BASIC PETROLEUM GEOLOGY

By

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Laramie, Wyoming

Paper 1

BIOGRAPHICAL SKETCH

Daniel N. Miller, Jr.

Dan Miller is State Geologist of Wyoming and Executive Director of the Wyoming Geological Survey in Laramie. He received Bachelor of Science and Master of Science degrees in Geology from Missouri School of Mines and Metallurgy, and a Ph. D. in Geology from the University of Texas in 1955. He was employed in the exploration phase of the petroleum industry for a total of eleven years, and then served six years as Professor and Chairman of the Department of Geology at Southern Illinois University from 1963 to 1969. He is presently serving a second six-year appointment as State Geologist and Commissioner with the Wyoming Oil and Gas Conservation Commission.

Mr. Miller is a member of many local, regional, and national professional organizations, and is President-elect of the Association of American State Geologists for 1978-79.

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Introduction to Sedimentary Geology

The concepts of sedimentary geology most often applied to exploration and development of petroleum resources are based on rather fundamental principles and physical laws, extensive data, and more than seventy years of practical application. They evolved over the years as geologists in industry collected and exchanged information among themselves and with geologists in universities and state and federal agencies. Basically, the concepts deal with the types of changes that have modified the earth's surface throughout geologic time.

To a non-geologist the concepts may at first seem vague and highly interpretive, but for the most part such an impression is both temporary and superficial. The following material is arranged to provide non-geologists with a better understanding of the principles that are applied in geological reasoning in an effort to explain definitions and illustrations most commonly used by the petroleum industry, with emphasis on technology and the adequacy and validity of data.

North America - a hypothetical model of sedimentary processes

Assume for the sake of brevity, that sometime long ago in the geologic past a broad bulge developed in the earth's crust, and smaller wrinkles occurred in the bulge as the result of the crust's mobility under the influence of the earth's internal heat and pressure. As the wrinkles developed, great masses of rocky material emerged as islands above sea level where they became exposed to the atmosphere and subject to weathering and erosion. The loosened particles of rock, now under the influence of gravity, wind and water, washed back down the slopes. Some of the sediment was deposited at lower levels on the islands and along the shoreline; but with time, and the addition of more and more material, periferal blankets of sand, silt, and clay, were formed that extended well out to sea.

Assume further that the crustal movements within the earth changed from time to time, and that the size of the bulge and the shape and orientation of the wrinkles also changed. Old wrinkles submerged and became basins of deposition and new wrinkles formed that created new islands, and consequently new patterns of sediment distribution. Again and again the bulging and wrinkling processes continued throughout millions of years. Great land masses emerged above sea level as other areas subsided and filled with layers of sediment.

Accumulations of mud and silt from nearby islands began to coalesce and overlap each other forming distinctive bedded layers of strata, and finally consolidated into a broad mass of land more recognizable today because of the position of sea level, as the continent of North America (Fig. 1).

HYPOTHETICAL MODEL OF SEDIMENTARY GEOLOGY

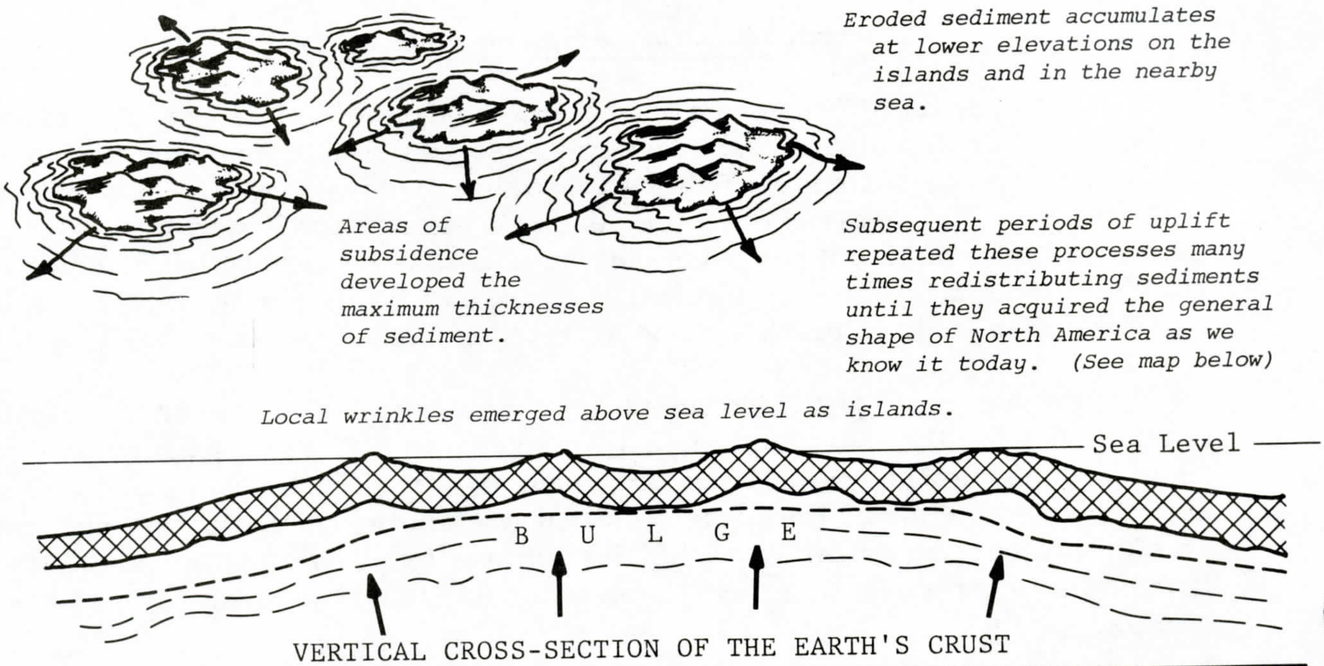


Figure 1 - Assume that the North American continent was once just a bulge in the earth's crust. Local wrinkles created islands that eroded to produce sediment that was later deposited at lower elevations. Assume further that this process was repeated many times and in different parts of the continent during the geologic past, and that it is still going on today.

In the western interior of the United States there are many deep structural basins where ten to twenty thousand feet of sedimentary rock are still preserved, and it is in these areas that the strata still contain vast accumulations of oil and gas as shown in Figure 1A.

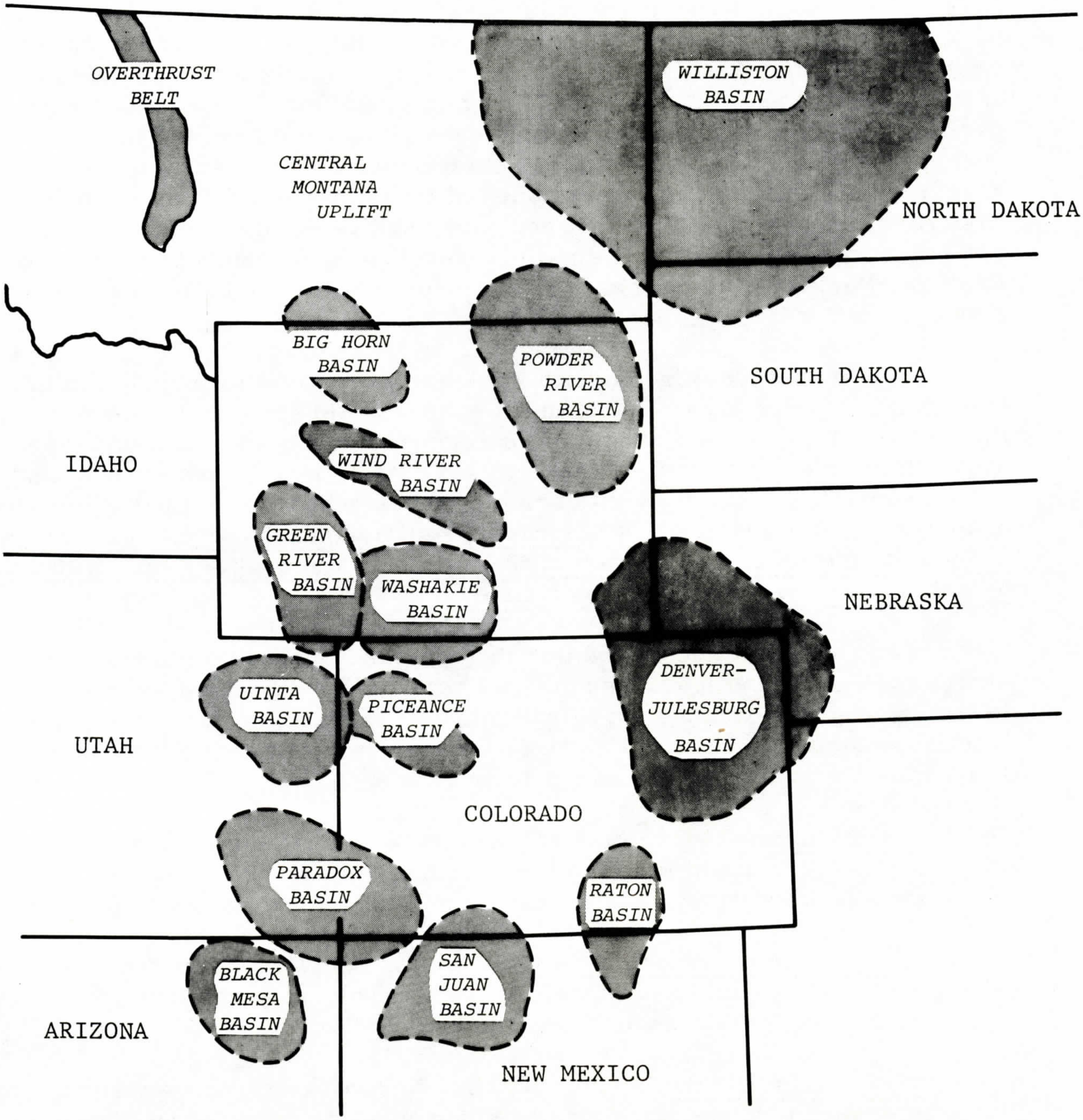


Figure 1A - Illustrates the outlines of the major structural basins in the Rocky Mountain states that still contain thick stratigraphic accumulations of sedimentary rock.

