, barrier islands, point bars, and river channels. As shown in figure 4-3b, these sandstones are generally encased in shales, which serve not only as the trap, but also as the source of the hydrocarbons. It is difficult to explore for shoestring sandstones, but once the depositional trend of a sequence has been established, large quantities of hydrocarbons may be produced.

Updip pinchouts of reservoirs form small but economically significant traps (figure 4-3c). Often, numerous small sandstone lenses pinch out in a well; the net footage of these small reservoirs can result in a sizeable hydrocarbon accumulation. These sandstones are also encased in shales, which serve as the source rock, and the trapping mechanism. The prolific production from the Altamont-Bluebell trend in the Uinta Basin of Utah is from thin sandstones pinching out into shales in an updip direction. Oftentimes, dozens of these sandstones are perforated in one well, creating an enormous amount of productive net footage.

Other types of traps include:

1. **Diapiric traps** caused by the upward movement of salt or mud (figure 4-4). Production can be es-

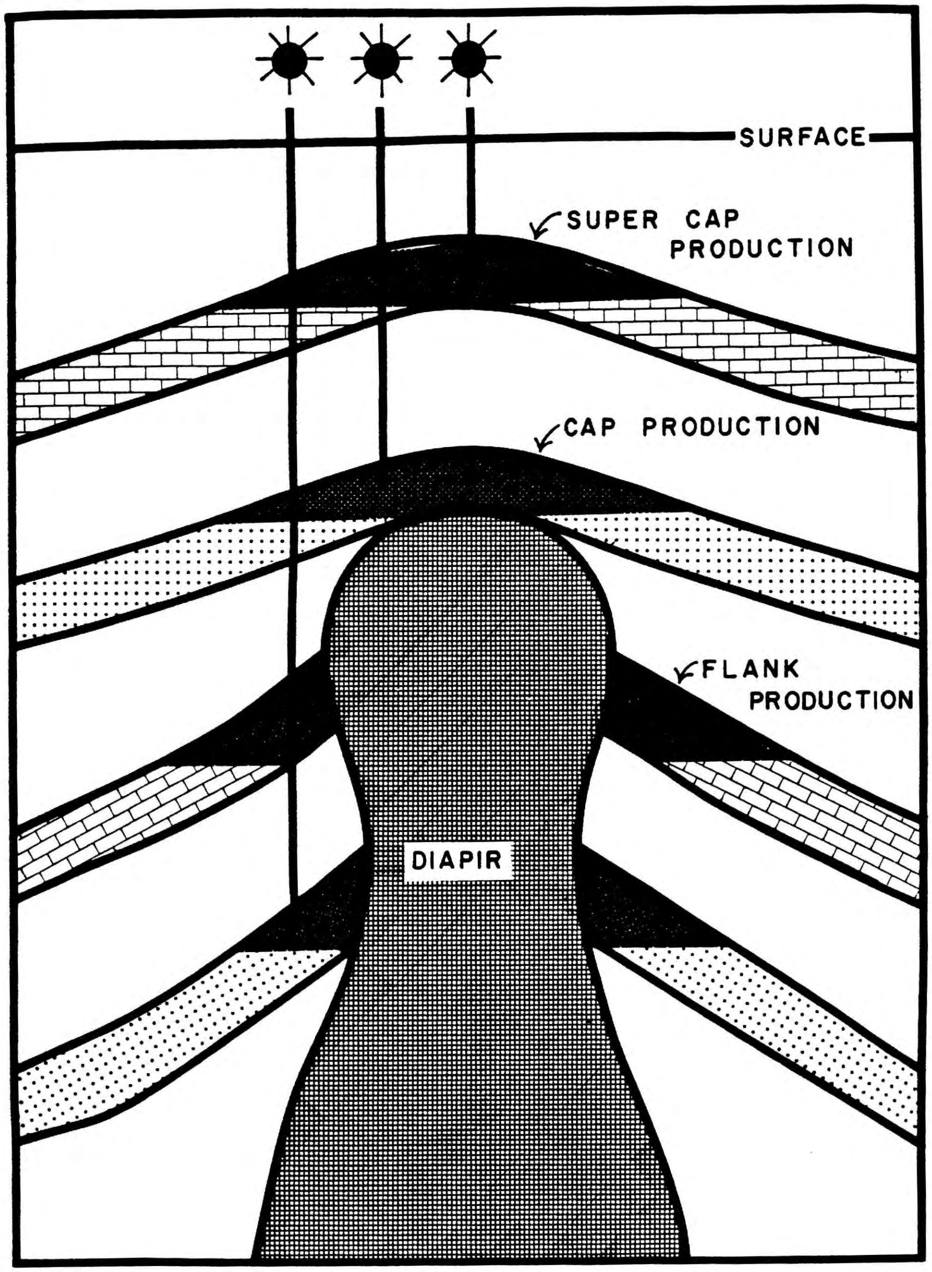


Fig. 4-4: Diagram showing hydrocarbon traps that may be productive when a diapir is present. (Modified from Spencer, 1962.)

■ = Trapped hydrocarbons

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tablished on the flanks of the diapir, immediately atop the diapir (on the cap), or towards the surface in the anticlines associated with the diapir (super cap production).

2. **Hydrodynamic traps** in which the oil-water contact of the reservoir is tilted, due to the flow of water in the reservoir. The Upper Valley Field in Garfield County, Utah, is an example of a structural trap which is hydrodynamically controlled.

3. **Combination traps** combine two or more trapping mechanisms. A great many fields produce because of a combination of structural and stratigraphic trapping.

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CHAPTER 5

THE OPERATION OF AN OIL AND GAS COMPANY

5.1 Introduction

An oil and gas company is typically composed of four departments. Depending upon the size of the company, each department may have between one or hundreds of employees. In very small companies, one individual may be in charge of two or more departments.

The four main departments in an oil and gas company are:

1. Lands and Leasing.

2. Exploration (includes both geological and geophysical departments).

3. Accounting.

4. Drilling and Reservoir Engineering.

Most importantly, there is the **President** of the company who makes the final decisions based on the input from the various departments.

5.2 Lands and Leasing

A company's land position in an area with oil and gas potential is crucial. If the company does not have leases on the acreage, a well cannot be drilled. It is the **landman's** job to successfully procure leases from landowners. Additionally, the landman is responsible for working with the government in areas that are environmentally or archeologically sensitive. Many of these areas have hydrocarbon potential that is significant enough to warrant drilling a well.

Several problems can occur that may complicate a landman's job. Some of these are discussed below.

Sometimes landowners are hesistant to lease their land to an exploration company because **they fear their land will be ruined.** The oil and gas company will usually try to get a lease for a ten year period. During that time, wells may or may not be drilled. If wells are drilled, the company works very closely with landowners to compensate them for inconveniences that may occur. Sometimes, the landowner wants roads removed and the area revegetated if the company drills an unsuccessful well. More often, however, the landowner requests that roads be left, and sometimes even asks that the roads be routed a certain way, to help him more effectively manage his land. Wells that do not produce oil and gas, often produce water that is of high enough quality for livestock or even humans to drink. In this case, the oil and gas company may give the well to the landowner. This is especially important in many areas of the west where water is extremely scarce. If the exploration company drills a successful well, the landowner is usually promised a share of the revenue from the sale of the hydrocarbons. This is known as an **overriding royalty interest (ORRI).** Many poor ranchers and farmers have become millionaires because of the overrides they have been able to negotiate.

Topographic problems may necessitate the rerouting of roads to future drillsites. The shortest road to a location may go through a very deep canyon, or over the top of a high mountain. Because of the extremely large and heavy loads that must be transported to a well site,the roads that currently exist in the area may be too steep, or too narrow. Topographic maps are imperative when the access to a future well location is being planned. It may be necessary to reroute a road around mountains, lakes, canyons, and rivers. This adds a great amount to the cost of drilling a well.

The area may have **significant archeological sites.** Each well location must be inspected by an archeologist who looks for artifacts. These can include arrowheads, pots, dwellings, cooking areas, and tools. If the findings warrant it, the well location must be moved to protect these artifacts.

The area may be **environmentally sensitive.** Rare plants and animals may live there. The landman must try to work out a compromise, that would allow the company to drill a well. Such a compromise may include: only allowing drilling during certain periods of the year when the animals are not breeding or bearing young; lining disposal pits with plastic and removing all materials from the site, instead of burying them; restoring the surface and replanting the area at the completion of drilling; only producing the well during the cold, frozen winter months and dry summer months, so the roads will not be rutted, and the soil structure of the area will not be damaged when heavy trucks drive on the muddy roads.

5.3 Exploration

The Exploration department analyzes all of the available data, both surface and subsurface, and makes recommendations as to where the best locations are for drilling. This course has attempted to explain how this is done.

It is essential that the geologists and geophysicists in the Exploration department, work closely with both the Land department, in the case of a wildcat or undrilled area, or the Drilling and Reservoir Engineering department in the case of a developed field that already has many producing wells. It is important the wells be "spaced" in an established field, so that a maximum amount of oil and gas can be recovered from an area, with the least number of wells. Each field has its own spacing regulations, which may allow as many as one well every 40 acres (16 wells per section), or as few as one well per 640 acres (1 well per section). These regulations are based on the producibility of the reservoir rock; permeability, porosity, thickness, and continuity are taken into consideration when determining producibility.

5.4 Accounting

The Accounting department is responsible for securing the funds for a drilling program, creating budgets for the Land, Exploration, and Drilling departments, and keeping track of how much is spent on the drilling of wells, and how much is recouped from the production which is established.

Oil and gas accounting is very complex and specialized. Numerous taxes must be paid out of production, and land owners typically receive a share of production in the form of an override. It is not within the scope of this course to attempt to give the reader an insight into the complexities of oil and gas accounting.

Before a well is drilled, an AFE, or Authorization for Expenditure, must be prepared. This form estimates land and drilling costs for the well. Expected production from the well is then analyzed to determine if the costs of drilling the well are acceptable. The payout time for a producing well to recoup the amount of money expended, and the return on investment or ROI, are very important. If not enough oil and gas can be expected to be produced to justify the costs of drilling, then the well is not drilled. The price per barrel, and the price per mcf that the company is able to get when it sells the oil and gas from the well, is critical when a company is deciding to drill wells. If the price of oil is low, then only wells that are not too deep, too risky, and offer large reserves of oil, are drilled. If the price of oil is high, then wells that are deep, more risky, and only have moderate reserves, can also be drilled. Unfortunately, in the United States, most of the shallow, large, low risk oil and gas prospects have been drilled and produced to depletion. Most of the remaining hydrocarbons are deep, and risky to drill. That is why the price of oil and gas must increase, in order for exploration to once again become active. The Middle East can afford to produce its oil and gas at $18 per barrel, because there is so much of it, and it is shallow and not too risky to drill for.

The drilling of oil and gas wells is very risky and very expensive. While the financial rewards can be substantial, the loses can be staggering. It is definite-ly not a good investment for an investor who is not willing to lose his money, or one who is looking for a "safe and secure" investment. **Oftentimes, the expected production from a well is either nonexistent, or not as high as anticipated.**

5.5 Drilling and Reservoir Engineering

The actual drilling of the well, getting it to produce, and keeping it productive, is the responsibility of the Drilling and Reservoir Engineering department.

Rotary rigs drill the vast majority of wells in the Rocky Mountains today. Years ago, cable tool rigs were popular. Cable drilling literally pounds a hole into the earth by repeatedly dropping a heavily weighted bit. It is very slow, and limited to shallow holes. Rotary rigs drill by using a rotating drilling string with a bit, that actually cuts through the rock. There are four component systems which make up a rotary rig: **the engines, and the hoisting, rotating, and mud systems.** Figure 5-1 is a diagram of a rotary rig and its component systems.

The **engines** on rotary rigs are usually diesel powered, and are used primarily to turn the drill string, and provide the power to raise and lower the equipment into and out of the well. Additionally, the engines generate electrical power for the drill site.

The **hoisting** system (figure 5-2), raises and lowers equipment into the drill hole. The support structure for the weight of the drilling is the steel derrick. Braided steel cable, approximately 1 1/8" in diameter, is wound around a reel in the draw works. The draw works are connected to the engines, enabling the drilling cable to be let in and out. At the top of the derrick is a pulley, known as the **crown block.** The steel cable, or drilling line, goes over the top of the crown block, and around another pulley called the **traveling block.** The traveling block has a hook on the bottom of it to which equipment is attached. As the drilling line moves in and out of the draw works, the traveling block moves up and down, raising and lowering equipment in the well. The derrick and the engines must be strong enough to support an enormous amount of weight. A deep well may require the lifting and support of 500,000 pounds.

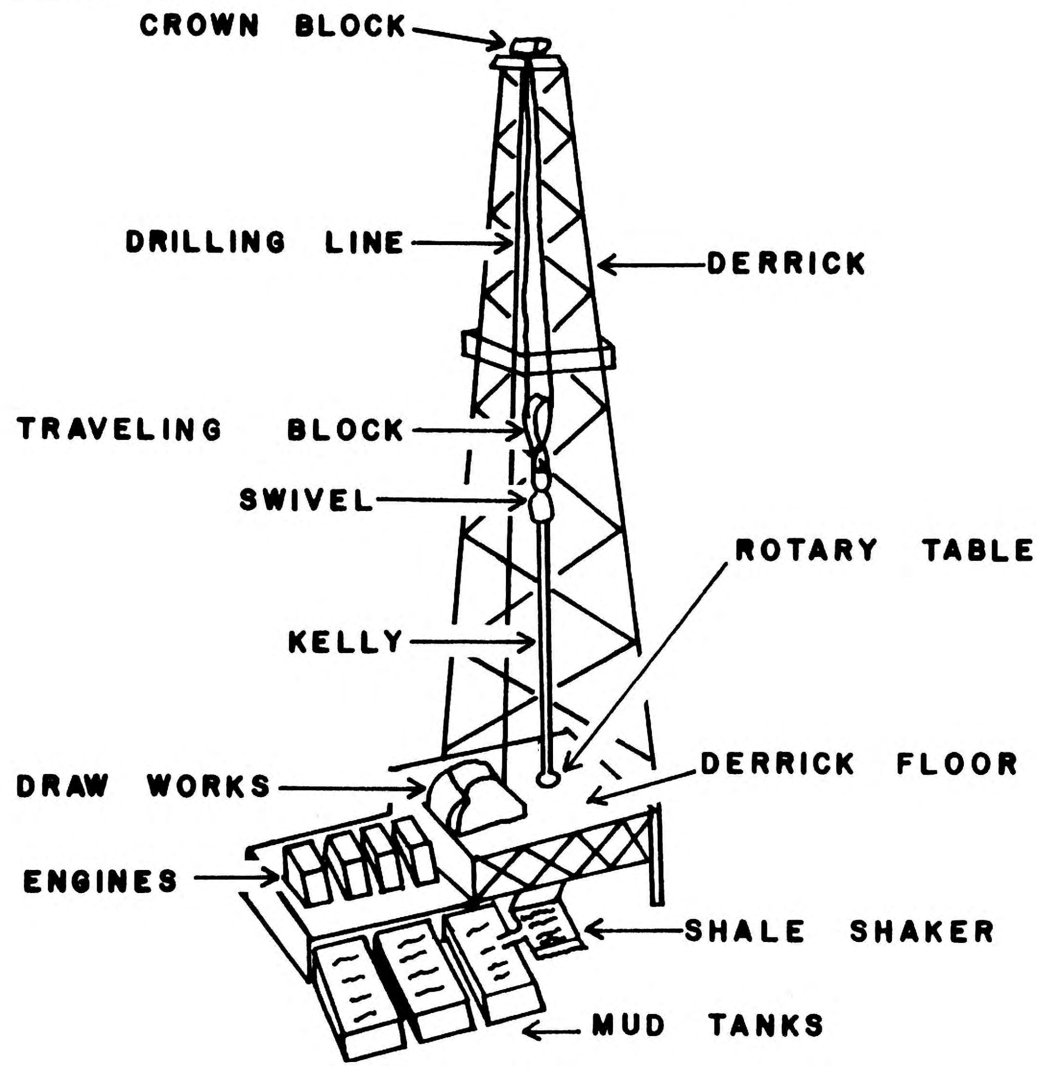

Fig. 5-1: A simplified sketch of a rotary rig. (Modified from Selley, 1985.)

