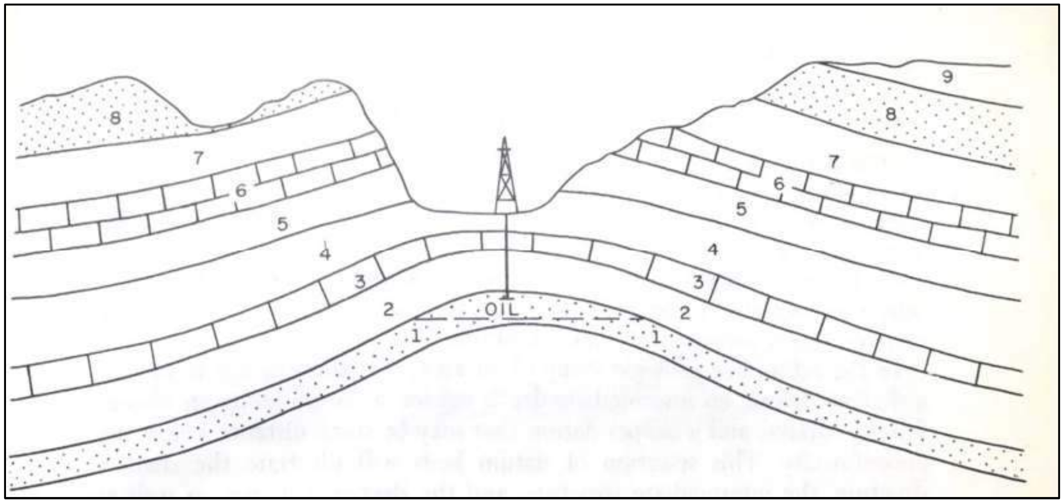
Subsurface Geology

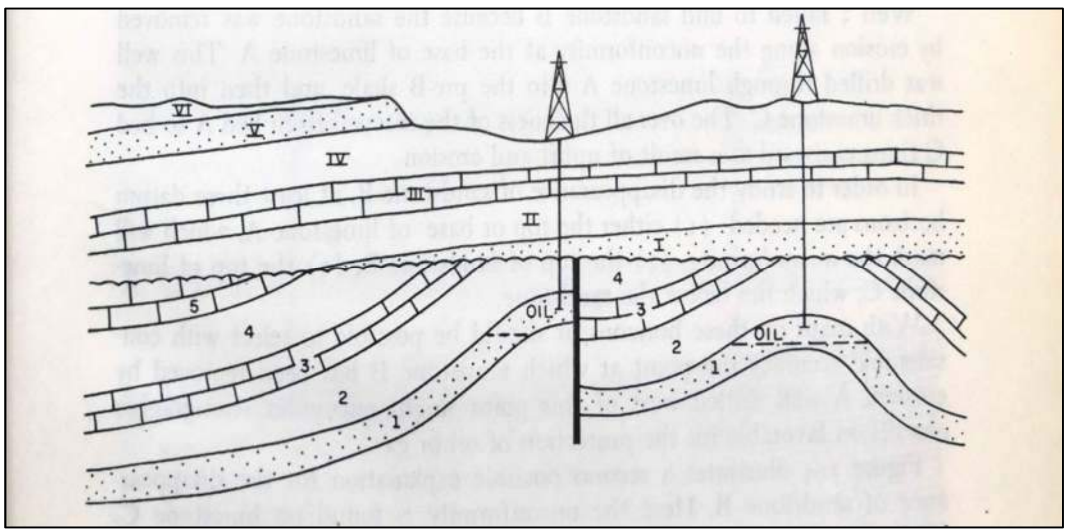
The study of geological structures, and stratigraphic relationships beneath the land or sea-floor surface as revealed or inferred by exploratory drilling, and geophysical methods.

Onshore well

Offshore well

Surface Geology vs. Subsurface Geology





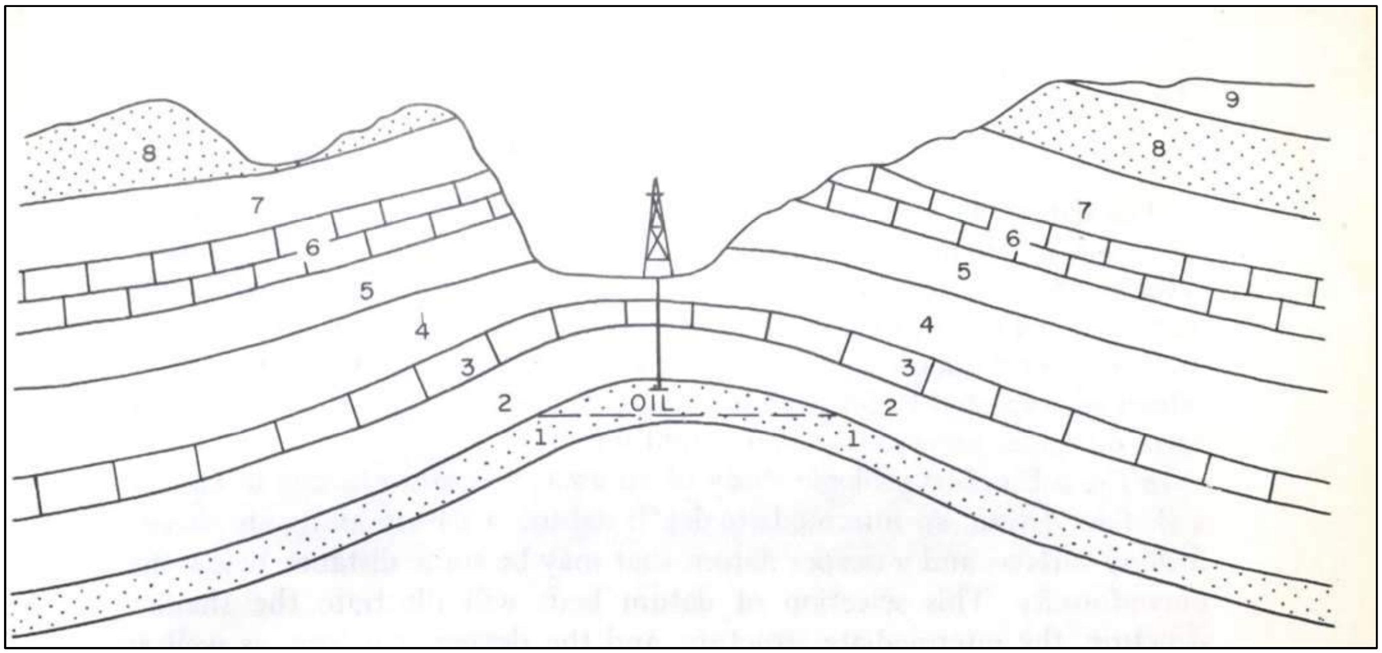
Data sources of Subsurface Geology

A – Surface geologic survey
B- Subsurface sources: 1-Direct (Drilling) 2- Indirect (Well logging)

A – Surface geologic survey

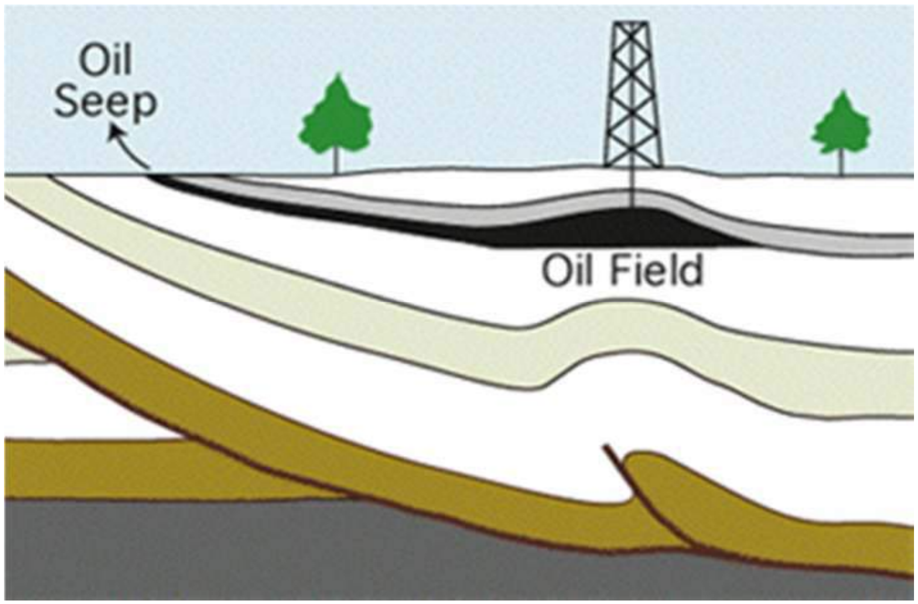
The aim of this survey is to draw a surface geologic map (field mapping). Outcrops provide information about type of rocks, their stratigraphic relation, the position and nature of unconformity surfaces , the time of folding and faulting and the facies changes in the section of the rock being mapped.

