GEOLOGY FOR OIL AND GAS TITLE PRACTITIONERS

PHILIP C. MANI
Mani Little & Wortmann
112 E. Pecan Street, Suite 1600
San Antonio, Texas
210.403.9461, x102 (Office)
210.860.6264 (Mobile)
pmani@mlwenergylaw.com

State Bar of Texas
3RD ANNUAL
OIL, GAS AND MINERAL TITLE EXAMINATION
June 9-10, 2016
Houston

CHAPTER 19

PHILIP C. MANI

112 E. Pecan Street, Suite 1600
San Antonio, Texas
210.403.9461, x102 (Office)
210.860.6264 (Mobile)
pmani@mlwenergylaw.com

Philip C. Mani received a Bachelor of Arts in Geology from Trinity University in 1980, a Master's of Science in Geology from Texas A&M University in 1983, and a Juris Doctor from St. Mary's University School of Law in 1990. He is Board Certified, Texas Board of Legal Specialization, in Oil, Gas and Mineral Law (since 1996), a member of the Oil, Gas and Energy Resources Law Section of the State Bar of Texas and the State Bar of Texas (since 1990), the State Bar of Pennsylvania (since 2009), the State Bar of Colorado (since 2012), and the San Antonio Bar Association.

Mr. Mani's oil and gas industry career began in 1980 as a Petroleum Geologist and later as a Petroleum Landman before becoming an Oil and Gas Attorney in 1990 working with horizontal drilling in the Austin Chalk trend. Mr. Mani is the founding partner of Mani Little & Wortmann, PLLC in San Antonio, Texas. He counsels oil and gas explorationists and developers of all sizes and in every producing area in Texas and Pennsylvania. He advises in day-to-day problem-solving associated with title examination, title curative, legal research, and issues involving horizontal drilling, forming pooled units and allocation units. Mr. Mani's work often begins at inception of projects in developing lease forms, leasing, title research and examination and, occasionally, working with the regulatory agencies involved with writing and/or interpreting regulations in conventional and unconventional plays. His extensive experience with horizontal drilling, title examination and the formation and reformation of pooled units covers rural areas through suburban, urban and industrial areas throughout Texas. Mr. Mani has also successfully tried cases concerning the construction and interpretation of deeds and wills involving mineral/royalty ownership and conveyancing.

Mr. Mani is also a member of the American Association of Professional Landmen, San Antonio Association of Professional Landmen, Houston Association of Professional Landmen and the Fort Worth Association of Professional Landmen. He is Registered Professional Geologist No. 108 in Arkansas (since 1985), and Registered Professional Geoscientist No. 6864 in Texas (since 2004).

Mr. Mani is especially proud to serve as Co-Founder and Co-Trustee of the Robert and John Ratliff Scholarship and Cancer Research Fund, a charitable organization formed for the purpose of assisting Fort Worth area Landmen and their families. He is also a member of the Trinity University Alumni Association, the Association of Former Students at Texas A&M, a society member of several historical and natural history museums in Texas, and a member of the Meteoritical Society. In his free time, Mr. Mani continues to be very active in public education and outreach in the fields of Geology and Meteoritics.

TABLE OF CONTENTS

GEOLOGY FOR OIL AND GAS TITLE PRACTITIONERS

I. INTRODUCTION

Oil and Gas exploration and development efforts in recent years have moved from grass-roots resource plays in undeveloped and minimally-developed areas of basins to exploring and developing mature basins for more prolific reserves of hydrocarbons. One such example is the Permian Basin in West Texas and Eastern New Mexico. The Permian Basin, comprised of the Midland Basin and the Delaware Basin, has been productive with hydrocarbons since 1921. More recently, horizontal drilling and evolving completion techniques have discovered additional productive formations or, in some instances, contacts between separate formations, for oil reserves.

In some of the areas of these basins oil and gas leases are held by production, many of them for decades. What has resulted in the area of these HBP leases is often complex title, frequently based on different depths, formations, strata or divided portions of formations, or all of the above, and under different or divided tracts of land. Oil and gas practitioners, including title examiners, who work these areas must have a working knowledge of basic geology in these areas in order to effectively report the title and/or establish record title accurately. In most instances, the oil and gas practitioners are not trained or are minimally trained in geology, petroleum geology principles, or have detailed working knowledge of the geology. However, formal training in this area is not necessary if the oil and gas practitioner understands the necessity for acquiring and utilizing such knowledge and geologic-related terms, knowing where to look or seek-out such information when preparing his or her reports or documents.