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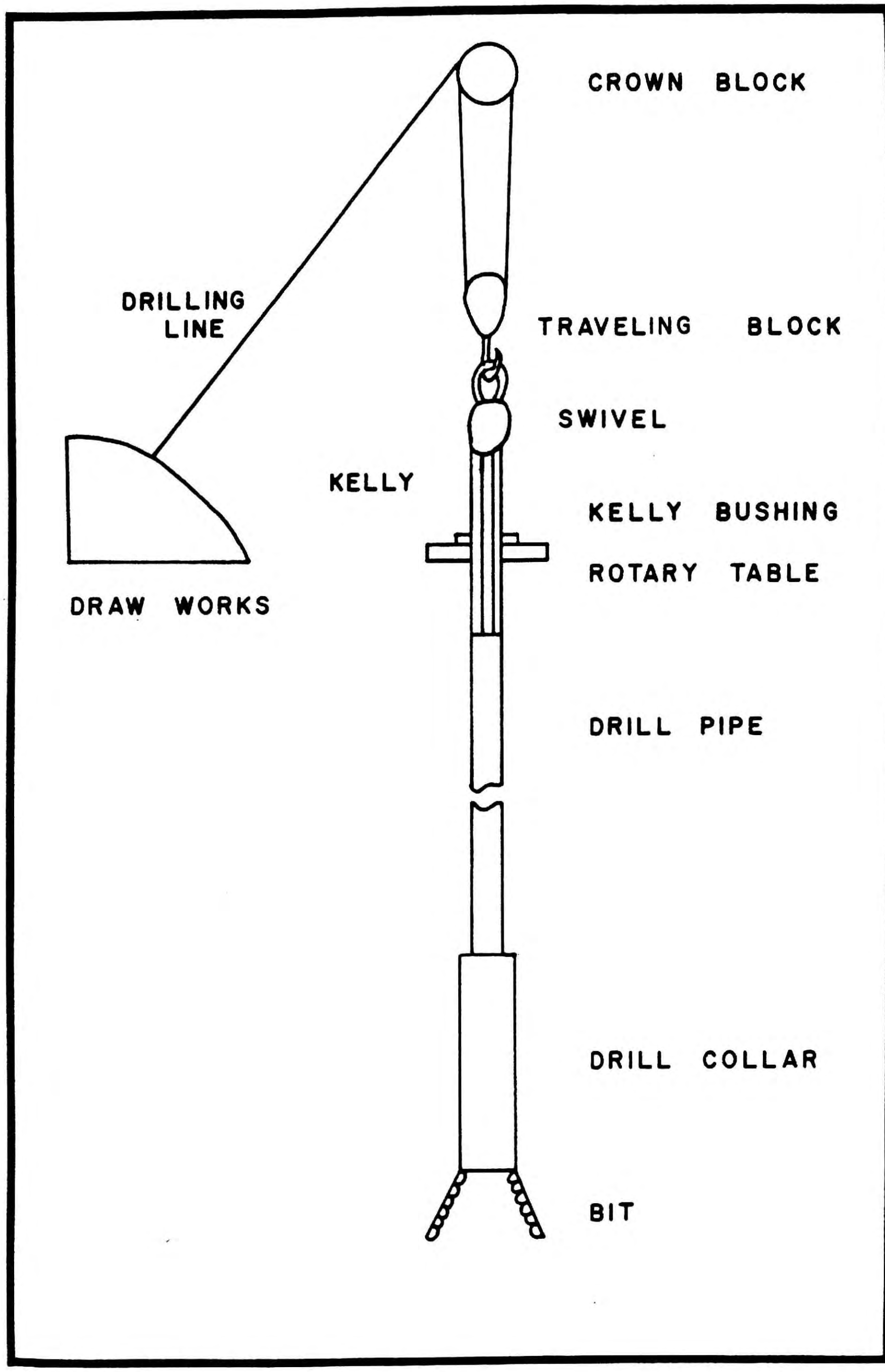

Fig. 5-2: The hoisting and rotating systems from a rotary rig. (Modified from Hyne, 1984, and Selley, 1985.)

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The **rotating system** cuts through the rocks to create the hole. Attached to the hook below the traveling block is the **swivel.** The swivel allows the drill **string** or pipe to rotate while the weight is suspended from the derrick. The **kelly** is a four or six sided 40' long pipe that hangs below the swivel. The sides allow the kelly to fit into the **kelly bushing,** which is attached to the **rotary table.** The rotary table sits on the derrick floor, and is connected to the engines. The rotary table, the kelly bushing, and the kelly, all rotate in a clockwise direction to turn the drill pipe that is attached to the end of the kelly. Each section of pipe is 30' long, and is called a **joint.** After the well is drilled the length of a joint, the kelly is raised, and a new joint of pipe is attached below the kelly. When joints of pipe are added to the drill string, it is called **making a connection.** Below the drill pipe, are heavier, larger diameter pipes called **drill collars.** These help to stabilize the drill pipe and put more weight near the bit. The **bit** screws onto the bottom of the drill collars. There are several types of bits. Some have cutting teeth made from diamonds, and others have teeth made of tungsten carbide. Depending upon the depth, diameter of the hole, and the rock type, different kinds of bits are used. Bits wear out after drilling for between 8 and 200 hours. How long a bit lasts is largely dependent on the type of rock that is being drilled. When the bit wears out, all of the drill pipe must be brought to the surface so that the bit can be changed. The pipe is brought out in **stands** of two or three joints and stacked upright in the derrick. Whether a 60' or a 90' stand is brought out depends upon the size of the rig. In the Rocky Mountains, the stands are typically **triples,** or 90', or 3 joints of 30' pipe. As the pipe is pulled from the well, the driller operates the controls. **Roughnecks,** or workers, stand on the derrick floor and unscrew the pipe. The pipe is unscrewed, the 90' piece is hoisted slightly, and swung over to the side, where it is racked up in the derrick in a vertical position. Meanwhile, up above, at the top of the derrick, is the derrickman. He swings the top end of the stand of pipe into a rack, and ties it into place. Another stand is then pulled out of the hole (Plate 1), unscrewed, and racked. This process is repeated until all of the pipe is out of the hole and the bit is on the surface. After the bit is changed, all of the pipe is run back into the hole, and drilling resumes. The process of going in and out of the hole is often referred to a making a **trip.** A round trip means that the equipment was brought out, and then run in again. On a 12,000' well, it takes approximately 12 hours with a good crew to change the bit and make a round trip. When drilling resumes, the kelly pipe is fit into the kelly bushing in the rotary table, and the rotary table is rotated, causing the entire string of pipe to rotate and drill the hole.

Plate 1: Roughnecks prepare to pull another stand of drill pipe from the well. (Photo used with permission of the Utah State Historical Society.)

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The **mud system** (figure 5-3), circulates drilling mud from the surface of the well, down into the hole, and back out again. The mud system serves four main functions. First, it conditions the well bore by creating a filter cake of mud along the sides of the hole that prevents the sides from caving in. Secondly, the viscosity and weight of the mud keeps the downhole pressure of the well under control by preventing blow outs. Thirdly, the mud picks up the small chips of rock that the bit cuts away, and brings them to the surface, where they are separated from the mud by the shale shaker. The mud is then returned to the hole, and the chips of rock are examined by the mudloggers. Fourth, the mud cools and lubricates the bit.

Sometimes, shallow wells are not drilled with mud, but with air. When this is done, the rock that returns to the surface is reduced to a fine powder. In this case, it is impossible to create a sample log, or a mudlog. Air drilling is exceptionally fast; a 2000' hole can usually be drilled in one or two days. In areas that have shallow wells, and are heavily drilled, a sample log is not necessary, and air drilling may be preferred. Air drilling is also desirable when the reservoir rock may be damaged by the drilling mud. Some reservoirs contain clays that swell when they come in contact with the water in the drilling mud. If these clays get wet, and the clays swell, the porosity and permeability of the reservoir is damaged, and the well cannot be produced.

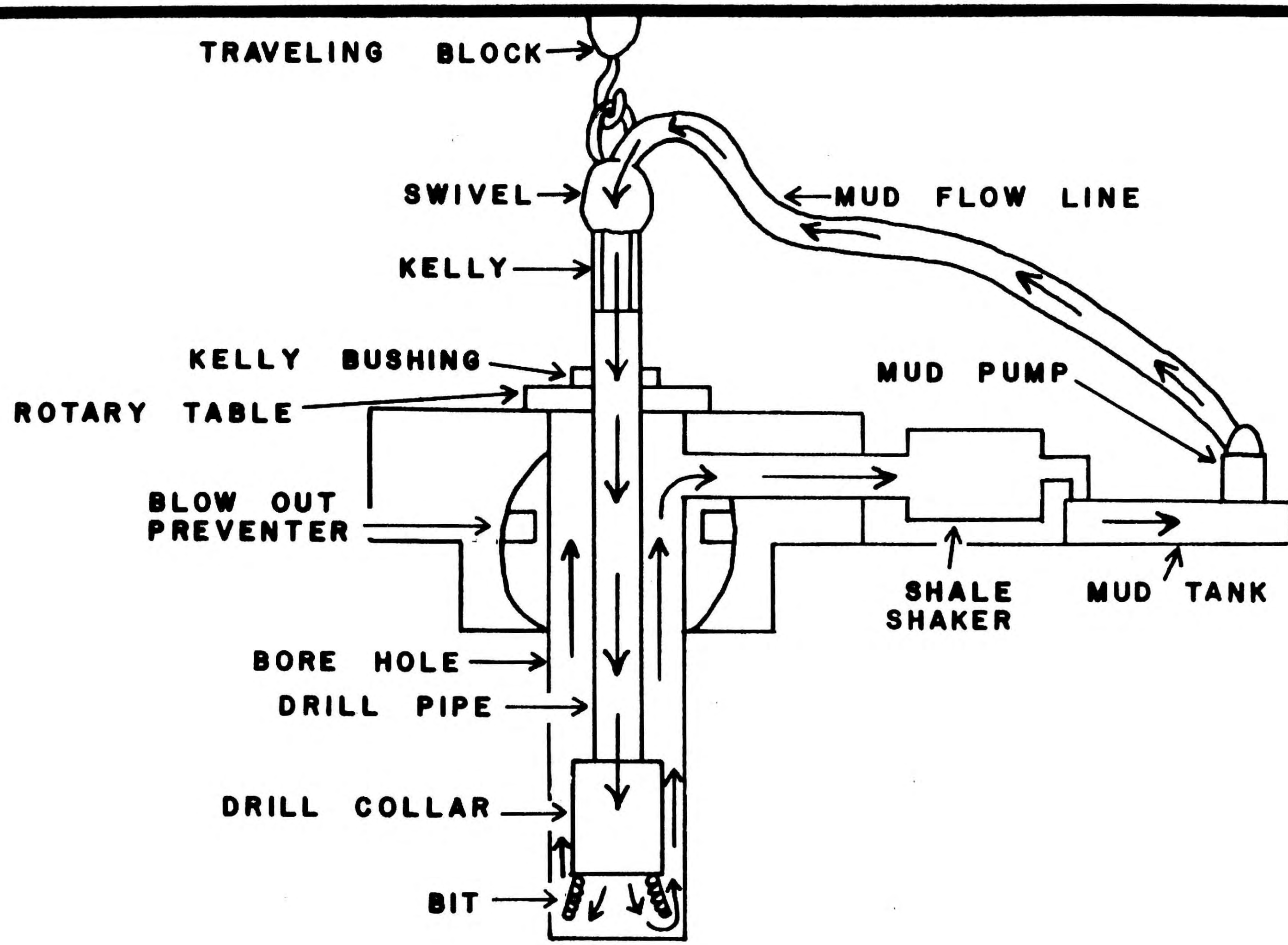

Fig. 5-3: The mud system. Arrows show direction of mud flow. (Modified from Hyne, 1984.)

Several problems can occur while the well is being drilled. Sometimes, part of the drill string will come apart and be left in the hole. Equipment left in the hole is called **junk,** and must be **fished** out, or removed. If the fishing job is unsuccessful, the well may have to be **whipstocked,** or drilled off at an angle above the junk.

Blow outs are a very serious problem that can occur on the well site. They are very dangerous, and often result in lives being lost, and the well burning out of control, until it can be capped or brought back under control. If the well blows out, it means the mud is not heavy enough to hold back the pressure and hydrocarbons from a zone downhole. The hydrocarbons flow into the well bore, and up towards the surface. The mud is literally blown up and out of the hole, followed by the gas in the reservoir. When the gas hits the surface, it may ignite. The well burns until it is either brought under control again, or the gas in the reservoir zone is depleted, which may take years. There are numerous safety precautions taken to prevent blowouts. The main precaution is the use of blow out preventers (BOPs). If the well is out of control, one BOP closes off the space between the sides of the well and the drill pipe. The other BOP seals off the drill pipe by actually shearing through the pipe, and closing off the open end. These BOPs are tested several times while a well is drilling to ensure that they operate correctly. Additionally, the mud weight and viscosity are constantly monitored to make sure that the reservoir pressure and hydrocarbons are being effectively held under control.

Drilling a well is very costly. Once a rig starts to drill, it is run 24 hours a day. This is because it is most economical to finish drilling as quickly as possible. In the winter, the rig is also run constantly, keep the flow lines from freezing.

A drilling site is full of people and equipment all working hard to get the well drilled as quickly and safely as possible. All of the work that goes into drilling a well is contracted out by the oil and gas exploration company, who has a **drilling foreman** on the rig site. It is his responsibility to make sure that the well is drilled according to the "Plan to Drill" that has been prepared by the geologists and engineers. The drill rig is owned and operated by the drilling company. The supervisor of the drill rig and personnel is called the **tool pusher.** He is also employed by the drilling company, and lives on location. He works very closely with the drilling foreman. People representing other companies are also present on the well site to mudlog, wireline log, cut core, run drill stem tests, haul water, do chores (roustabouts), fish for lost equipment, monitor the drilling mud, cement the casing, inspect the casing and drill pipe for defects, supply drilling bits, and to perform various other services. All of these people are not present at once, but rather come and go as the need arises. By the end of a well, hundreds of people may have been involved.

The length of time that it takes to drill a well varies considerably, from 2 or 3 days to over a year. It is dependent on the depth, whether it is in an area that has a lot of wells, the type of rig used, the weather, the amount of coring, testing, and logging to be performed while the well is drilling, and how many problems are encountered.