The rule of surface geologic survey is “any surface structure reflects the subsurface structure for a limit depth”.



Hydrocarbon seepages

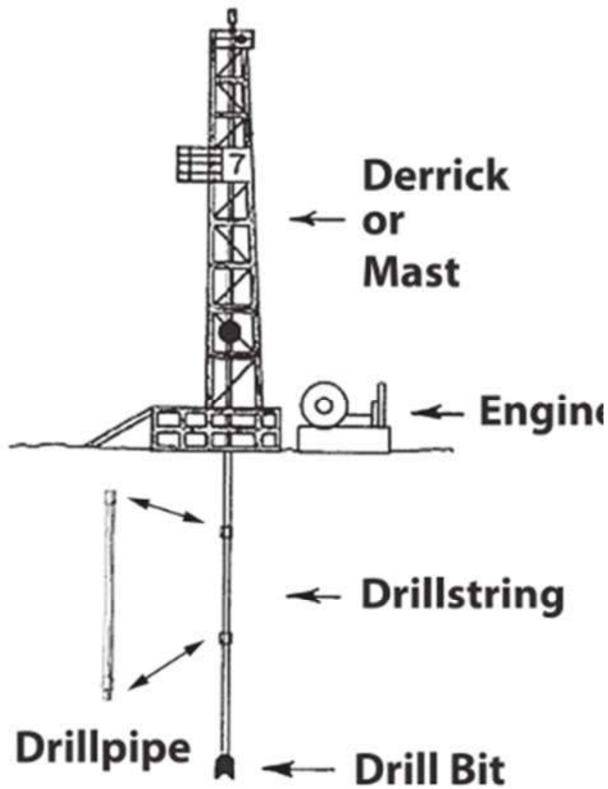
Hydrocarbon seepages include asphalt, or gases or spots of oil in the exposed rocks with dark brown color. These phenomena can be interpreted to the presence of subsurface hydrocarbon accumulation as source feeding these phenomena.



Hydrocarbon seepages

B- <u>Subsurface sources:</u>
Direct (Drilling)

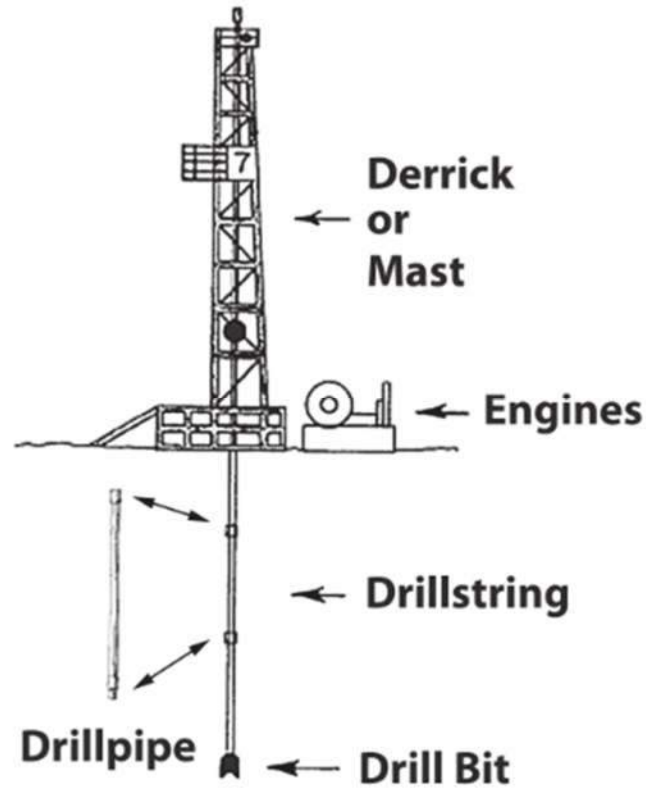
- **Rotary drilling:** A method of drilling that employs a sharp, rotational drill bit to drill its way through the earth’s crust. The spinning of the drill bit allows for penetration of even the hardest rock.



drill bit

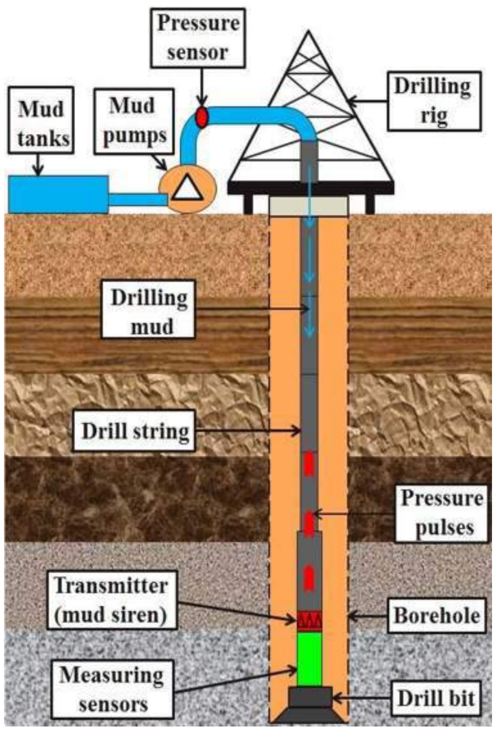
Rotary drilling system

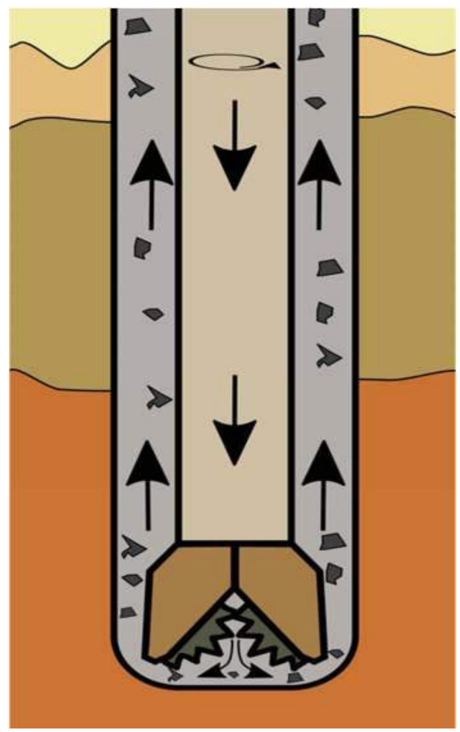
In rotary drilling rig ,there can be thousands of feet of steel drillpipe with a bit on the end, called the drillstring, suspended in the well. By rotating the drillstring from the surface, the bit on the bottom is turned and cuts the hole. As the well is drilled deeper, every 30 ft (9.1 m) drilling is stopped and another section of drillpipe is screwed on the drillstring to make it longer. The power to the rig is supplied by diesel engines. A steel tower above the well the derrick or mast—along with a hoisting line and pulley system, is used to raise and lower equipment in the well.



Drilling Mud

An important system on the rig is the circulating mud system. Drilling mud is suspension, semicolloidal material dissolved in fluid. The fluid may be fresh water brine or oil depending on the penetrated lithology and type of formation fluid. It is pumped down the inside of the drillpipe where it jets out of nozzles on the bit and returns up the outside of the drillpipe to the surface.





The component of drilling mud:

1 – Fluid

2 – Solid material: which include various materials such as:

A **–** Bentonite: added to fresh water to increase viscosity and to precipitate mud cake (no permeability) to prevent the entrance of fluid to the penetrated formation

B **–** Barite: added to increase the density

C- Graphite: added to prevent pipe sticking especially in deviated drilling, it is a lubrication material.

D- Sodium chromite (Na_2CrO_4Na): it is used at temperature increase to control the viscosity.

The importance of drilling mud:

1 – To clean the borehole by removing the cuttings of the rocks to the earth surface.