The purpose of this paper is to provide a basic outline for the title examiner and oil and gas practitioner so that he or she is familiar with some of the often-used terms and concepts relative to researching, reporting, transferring and conveying and establishing mineral, royalty, overriding royalty, leasehold and lien holders' interests in the real property with which they are charged.

Some of the geologic concepts regarding geologic principles, petroleum geology principles, and definitions for often-used geologic terms are included in this paper for reference purposes. Additionally, this paper proposes methods for the title examiner and oil and gas practitioner for where to seek-out and acquire the requisite geologic-related information essential to a report, title opinion, lease, assignment, etc.

The short continuing legal education presentation covering this paper will focus on the most commonly-used terms which arise in research, title examination, reporting and conveyancing, together with some examples and suggestions. It is also important to note the long passage of time between the creation of some leases, assignments and other instruments, combined with long periods of continuous production, impact the ability for operators to employ newer exploration and completion concepts and techniques required with current development activities. This can result of a "collision" between interests in the parties affected and difficulties determining and establishing solutions for the same. Additionally, the I will try to make some helpful suggestions which, hopefully, provide title-related solutions with a view for the very long-term and not only for an immediate, quick fix. Quick fixes are helpful and can solve immediate problems, but often fail to provide long-term solutions and marketable title for the parties affected and their successors and assigns.

II. GENERAL PRINCIPLES OF GEOLOGY AND PETROLEUM GEOLOGY

Three Basic Rock Types

- The Earth's crust is composed of three basic rock types: igneous, sedimentary and metamorphic.
- Igneous rocks are formed from the crystallization of molten rock (magma or lava) from within the Earth's mantle. Common igneous rocks include granite, basalt, and gabbro.
- Metamorphic rocks are formed from pre-existing rocks by mineralogical, chemical and/or structural changes in response to marked changes in temperature, pressure, shearing stress, and chemical environment. These changes generally take place deep within the Earth's crust. Examples of common metamorphic rocks include slate, marble and schist.
- Sedimentary rocks are formed as sediments, either from eroded fragments of older rocks or chemical precipitates. Sediments lithify by both compaction, as the grains are squeezed together into a denser mass than the original, and by cementation, as minerals precipitate around the grains after deposition and bind the particles together. Sediments are compacted and cemented after burial under additional layers of sediment. Thus sandstone forms by the lithification of sand particles and limestone by the lithification of shells and other particles of calcium carbonate. These types of rocks are typically deposited in horizontal layers, or strata, at the bottom of rivers, oceans, and deltas. Limestone, sandstone, and clay are typical sedimentary rocks.

Petroleum-Bearing Rocks

- Sedimentary rocks are the most important and interesting type of rock to the petroleum industry because most oil and gas accumulations occur in them; igneous and metamorphic rocks rarely contain oil and gas.

- All petroleum source rocks are sedimentary. Most of the world's oil lies in sedimentary rock formed from marine sediments deposited on the edges of continents. For example, there are many large deposits that lie along the Gulf of Mexico and the Persian Gulf.

Geologic Time

- Geologic time and Earth's geologic history are concepts that need to be clearly understood and how they relate to the petroleum industry. It takes millions of years and specific conditions for organic and sedimentary materials to be converted to recoverable hydrocarbons.
- The late eighteenth century is generally regarded as the beginning of modern geology. James Hutton, a Scottish physician and farmer, published his Theory of the Earth with Proof and Illustrations in 1785, which put forth the principle of Uniformitarianism. This principle states that the geologic processes and forces now operating to modify the Earth's crust have acted in much the same manner and with essentially the same intensity throughout geologic time, and that past geologic events can be explained by forces observable today. This is known as the classic concept "the present is the key to the past."