Once a well is drilled, the exploration company must make a decision as to whether to try to produce the well, or abandon it. All available information is gathered and reviewed; drilling reports, the mud log, drill stem test information, wireline logs, and core analyses. Additionally, the well is compared to others in the area that have or have not produced. The objective reservoir rocks are compared between the wells, so that a feeling can be gained for how much the well might be expected to produce.

Often, the exploration company decides to not continue with the well, and abandons it. The reasons for abandoning a well include the lack of good oil and gas shows in any of the potential reservoir rocks, the absence of the primary objective reservoir, or poor permeability and porosity of the reservoir due to a facies change. If the well is abandoned, cement **plugs** are poured into the well bore to effectively seal off the horizons. A small pipe is then left sticking out of the hole and an abandonment marker is attached. The well site is then recontoured, and revegetated. The environmental impact of an abandoned well is typically negligible.

Hopefully, the exploration company is encouraged enough by the data gathered while the well is being drilled to attempt a **completion** for production of hydrocarbons. The first step towards completion, is to run **casing,** a steel lining that extends from the surface to the bottom of the hole. Cement is then pumped into the well to seal off the area between the casing and the well bore.

In a deep well, surface and intermediate casing is often run while the well is drilling. This casing serves many functions: it prevents the well from caving in, it protects fresh water aquifers from contamination, and it protects hydrocarboon reservoirs from water producing reservoirs. When casing has been run, and there is still footage left to be drilled, the remaining footage must be drilled with a smaller diameter pipe and bits in order to get the equipment past the cased part of the hole.

After the well has been cased, the geologists and engineers decide which zones or reservoirs the hole should be completed in. Attempts are made starting with the bottommost zone first. That way, if production is established, then a minimum of time and money has been spent, and there may still be future zones later that the well can be **recompleted** in when the original zone is depleted of hydrocarbons. Sometimes more than one zone is completed, because the flow of hydrocarbons from only one interval is not enough to economically justify producing the well.

Perforations or holes are shot into the casing through the cement, and into the rock. The well is then allowed to flow. Depending on the results, well **stimulation** may be tried on the zone. This usually involves acidizing and/or fracturing of the reservoir rock. Acidizing dissolves some of the cement holding the reservoir rock together, and enlarges the pore spaces to increase porosity and permeability. Fracturing creates cracks in the reservoir rock that allows hydrocarbons to flow more freely into the perforated well bore.

After a well has been completed, a potential test is run. This shows the maximum amount of oil, gas, and water that a well is capable of producing in a 24 hour period. This flow rate is referred to as a well's **IP, or Initial**

Potential and indicates the amount of daily production that can be expected. As more and more hydrocarbons are produced from the zone, the pressure of the reservoir declines, and the production rate drops. Engineers run several types of production tests to estimate a well's **decline curve** and arrive at an approximation of how much a particular zone may be expected to produce, and for how long it will produce.

When production has been established, the well is hooked up for production. **Production tubing** is run into the hole and is connected to a surface pumping unit (Plate 2), in the case of oil wells. Sometimes, an oil well produces not only oil, but gas and water, as well. In this case, a **separator** unit is installed to separate the oil, gas, and water. A **Christmas tree** is oil field jargon for the series of valves, gauges, and chokes that must be installed in order to control the flow from a gas well.

When a particular zone has been depleted of hydrocarbons, other zones within a well are perforated and produced. This is called a **recompletion.**

When all of the zones in a well have been depleted, the well is **plugged and abandoned, or P and A'd,** by setting cement plugs in the well bore to seal the casing. Surface

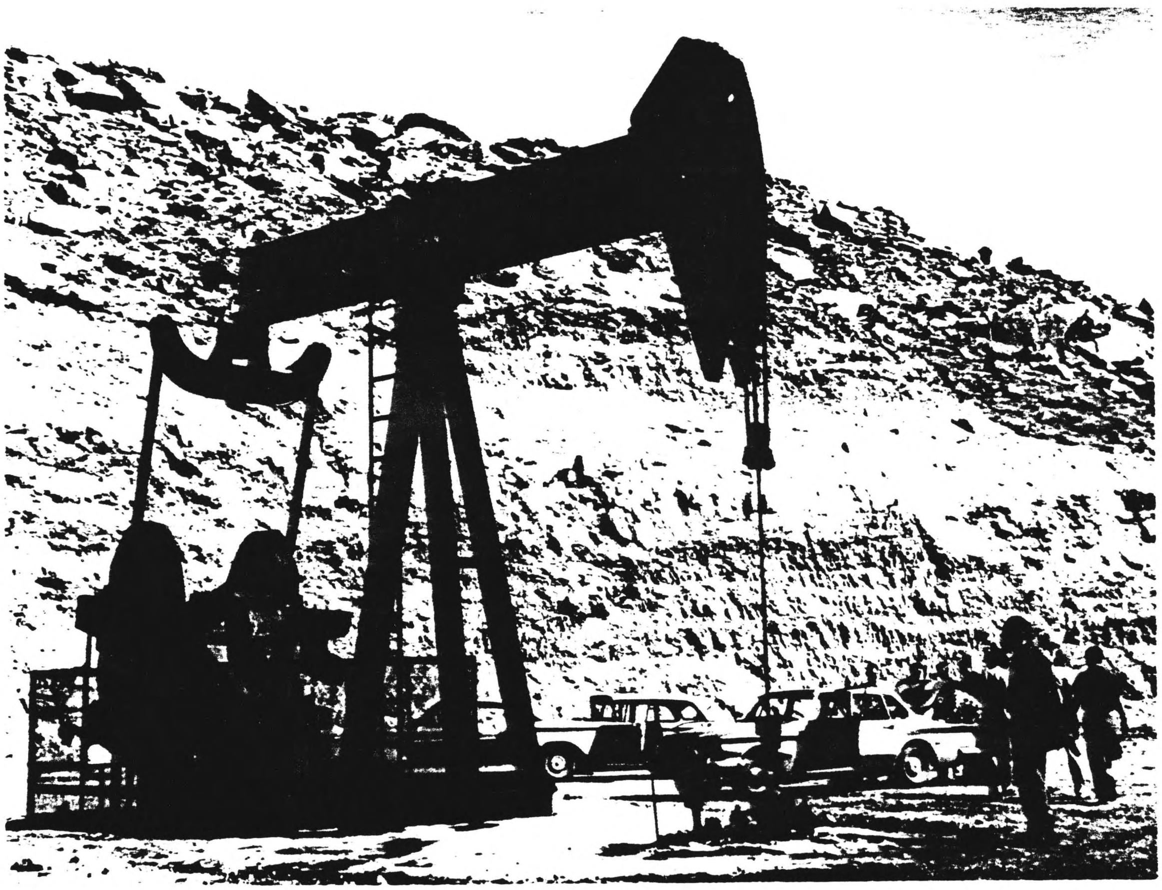

Plate 2: Pumping unit at a well in the White Mesa field of the greater Aneth field complex. (Photo used with permission of the Utah State Historical Society.)

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equipment is then removed, and a small abandonment marker is placed near the well bore.

A well is also abandoned if no production was established after casing was run. Sometimes, a company goes to great expense in perforating and stimulating numerous zones in a well, only to never establish production. This is extraordinarily expensive, and reinforces the importance of making the correct decision at the **casing point,** or before casing is run, as to whether to attempt to complete the well.

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CHAPTER 6

SELECTED EXAMPLES FROM UTAH'S PETROLEUM PROVINCES

6.1 Introduction

Utah has abundant oil and gas reserves in diverse geologic settings. Significant quantities of gas have been produced in Utah since the early 1900's. The first commercial oil field was established at Ashley Valley in 1948. The discovery well, the #1 Ashley Valley, located approximately 10 miles southeast of Vernal, is shown in Plate 3 as oil flows from the well. Figure 6-1 shows a base map of Utah with the major oil and gas provinces delineated. The most productive hydrocarbon provinces are: the Uinta Basin, the Uncompahgre Uplift, and the Paradox Basin. The Green River Basin/Overthrust Belt is also very significant; most of the province and the production lies in Wyoming.

This chapter will highlight five examples from productive oil and gas fields in Utah. Emphasis is on presenting varied examples of reservoir and trap types, to enable the reader to better understand the geological principles that have been presented in this course. Fields

Plate 3: J.L. Dougan, left, and (?) watch as oil flows from the first commercial oil well in Utah: the #1 Ashley Valley, located approximately 10 miles southeast of Vernal. (Photo used with permission of the Utah State Historical Society.)

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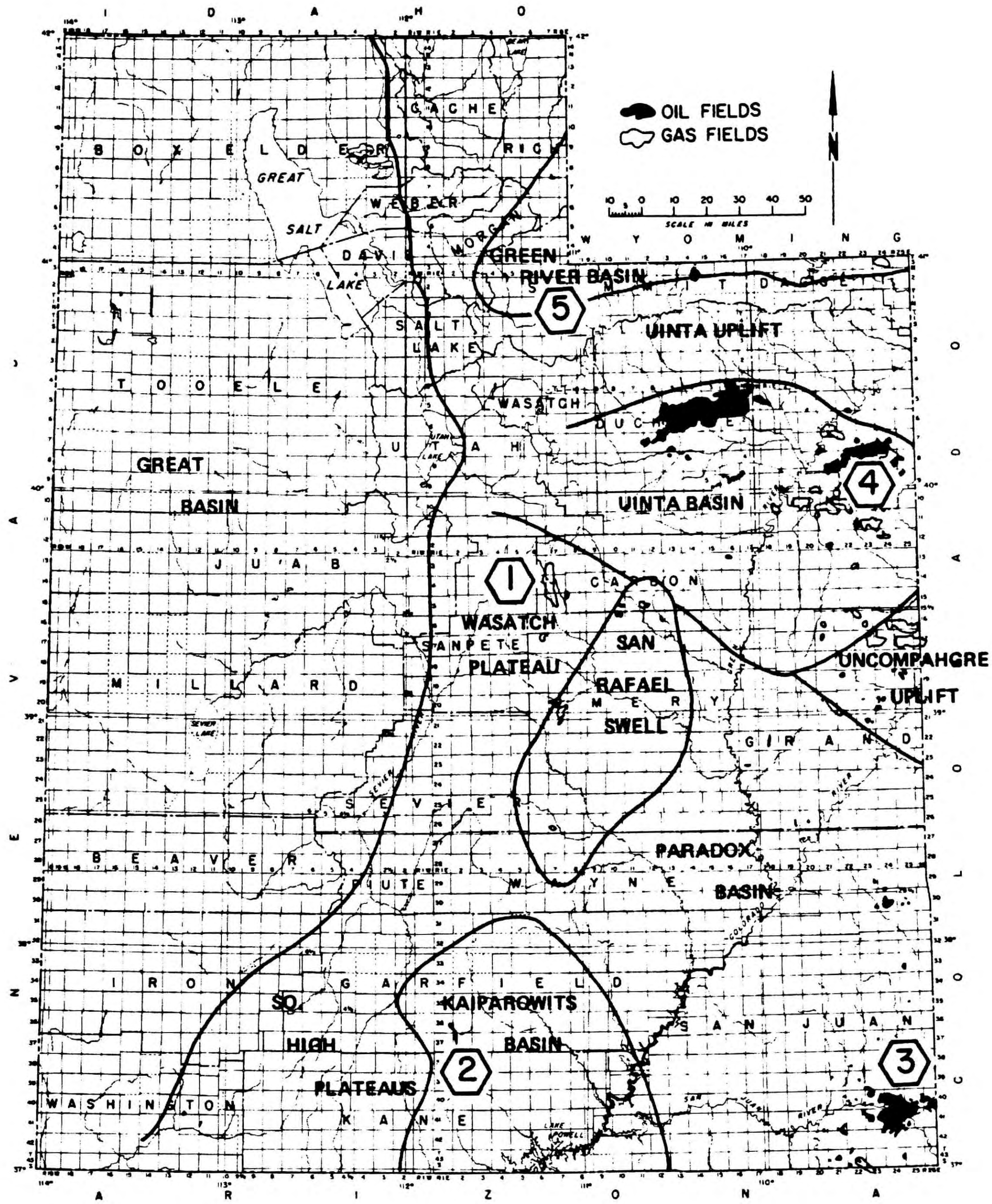

Fig. 6-1: Map of Utah showing petroleum provinces. Locations 1-5 on map correspond with field examples discussed in text: 1= Clear Creek, 2= Upper Valley, 3= Aneth, 4= Red Wash, 5= Pineview. (From Campbell and Bacon, 1976.)

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discussed are: Clear Creek, Upper Valley, Aneth, Red Wash, and Pineview. The locations of these fields are shown in figure 6-1.

Included with each example is a structure map, a wire-line log showing the major producing horizon, and a **penetration chart.** Penetration charts show the stratigraphic column for the well, the age of the producing rocks, and the age of the rocks for the deepest wells drilled. The legend for interpreting the symbols on the charts is shown as figure 6-2.

It should be noted by the reader that the stratigraphic unit names, or formation names for the different ages of rocks change significantly for each example, and that different ages of rocks are encountered in the different examples. An example of this can be seen when comparing the Red Wash and the Upper Valley examples. The Red Wash field produces oil and gas from the Tertiary Green River and Wasatch Formations and the Cretaceous Mesaverde Group. The Upper Valley field produces oil from the Triassic Timpoweap Member of the Moenkopi Formation and the Permian Kaibab Formation.