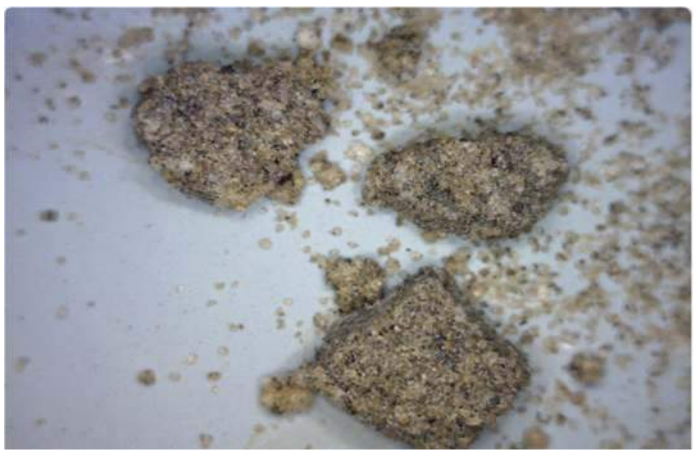
2 – Cool and lubricate the bit and drilling pipe by decrease the fraction.

3 – Bulid and precipitate mud cake (not permeable) layer to prevent entering of fluid to the penetrated formations.

4 – Control formations pressure.

Rotary drilling data

1-Well cuttings: samples are produced from drilling operations, by the drill bit penetrating the formation encountered in the subsurface. Samples are taken at regular intervals. They are used to establish a lithologic record of the well.

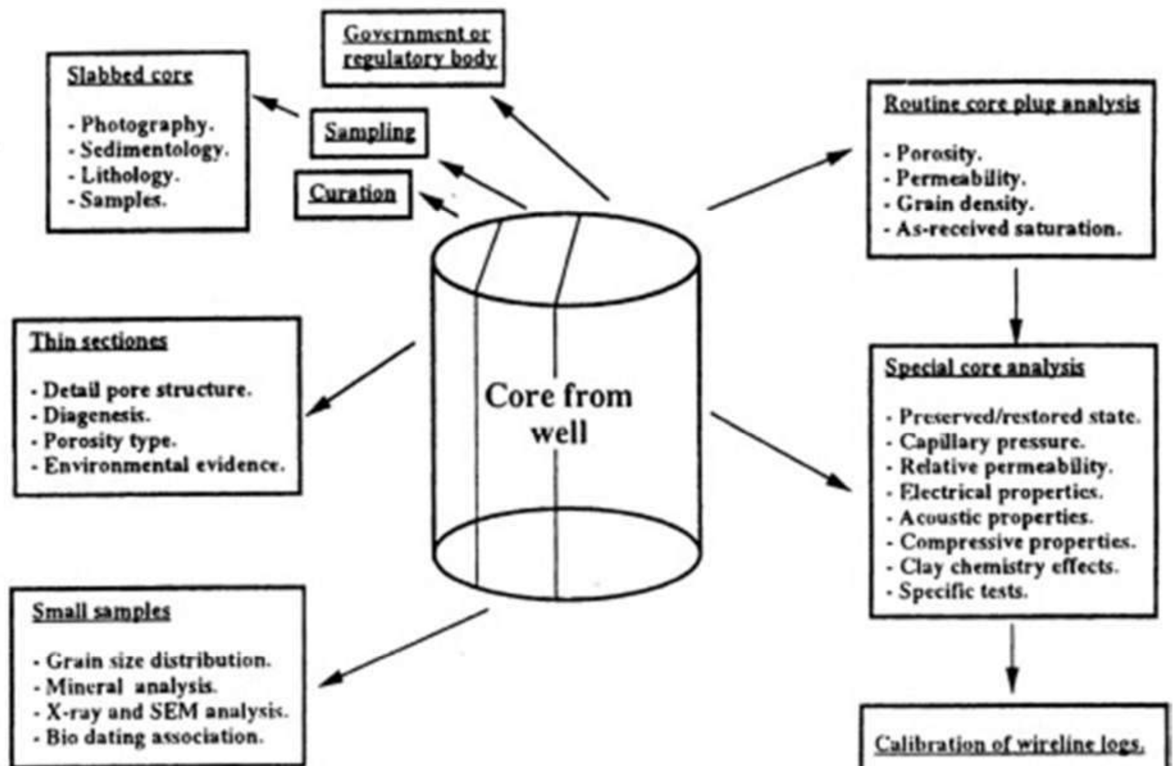


Scale in Cm

Rotary drilling data

<u>2-Cores: </u>They are rock samples cut by a hollow core barrel, which goes down around the rock core as drilling proceeds. The core occupies the entire interior of the core barrel, it is brought to the surface, and the core is removed and laid out in stratigraphic sequence. Cores are cut where specific lithologic and rock parameter data are required. Cores are preferable to well cuttings because they produce coherent rock. They are significantly more expensive to obtain.

Data obtained from cored well



Directional drilling

As the well is being drilled, it can be drilled straight down, out at an angle as a deviated well, or out horizontally as a horizontal well through the oil and gas reservoir.

Modern rotary rigs can be controlled so that a straight hole is drilled. They can also drill a directional or deviated well out at a predetermined angle during directional or deviation drilling

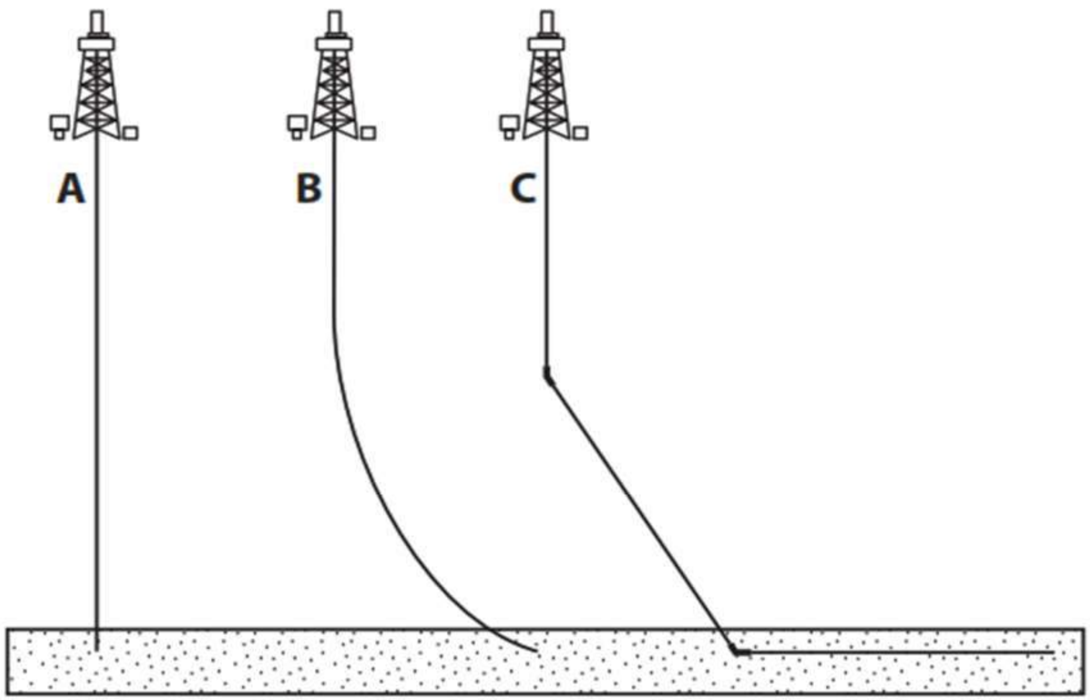
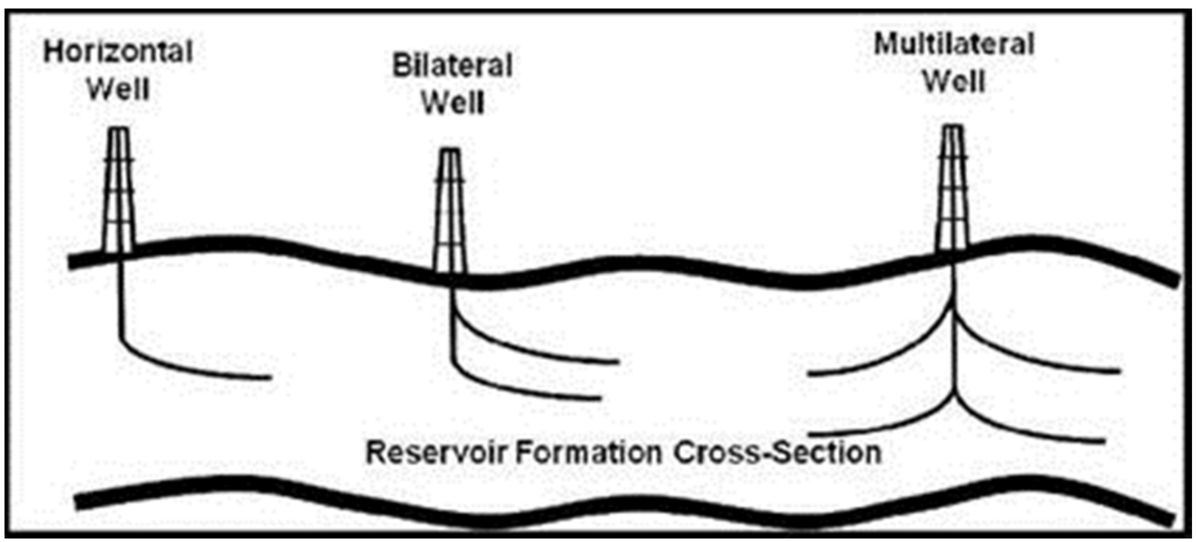