Age Dating

- Before radioactive materials were discovered, geologists used this and other principles and an understanding of fossils to determine the relative ages of sedimentary rock layers. That is, how old they are in relation to one another. Relative dating does not tell us how long ago something took place, only that it followed one event and preceded another. Once radioactivity was discovered, geologists used the physics of radioactive decay to pinpoint a rock's absolute age, that is, how many years ago it formed. Absolute dating did not replace relative dating, but simply supplemented the relative dating technique.

Basic Age Dating Principles

- Stratigraphy is the study of the origin, composition, distribution, and sequence of layers of sedimentary rock, or strata. Stratification is the characteristic layering or bedding of sedimentary rocks. This characteristic is basic to two of the principles used to interpret geologic events from the sedimentary rock record. First, is the principle of original horizontality, which states that most layers of sediment are deposited in a nearly horizontal layer. If a sequence of sedimentary rock layers are folded or tilted, then generally it is understood that these layers were deformed by tectonic events after their initial deposition. Second, is the principle of superposition which states that each layer of sedimentary rock in a sequence that has not been tectonically disturbed is younger than the layer beneath it and older than the layer above it. Therefore, a series of sedimentary layers can be viewed as a vertical time line. This produces either a partial or complete record of the time elapsed from the deposition of the lowermost bed to the deposition of the uppermost bed. This rule also applies to other surface deposited materials such as lava flows or beds of ash from volcanic events. If igneous intrusions or faults cut through strata, they are assumed to be younger than the structures they cut and is known as the principle of cross-cutting relationships.
- Paleontology is the study of life in past geologic time, based on fossil plants and animals. It is an important consideration in the stratigraphic record and is significant in assigning ages to rock units. In early geologic endeavors, index fossils (fossils with narrow vertical stratigraphic ranges) represented the only means for realistic correlation and age assignment of rock sequences. Correlation is the process of relating rocks at one site with those at another site. One could map rock units from coal quarry to coal quarry over a large distance if one characterized the layers by their lithology and fossil content. While mapping the vertical rock sequences, it is understood that a general order of fossils and strata emerges, from the oldest at the bottom to the youngest at the top. This stratigraphic ordering of fossils eventually became known as the principle of faunal succession and states that fossil faunas and floras in stratigraphic sequence succeed one another in a definite, recognizable order.

William Smith was the first person to define formations within a rock unit. A formation is a rock unit that is mappable over a laterally extensive area and has the same physical properties and contains the same fossil assemblages. Some formations consist of one rock type, like limestone. Others may be interbedded, for example, alternating layers of sandstone and shale, but can be mapped as one unit.

By combining faunal succession and stratigraphic sequences, geologists can correlate formations in a local area or around the world. The petroleum industry relies on the application of these principles for exploration and production.

- Geologic Time Scale - During the nineteenth and twentieth centuries, geologists built on the knowledge of their predecessors and started to build a worldwide rock column. Although it will never be continuous from the beginning of time, the above principles have allowed geologists to compile a composite worldwide relative time scale.

Basic Classification and Types of Sedimentary Rocks

The two main groups of sedimentary rocks are classified on the basis of their origin.

- Clastic Sedimentary Rocks, formed as a result of the weathering or fragmentation of pre-existing rocks and minerals and classified on the basis of their textures, primarily the sizes of the grains. Sedimentary rocks are divided into coarse-grained: conglomerates, medium-grained: sandstones, and fine-grained: siltstones, mudstones, and shales. Within each textural category, clastics are further subdivided by mineralogy, which reflects the parent rock, for example, a quartz-rich sandstone or a feldspar-rich sandstone.
- Chemical or Biochemical Sedimentary Rocks, formed as a result of chemical processes. Primary carbonate deposition results from the precipitation and deposits formed by plants and animals that utilize carbonates in their life processes. The most abundant mineral chemically or biochemically precipitated in the oceans is calcite, most of it the shelly remains of organisms and the main constituent of limestone. Many limestones also contain dolomite, a calcium-magnesium carbonate precipitated during lithification. Gypsum and halite are formed by the chemical precipitation during the evaporation of seawater.