During the hundreds of millions of years while this activity was going on, the sediments were affected by periodic changes in climate and the local chemistry of their immediate environment. Primative forms of life evolved; first in the sea and later in brackish water swamps and fresh water rivers, and finally on land. Great forests and deserts were formed, and later destroyed. Large rivers contributed great volumes of sediment to the shorelines where huge deltas formed only to be destroyed completely, or in part, by subsequent uplift and erosion. The remains of some of these deposits, containing fossils of early forms of life, are still readily recognizable. Through extensive comparison of fossils and the distribution and type of rock in which they occur, geologists are able to piece together evidence of what the earth's surface must have been during the changing episodes of those primeaval times. In fact, they have gone much farther than that and have subdivided the hundreds of millions of years of geologic time into smaller more usable increments called geologic Eras and Periods, and Epochs, based on some of the major events in earth history.

Many thousands of geologists working in this country and abroad have contributed to our knowledge of uplifted areas, old erosional surfaces, and the relationships of the blankets of sedimentary rocks that surround them. Through their efforts a sub-science called "Stratigraphy" has evolved that permits geologists to interpret with some confidence at least the more important chapters of earth history. Stratigraphy, or stratigraphic geology, is the study of the character and distribution of the layers of sedimentary rock with respect to well-defined periods of geologic time.

In the broadest sense, and for the practical purpose of discussion here, strata are subdivided into three general categories:-those that were deposited in the sea (marine strata), marginal-marine strata that were formed in conjunction with shorelines, and those that were deposited on the land or in lakes and swamps that are called "non-marine strata".

"Marine strata" - are typically siltstone or shale or limestone having broad areal distribution over hundreds or thousands of square miles with relatively uniform composition and continuity.

"Marginal-marine strata" - are typically conglomerates and sandstones distributed in well defined sinuous patterns that in essence represent ancient shorelines.

"Non-marine strata" - are typically combinations of clayey sandstone and siltstone having more heterogeneous composition and more localized and erratic distribution.

Sediments that were deposited in conjunction with beaches and shorelines where wave agitation was greatest are normally the cleanest and have the most intergranular (pore) space. At the time of deposition the space between the grains was filled with water, air bubbles and bits of organic debris. Farther offshore the sediments were more poorly sorted and contained greater amounts of organic mud. As the organic matter in the sediments decomposed to form gases such as carbon dioxide, sulfer dioxide and methane, tiny bubbles percolated through the intergranular pore space wherever they could on their way to the surface, displacing the water.

During burial, as new sediments accumulated over the top, the deposits readjusted to the weight and the underlying sediments became more compact. Water and the more volatile gases shifted about in the pore space between the grains until the pressures, acting in all directions, reached an equilibrium. As pressure and temperature conditions changed in the sediment, the pore space, and the distribution of fluids all changed correspondingly. Eventually the physical structure of the sediments reached a more solidified state, normally referred to as rock, due in part to compaction and in part to mineral precipitation. From that point on the beds of rock material responded in a more rigid manner to physical and chemical changes by fracturing, jointing, folding, or even faulting.

Stratigraphic concepts - interpretation of layered rock sequences

Stratigraphy, as a sub-science of geology, is the interpretation of layered, sedimentary, rock sequences in relation to a specific period of geologic time. In other words, a stratigrapher is a geologist who studies the lateral distribution and character of strata. The ultimate goal of a stratigrapher is to be able to correlate individual rock units (strata) with contemporaneous geologic events in other nearby areas. For purposes of this discussion, simply accept the fact that geologists have defined and established nomenclature for the thicker and significant strata and for the intervals of time they represent. For convenience and simplicity in visualization the rock and time units are most often illustrated as a (vertical) geologic column (Fig. 2).

In every case there are two basic assumptions that are fundamental to all stratigraphic interpretation (Fig. 3):

"Law of original horizontality" - It is assumed that most sedimentation takes place, i.e. bedded deposits are formed, on a nearly horizontal surface; in other words the original beds of sediment were deposited as flat-lying beds, parallel to sea level.

"Law of superposition" - Is the assumption that sedimentation can only take place on top of some pre-existent surface and that for any given sequence of normal, undisturbed strata the oldest beds are on the bottom, and each overlying unit is progressively younger.

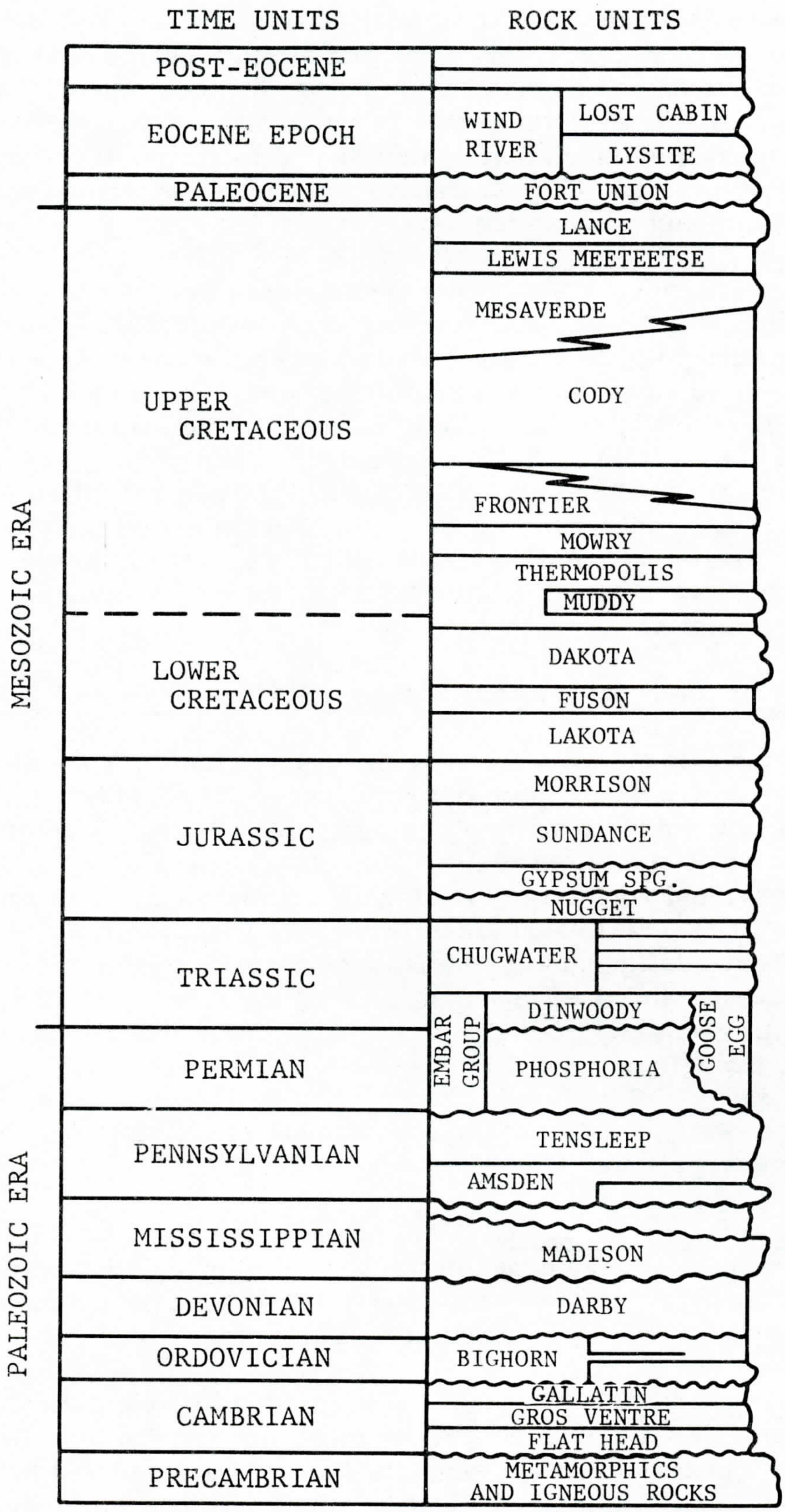


Figure 2 - Illustrates a generalized stratigraphic column showing the rock units (formation names) and their approximate correspondence with standard geologic time units as they might occur in northern Wyoming.