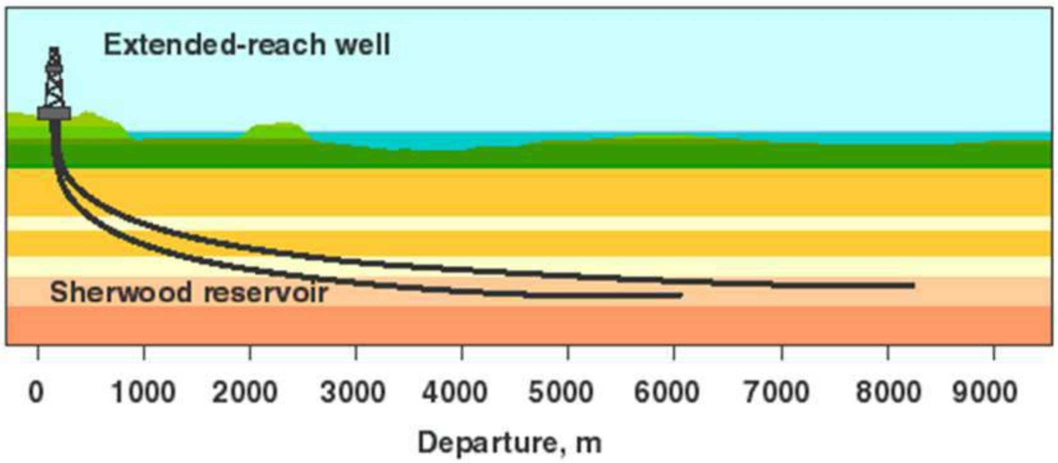
Fig. I–7. Types of wells: (a) straight hole, (b) deviated well, and (c) horizontal well

Types of directional wells

The major types of directional wells are:
1-Horizontal wells: Horizontal wells are high-angle wells (with an inclination of generally greater than 85°) drilled to enhance reservoir performance by placing a long wellbore section within the reservoir.
2-Multilateral wells: Multilateral wells are new evolution of horizontal wells in which several wellbore branches radiate from the main borehole.

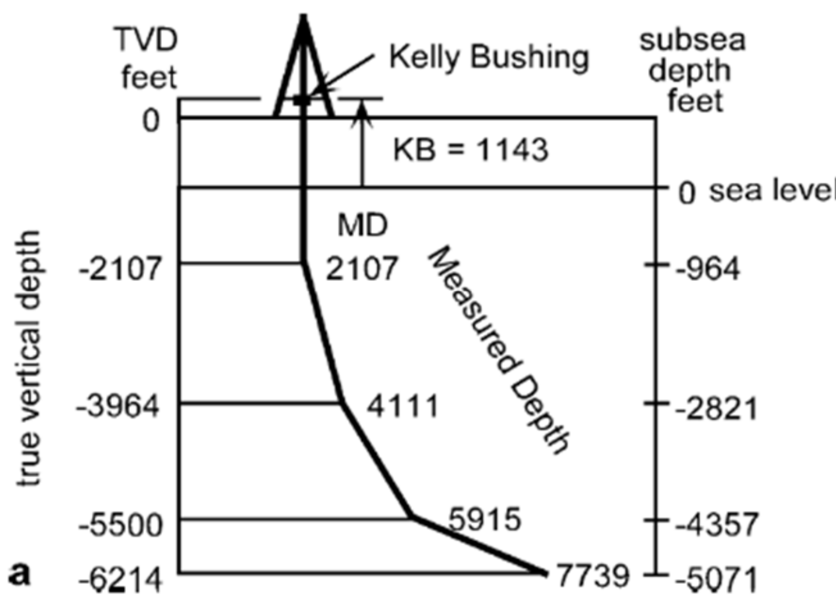


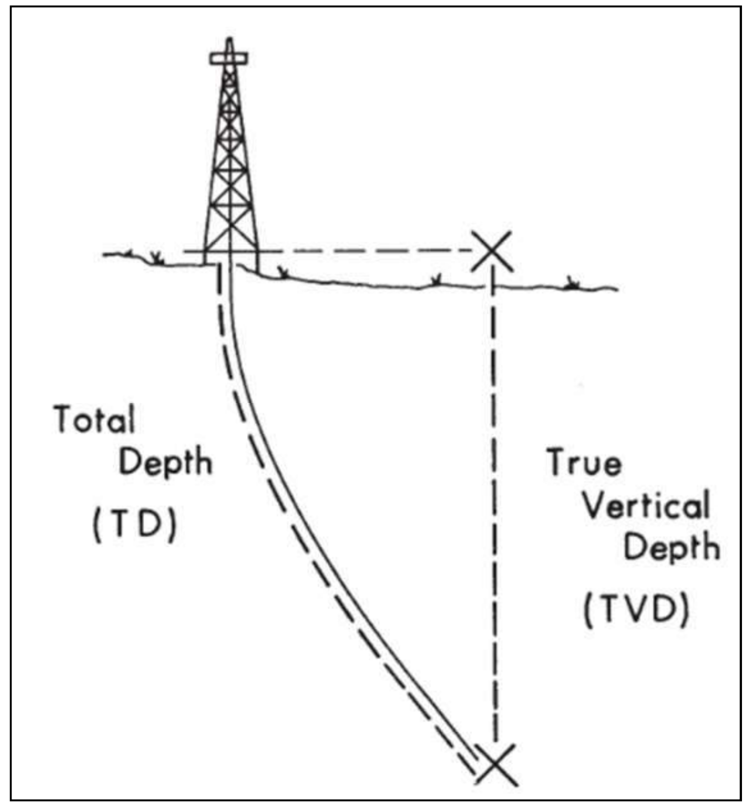
3-Extended reach wells: They are very long horizontal wells that reach a larger area from one surface drilling location.