Five types of sedimentary rocks are important in the production of hydrocarbons:

- Sandstones, are clastic sedimentary rocks composed of mainly sand size particles or grains set in a matrix of silt or clay and more or less firmly united by a cementing material (commonly silica, iron oxide, or calcium carbonate). The sand particles usually consist of quartz, and the term “sandstone”, when used without qualification, indicates a rock containing about 85-90% quartz.
- Carbonates are broken into two categories, limestones and dolomites. Carbonates are sediments formed by a mineral compound characterized by a fundamental anionic structure of CO_3 . Calcite and aragonite $CaCO_3$, are examples of carbonates. Limestones are sedimentary rocks consisting chiefly of the mineral calcite (calcium carbonate, $CaCO_3$), with or without magnesium carbonate. Limestones are the most important and widely distributed of the carbonate rocks. Dolomite is a common rock forming mineral with the formula $CaMg(CO_3)_2$. A sedimentary rock will be named dolomite if that rock is composed of more than 90% mineral dolomite and less than 10% mineral calcite.
- Shales are a types of detrital sedimentary rock formed by the consolidation of fine-grained material including clay, mud, and silt and have a layered or stratified structure parallel to bedding. Shales are typically porous and contain hydrocarbons but generally exhibit no permeability. Therefore, they typically do not form reservoirs but do make excellent cap rocks. If a shale is fractured, it would have the potential to be a reservoir.
- Evaporites generally do not form reservoirs like limestone and sandstone, but are very important to petroleum exploration because they make excellent cap rocks and generate traps. The term “evaporite” is used for all deposits, such as salt deposits, that are composed of minerals that precipitated from saline solutions concentrated by evaporation. On evaporation the general sequence of precipitation is: calcite, gypsum or anhydrite, halite, and finally bittern salts. Evaporites make excellent cap rocks because they are impermeable and, unlike lithified shales, they deform plastically, not by fracturing. The formation of salt structures can produce several different types of traps. One type is created by the folding and faulting associated with the lateral and upward movement of salt through overlying sediments. Salt overhangs create another type of trapping mechanism.

Source Rock and Hydrocarbon Generation

- Source rock refers to the formation in which oil and gas originate. Hydrocarbons are generated when large volumes of microscopic plant and animal material are deposited in marine, deltaic, or lacustrine (lake) environments. The organic material may either originate within these environments and/or may be carried into the environment by rivers, streams or the sea. The microscopic plant and animal material generally is deposited with fine clastic (silt and/or clay) sediments. During burial the sediments protect the organic material by creating an anoxic (oxygen depleted) environment. This allows the organic material to accumulate rather than be destroyed by aerobic organisms such as bacteria. Over time, the organic remains are altered and transformed into gas and oil by the high temperatures and increased pressure of deep burial. This process can take tens of thousands of years to occur. The amount of petroleum generated is a function of the thickness of the accumulated sediments and organic material, the burial of these materials, and time.

Organically rich, black-colored shales deposited in a quiet marine, oxygen depleted environment are considered to be the best source rocks.

Migration of Hydrocarbons

- Primary migration is the process by which petroleum moves from source beds to reservoir rocks. Secondary migration is the concentration and accumulation of oil and gas in reservoir rock. Evidence that petroleum does migrate is suggested by the very common occurrence of active seeps where oil and gas come to the surface either directly from the source rock or from reservoir rocks. In either case, the petroleum had to migrate through rocks with enough permeability and porosity to allow the fluids to flow to the surface. Therefore, migration involves rock properties and fluid properties, including the petroleum, moving through the rocks. Some of the rock and fluid properties include porosity, permeability, capillary pressure, temperature and pressure gradients, and viscosity. These and other properties will be discussed in detail in the sections to follow.

Basic Hydrocarbon Chemistry

- Petroleum is a general term for all naturally occurring hydrocarbons, whether gaseous, liquid, or solid. It is both simple and complex and is composed almost entirely of carbon and hydrogen. Impurities like, nitrogen, sulfur, and oxygen play a somewhat important role in the formation of hydrocarbon molecules. The numerous varieties of petroleum are due to the way carbon and hydrogen can combine and form different sized molecules, thus creating different molecular weights. A thick black asphalt and yellow light crude are examples of two varieties of petroleum with different molecular weights.