The future of oil and gas exploration in Utah is dependent upon the increase in oil and gas prices to high enough levels (minimum of mid 20's/ barrel of oil) to jus-

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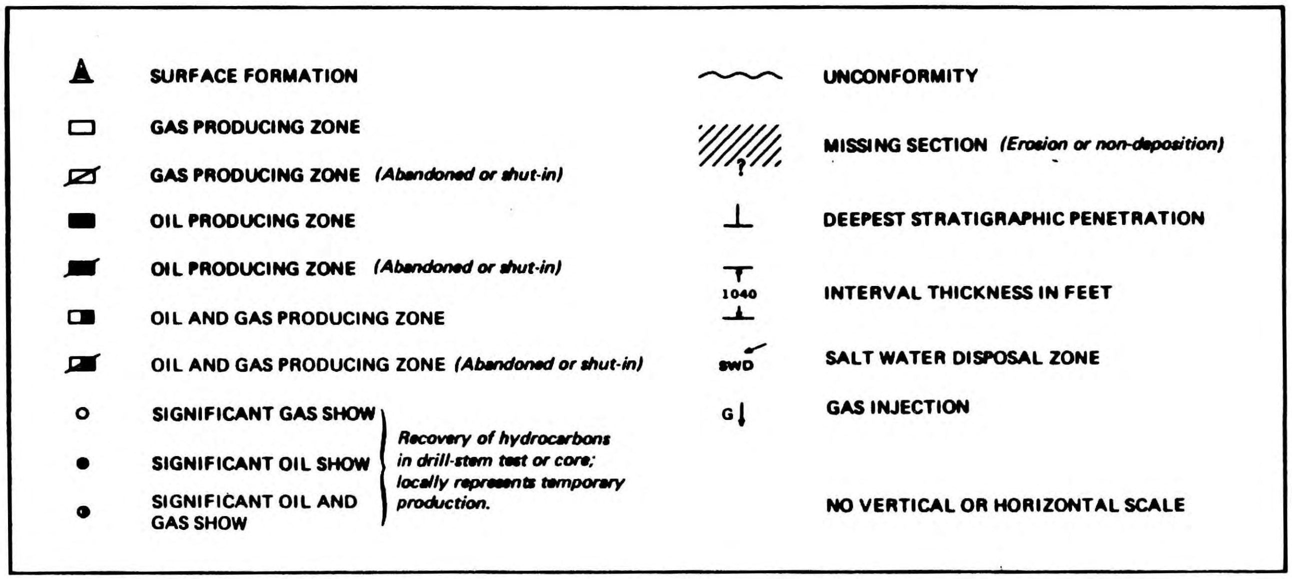

LIST OF ABBREVIATIONS

ANT—Anticline or anticlinal
API—American Petroleum Institute
AVG—Averaged
BBL—Oil-field barrels (42 U. S. gallons)
BTU—British thermal units
BW—Brackish water
CF—Cubic feet
CO_2—Carbon dioxide
FL—Flared
FA—Fault or faulted
FR—Fractured reservoir rock
FT—Feet
FW—Fresh water
He—Helium
MMCF—Millions of cubic feet
N—Nitrogen
P&A—Plugged and abandoned
PPM—Parts per million
STRAT—Stratigraphic trap
STRAT B—Biohermal reservoir bodies
STRAT C—Channel sands
STRAT L—Lenticular reservoir bodies
STRUCT—Structural trap
SWD—Salt water disposal
U.S.M.—Uinta Special Meridian
V—Gas vented to atmosphere
WF—Waterflood (secondary recovery)

Fig. 6-2: Legend and list of abbreviations for penetration charts used in field examples. (From Campbell and Bacon, 1976.)

tify the risk of exploring for and producing the many small stratigraphic traps that are still left in the Uinta Basin, Wasatch Plateau, San Rafael Swell, Uncompahgre Uplift, and Paradox Basin. Production from the Utah portion of the Overthrust Belt/Cordilleran Hingeline is currently limited to the area northeast of Salt Lake City. Exploration in the Great Basin region has proven largely unsuccessful to date. This region gained notoriety in the late 1970's when Amoco drilled Utah's first "offshore" wells in the Great Salt Lake. Plate 4 shows the offshore rig used for Amoco's unsucessful drilling program being transported to one of the well sites.

6.2 Clear Creek Field

The Clear Creek field is situated in the Wasatch Plateau geologic province. It is approximately 6 miles south of Scofield Reservoir, and approximately 19 miles west of Price, Utah in Townships 13-15 South, Range 6-7 East, Carbon and Emery Counties. Plate 5 is a historical photo showing one of the first wells drilled in the Clear Creek area by the Clear Creek Gas Company. Note the extremely rugged topography; drilling within the field has been limited because of the difficult access caused by the steep mountains and valleys within this province.

Figure 6-3 is a structure map based on the top of the

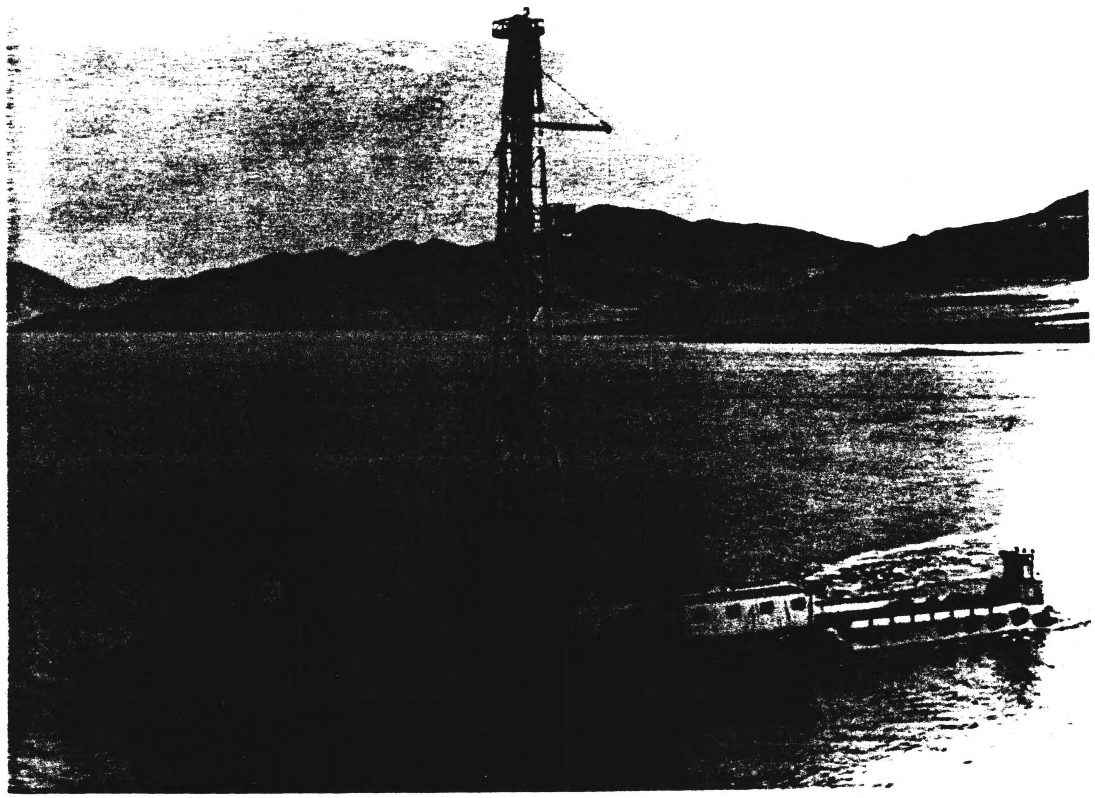

Plate 4: Utah's first and only "offshore" drilling program was conducted in the late 1970's by Amoco. Rig is being transported to drill site. (Photo used with permission of the Utah State Historical Society.)

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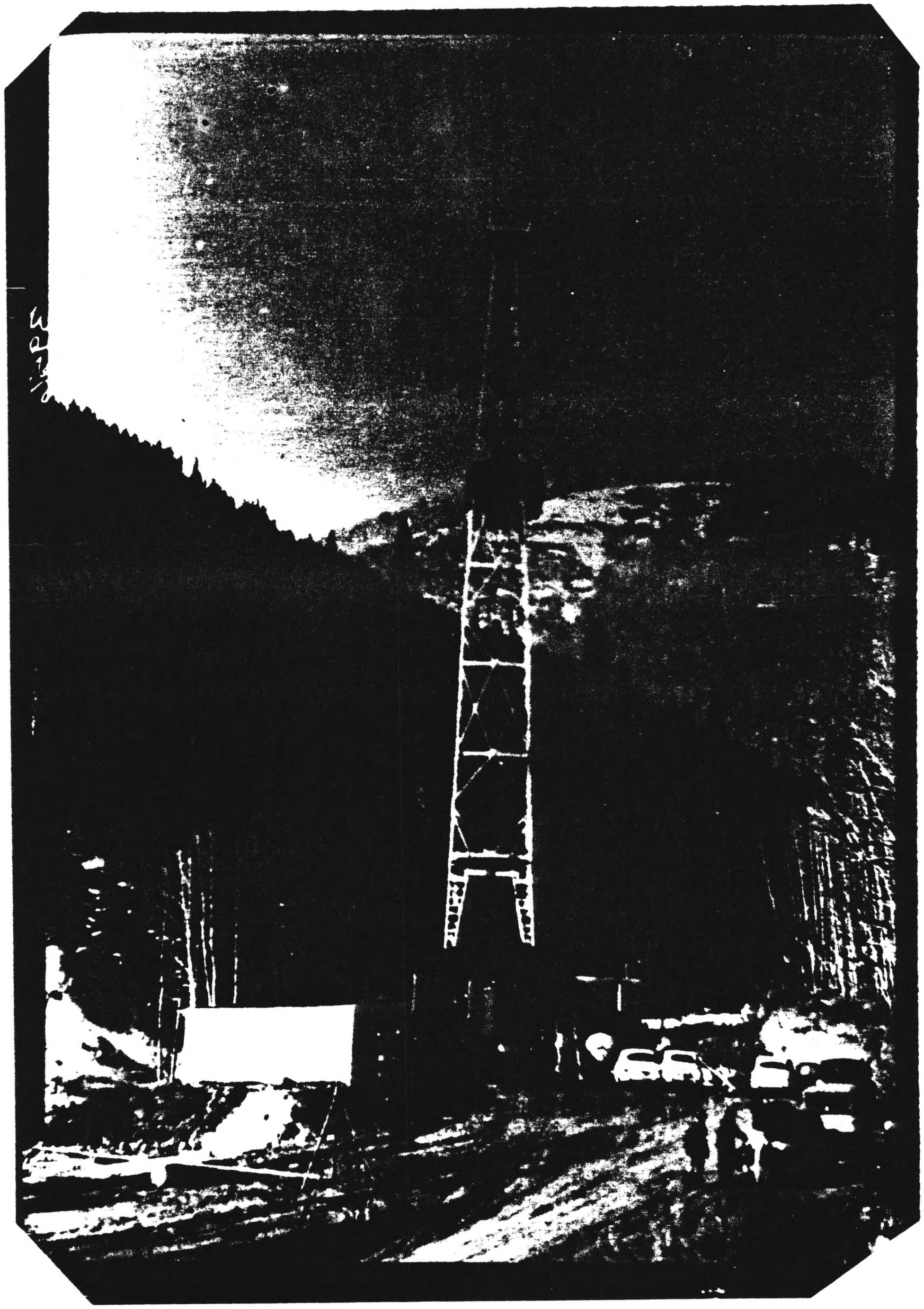

Plate 5: One of the first wells drilled at the Clear Creek field. Note the steep terrain, which hinders access to drill sites, and increases costs. (Photo used with permission of the Utah State Historical Society.)

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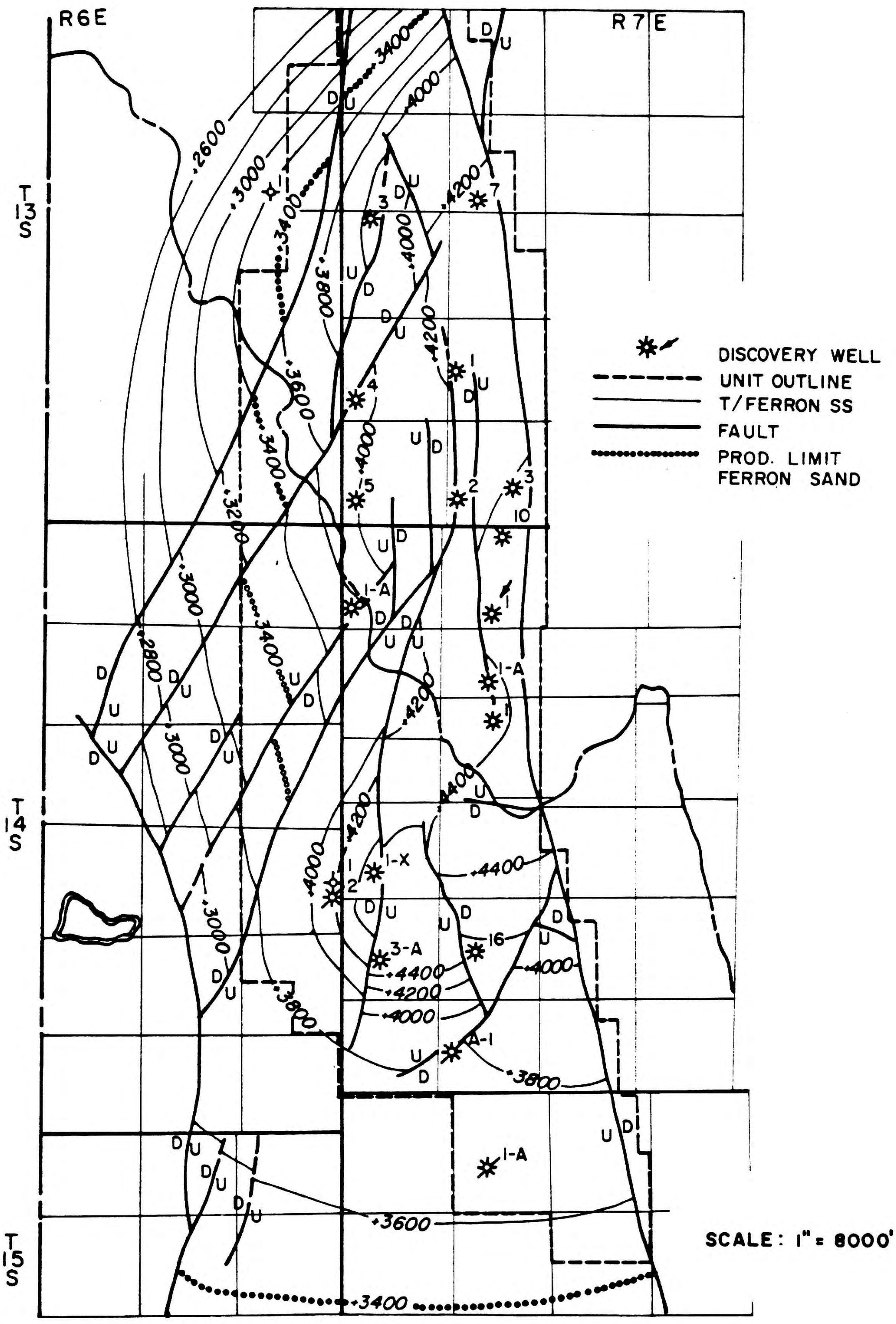

Fig. 6-3: Structure map of the Clear Creek field. (From Preston, 1961.)

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Ferron Sandstone. The Clear Creek structure is an anticline with numerous faults. Upthrown and downthrown sides of the faults are marked by "U" for up, and "D" for down. The highest point on the anticline is in the vicinity of section 30, Township 14 South, Range 7 East, where the Ferron structure is at approximately 4500' above sea level. The gas-water contact is at 3400', and is shown by a series of small circles along the contour lines that are at 3400'.

Figure 6-4 is a penetration chart for the Clear Creek field. Wells begin, or are **spudded** in the Blackhawk Formation. Gas is produced from the Ferron Sandstone at approximately the 5,000' level. The deepest drilling has been to a depth of 15,700' in the Hermosa Formation. The field was discovered in 1951 through the use of detailed geologic surface mapping, aerial photographs, and subsurface studies. When the anticlinal structure was mapped, a well was drilled, and gas was produced. As of November, 1987, there were 16 wells capable of producing. Total cumulative production for the field as of November, 1987 was 114,345,685 mcf, and 3,858 BW.