Well Depth

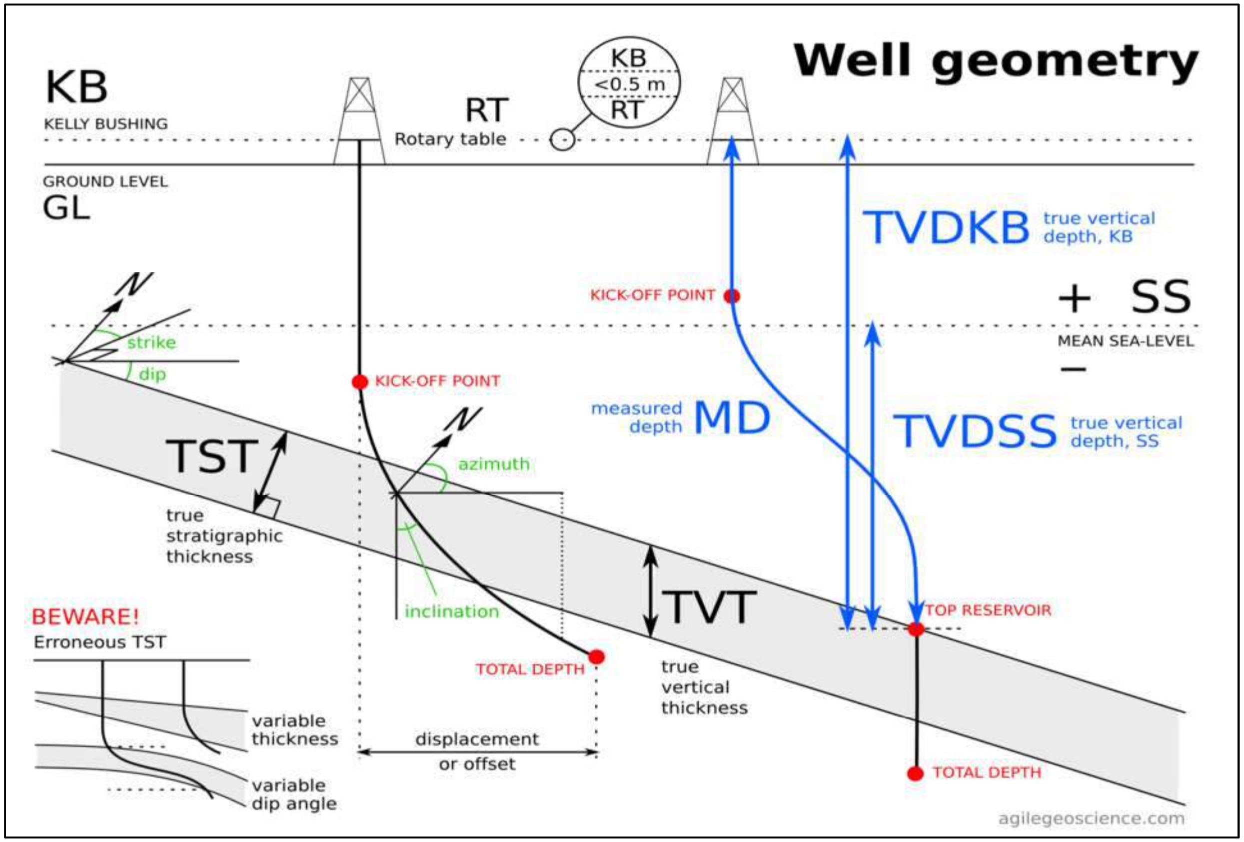
The depth of a well can be measured two ways.Total depth (TD), also called measured (MD), logged, or driller’s depth, is measured along the length of the wellbore. True vertical depth (TVD) is measured straight down and is less than total depth. It cannot be directly measured and has to be calculated.





Well Depth

In perfectly vertical wells, the TVD equals the MD; otherwise, the TVD is less than the MD measured from the same datum. Common datums used are ground level (GL), drilling rig floor (DF), rotary table (RT), kelly bushing (KB or RKB) and mean sea level (MSL).



Well Depth

-Well depth values taken during the drilling operation are referred to as "driller's depth". The "total depth" for the well, core depths and all analysis of core / mud and other materials from the drilling hole are measured in "drillers depth".

-Well depth values from the wireline loggers operation are referred to as "logger's depth". The loggers depth are typically considered more reliable than the drillers depth.

-The acronym TVDSS is commonly used in the oil industry to represent TVD minus the elevation above mean sea level of the depth reference point of the well. The depth reference point is the Kelly Bushing in the United States and a few other countries, but is the drill floor (DF) in most places.

-The acronym TVDKB is used in the oil industry to represent True Vertical Depth referenced to Top Kelly Bushing (KB).

Well Depth

-The coordinates of points in a well need to be corrected to a common datum elevation, normally sea level. The depths should be adjusted so that they are positive above sea level and negative below. In a vertical well the log depths are converted to a sea-level datum with the following equation:

SD = KB – MD

where SD = subsea depth, KB = elevation of Kelly bushing or other measurement of surface elevation, MD = measured depth on well log.

-In deviated wells, TVD must be corrected for the elevation of the Kelly bushing to give the locations of points with respect to the datum. In a deviated well the log depths are converted to a sea-level datum with the following equation:

SD = KB – TVD

where SD = subsea depth, KB = elevation of Kelly bushing or other measurement of surface elevation, TVD = true vertical depth from the deviation survey.

Subsurface Maps

When conducting any detailed subsurface geological study, a variety of maps and cross sections are required. There are various kinds of subsurface maps such structure, Isopach, and facies maps.

Each map presents a specific type of subsurface data obtained from one or more sources. The purposes of these maps are to present data in a form that can be understood and used to explore for, develop, or evaluate energy resources such as oil and gas.

Contouring

The majority of subsurface maps use the *contour line* to represent the various types of subsurface data. By definition, a contour line is a line that connects points of equal value. Usually this value is compared to some chosen reference, such as sea level in the case of structure contour maps. In preparing subsurface maps, the data beneath the earth’s surface cannot be seen or touched directly

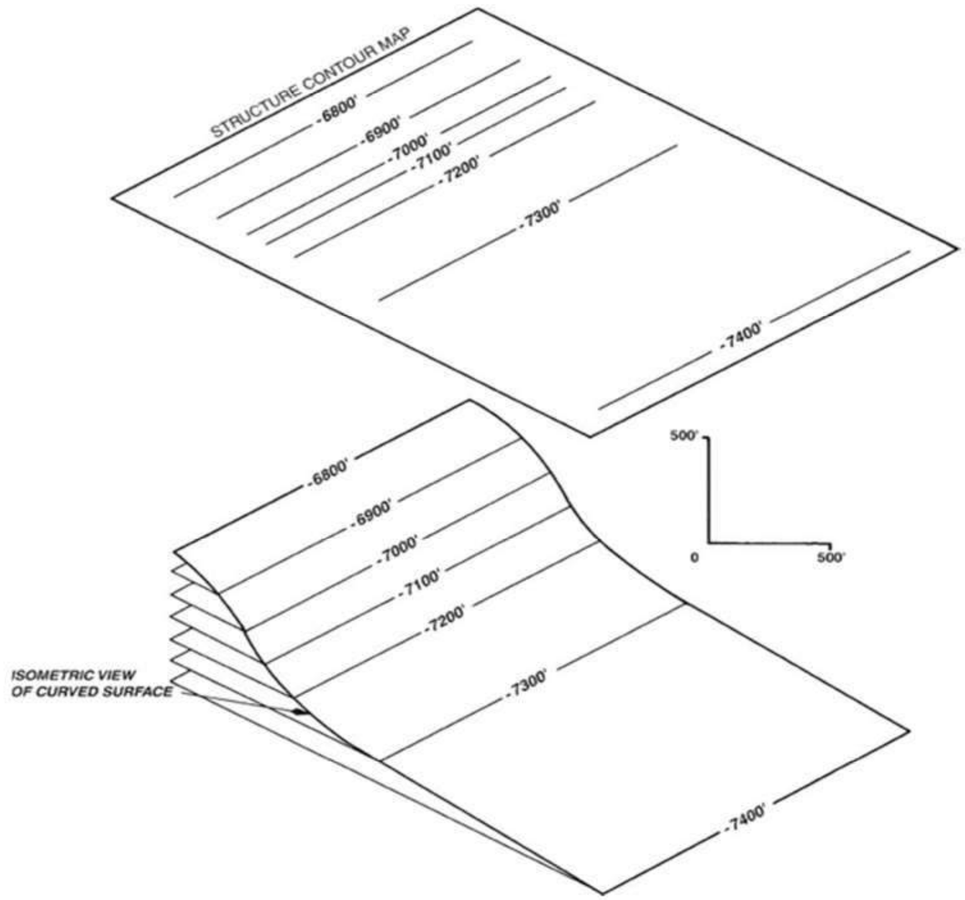
Contouring

Any map that uses the contour line for illustration is called a *contour map.* A contour map illustrates a 3D surface or solid in 2D plan (map) view. Any set of data that can be expressed numerically can be contoured.

The following list shows examples of contourable data and the associated contour map.