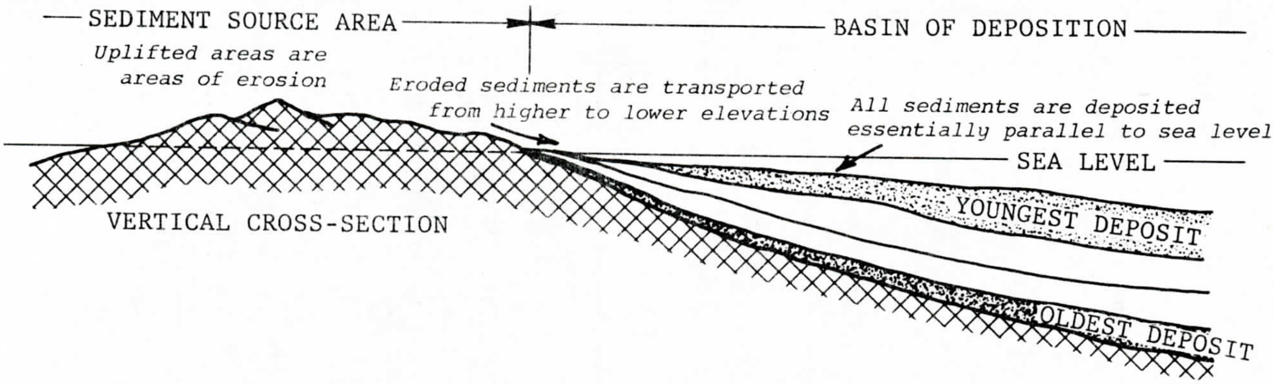


Figure 3 - As sediments are eroded they are transported to lower elevations and deposited on a horizontal bedding surface. As uplift is renewed at the source, or as subsidence occurs in the basin of deposition, the younger sediments are deposited over older beds.

With these laws and concepts in mind, geologists have established two types of nomenclature in order to communicate their findings. They establish names for specific sets of strata that seem to have some commonality, and they utilize a world standard reference time scale. Then, by combining the names, geologists are able to describe stratigraphic information in a more meaningful manner. For example, a geologist in the Williston Basin may refer to the Ordovician Bighorn Dolomite, or the Cretaceous Dakota Sandstone, and other geologists will understand the age of the strata and something of its character. As geologists become more familiar with the stratigraphic nomenclature of an area they tend to omit the time term and simply refer to the strata as Bighorn Dolomite and Dakota Sandstone, or simply Bighorn or Dakota, because their colleagues already understand the other connotations.

Stratigraphic nomenclature also changes laterally because the character of the strata changes laterally. For example, the Tensleep Sandstone of the Big Horn Basin in Wyoming is several hundred feet thick, and well known as an important oil reservoir. But, the character of the sandstone changes laterally. Farther south in Wyoming and in southern Idaho and northeastern Utah it may be referred to as the Weber Sandstone, or as part of the Wells Formation; in eastern Wyoming strata representative of the same time interval are significantly different and have been named the Minnelusa Formation. Learning the proper nomenclature to be applied in any given area is strictly a function of familiarity with the subject. Stratigraphic nomenclature charts are available from the professional geological association in each state. An example of Wyoming's most recent chart is shown in Figure 4 that shows the geologic time periods on the left and the appropriate rock unit nomenclature as it is applied in different parts of the state. As an example, trace the strata of Pennsylvanian age across the page from left to right and the changes in rock unit nomenclature, from place to place, will become apparent.

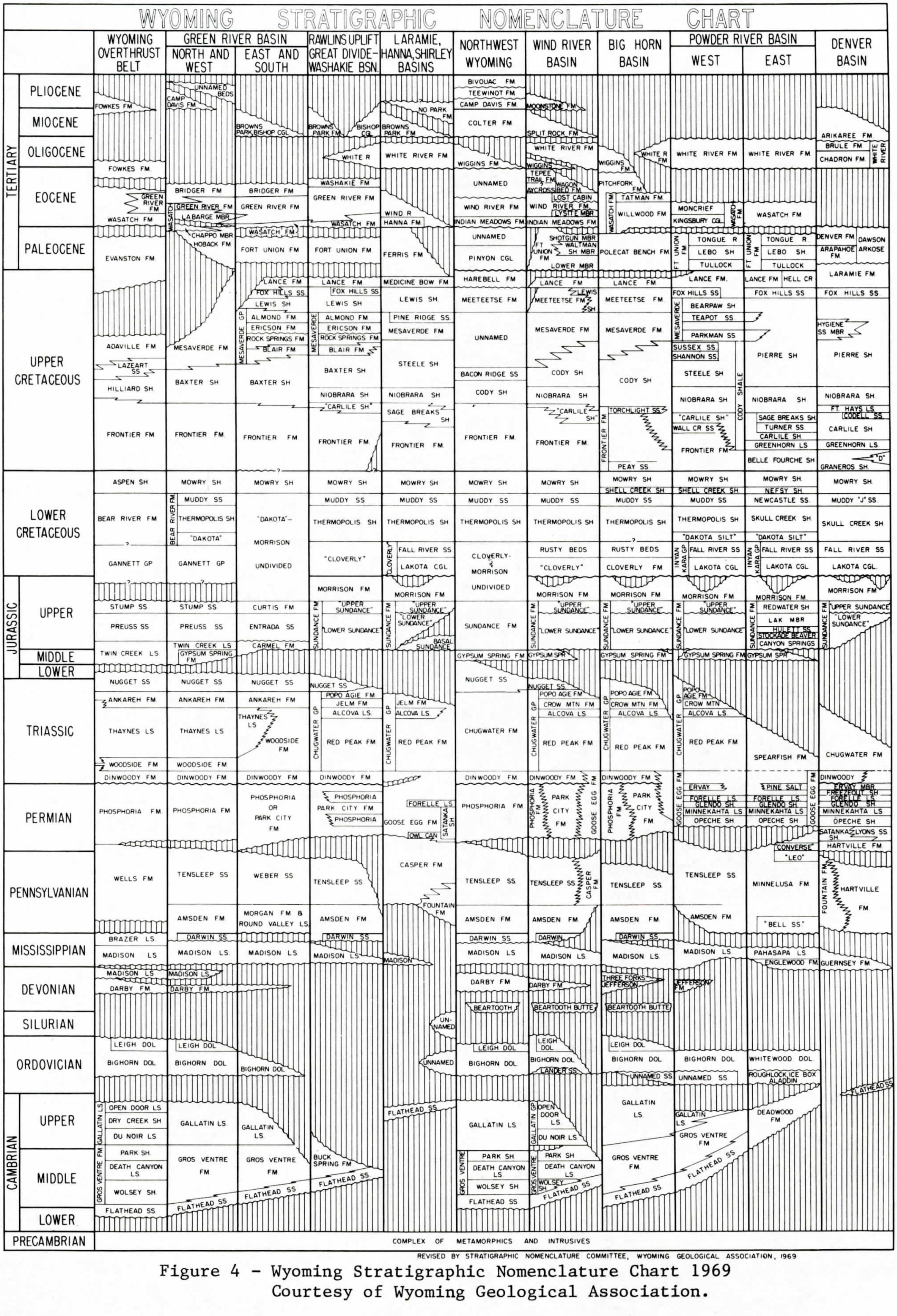


Figure 4 - Wyoming Stratigraphic Nomenclature Chart 1969
Courtesy of Wyoming Geological Association.

All stratigraphic units have upper and lower contacts with other units above and below that are important to a stratigrapher. Contacts are considered "conformable" if the sedimentation across the boundary appears to have taken place without a major interruption in sedimentation. In other words, there is no significant gap in time between the deposition of the underlying and overlying beds. Unconformable or non-conformable contacts indicate that there was a hiatus between the time the lower beds were deposited and the time the overlying beds were laid down over the top. In some cases the hiatus may have been only a few hundreds or thousands of years. In other cases it might have been hundreds of millions of years; hence an understanding of the time interval represented by the hiatus is essential to a stratigraphic interpretation. Geologists rely heavily on their background knowledge of formational contacts during all stratigraphic interpretation, but rarely take time to explain these relationships to non-geologists. As an example, in places like the Powder River Basin of Wyoming the unconformable contact between permeable sandstones in the Minnelusa and the overlying impermeable Opeche red beds is one of the principal causes of oil entrapment as illustrated in Figure 5.

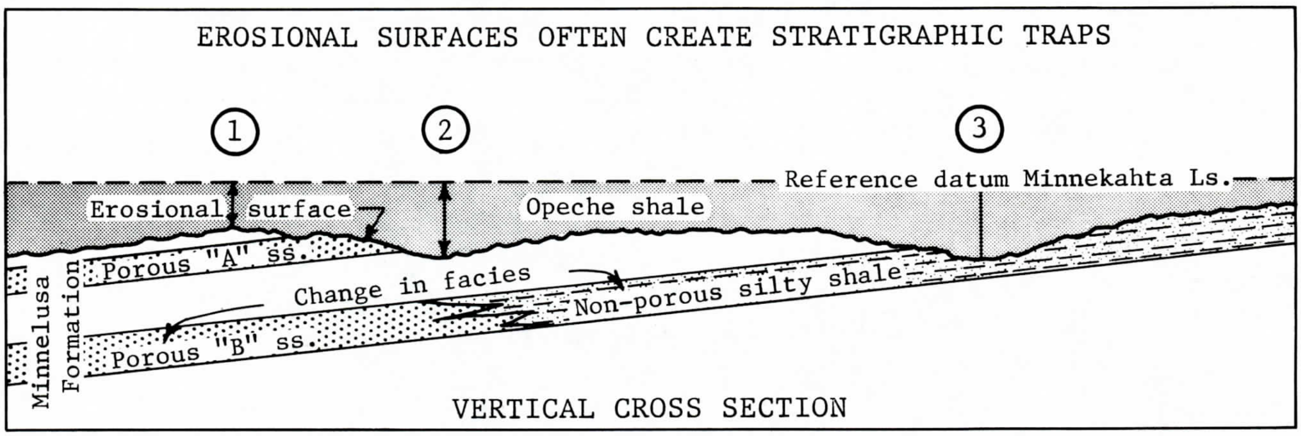


Figure 5 - Erosional surfaces (unconformities) may result in impervious shale, like the Opeche, overlying truncated porous sandstones to form petroleum reservoirs within the Minnelusa Formation. Isopach maps of the Opeche Shale interval showing the thick areas (2) in contrast to the thin areas (1) can be helpful in locating potential traps. In other instances lateral changes in rock type (facies) from porous to non-porous strata, may create stratigraphic traps at the updip limit of the porosity.