Figure 6-5 is an example of a wireline log from the producing Ferron interval at Clear Creek. The wireline log curve is from a gamma ray tool. Sandstones cause the log to kick to the left, and shales cause it to stay towards

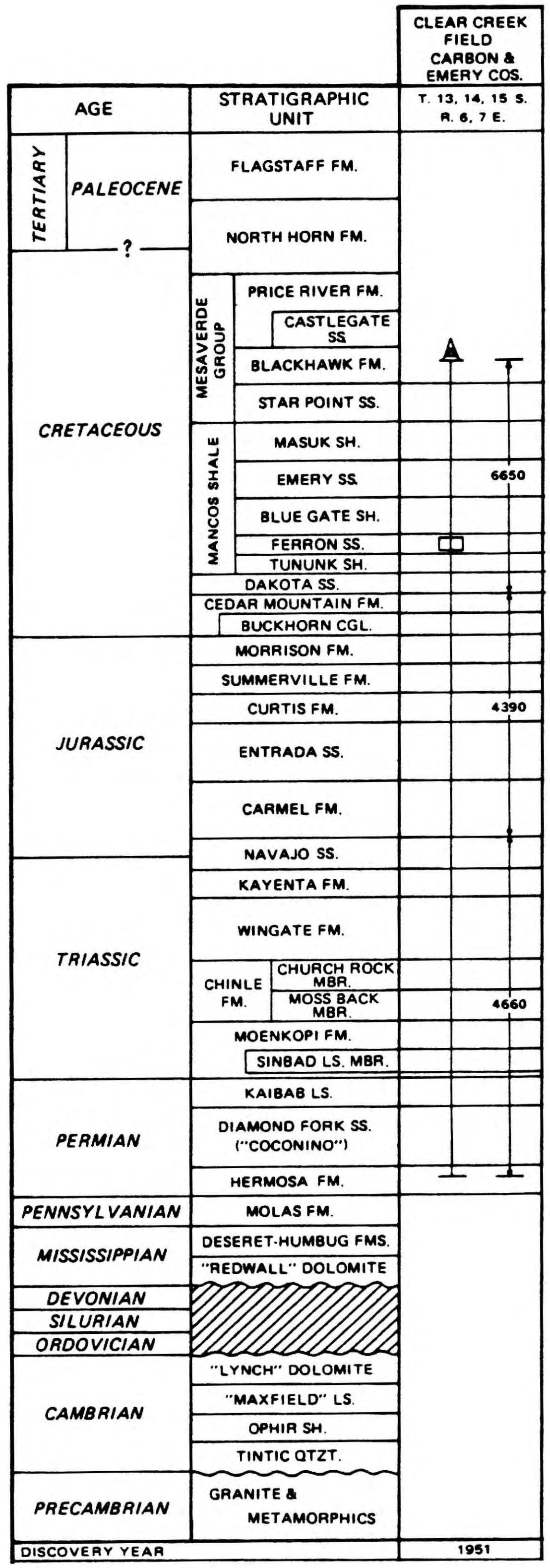

Fig. 6-4: Penetration chart for Clear Creek field. (From Campbell and Bacon, 1976.)

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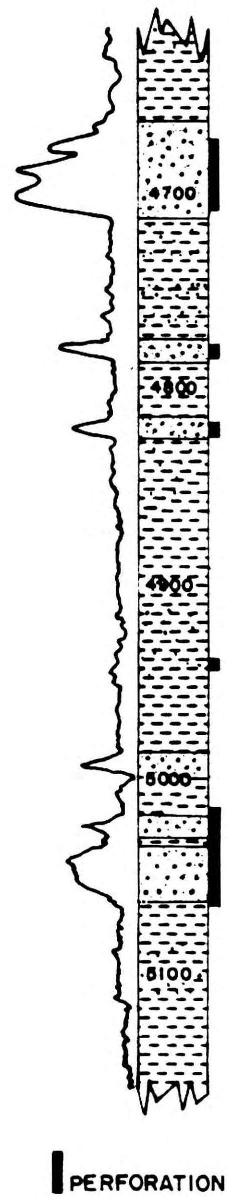

Fig. 6-5: Example of a wireline log (gamma ray tool), and sample log from the Clear Creek field showing the Ferron sandstone. (From Preston, 1961.)

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the right. The lithology of the well is plotted next to the gamma ray curve. The standard geologic symbols (see Appendix) are used to represent rock type. Also plotted on the wireline log is the depth of the well, and the sandstone intervals where the well has been perforated.

These sandstones were deposited along the shoreline of the ancient Cretaceous seaway (figure 1-9). The ocean level fluctuated during the time of deposition of the Ferron. When the ocean was deep in the Clear Creek area, shales were deposited. When the ocean was shallow, sandstones were deposited.

The reservoir characteristics (porosity and permeability) of these sandstones are enhanced because of the extensive faulting in the area. This faulting has created fractures within the rocks which enable the gas to migrate more freely into the well bores.

6.3 Upper Valley Field

The Upper Valley Field is located in the Kaiparowits Basin, and is the only productive field in this province. It is 23 miles east of "Ruby's Inn" at Bryce Canyon, and 11 miles southwest of the town of Escalante, in Townships 36 and 37 South, Ranges 1 and 2 East, Garfield County.

Figure 6-6 is a structure map based on the top of the "Beta" marker or the top of the Kaibab Formation. The structure of the field is an anticline, which has steeper dips on the west side. There is no faulting present. The highest point on the structure is shown by the 1000 foot contour in the vicinity of Section 12, Township 36 South, Range 1 East. The productive limits of the field are shown by the dashed line. Upper Valley is a unique example of an anticlinal trap with a hydrodynamic (water) drive. The productive limit does not include all of the crest of the anticline, but rather, production is offset to the southwest because of this water drive.

Figure 6-7 is a penetration chart for the Upper Valley field. The formation at the surface is the Cretaceous Dakota. Oil is produced from the Triassic Timpoweap Member of the Moenkopi Formation, and the Permian Kaibab Formation at a depth of approximately 6500'. Significant oil shows have been reported from the White Rim and the Cedar Mesa. Production was established in the Redwall Formation, but has been abandoned. The deepest well penetrated to 10,120' in the Cambrian Muav Formation. Tenneco Oil discovered the field in 1964 by surface geologic mapping and seismic surveying. The first well drilled was on the crest of the structure, and was plugged and abandoned. It was drilled by the California Company in 1947 and 1948 to a depth of 8857' in the Mississippian, and encountered water and mud

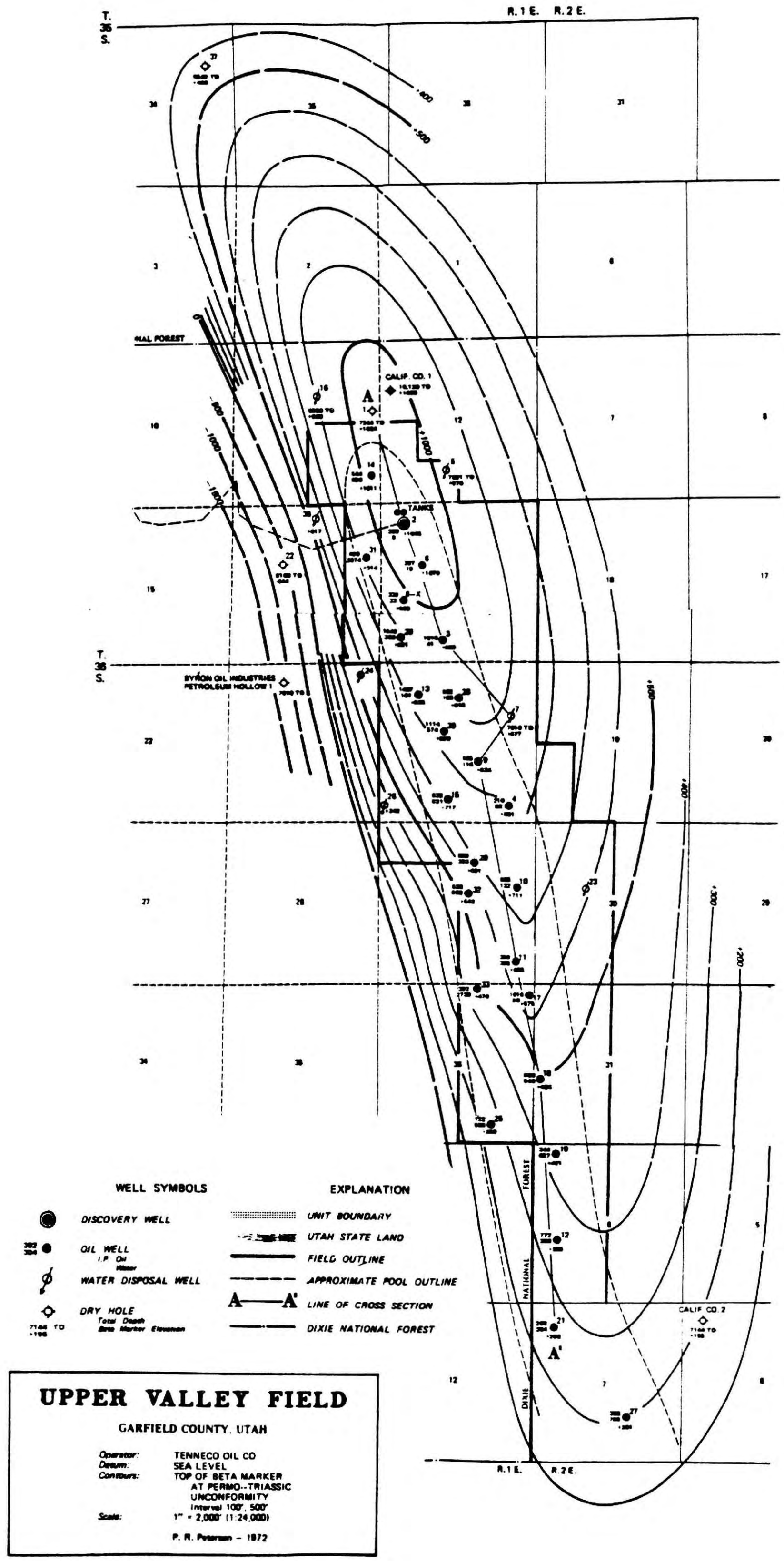

Fig. 6-6: Structure map of the Upper Valley field. (From Peterson, 1972.)

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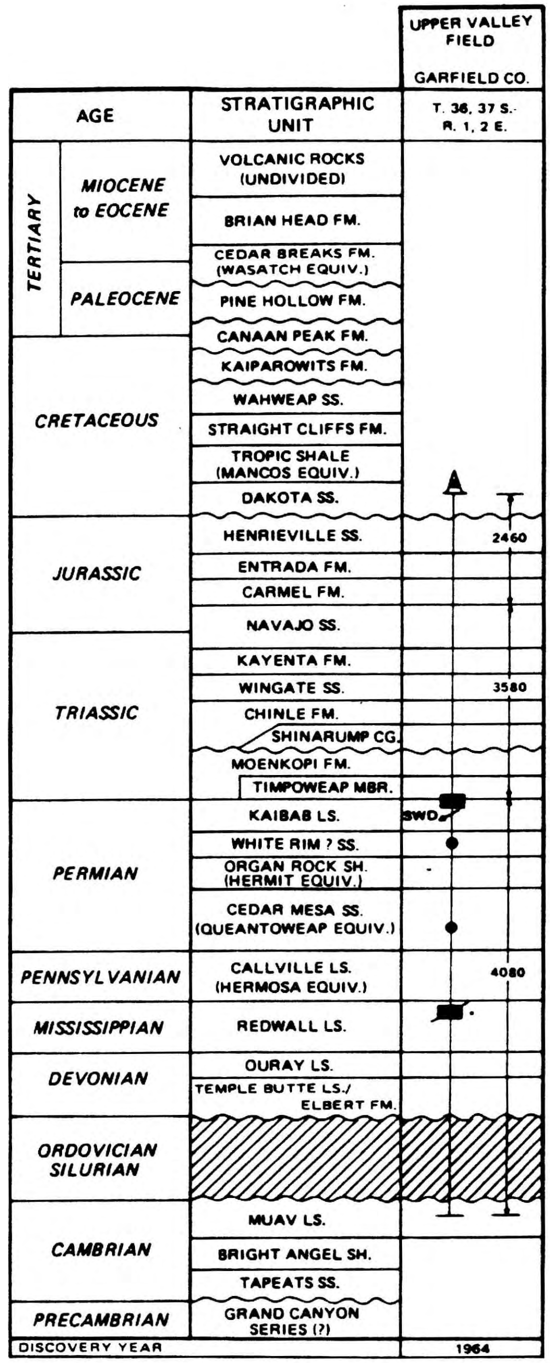

Fig. 6-7: Penetration chart for Upper Valley field. (From Campbell and Bacon, 1976.)

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with oil and gas shows during numerous drill stem tests. The well was finally completed as a Mississippian oil producer, but later abandoned after producing only 17,000 barrels of oil, because of the high water content associated with the oil. Two more dry holes were drilled on the structure in 1952, and 1962. Finally, Tenneco Oil drilled a fourth well in 1964 that had an IP of 300 BOPD from the Timpoweap/Kaibab section, and the Upper Valley field was discovered. As of November, 1987 there were 24 wells producing in the field. Total cumulative production as of November, 1987 was: 20,439,437 BO, and 250,231,610 BW.

Figure 6-8 is a wireline log from the Upper Valley #4 well, showing the productive intervals. The wireline log curves include a gamma ray log on the left, and a neutron log on the right. In general, when both logs kick towards the left, it indicates that potential reservoir rock has been encountered. The lithology of the Timpoweap/Kaibab interval is dolomite. Porosity and permeability variations within the field are caused by varying amounts of mud associated with the dolomites.

Tenneco has separated the Timpoweap and Kaibab units into separate zones, based upon samples, and wireline log correlations. They have named these zones K-1 through K-4**Ø**. All of the zones are productive, in varying degrees,

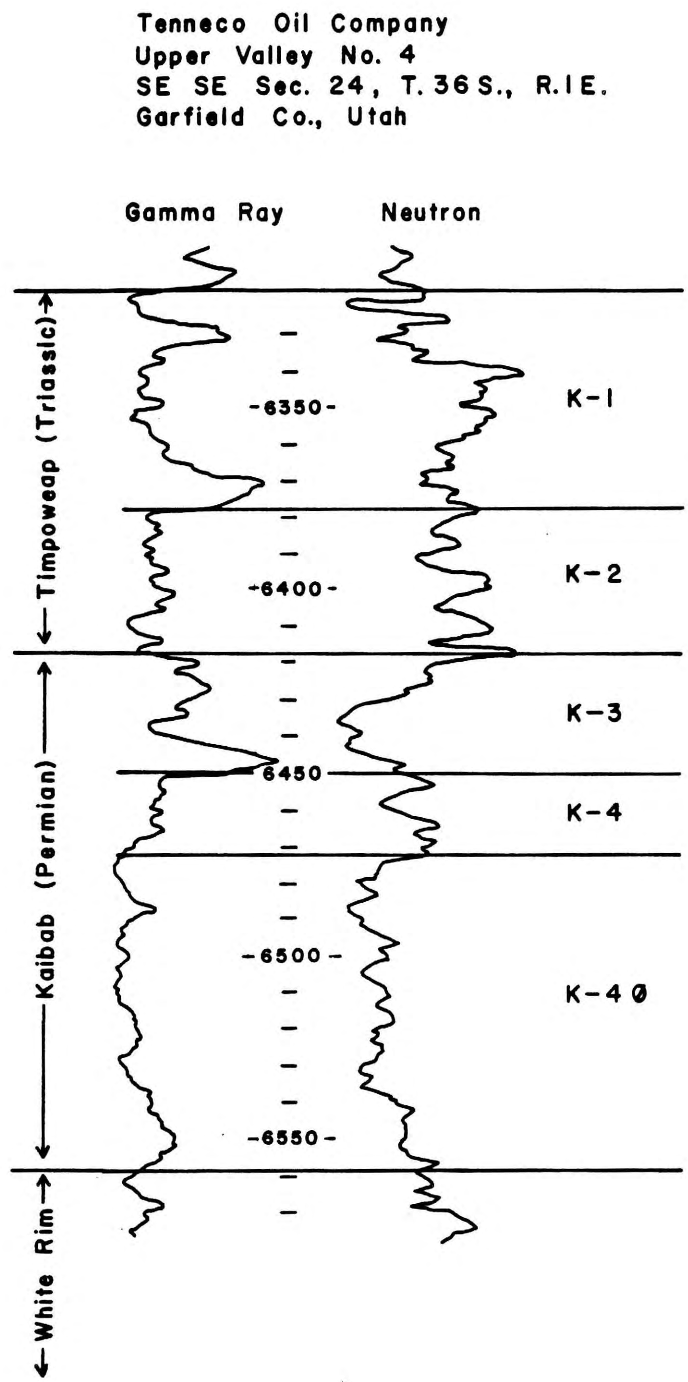

Fig. 6-8: Example of a wireline log from the Upper Valley field. (Modified from Sharp, 1976.)