Data	*Type of Map*
Elevation	Structure, Fault, Salt
Thickness of sediments	Interval Isopach
Percentage of sand	Percent Sand
Feet or meters of pay	Net Pay Isochore
Pressure	Isobar
Temperature	Isotherm
Time	Isochron
Lithology	Isolith

Contouring

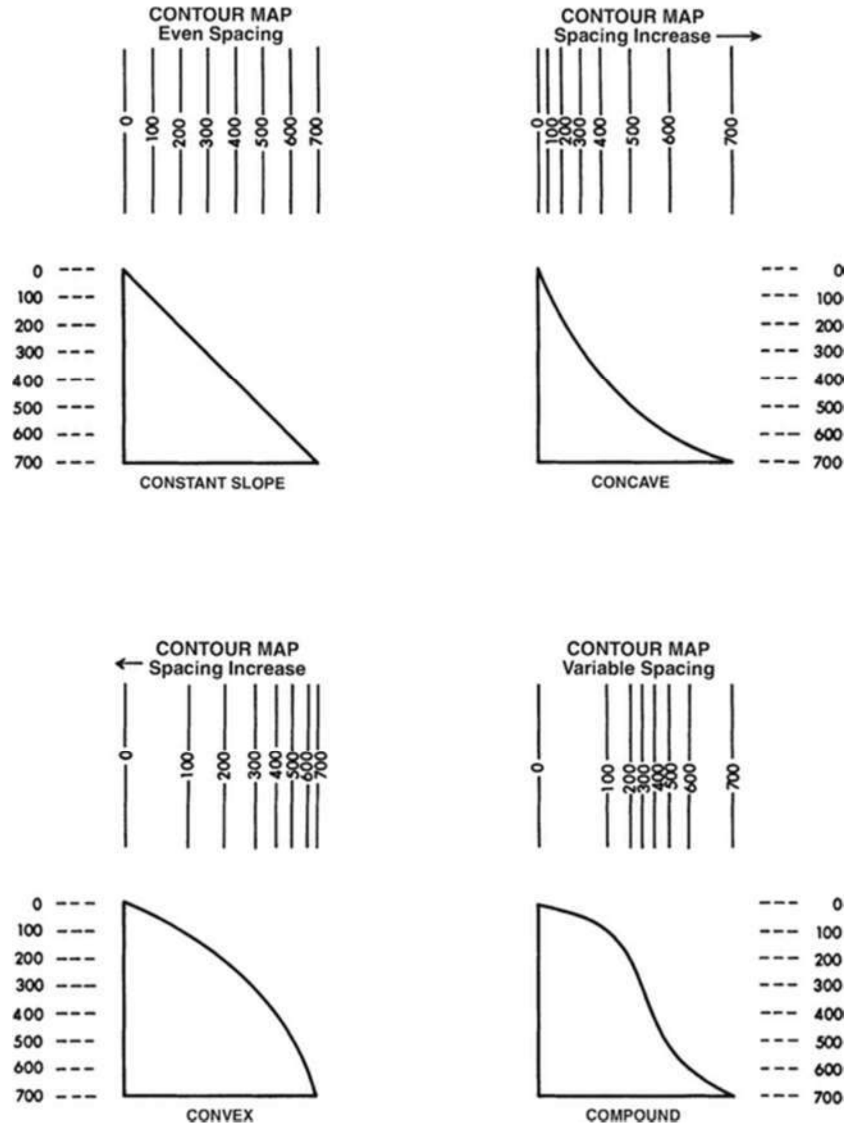


Isometric view of a curved surface represented by a structure contour map

Contouring

Steep slopes are represented by closely spaced contours, and gentle slopes are represented by widely spaced contours. This relationship of contour spacing to change in slope angle assumes that the contour interval for the map is constant.

The spacing of contour lines is a function of the shape and slope of the surface being contoured.

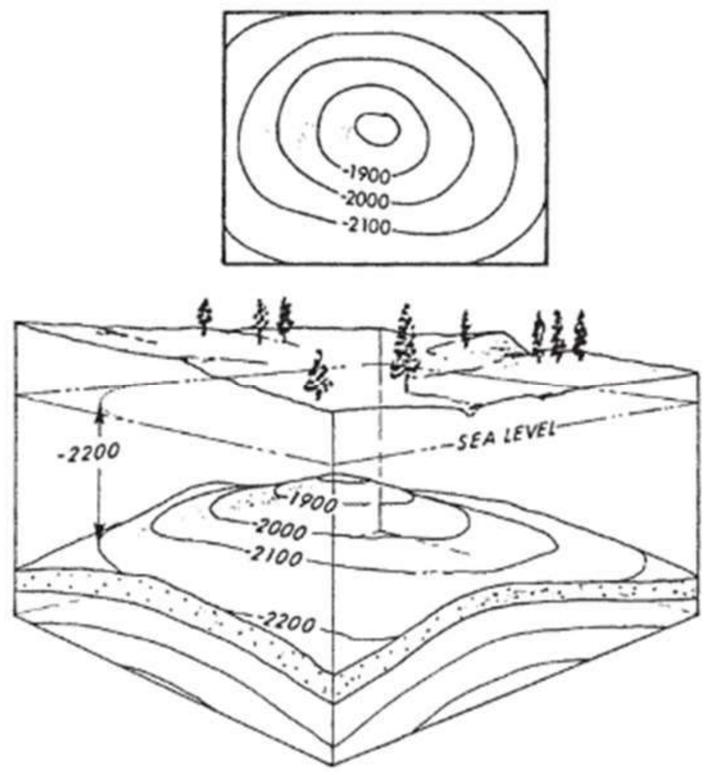


Subsurface Structure Map

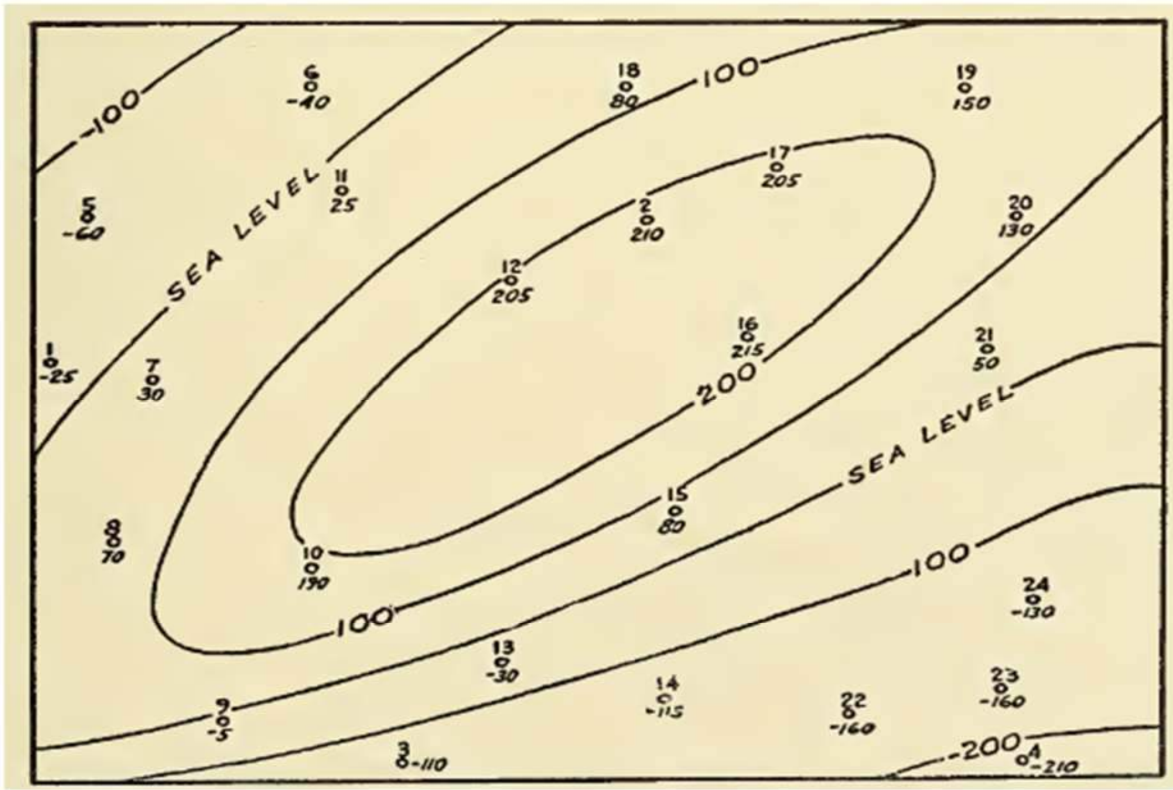
It is a map showing the structural attitude of the top (or bottom) of any significant subsurface bed by using contour lines.

Data for subsurface structural maps come from surface measurement, drilled wells and geophysical information. Depths of a given datum horizon are either below sea level (-) values, or above sea level (+) values.

The structural elevations on which the contours are drawn are obtained by the simple process of subtracting the depth to the datum horizon (the layer) from the surface elevation of the well.