Correlation - In an effort to gain a better understanding of the stratigraphic relationships, geologists must "correlate" between the places where data is available. Correlation in its simplest form is the matching up of information about the beds from one place to another; but, all correlation must be done with the fundamental laws of geology clearly satisfied, and in accordance with specific rules of stratigraphy. In some cases such as field mapping where just a general understanding is required, only the upper and lower contacts of a stratigraphic unit need be defined. When the relationships are to be illustrated on cross-sections these surfaces are simply established at each place of control and lines are drawn to indicate correlation. In other types of investigation where greater detail is required, correlation must be done in a more detailed and precise manner. It should be noted that there are two general types of correlation in common use:- correlation of time units, and correlation of rock units. The validity of rock unit correlation is enhanced significantly if a time datum can be established within the interval being correlated. Because of the law of original horizontality, the "time" datum is assumed to have been essentially horizontal during deposition of the sediments. Figure 6 illustrates how these different types of correlation appear on a more or less standard electric log cross-section of drill holes across a twenty-five mile interval.

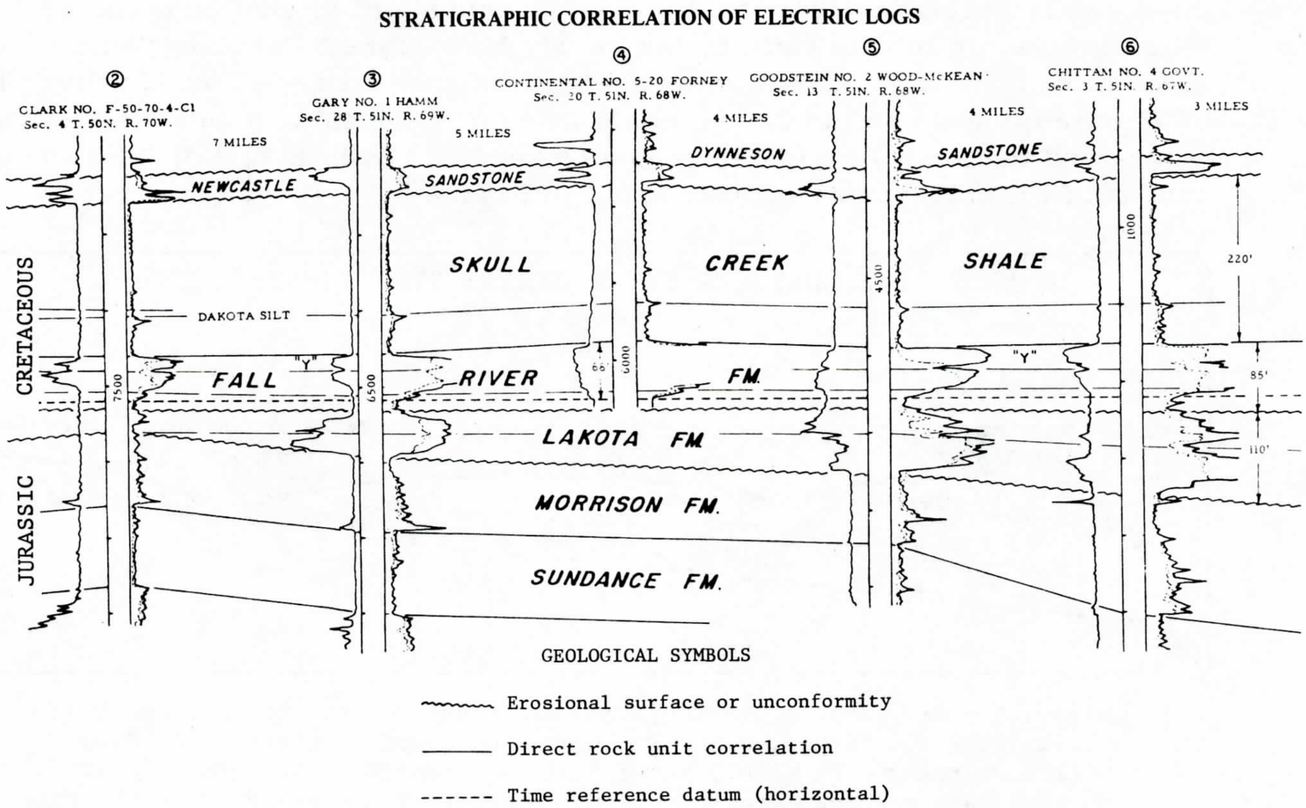
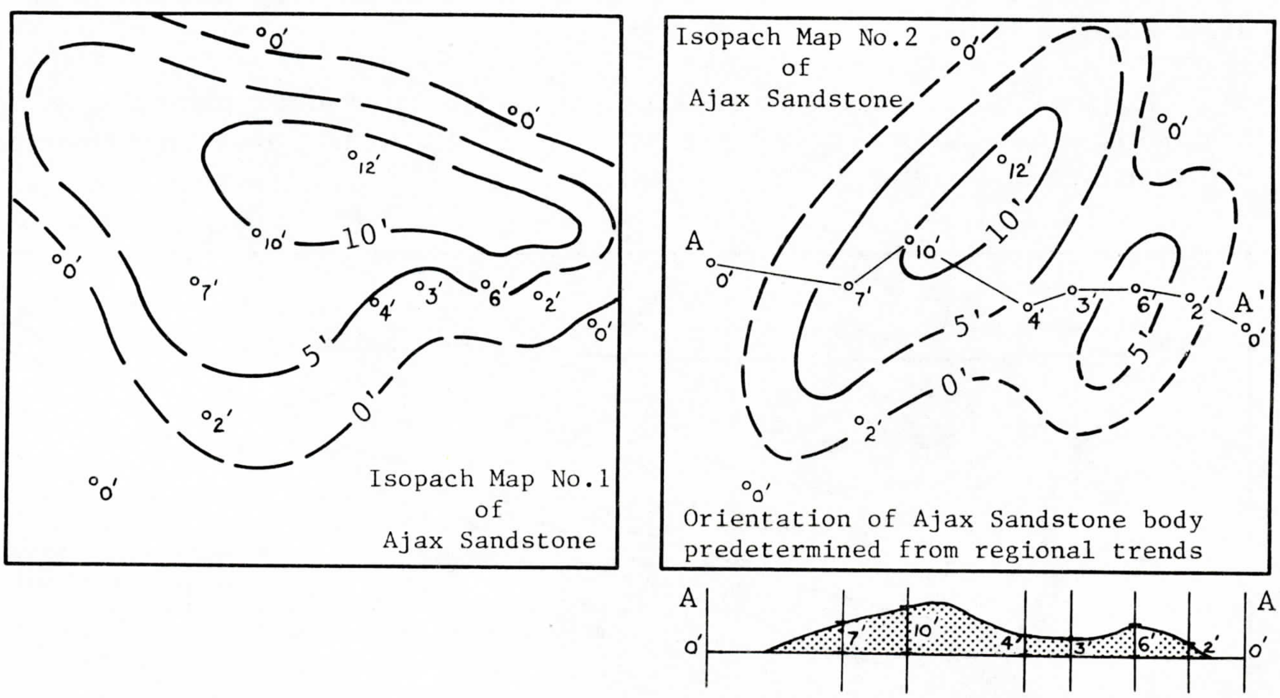


Figure 6 - Correlation of geologic surfaces and stratigraphic relationships is fundamental to exploration for petroleum and natural gas. Electrical logs of previously drilled holes provide a means for comparing the features from one point to another.

It is not uncommon for geologists to disagree on the validity of correlations. In most instances differing interpretations are the result of the type or amount of information that is available to each geologist, and is not ordinarily a dispute involving geological principles, i.e., one or the other of the contestants has more, or better, information upon which to base a judgment. Final decisions on such matters should be resolved by an unbiased expert.

Isopach mapping - one of the more common methods of understanding and illustrating stratigraphic relationships is through compilation of thickness relationships. "Iso" means equal, the "pach" means thickness. An isopach map employs contours to show the thickness configuration of some important aspect of a problem. The validity of an isopach depends upon the nature of the interval being defined, quality of data being compared, the manner in which the numerical data is determined, and the individual interpretations that geologists may employ in fitting contours to the data. Most disagreements arise because an interpreter has attempted to isopach data that is really not comparable. Another common failing among inexperienced geologists is that they contour the data to illustrate a preconceived idea that simply cannot be justified on the basis of the information at hand.

Isopach maps are useful in helping to determine structural relationships, the configuration of an erosional surface, or for illustrating the geographic extent of a specific stratigraphic unit. For example, if the shape of a lense of sandstone is important, the geologist will simply determine the thickness of the lense at every data point available, and then construct contour lines from place to place on the map that connect points of equal thickness (Fig. 7). If the distribution of porosity is important, the geologist may prepare an isopach of the distribution of porosity; again based on the data at hand and subject to individual interpretation.



Vertical cross section of Ajax ss.