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with the exception of the K-4 zone. The zone immediately underlying the K-4 zone, however, is the most prolific in the field, and is called the K-4Ø. This zone is composed of grain-supported dolomite, that was deposited in an open, shallow marine setting. Porosity averages approximately 18% for the zone; porosities below 14% are considered to be nonproductive. Variations in reservoir quality throughout the field caused by mud associated with the dolomite, are due to a facies change; this causes a significant decrease in permeability. The wireline logs and the core porosity values do not always reflect this facies change. It is, however, evident when permeability measurements are made on cores taken from the Timpoweap/Kaibab intervals.

There has been some fracturing of the reservoir rocks due to structural uplift. In zones K-1 through K-3, it is thought to aid production. It is apparently does not aid production from the K-4Ø zone.

6.4 Aneth Field

The Greater Aneth field complex lies within the Paradox Basin geologic province, and is the largest oil field in Utah. It is actually composed of six fields: Aneth, McElmo Creek, Big Wash, Cahone Mesa, White Mesa, and Ratherford. Aneth is the largest of the six, and forms the north side of the horseshoe-shaped complex. Situated in the southeast corner of the state, it is about 25 miles southeast of Blanding in Township 40 South, Ranges 23-25 East, in San Juan County.

Figure 6-9 is a structure map of the Aneth field based on the top of the Desert Creek, which is the main producing zone. Structurally, the field lies on a northwest trending anticlinal nose.

Figure 6-10 is a penetration chart for the Greater Aneth field complex. This area covers Townships 40-42 South, and Ranges 23-25 East. Wells are spudded in the Brushy Basin Member of the Morrison Formation. Oil and gas are produced from the Ismay and Desert Creek Members of the Pennsylvanian Paradox Formation, at about the 5700' level. The deepest drilling penetrated to the Devonian Ouray Formation at 7640'. Discovery was in 1956 by the Texas (now Texaco) Company, who drilled the Texaco No. 1C Navajo well in the NW1/4 NE1/4 of Section 23, Township 40 South, Range 24 East, because it was on an anticlinal trend. Plate 6 is a photo of the discovery well. IP was 1704 barrels of oil per day. As of November, 1987, there were 682 wells capable of producing in the Greater Aneth field complex. Total cumulative production as of November, 1987 is 213,640,884 BO; 195,727,743 mcf; and 628,704,596 BW from the six fields in the complex.

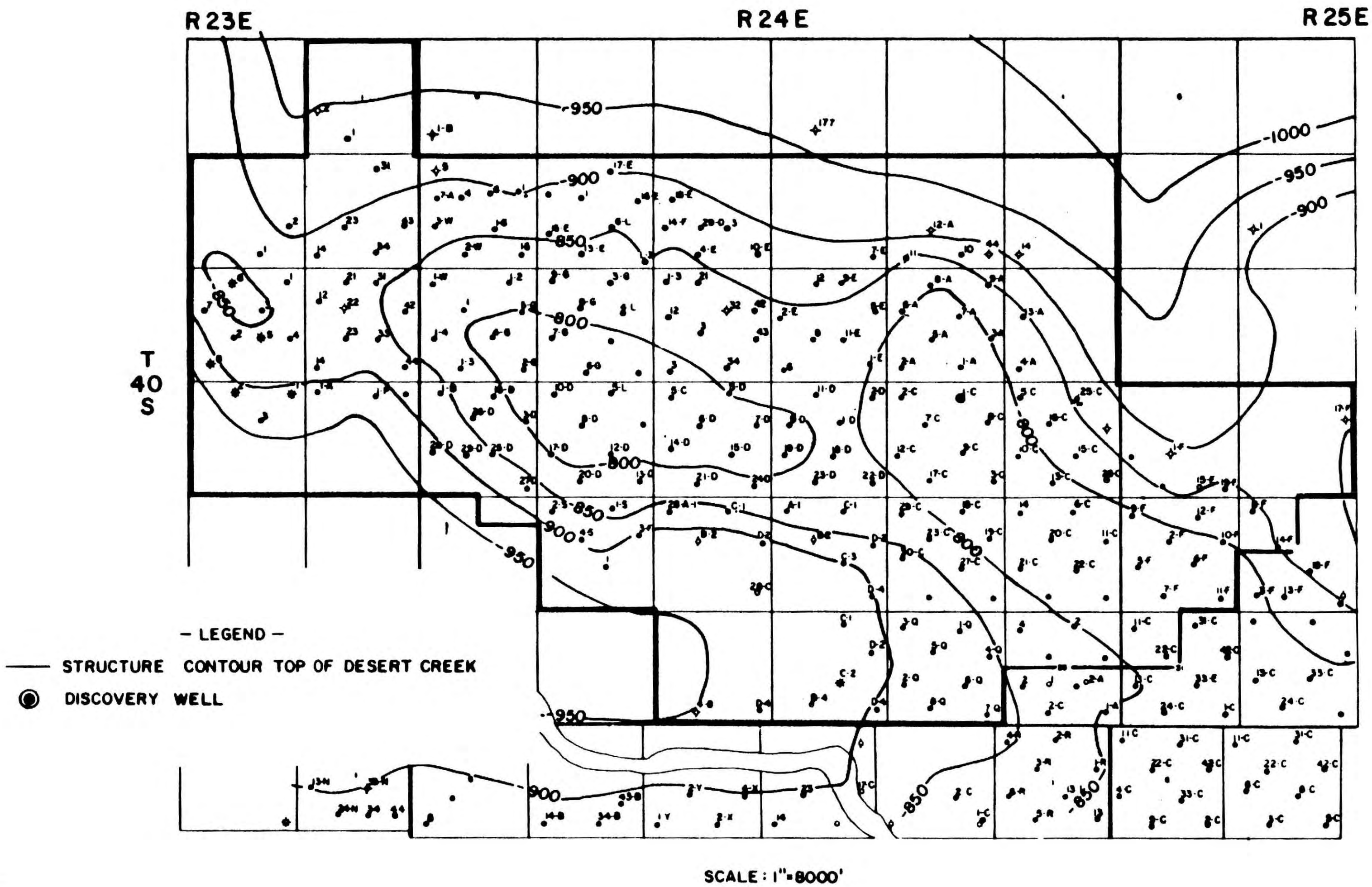

Fig. 6-9: Structure map of the Aneth field. (From Preston, 1961.)

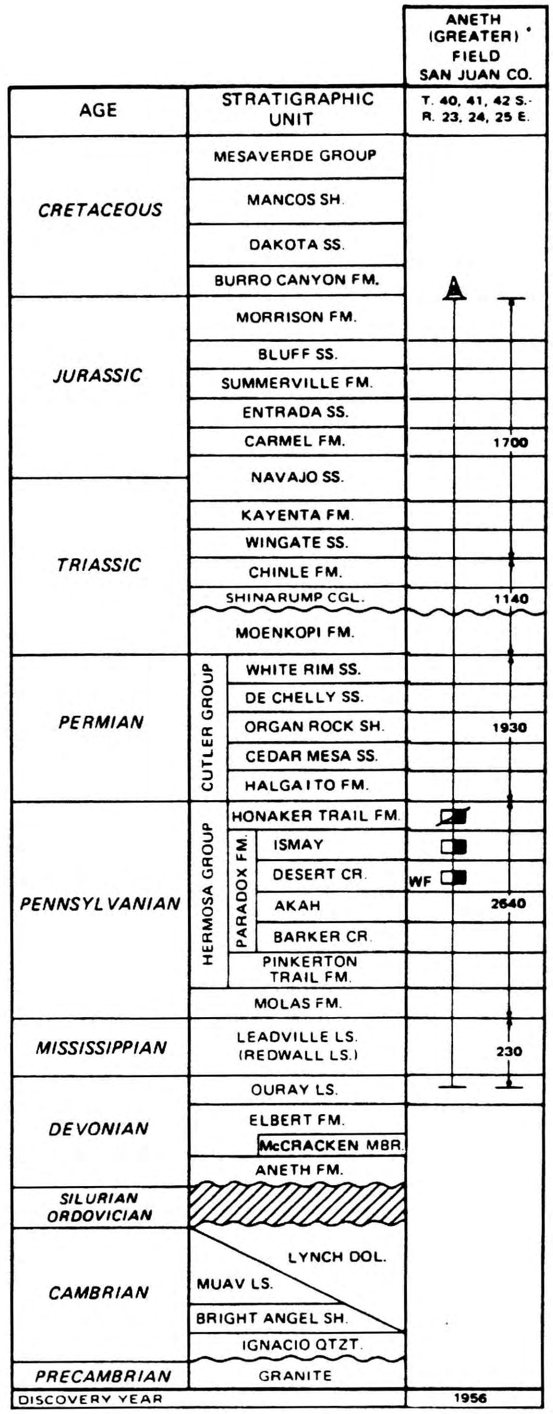

Fig. 6-10: Penetration chart for Aneth field.
(From Campbell and Bacon, 1976.)

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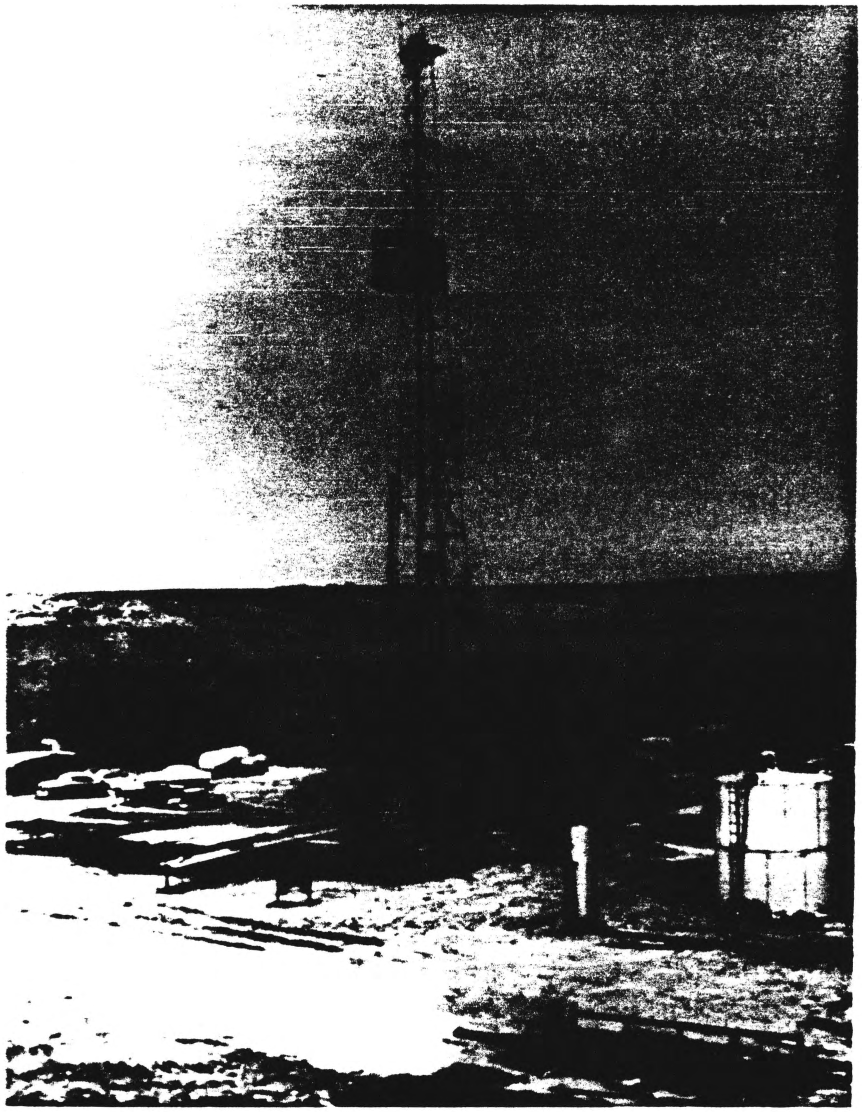

Plate 6: The Aneth field discovery well (Texaco No. 1C Navajo) had an IP of 1704 barrels of oil per day. Beds of Jurassic Morrison formation (Brushy Basin member) in background. (Photo used with permission of the Utah State Historical Society.)

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Most of the production in the Aneth area is from the Desert Creek interval which is being waterflooded. Waterflooding is a type of secondary recovery method. When most of the oil and gas in a field has been produced, secondary recovery methods are sometimes used. Waterflooding involves pumping water into the well bores of some of the wells. When this is done, the water goes into the reservoir rock, and pushes some of the remaining oil and gas ahead of it. Other wells in the field are selected as producer wells, and as the water is pumped into the well bores, and pushes the oil and gas along, these producer wells are pumped to produce the oil and gas that has been moved through the reservoir by the water. Sometimes, other recovery methods are tried after secondary recovery methods. This is called tertiary (for third) recovery. Unfortunately, primary, secondary, and tertiary recovery methods combined, still leave 50-75% of the oil behind in the reservoir rock. About 25% of the oil is recovered by primary means (when the well is pumped). Secondary and tertiary methods are able to recover only an additional 10-25% of the oil.

Figure 6-11 is an example of a wireline log from a well in the Aneth field. The rocks with good porosity and permeability cause the gamma ray curve on the left, and the neutron curve on the right, to kick to the left. In between the wireline curves is a sample log, using the

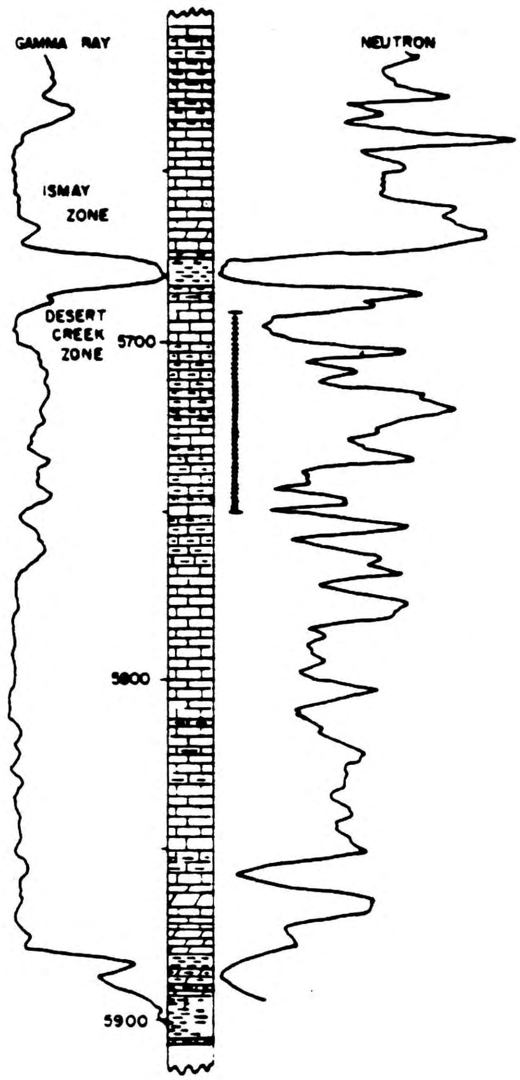

Fig. 6-11: Example of a wireline and sample log from the Aneth field, showing the perforated zone in the upper Desert Creek. (From Preston, 1961.)