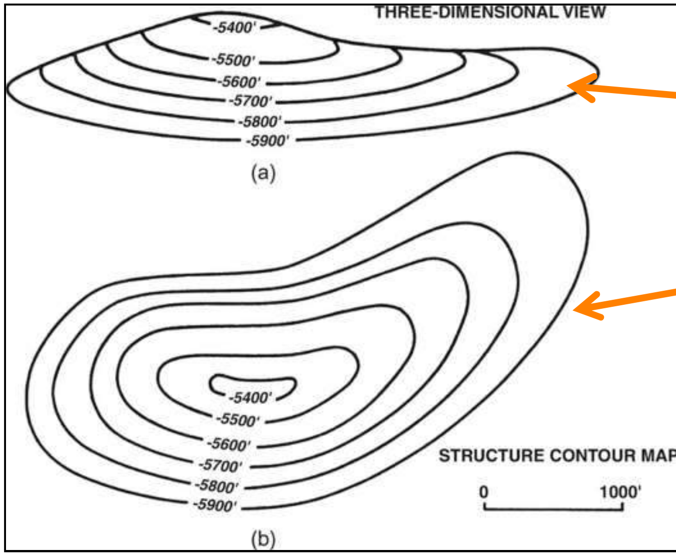
Subsurface Structure Map



Uses of Subsurface structural maps:

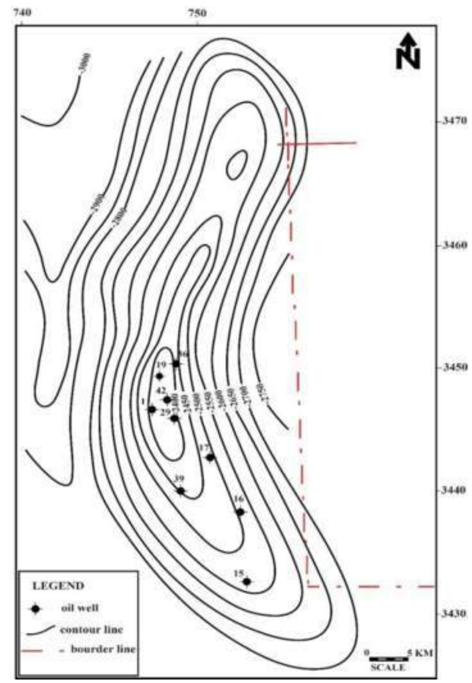
1 –Portray the structural attitude of any given horizon below the surface.
2 – Know the depth of any bed of interest or importance at any given point on a map.
3 – Regional dips may be calculated; anticlinal and domal axes as well as trends may be located and synclinal areas may be avoided in further exploration.
4 – From constructing a number of structural map on different datum horizon it is possible to study the structural history and development of the area.
5 – Checking the depth to possible producing horizons and to important marker horizon by petroleum companies by using regional maps on given datum horizon.

Subsurface Structure Map: Folded structure



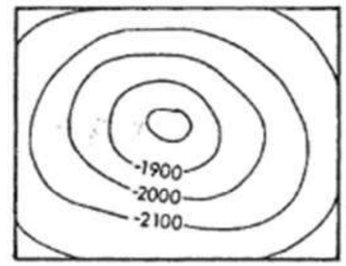
A <u>3D view</u> of an anticlinal structure and a <u>structure map</u> representing the structure.

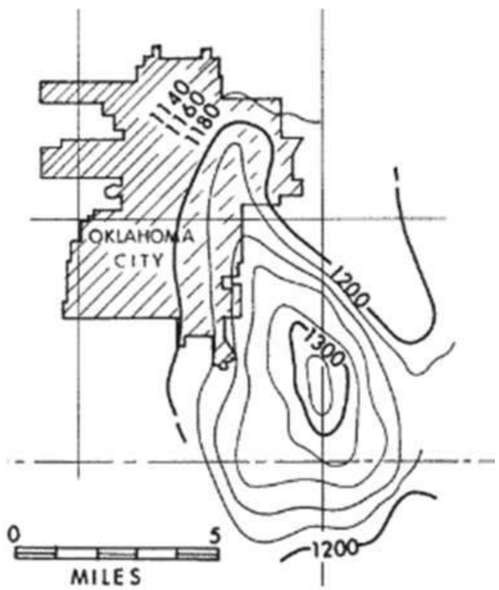
Majnoon oilfield

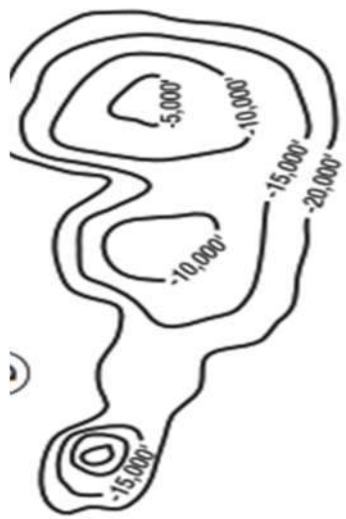


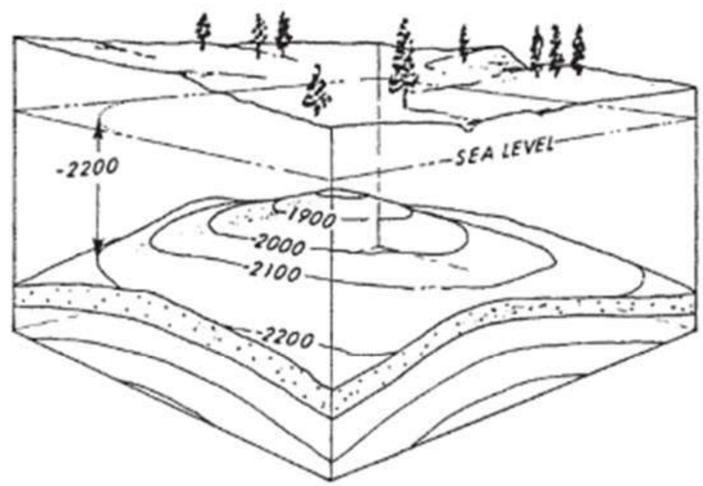
Subsurface Structure Map: Folded structures

A type of anticline that is circular or elliptical rather than elongate. The upward migration of salt diapirs can form domes, called salt domes.