Figure 7 - The configuration and orientation of a sandstone body based on thickness alone can be misleading. Isopach Maps Nos. 1 and 2 above show the same data; but with two different interpretations essentially at right angles to each other. The validity of an isopach depends on the nature of the feature being mapped, the regional trends of similar features nearby, and upon other types of supporting data.

Geological perspectives of a typical Rocky Mountain basin - For more than 600 million years the continent of North America has been undergoing geologic changes that still continue today. Parts of the continent have been uplifted and eroded many times while other parts have rather consistently subsided as structurally deformed basins, and been covered over with deposits of flat-lying sediments.

Within the Rocky Mountain geologic province there is clear evidence of the types of structural deformation that the earth's crust has undergone: mountains that rise nearly 13,000 feet above present day sea level are in marked contrast to some of the structural basins that have been warped downward more than 25,000 feet below sea level. In some areas strata can be observed on outcrop that are still horizontal, in essentially the same attitude in which they were deposited, while the same strata in nearby areas are steeply tilted, folded, faulted, or even completely overturned.

In a few places like the Green River, Denver-Julesberg and Williston basins, the strata for the most part are simply inclined at low angles toward the deeper parts of the basin where the greatest subsidence occurred. In other places like the Big Horn and Hanna basins, the area not only subsided with accompanying gentle tilt of the strata, but great folds and wrinkles developed around the margins.

Figure 8 illustrates a cross-sectional perspective of a typical Rocky Mountain basin with additional detail to show some of the stratigraphic and structural relationships and nomenclature.

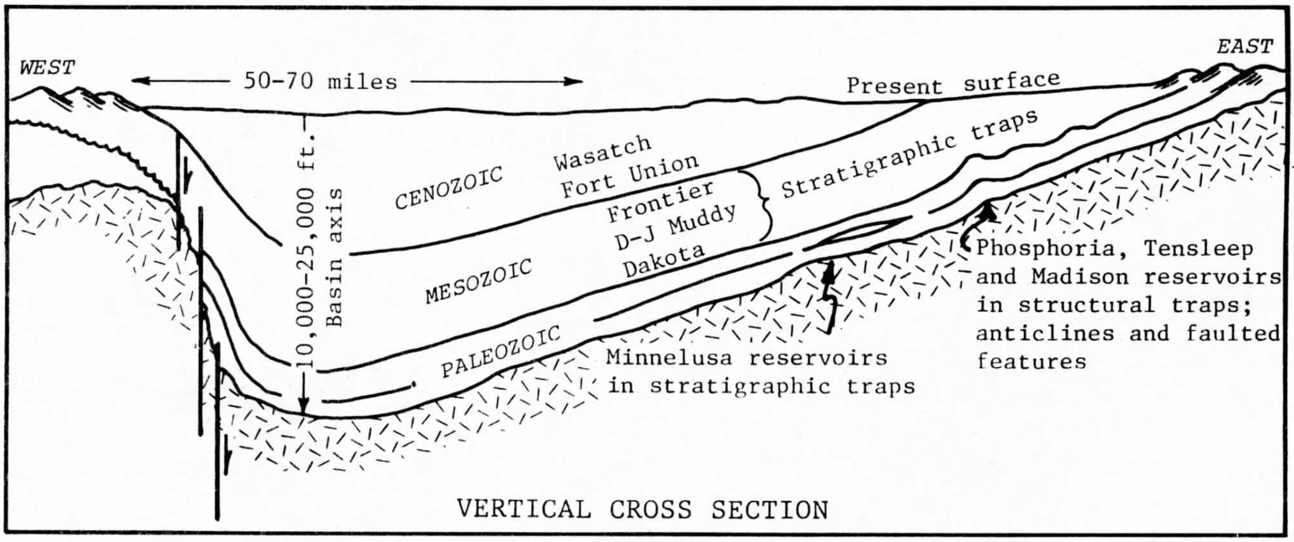


Figure 8 - Illustrates diagrammatically some of the more important aspects of a typical Rocky Mountain basin which is 50-70 miles wide, 10,000-25,000 feet deep, and includes strata of Paleozoic, Mesozoic and Cenozoic ages. Structurally controlled petroleum reservoirs are more common around the margins of the basin adjacent to areas of uplift. Stratigraphic traps are more numerous farther out in the basin where the strata have more uniform regional dip.

Structural geology

Geologists use the words structural geology to mean "disturbed geology". The term "structure" is used in a variety of ways. For example:

a. Structure - to mean a particular fold, dome, faulted complex, or some other type of feature where the strata have been disturbed or broken.

b. Structure map - Illustrates, through the use of contours, the position of a particular reference datum with respect to present day sea level.

c. Structural cross-section - Illustrates a vertical view of the configuration of the strata with respect to present day sea level.

In other words, "structure" implies that compared to a flat surface, with sea level as a reference datum, the strata have such and such a configuration.

There are several structural terms in common usage by the petroleum industry that are worthy of note:

Axis (of a fold) shows the position and direction of a fold along its crest (if bowed upward), or along its trough (if bowed downward).

Dip is the direction and degree of inclination of a strata. A dip of one degree equals an inclination of 92 feet per mile.

Strike is the direction at right angles to the dip. In effect a structural contour of a bed defines the strike.

Depositional strike is the direction of greatest uniformity of a specifically defined stratigraphic interval.

Anticline is the name applied to a fold wherein the strata have been bowed upward.

Syncline is the name applied to a fold wherein the strata have been bowed downward.

Fault is a rupture in the strata wherein the beds are displaced. The amount of movement is normally represented as "feet of vertical displacement".

Figure 9 shows the more common type of subsurface structural map and cross-section, and nomenclature used in the petroleum industry.

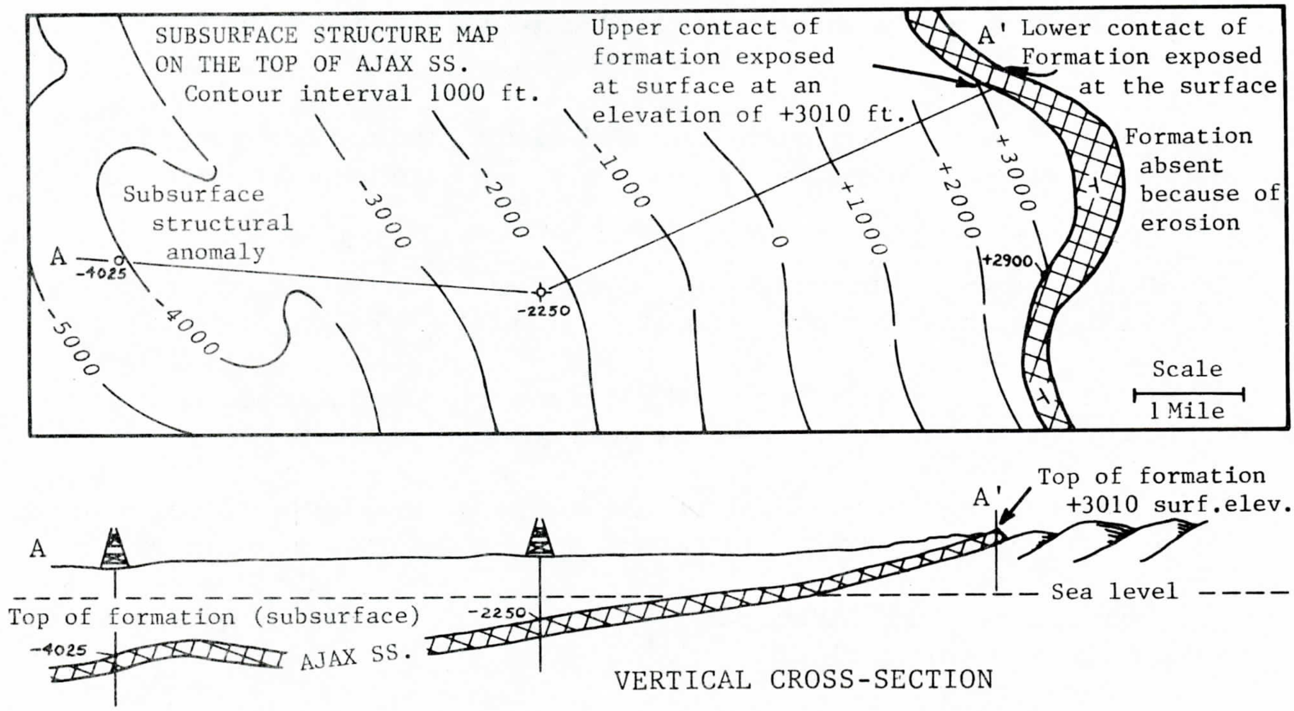


Figure 9 - Illustrates a vertical cross-section view of a uniformly inclined stratigraphic unit that is exposed at the surface at A' and dips to the west at about 1000 ft. per mile (10 degrees). The subsurface structure map above shows how this relationship would appear on a map contoured with a 1000 ft. contour interval.

Figure 10 shows the three most common types of fault movement and their respective nomenclature.