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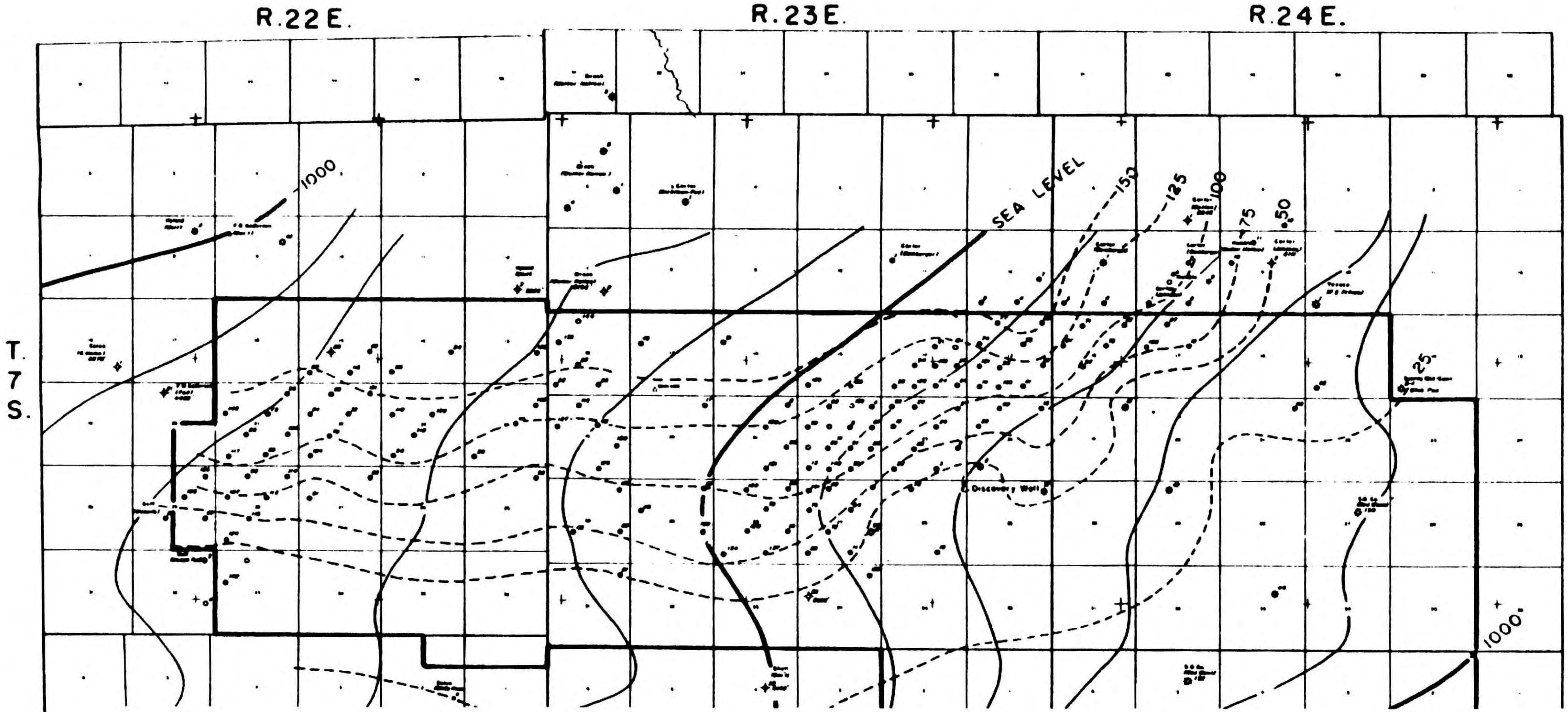
standard lithologic symbols shown in the Appendix. The productive interval in the Desert Creek, is shown from 5680' to 5750'.

The entrapment of hydrocarbons in the Greater Aneth field complex is only partially due to the anticlinal noses present. The Desert Creek production in this area is from a reef-like circular mound of porous, fossiliferous carbonates. As in the case of the reef depositional model shown in figure 1-6, these carbonates thin rapidly as drilling moves off of the main reef trend. They grade into an impermeable shaley limestone section. This permeability barrier forms the trapping mechanism.

6.5 Red Wash Field

The Red Wash field is located in the northeastern portion of the Uinta Basin geologic province. It is approximately 22 miles southeast of Vernal, in Township 7 South, Ranges 22-24 East, Uintah County.

Figure 6-12 is a structure map of the Red Wash field, based on the top of the producing zone in the lower Green River formation. Although Red Was produces primarily due to stratigraphic entrapment, a westerly plunging anticlinal nose is partially responsible for the hydrocarbon accumulation.



NET SANDSTONE ISOLITHS OF MAIN PRODUCING ZONE ISOLITH INTERVAL-25'

STRUCTURE CONTOURS ON TOP OF MAIN PRODUCING ZONE IN LOWER GREEN RIVER FM. CONTOUR INT-200'

SCALE : 1" = 12,000'

Fig. 6-12: Structure map of the Red Wash field. (From Preston, 1961.)

Figure 6-13 is a penetration chart for the Greater Red Wash field area. This area includes not only Red Wash field, but also Gypsum Hills, Powder Spring, Refuge, Stagecoach, Walker Hollow, White River, and Wonsits Valley fields. Wells are spudded in the Duchesne River Formation. Gas is produced from the Uinta Formation, and oil and gas are produced from the Green River, Wasatch, and Mesaverde Formations. A significant oil show was noted in the Weber. Gas injection and waterflooding are being used as secondary recovery methods in the Green River Formation, which is the primary productive horizon. The Red Wash field produces from a depth of approximately 5500', in the lower Green River Formation. The deepest drilling in the field complex, has been to a depth of 18,610' in the Permian Weber Formation. Discovery of the Red Wash field was made in 1950 after surface geologic mapping and seismic surveying delineated the anticlinal nose. As of November 1987, there were 221 wells in the Red Wash field. Total cumulative production from the Red Wash field as of November 1987, was 69,505,533 BO, 252,357,499 mcf, and 205,514,535 BW.

Figure 6-14 is a type log from the Red Wash field for the producing interval in the lower Green River Formation. The S.P. curve kicks to the left when potential reservoir rocks are encountered. As can be seen from the log, there are numerous thin sandstone horizons which are productive.

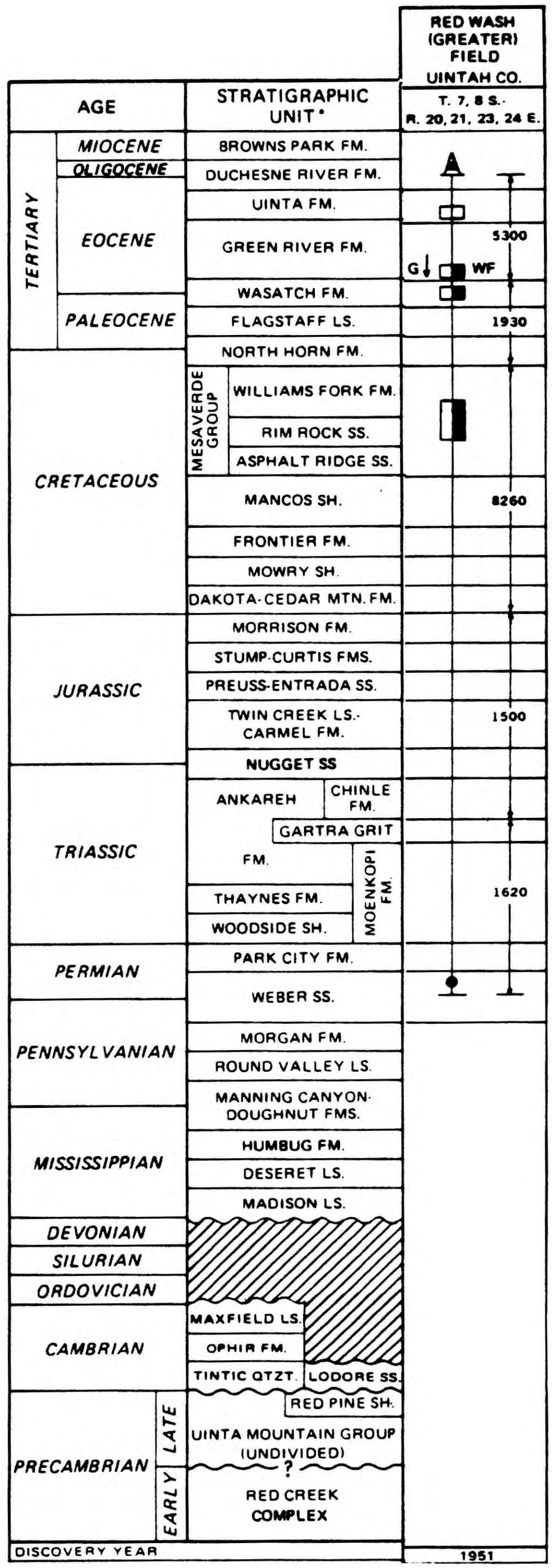


Fig. 6-13: Penetration chart for Red Wash field.
(From Campbell and Bacon, 1976.)

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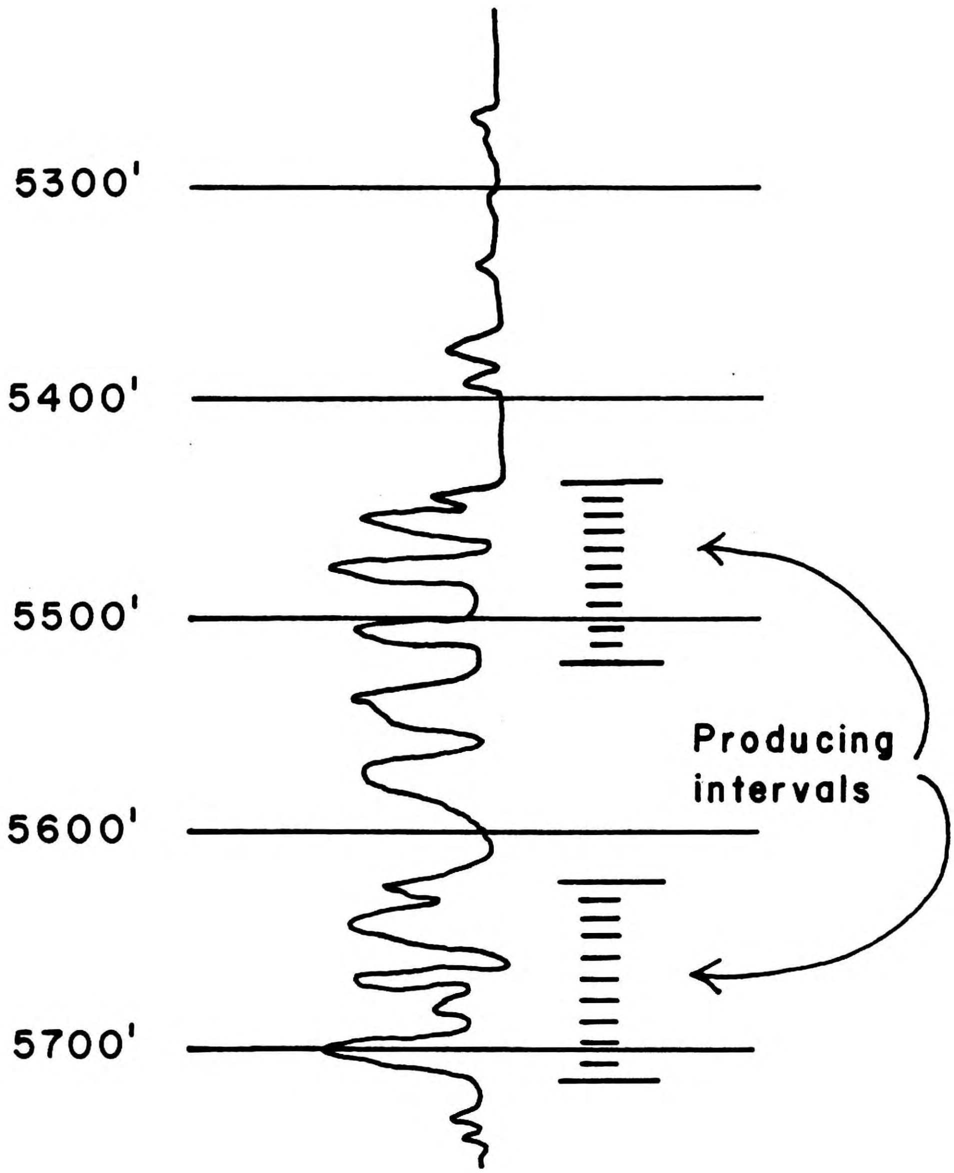

Fig. 6-14: Example of a wireline log from the Red Wash Field. Log shows the Spontaneous Potential curve and perforated intervals in the lower Green River formation. (Modified from Preston, 1961.)

The primary reason for hydrocarbon entrapment at Red Wash, is due to the updip pinchout of these thin lacustrine shoreline sandstones into open lacustrine, organic-rich shales. Deposition of these sandstones has been within the marginal lacustrine facies of Fouch's lake model (figure 1-8). The depositional trend and thickness of these reservoir rocks is shown by a sandstone isopach map, which is overlain on the structural contour map in figure 6-12. The open lacustrine facies provides not only the trapping mechanism, but the source rocks, as well.

6.6 Pineview Field

The Pineview field is located approximately 7 miles from the southwest corner of the state of Wyoming and approximately 11 miles east of Coalville, in Township 2 North, Range 7 East, Summit County, Utah. It is situated within the Overthrust Belt portion of the Green River Basin geologic province.