A hydrocarbon molecule is a chain of one or more carbon atoms with hydrogen atoms chemically bonded to them. At room temperature and pressure, molecules with up to four carbon atoms occur as gases; molecules having five to fifteen carbon atoms are liquids; and the heavier molecules with more than fifteen carbon atoms occur as solids. Some petroleum contains hydrocarbon molecules with up to sixty or seventy carbon atoms. The molecular structure of hydrocarbons can vary from simple straight chains to more complex branched chains or closed-ring structures.

Temperature affects the chemical structure of hydrocarbons and can break heavier long- chain molecules into smaller and lighter molecules.

What is a reservoir and how does it develop over time?

- A reservoir is a subsurface volume of porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it. Hydrocarbons migrate upward through porous and permeable rock formations until they either reach the surface as seepage or become trapped below the surface by a non-permeable cap rock which allows them to accumulate in place in the reservoir. Porosity and permeability are influenced by the depositional pore-geometries of the reservoir sediments and the post-depositional diagenetic changes that take place.

Sandstone reservoirs are generally created by the accumulation of large amounts of clastic sediments which is characteristic of depositional environments such as river channels, deltas, beaches, lakes and submarine fans. Sandstone reservoirs have a depositional porosity and permeability controlled by grain size, sorting, and packing of the particular sediments. Diagenetic changes may include precipitation of clay minerals in the pore space, occlusion of pores by mineral cements, or even creation of additional pores by dissolution of some sediments.

Carbonate reservoirs are created in marine sedimentary environments with little or no clastic material input and generally in a location between 30° north and south of the equator. Porosity types of carbonate reservoirs include vuggy (pores larger than grains), intergranular (between grains), intragranular or cellular (within grains), and chalky. Diagenetic changes such as dolomitization, fracturing, dissolution, and recrystalization (rare) are extremely important because they have the ability to create very effective secondary porosity. Cementation, another type of diagenesis, generally reduces porosity and permeability.

Porosity

- Porosity is the ratio of void space in a rock to the total volume of rock, and reflects the fluid storage capacity of the reservoir.
- Fracture porosity results from the presence of openings produced by the breaking or shattering of a rock. All rock types are affected by fracturing and a rocks composition will determine how brittle the rock is and how much fracturing will occur. The two basic types of fractures

include natural tectonically related fractures and hydraulically induced fractures. Hydraulic fracturing is a method of stimulating production by inducing fractures and fissures in the formation by injecting fluids into the reservoir rock at pressures which exceed the strength of the rock. Hydraulic fracturing can tremendously increase the effective porosity and permeability of a formation

Permeability

- Recovery of hydrocarbons from the reservoir is an important process in petroleum engineering and estimating permeability can aid in determining how much hydrocarbons can be produced from a reservoir. Permeability is a measure of the ease with which a formation permits a fluid to flow through it. To be permeable, a formation must have interconnected porosity (intergranular or intercrystalline porosity, interconnected vugs, or fractures).

To determine the permeability of a formation, several factors must be known: the size and shape of the formation, its fluid properties, the pressure exerted on the fluids, and the amount of fluid flow. The more pressure exerted on a fluid, the higher the flow rate. The more viscous the fluid, the more difficult it is to push through the rock. Viscosity refers to a fluid's internal resistance to flow, or it's internal friction. For example, it is much more difficult to push honey through a rock than it is to push air through it.

Permeability is measured in darcies. Few rocks have a permeability of 1 darcy, therefore permeability is usually expressed in millidarcies or 1/1000 of a darcy.

Permeability is usually measured parallel to the bedding planes of the reservoir rock and is commonly referred to as horizontal permeability. This is generally the main path of the flowing fluids into the borehole. Vertical permeability is measured across the bedding planes and is usually less than horizontal permeability. The reason why horizontal permeability is generally higher than vertical permeability lies largely in the arrangement and packing of the rock grains during deposition and subsequent compaction. For example, flat grains may align and overlap parallel to the depositional surface, thereby increasing the horizontal permeability, see Figure 25. High vertical permeabilities are generally the result of fractures and of solution along the fractures that cut across the bedding planes. They are commonly found in carbonate rocks or other rock types with a brittle fabric and also in clastic rocks with a high content of soluble material. As seen in Figure 25, high vertical permeability may also be characteristic of uncemented or loosely packed sandstones.