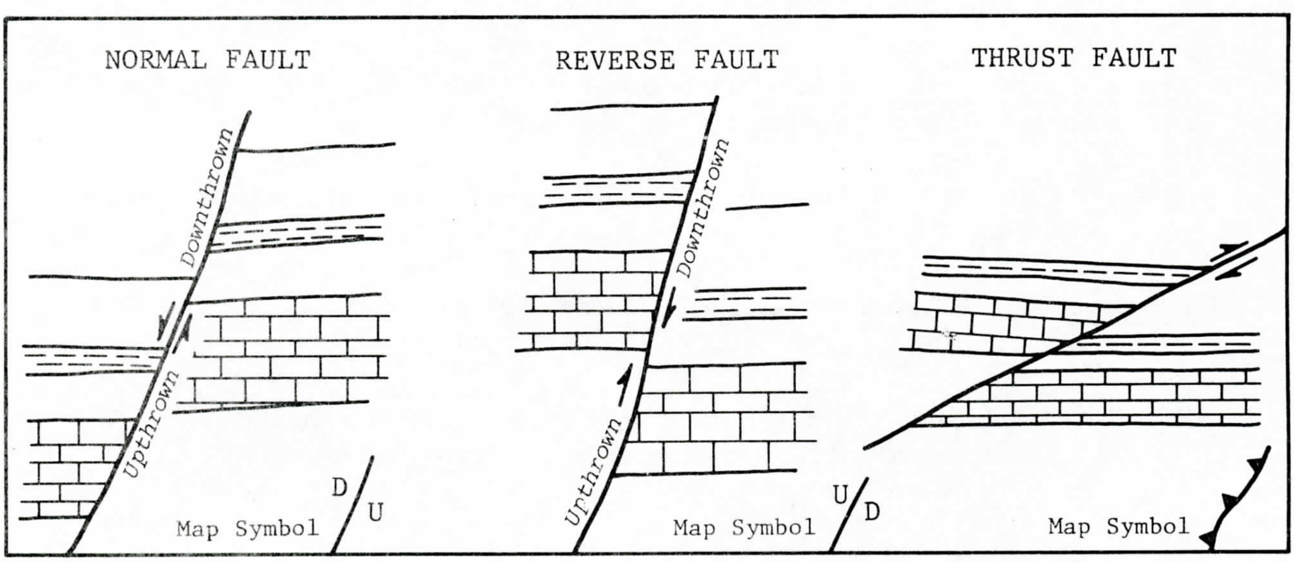


Figure 10 - Illustrates vertical views of the three most common types of faults. All nomenclature is based on the type of movement on the top-side of the fault plane: if movement is down it is a normal fault, if movement is upward it is a reverse fault, if the inclination of the fault is more nearly horizontal than vertical it is a thrust fault with the beds above the fault thrust over the underlying beds.

Petroleum geology

The terms "petroleum geology" refer to the application of geological principles to the locating of economic deposits of oil and gas. As previously described, the geologist relies heavily on established axioms of stratigraphy and structure in the preparation of maps and cross-sections to define geological conditions where oil and gas can be expected to have accumulated in substantial quantities, either in structural traps or stratigraphic traps.

Petroleum and natural gas as we know them at the surface are the chemically altered remains of organic matter that was originally part of the sediment at the time of deposition. Sediments of marine origin that have not been subjected to excessive heat (+200°F) normally yield oil or petroleum. Sediments of non-marine origin, wherein the hydrocarbons are normally of decayed plant material, ordinarily yield natural gas. The movement of hydrocarbons through the pore spaces of strata is referred to as "migration". Some notable reservoirs of petroleum appear to have been the result of substantial migration. In other areas the petroleum and natural gas accumulations appear to have been of more local origin, i. e., relatively close to the present reservoir. Kerogen, the hydrocarbon product in oil shale, does not appear to have migrated at all.

As a general rule, the tiny globules of petroleum and natural gas ordinarily percolate in an upward direction through that part of the sedimentary rocks that have porosity, permeability and/or fractures or joints. Inasmuch as the strata are constantly subjected to changes in stress, temperature changes, earth tremors and other disturbances, the direction of movement of the globules is determined by nearby rock and fluid pressures in their attempt to establish uniform equilibrium.

The simplest form of petroleum or natural gas reservoir is the stratigraphic circumstance wherein a porous bed of relatively undisturbed sandstone is completely surrounded (encased) by shales that have become impervious. The hydrocarbons accumulate within the pore space from which they are unable to escape. If the sandstone body, or the porosity within the sandstone are irregularly shaped, then the reservoir will conform to that shape. If the sandstone body is inclined, the petroleum or natural gas will migrate under pressure toward the highest places. Even when the pressures within a reservoir reach an overall equilibrium the oil and gas will attempt to separate out above the water level. The apparent complexities of stratigraphic reservoirs are primarily due to the distribution of porosity within two or more lenses of sand that overlap each other in a non-uniform manner. Figure 11 illustrates the circumstances that are conducive to the entrapment of oil and/or gas due to stratigraphic conditions where the beds are inclined to the southeast.

STRATIGRAPHIC TRAP

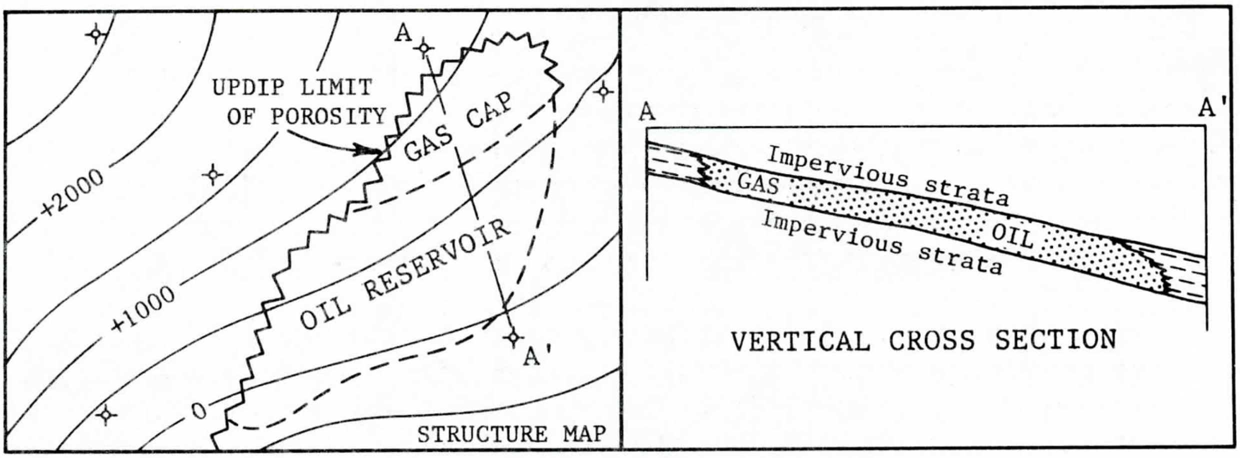


Figure 11 - Stratigraphic accumulations of oil and gas simply imply that the trap is created through stratigraphic conditions rather than structural deformation. The up-dip limit of porosity may be due to a variety of causes: it may be the depositional edge of the sandbody, or it may be due to cementation, or it may be due to erosional truncation.

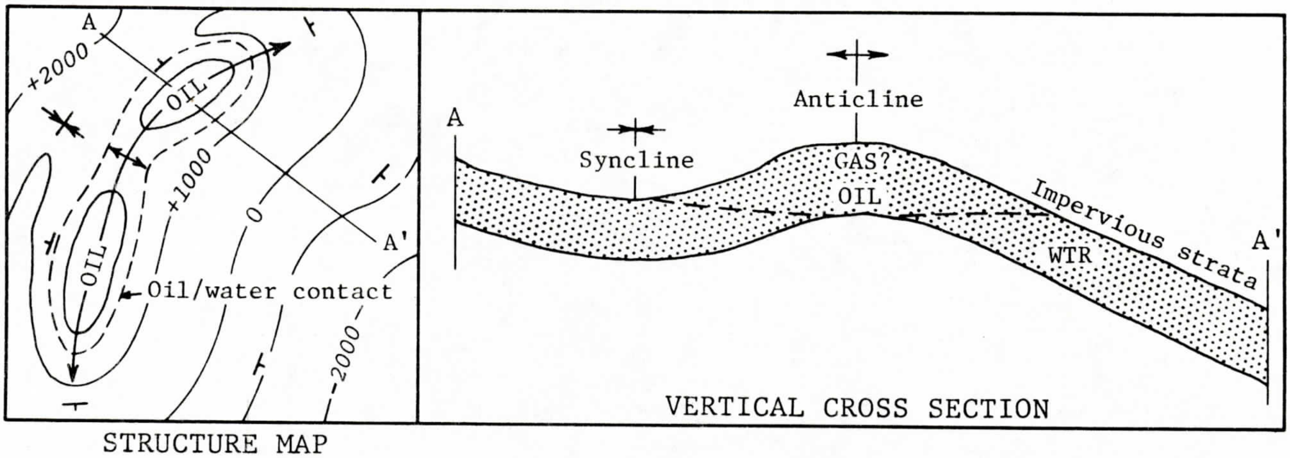
Structural reservoirs are those accumulations of oil and gas that are trapped because of structural deformation of the strata, either by folding or faulting. Again, the hydrocarbons attempt to move into the porosity and then migrate upward as far as they can as the fluids adjust to the changes in rock pressures. Figure 12 illustrates different views of the most common types of structural traps, anticlinal folds and faulted areas.

One of the exploration geologist's principal objectives is to identify areas where structural or stratigraphic conditions involve strata that have appropriate physical properties for the entrapment of oil or gas. In order to establish certain basic criteria, all of the available geological information is assembled from previously drilled holes and the data that appears relevant to the problem is plotted on maps; this includes all published material, rock descriptions from outcrops and sample logs, core descriptions and core analyses, data from electrical and other types of drill hole logs, the results of drill stem tests, water and "gas sniffer" analyses, etc. Figure 13 illustrates the general character of electric log curves with regard to the more common combinations of strata. Then, utilizing a basic knowledge of petroleum entrapment, the geologist attempts to define the most likely places for accumulation that have not previously been drilled and/or adequately tested, and outlines the area(s) on a mineral ownership map.