The Overthrust Belt trends in a roughly north-south direction from Canada, to Mexico (figure 6-15). In Canada, and Montana, it is called the Disturbed Belt; in Woming and northern Utah, it is known as the Overthrust Belt; in central and southern Utah, it is called the Cordilleran Hingeline. This major geologic feature is a vast zone of thrust faulting caused by the compressional

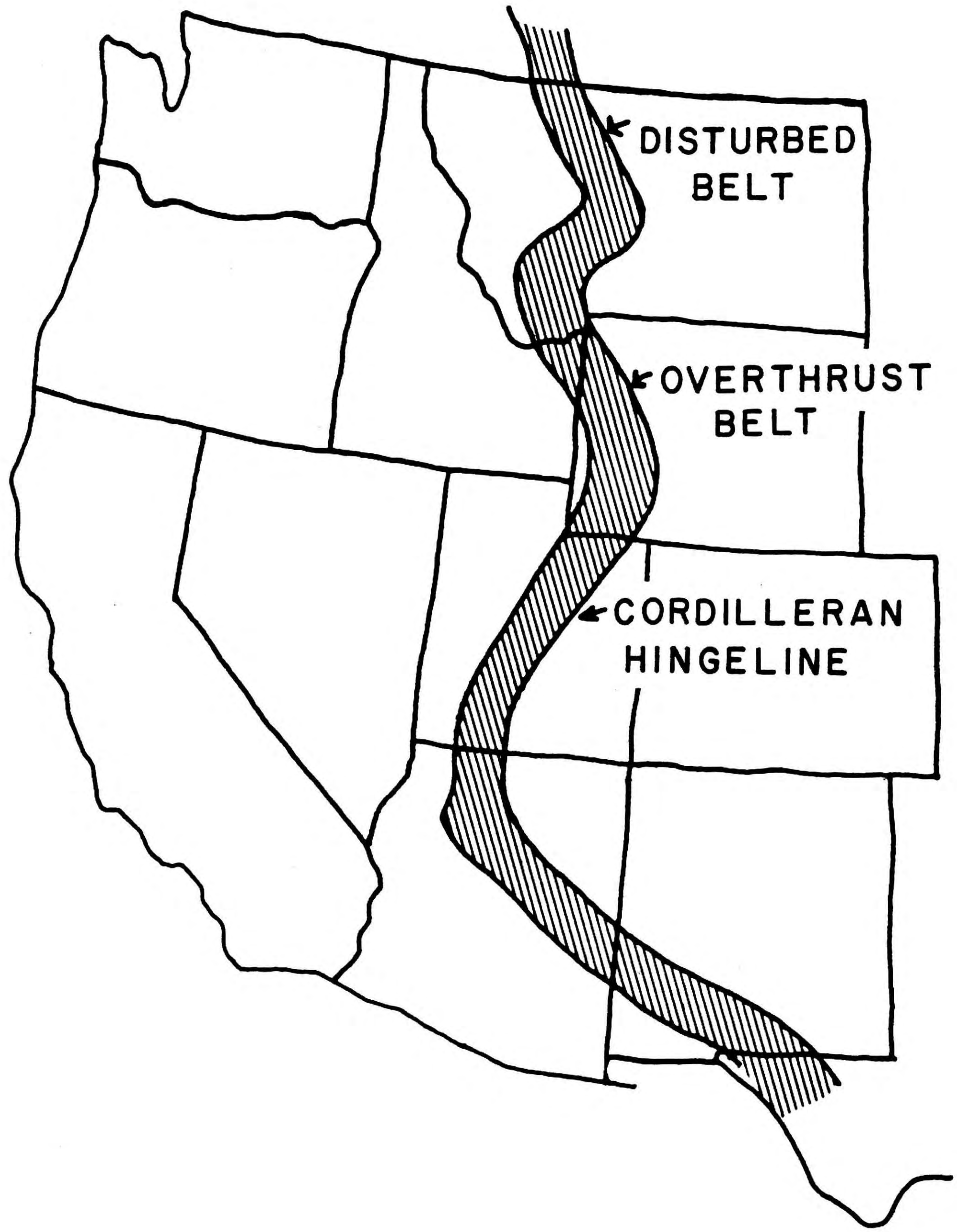

Fig. 6-15: Map of western U.S. showing trend and nomenclature of Rocky Mountain Thrust Belt. (Modified from Hyne, 1984.)

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forces which shaped the Rocky Mountains. In the late Cretaceous through early Tertiary, thrusting moved rock sequences tens of miles horizontally (figure 2-7). The types of traps created in response to this thrusting are called drag folds (figure 4-3c). Drag folds are formed by friction between the fault blocks. This friction causes the beds on either side of the fault plane to be dragged up on one side, and down on the other. A west-east subsurface cross-section (figure 6-16) of the Pineview field shows these drag folds.

A penetration chart for the Pineview field (figure 6-17), shows wells have spudded in Tertiary Wasatch Formation, and have established oil and gas production in the Twin Creek Limestone and Nugget Sandstone intervals at approximately 9900'. Since this chart was prepared in 1976, significant production has been established in the Stump Formation, and minor production in the Frontier and Kelvin Formations. There is no production below the main thrust. The deepest well penetrated to 14,500' in the **subthrust** (or below the thrust) Cretaceous section. The field was discovered in 1975 by seismic surveying and surface geologic mapping. As of November 1987, there were 41 wells in the field. Total cumulative production as of November 1987, has been 22,707,716 BO; 26,996,329 mcf; and 31,775,725 BW.

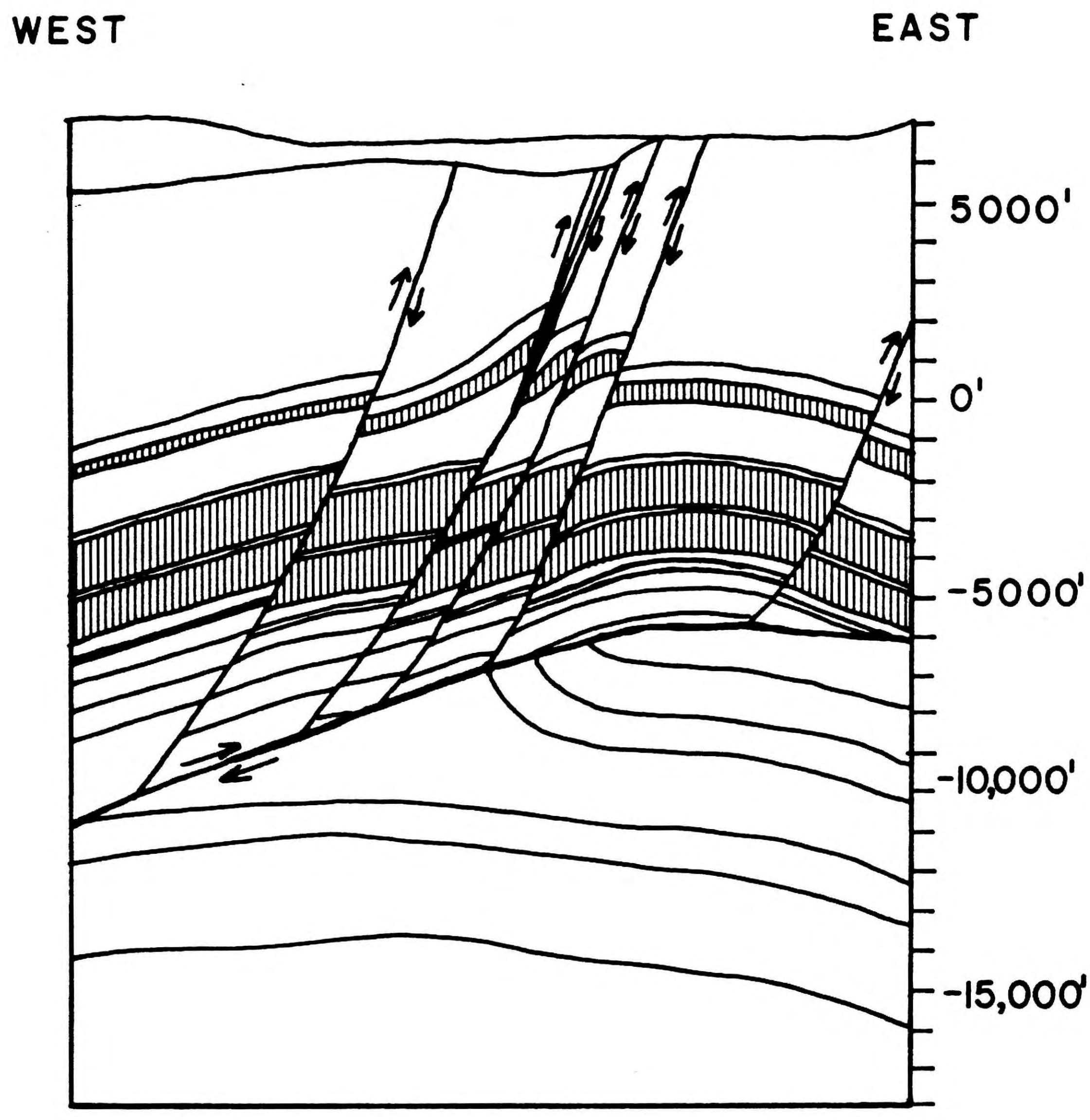

Fig. 6-16: Structural cross-section of the Pineview field. From surface down, zones with hydrocarbons are Stump, Twin Creek, and Nugget, and are shown by [vertical-ruled pattern]. (Modified from Maher, 1976.)

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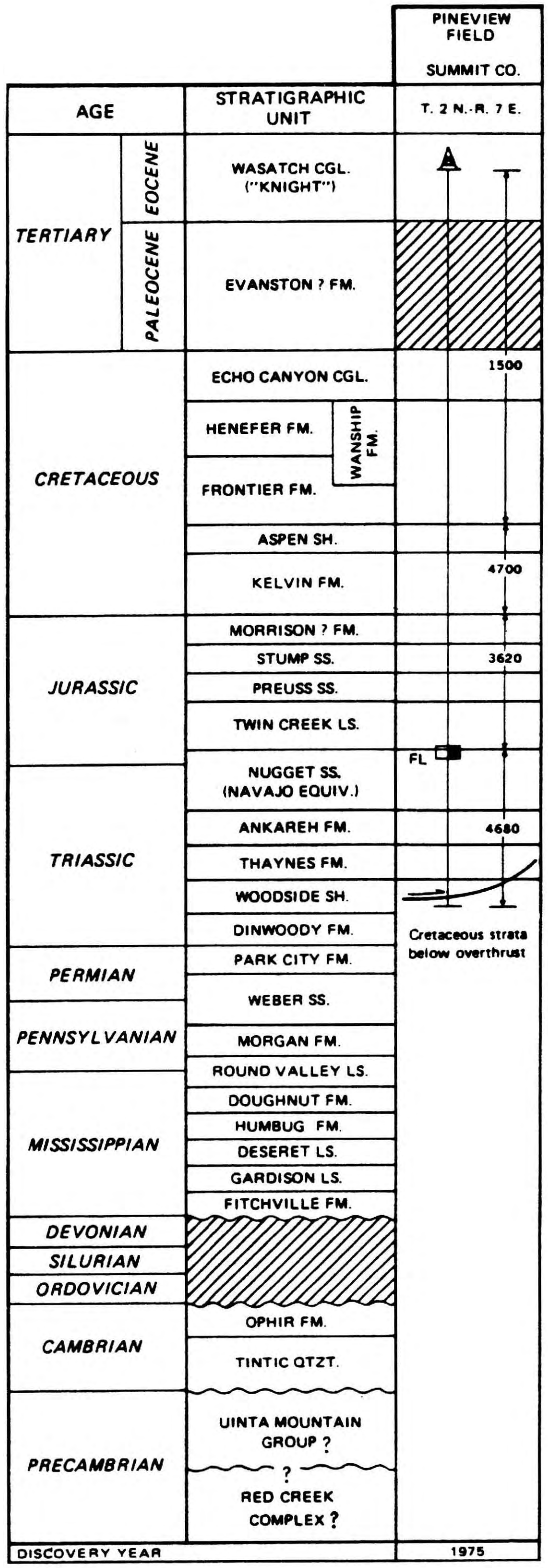

Fig. 6-17: Penetration chart for Pineview field.
(From Campbell and Bacon, 1976.)

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The producing horizons at Pineview are Jurassic in age. The Stump Formation varies in thickness from 300 to 400 feet thick. It is predominantly sandy, with interbedded, varicolored shales. Glauconite, a mineral generally indicative of shallow marine conditions is present. The Twin Creek Formation is approximately 1300' thick and is composed of interbedded light to dark limestone and hard, grey, calcareous shales. The depositonal environment was shallow marine. The Nugget Formation is approximately 1100' thick and was deposited by the wind (eolian). It is a white to tan, fine to coarse-grained sandstone, grading downward into a red and salmon colored sandstone.

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APPENDIX

GEOLOGIC TIME SCALE

ERA	PERIOD OR SYSTEM	EPOCH OR SERIES (1)	M.Y. AGO (2)	DURATION M.Y. (2)	SIGNIFICANT BIOLOGICAL EVENTS (FIRST OCCURRENCE)
CENOZOIC	QUATERNARY	Holocene	Last	10,000 yrs.	
		Pleistocene	.010	1.59	
	TERTIARY	Pliocene	1.6	3.7	Man
		Miocene	5.3	18.4	Manlike Primates
		Oligocene	23.7	12.9	Apes
		Eocene	36.6	21.2	Elephants, grasses
		Paleocene	57.8	8.6	Horses
MESOZOIC	CRETACEOUS		66.4	77.6	Extinction of: Dinosaurs, giant marine and flying reptiles; Snakes; Primates
	JURASSIC		144	64	Sequoias; Birds
	TRIASSIC		208	37	Turtles and lizards; Dinosaurs and Mammals; Last of giant amphibians
PALEOZOIC	PERMIAN		245	41	Extinction of: trilobites, many corals, many invertebrates; Mammal-like reptiles
	PENNSYLVANIAN		286	34	Conifers, ferns, ginkgoes, reptiles; Flying insects
	MISSISSIPPIAN		320	40	Seed plants
	DEVONIAN		360	48	Land living vertebrates; Sharks; Forrests and insects; Ammonites
	SILURIAN		408	30	Land vegetation and air breathing animals
	ORDOVICIAN		438	67	Bone-bearing animals; Corals and bryozoans
	CAMBRIAN		505	65	Pelecypods; Conodonts; Gastropods; Arthropods, mollusks, sponges
PRE-CAMBRIAN	Oldest known rocks in U.S. are 3.6 billion years old.		570		

(1) Epoch names are less frequently used in Mesozoic and Paleozoic eras.

(2) M.Y. = Millions of years

Modified from Stokes, 1973 and Palmer, 1983.

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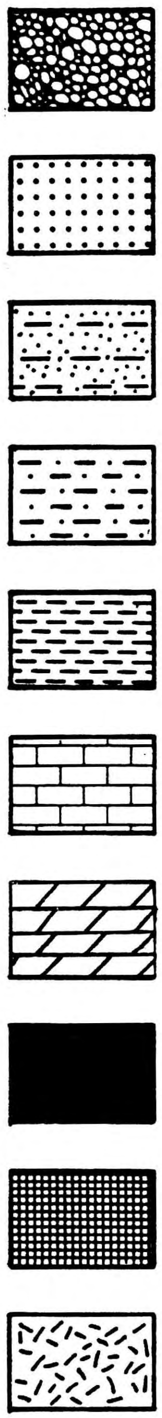
LITHOLOGIC SYMBOLS



CONGLOMERATE

SANDSTONE

SHALEY SANDSTONE

SILTSTONE

SHALE

LIMESTONE

DOLOMITE

COAL

SALT

IGNEOUS ROCKS

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OIL AND GAS SYMBOLS

- LOCATION
- OIL WELL
- GAS WELL
- OIL AND GAS WELL
- DRY HOLE
- DRY HOLE WITH OIL SHOW
- DRY HOLE WITH GAS SHOW
- DRY HOLE WITH OIL & GAS SHOW
- SHUT-IN WELL
- ABANDONED OIL WELL
- ABANDONED GAS WELL
- INJECTION WELL
- PERFORATIONS
- CORED INTERVAL
- DRILL STEM TEST INTERVAL

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