Basic Geological Conditions That Create Petroleum Traps

- Hydrocarbon traps are any combination of physical factors that promote the accumulation and retention of petroleum in one location. Traps can be structural, stratigraphic, or a combination of the two.
- Geologic processes such as faulting, folding, piercement, and deposition and erosion create irregularities in the subsurface strata which may cause oil and gas to be retained in a porous formation, thereby creating a petroleum reservoir. The rocks that form the barrier, or trap, are referred to as caprocks.

Structural Traps

- Structural traps are created by the deformation of rock strata within the earth's crust. This deformation can be caused by horizontal compression or tension, vertical movement and differential compaction, which results in the folding, tilting and faulting within sedimentary rock formations.
- Anticlinal and Dome Trap is where the rock layers in an anticlinal trap were originally laid down horizontally then folded upward into an arch or dome. Later, hydrocarbons migrate into the porous and permeable reservoir rock. A cap or seal (impermeable layer of rock) is required to permit the accumulation of the hydrocarbons.
- Salt Dome or Salt Plug Trap is where a trap created by piercement or intrusion of stratified rock layers from below by ductile nonporous salt. The intrusion causes the lower formations nearest the intrusion to be uplifted and truncated along the sides of the intrusion, while layers above are uplifted creating a dome or anticlinal folding. Hydrocarbons migrate into the porous and permeable beds on the sides of the column of salt. Hydrocarbons accumulate in the traps around the outside of the salt plug if a seal or cap rock is present.
- Fault Trap is where the faulting of stratified rock occurs as a result of vertical and horizontal stress. At some point the rock layers break, resulting in the rock faces along the fracture moving or slipping past each other into an offset position. A fault trap is formed when the faulted formations are tilted toward the vertical. When a non-porous rock face is moved into a position above and opposite a porous rock face, it seals off the natural flow of the hydrocarbons allowing them to accumulate.

Stratigraphic Traps

- Stratigraphic traps are formed as a result of differences or variations between or within stratified rock layers, creating a change or loss of permeability from one area to another. These traps do not occur as a result of movement of the strata.
- Lenticular trap is where a porous area surrounded by non-porous strata. They may be formed from ancient buried river sand bars, beaches, etc.
- Pinch-out or lateral graded trap is where a trap created by lateral differential deposition when the environmental deposition changes up-dip.

Exploration and Mapping Techniques

- Exploration for oil and gas has long been considered an art as well as a science. It encompasses a number of older methods in addition to new techniques. The explorationist must combine scientific analysis and an imagination to successfully solve the problem of finding and recovering hydrocarbons.

Subsurface Mapping

- Geologic maps are a representation of the distribution of rocks and other geologic materials of different lithologies and ages over the Earth's surface or below it. The geologist measures and describes the rock sections and plots the different formations on a map, which shows their distribution. Just as a surface relief map shows the presence of mountains and valleys, subsurface mapping is a valuable tool for locating underground features that may form traps or outline the boundaries of a possible reservoir. Once a reservoir has been discovered, it is also the job of the geologist to present enough evidence to support the development and production of that reservoir.
- Subsurface mapping is used to work out the geology of petroleum deposits. Three- dimensional subsurface mapping is made possible by the use of well data and helps to decipher the underground geology of a large area where there are no outcrops at the surface.
- Some of the commonly prepared subsurface geological maps used for exploration and production include; (1) geophysical surveys, (2) structural maps and sections, (3) isopach maps, and (4) lithofacies maps.
- Structural Contour Maps show a series of lines drawn at regular intervals. The points on each line represent equal values, such as depth or thickness. One type of contour map is the structural map, which depicts the depth of a specific formation from the surface. The principle is the same as that used in a topographic map, but instead shows the highs and lows of the buried layers.
- Contour maps for exploration may depict geologic structure as well as thickness of formations. They can show the angle of a fault and where it intersects with formations and other faults, as well as where formations taper off or stop abruptly. The subsurface structural contour map is almost or fully dependent on well data for basic control.
- Cross-Sections are used to depict structural, stratigraphic, and topographic information can be portrayed on cross-sections that reproduce horizontally represented map information in vertical section. Maps represent information in the plan view and provide a graphic view of distribution. Cross-sections present the same information in the vertical view and illustrate vertical relationships such as depth, thickness, superpostion, and lateral and vertical changes of geologic features. Raw data for cross-sections come from stratigraphic sections, structural data, well sample logs, cores, wireline logs, and structural, stratigraphic, and topographic maps.