Figure 14 shows the standard, base map, survey system; along with the most common geologic symbols and abbreviations used on industry maps.

The type of exploration conducted is often determined by timing and the constraints of the exploration budget, the availability, distribution and expiration date of oil and gas leases, and decisions by management regarding risk in comparison to a possible pay-out on the investment in the event of a marginal economic discovery.

STRUCTURAL TRAPS



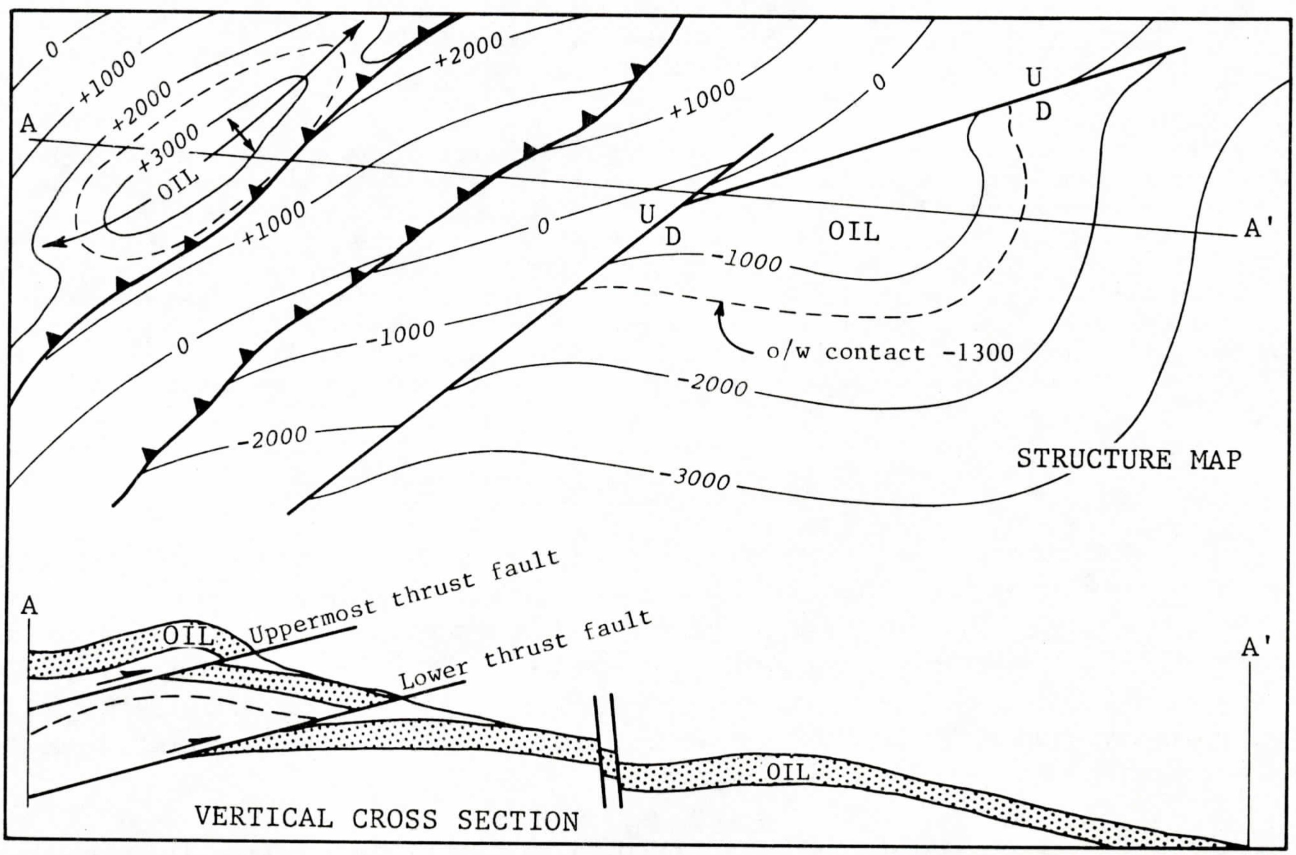
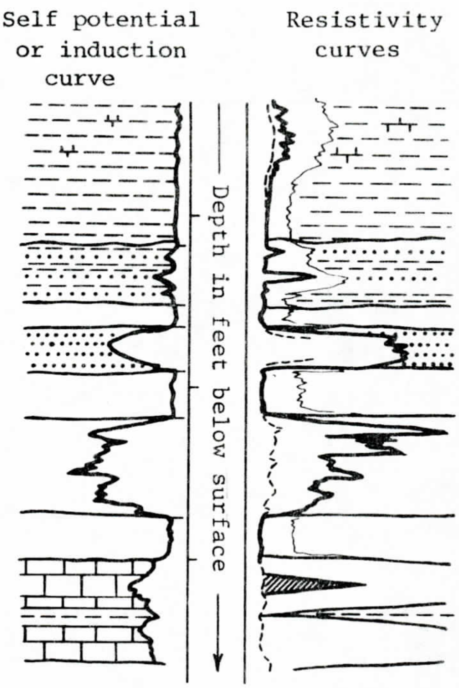


Figure 12 - Illustrates a structural map and cross section of an anticlinal fold with oil and/or gas accumulation. Anticlinal traps may or may not be faulted. The lower diagram illustrates an overthrust situation showing the configuration of a sandstone bed under different conditions where reservoirs might be anticipated.

ELECTRIC LOG CHARACTER FOR DIFFERENT TYPES OF SEDIMENTARY ROCKS

← Title block contains operator's name, well number and lease name, location of hole, surface elevations, run number, date, etc.



	Typical of
Shale with varying amounts of calcium carbonate	Mowry or Niobrara sh.
Silty shale interval with thin beds of sandstone	D-J, Muddy
Porous sandstone	Dakota or Dynneson ss.
Shale	Pierre, Mancos sh.
Thick sandstone interval with numerous thin beds of shale	Tensleep or Lakota ss.
Shale	
Dense limestone, dolomite or anhydrite beds with a thin shale in the middle	Mission Canyon, Charles Bighorn, Interlake and other dense strata

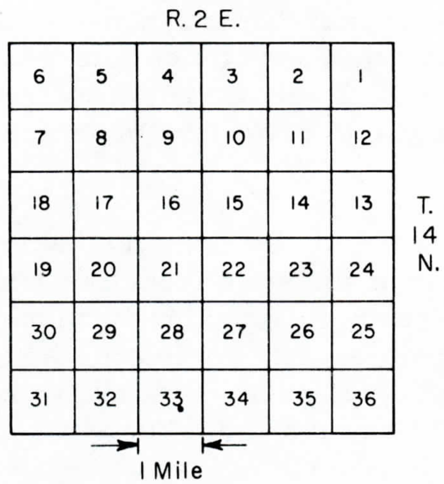
Figure 13 - Electrical logs are the graphic representations of the electrical properties (either natural or induced) of the fluids in the strata. In order to interpret the logs geologists must know the type of rock they are dealing with which is obtained from sample descriptions or cores recovered during drilling, or from other sources such as outcrops, or previously published information. Only qualitative estimates of porosity can be made from simple visual inspection of the logs. Quantitative estimates can be determined using calculations based on actual measurements obtained from certain types of logs. There are many different types of logging methods. Each is designed to measure some special property of the strata that is useful for the geologist, engineer or geophysicist.

Geologic illustrations in common use

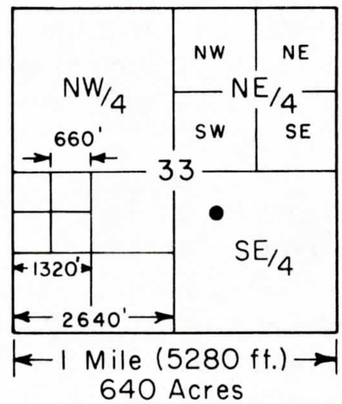
Because petroleum exploration is a highly competitive business wherein the majority of operators have access to the same basic geologic data, successful companies depend heavily on the individual knowledge and initiative of the staff. To be effective, the geologist must be able to grasp the full significance of new geological data as it becomes available, and extrapolate stratigraphic, porosity, and structural interpretations more rapidly and accurately than the competitors.

To accomplish these purposes then, the geologist ordinarily maintains a variety of up-to-date work maps:- structure maps of special areas contoured on one or more reference datums, and stratigraphic maps showing important

STANDARD TOWNSHIP



STANDARD SECTION



Oil well location - C NW¼SE¼ Sec.33, T.14 N., R.2 E.

Standard Map Symbols

- ○ Drill site location
- Abandoned oil or gas test hole (3976) Total depth drilled 3976 ft.
- ● Producing oil well
- Producing gas well
- Producing oil and gas well
- Junked and abandoned hole (J&A)
- Water injection well

Standard Geologic Symbols

- Axis of anticlinal fold
- Axis of synclinal fold
- Fault (U D)
- Thrust fault
- Strike northwest, dip southwest

Standard Abbreviations

BHP - Bottom hole pressure
BOPD - Barrels of oil per day
BWPD - Barrels of water per day
Cas. - Casing
C - Cored
D&A - Dry and abandoned
DST - Drill stem test
FFP - Final flow pressure
GTS - Gas to surface
IFP - Initial flow pressure
ISIP - Initial shut-in pressure
KB - Kelly bushing
MCF - Thousand cubic feet
md - Millidarcies (permeability)
NDE - Not deep enough
P&A - Plugged and abandoned
Perf.- Perforated
PB - Plugged back
SIP - Shut-in pressure
SWC - Side wall cores
TD - Total depth drilled

Figure 14 - Illustrates a standard base map survey of a township, and subdivisions of a section, that are most frequently used for locating drill-site locations; along with the more significant map and geological symbols, and the more common abbreviations used by the petroleum industry.

details of potentially productive beds such as porosity distribution, and oil and gas shows. As new information is incorporated onto the maps the structural and stratigraphic interpretations become more definite, prospect areas are outlined and effort is made to acquire oil and gas leases or an interest in the properties. If the seismograph can be used effectively to help localize the most favorable sites in the prospect area, a geophysical crew may be employed to conduct the work.

Although all geologists have access to essentially the same basic information, their interpretations may differ because of the significance that they place on different kinds of data. Certain types of geological and geophysical data such as structural trends and faults can be extrapolated with confidence for great distances, perhaps tens of miles; other types of data, such as porosity distribution and the depositional patterns of sandstone bodies, may only be extrapolated with any degree of certainty for a mile or so. Therefore, the extent to which a geologist may project a geological interpretation beyond the last data (control) point depends upon:

a. The type of feature or relationship being projected.
b. The number and distribution of control points that define the feature.
c. Regional relationships of similar features on trend or in the vicinity.
d. Indirect evidence of a related nature.
e. The geologist's overall familiarity with the area under consideration and the level of personal confidence.

In essence, there is no pat answer for determining the adequacy of data. It is assumed that the geologist will incorporate all of the data that is available into a final geological interpretation.

The validity of geological data is quite another matter. Geologists frequently use data collected by themselves, or others, where there is opportunity for error, or where individual judgment plays a part; or where the weighting of parameters is used in mathematical equations to arrive at a specific answer. The more common types of questions over validity are listed below.

a. Are the survey and lease lines on the base map accurate? Are the locations of data control points accurately plotted?

b. Are the stratigraphic reference datums, used to determine structural and isopach data, accurately correlated, is the arithmetic accurate, and do the resulting maps and cross-sections actually portray what the author claims?

c. Do the structure contours or isopach lines on a map honor <u>all</u> of the data (control) points, or are there errors in the manner in which the maps have been contoured, or has the author of the maps taken unnecessary license in the contoured interpretation beyond the point of being reasonable?

d. Are the cores (and resulting core analysis data) actually representative of the stratigraphic interval they were intended to measure? Was the core recovered (and analyzed) in its entirety or were the more friable parts of the core destroyed or lost? What types of tests were used to determine porosity and permeability? Were separate pieces of the core analyzed by other laboratories in order to permit comparison of test results?

e. Were the fluid recoveries of drill stem tests compatible with what you would expect, based on porosity calculations computed from electrical logs, or core analysis data?

f. Is the data portrayed on cross-sections plotted at a reasonable scale to serve its intended purpose?

In most instances the question of validity should be determined by an unbiased expert familiar with the area and the specific geological conditions under discussion.

Geologists as expert witnesses

Prior to the presentation of geological evidence before oil and gas commissions, federal hearing bodies, or in the courts, the attorney needs to advise the witnesses of the type of presentation to be made, the conditions under which testimony will be given, the procedure to be followed, and the importance of findings of fact and conclusions of law.

The following suggestions will enhance the testimony:

a. Geologists should be given as much lead time as possible to gather all pertinent evidence, prepare and reproduce an adequate number of copies of the exhibits, and organize the presentation.

b. Establish with the attorney the specific documentation and supportive arguments that will provide the necessary findings of fact.

c. A word or two of caution by the attorney concerning presentation of too much (or too little) background information that is not especially relevant to the subject under consideration.

d. Anticipate controversy from the beginning, and attempt to build an orderly record of valid geological testimony that would be acceptable in the highest courts.

All geological testimony can and should be supported by clearly annotated exhibits that emphasize the findings of fact. All exhibits should include:

a. Illustrations of an appropriate size and at an appropriate scale for their intended use.

b. A self-explanatory title.

c. Identification of company, corporation, or individual, author, date, exhibit number, and docket reference.

d. A complete annotated legend of colors, symbols, or patterns used on the illustration.

<u>In point of fact each exhibit should stand on its own merits without the need for further explanation by the witness.</u>

<u>Common problems with geological semantics</u> - It is not uncommon for an attorney to modify the meaning of geological terminology used by a witness, or for the witness to misinterpret the questions posed by an attorney. In part, this happens because geological terms have scientific and technical definitions that differ from the way in which the terms are defined and used in the laws or in the rules of regulatory agencies.

The following material is a list of the most misunderstood terms used in petroleum geology, with further elaboration as to their application:

"<u>Strata</u>" - (either singular or plural) may refer to a single bed of sedimentary rock, or to a specific group of beds, or to a great thickness of beds. For practical purposes, all sedimentary rocks are stratified. A stratigraphic column is an illustration showing a vertical sequence of beds and their nomenclature. A stratigraphic cross-section is designed to show the correlations that have been interpreted, and the vertical relationship of the beds with respect to a specific time (reference) horizon.

"<u>Formation</u>" - A specific sequence of strata that has sufficient similarity in its character, and is geographically widespread enough to warrant a formal name by the American Stratigraphic Rules and Nomenclature Committee. Formations are the basic stratigraphic units that geologists map in the field or in the subsurface. Every formation has an upper and lower contact that is carefully defined. The individual names, age, and stratigraphic position of each formation are shown on the Stratigraphic Nomenclature Chart of each state. Similar charts showing the interstate relationships are available from the U.S. Geological Survey.

Formations are often subdivided into thinner stratigraphic units called "members", "zones" or "facies"; or incorporated into larger stratigraphic units called "Groups". Examples might include the Charles, Mission Canyon or Lodgepole facies of the Madison Formation that are recognizable in the Williston Basin; or the Almond, Ericson, Rock Springs or Blair formations of the Mesaverde Group in southwestern Wyoming. The petroleum industry also uses local nomenclature to identify even smaller stratigraphic intervals that contain oil or gas. In some instances they use a landowner's or a geographic, name. In other instances they may simply use letters "A", "B", "C", etc., or designations such as "First", "Second", "Third". Example - Minnelusa "A" zone, or Second Frontier Sandstone.

"Porosity" - Is simply the percentage of space within the solid parts of a rock with respect to the whole. The space may occur between the grains (intergranular void space), as cavities or holes (where material has been dissolved away), or even minute fractures or cracks. Porosity values of most sedimentary rocks range from 5 to 25%. In sandstones, porosity values of 10% or more, ordinarily indicate that the pore spaces connect to some degree with each other and will allow gaseous fluids to pass through the rock. Porosity values of 12%, or more, in sandstones normally indicate that the rock is permeable to medium and high gravity oil. This is not true of limestone or other sedimentary rocks of chemical origin where the dissolved void spaces may not be connected with each other.

Porosity is determined by means of laboratory tests on cores, or it can be calculated with some degree of accuracy from the data provided on some types of electrical logs. Geologists illustrate the distribution of porosity within any given stratigraphic interval on maps by setting a minimum limit (ordinarily 10%), and then adding up the total thickness of strata having porosity values greater than 10%. The thickness values are then plotted at each control point (drill hole) on the map and contoured. Such maps are called "isopore maps"; they show the geologists' interpretation of how the porosity is distributed over an area, which may or may not correspond to the shape of the sandstone body.

"Reservoir" - Any porous part of a strata with interconnecting permeability containing oil or gas may be referred to as a reservoir. Reservoirs ordinarily contain some water in addition to oil and gas. That specific part of a reservoir that contains recoverable quantities of oil and gas is ordinarily referred to as a "pool". Geological witnesses should be advised on the use of the term "pool" because it has other engineering and legal implications.

Sources of additional geological information

ARIZONA (602) 626-2733
Bureau of Geology and
Mineral Technology
Geological Survey Branch
845 N. Park Ave.
Tucson, AZ 85719

COLORADO (303) 839-2611
Colorado Geological Survey
1313 Sherman St., Room 715
Denver, CO 80203

IDAHO (208) 885-6785
Idaho Bur. of Mines & Geol.
Moscow, ID 83843

KANSAS (913) 864-3965
Geological Survey of Kansas
Raymond C. Moore Hall
1930 Ave. A, Campus West
Lawrence, KS 66044

MONTANA (406) 792-8321
Mont. Bur. of Mines & Geol.
Montana College of Mineral
Science and Technology
Butte, MT 59701

NEBRASKA (402) 472-3471
Conservation & Survey Div.
University of Nebraska
Lincoln, NE 68508

NEW MEXICO (505) 835-5420
New Mexico Bur. of Mines
& Mineral Resources
New Mexico Tech
Socorro, NM 87801

NORTH DAKOTA (701) 777-2231
North Dakota Geological Survey
University Station
Grand Forks, ND 58202

SOUTH DAKOTA (605) 624-4471
S.D. State Geological Survey
Science Center
University of South Dakota
Vermillion, SD 57069

UTAH (801) 581-6831
Utah. Geol. & Mineral Survey
606 Black Hawk Way
Salt Lake City, UT 84108

WYOMING (307) 742-2054
Wyoming Geological Survey
Box 3008 University Station
Laramie, WY 82071