III. DEFINITIONS OF OFTEN USED GEOLOGIC TERMS

Formation -

- In geology, the primary formal unit of lithostratigraphic classification. A Formation is a rock unit which is distinctive enough in appearance so that a geologic mapper can tell it apart from the surrounding rock layers. It must also be thick enough and laterally extensive enough to plot on a map. Formations are given names that include the geographic name of a permanent feature near the location where the rocks are well exposed (outcrop). Formations can contain a variety of related or interlayered rock types or lithologies.

Formations are the only formal lithostratigraphic units into which the stratigraphic column everywhere should be divided completely on the basis of lithology.

The contrast in lithology between Formations required to justify their establishment varies with the complexity of the geology of a region and the detail needed for geologic mapping and to work out its geologic history.

No Formation is considered justifiable and useful that cannot be delineated at the scale of geologic mapping practiced in the region. The thickness of Formations may range from less than a meter to several thousand meters.

Member -

- The formal lithostratigraphic unit next in rank below a Formation. Formations can be divided into smaller units called Members. Members are useful where it is important to study or keep track of a particular subdivision of a Formation.

A Member possesses lithologic properties distinguishing it from adjacent parts of the Formation.

No fixed standard is required for the extent and thickness of a Member.

A Formation need not be divided into members unless a useful purpose is thus served.

Some formations may be completely divided into Members; others may have only certain parts designated as Members.

A Member may extend from one Formation to another.

Specially shaped forms of Members (or of Formations) are lenses and tongues.

A lens is a lens-shaped body of rock of different lithology than the unit that encloses it.

A tongue is a projecting part of a lithostratigraphic unit extending out beyond its main body

Zone

- A region or stratum distinguished by composition or content, a Horizon.

Horizon

- Either a bedding surface where there is marked change in the lithology within a sequence of sedimentary rocks, or a distinctive layer or thin bed with a characteristic lithology or fossil content within a sequence.

Strata

- Refers to stacked-up layers of sedimentary rock**.** Strata are distinguished from one another on the basis of their physical composition, in other words, the composition of sediment from which they are comprised. A sedimentary rock layer bounded by two stratification planes, the latter being produced by visible changes in the grain size, texture, or other diagnostic features of the rocks above and below the plane.

Facies

- The characteristics of a rock or sediment unit that reflect its environment of deposition and allow it to be distinguished from rock or sediment deposited in an adjacent environment at the same time.

Facies show a transgressive pattern when the sediment supply is overwhelmed by a relative rise in sea level, or when the land subsides tectonically.

Facies show a regressive pattern when the shoreline move seaward due to an excess sediment supply from the land, when the land is tectonically uplifted and the sea retreats, or when there is a relative lowering of sea level.

Each depositional environment grades laterally into other environments, each change is referred to as a "facies change" when dealing with the rock record.

Depth

- A dimension taken through an object or body of material, usually downward from an upper surface, horizontally inward from an outer surface, or from top to bottom of something regarded as one of several layers.

Elevation

- Height above a given datum or level, usually sea level.

Topography

- The art or practice of graphic delineation in detail usually on maps or charts of natural features of a place or region in a way to show their relative positions and elevations.

Fault

- A planar fracture or discontinuity in a volume of rock across which there has been significant displacement along the fractures as a result of rock mass movement. Large faults within the Earth's crust result from the action of plate tectonic forces, with the largest forming the boundaries between the plates. Energy release associated with rapid movement on active faults is the cause of most earthquakes. Two types are normal faults and reverse or thrust faults.

Growth fault

- Syn-depositional or syn-sedimentary extensional faults that initiate and evolve he margins of continental plates. They extend parallel to passive margins that have high sediment supply. Their fault plane dips mostly toward the basin and has long-term continuous displacement. A growth fault possesses a concave upward fault plane that has high updip angle and flattened at its base into zone of detachment or décollement. This angle is continuously changing from nearly vertical in the updip area to nearly horizontal in the downdip area. Sedimentary layers grow thicker on the downthrown, basinward sides of growth fault planes.