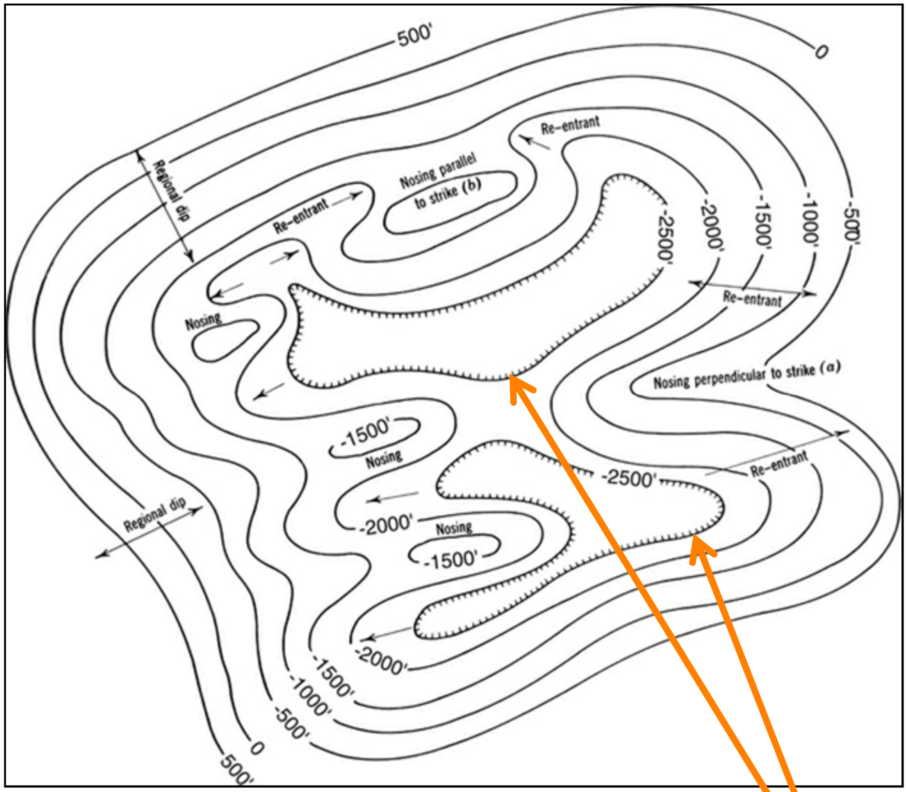








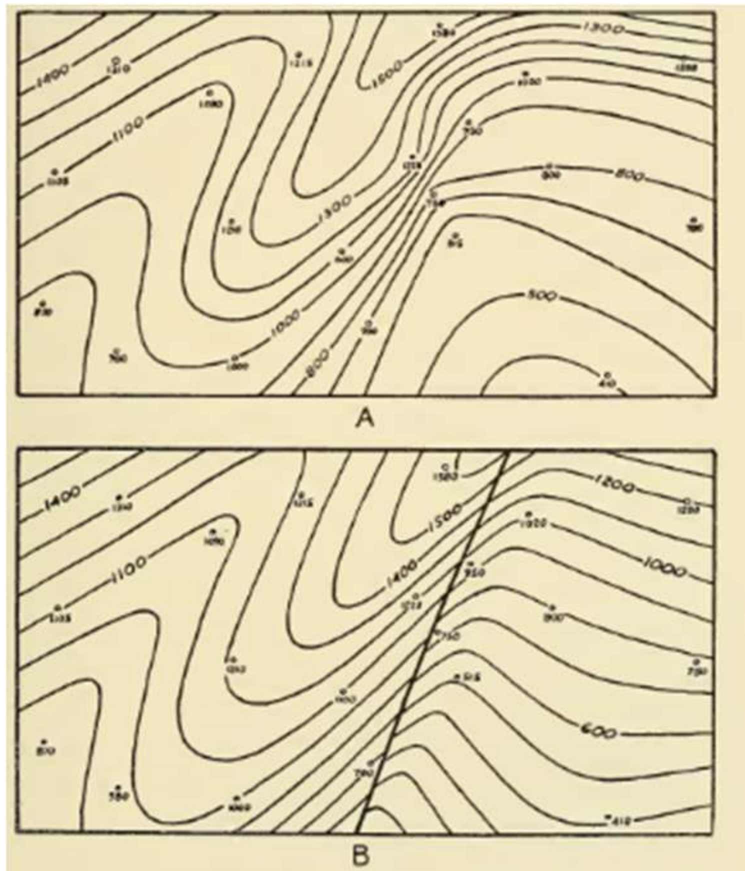
Subsurface Structure Map: Basins



A structure contour map of a basin. *Hachured lines* should be used to indicate a closed depression

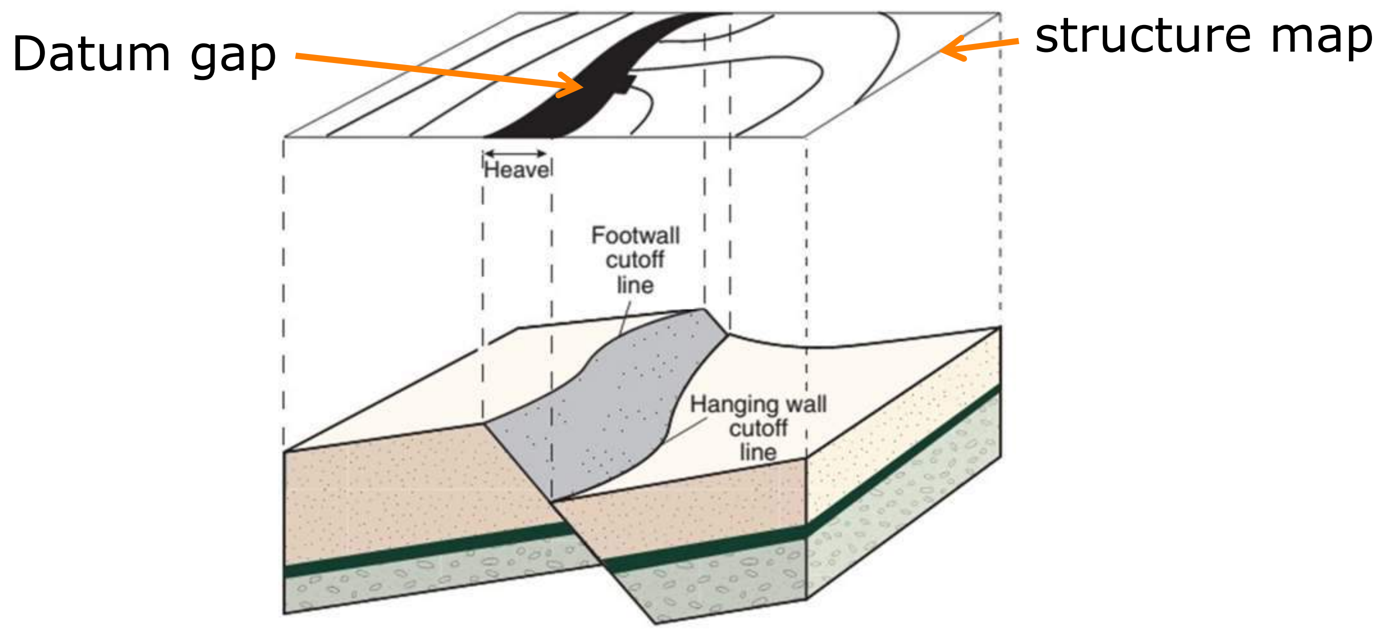
Subsurface Structure Map: Faults

Anomalous (steep) dip in structural maps can indicate the presence of faults. For example, in map A below an steep dip is indicated on the east flank of the anticlinal structure.In map B, the same wells have been carefully contoured from the east and west edges of the area toward the locality of erratic elevations, each side being treated independently of the other. When this procedure is followed, a fault is clearly indicated.



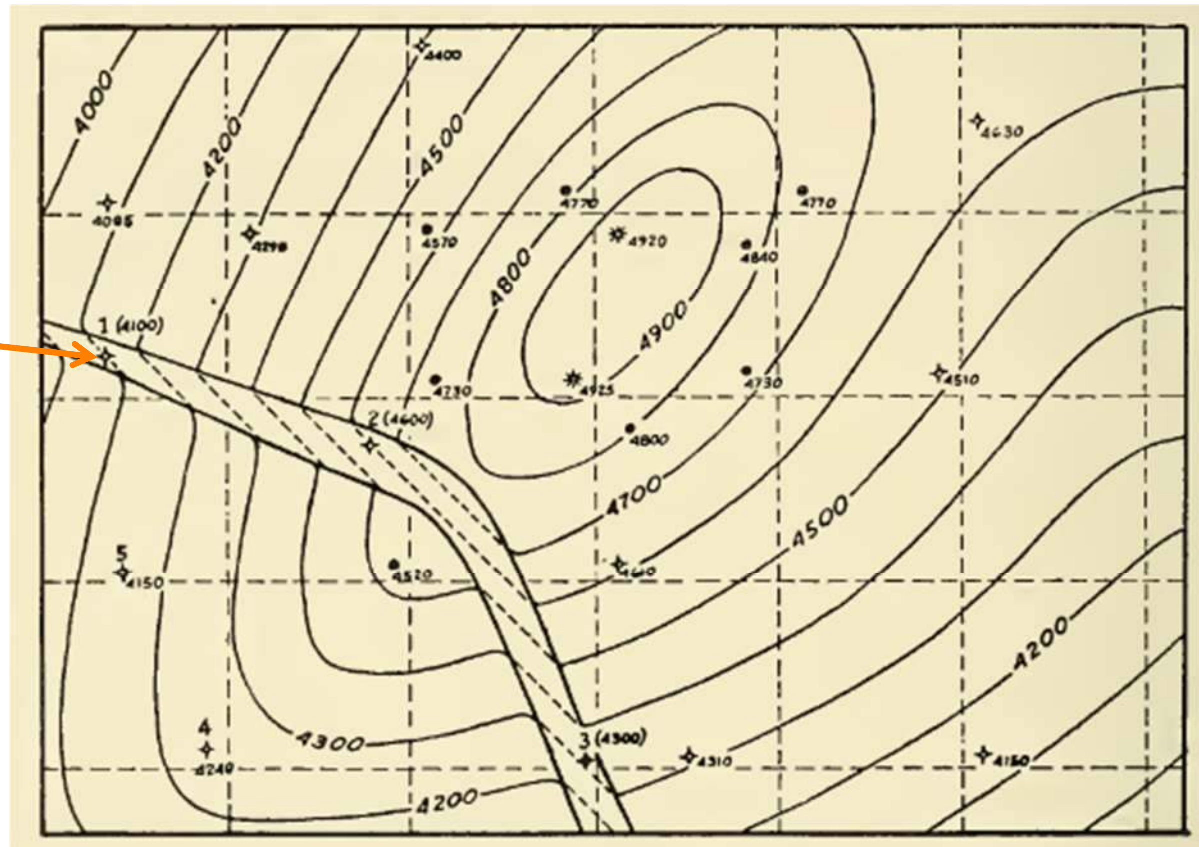
Subsurface Structure Map: Faults

Although a fault is commonly represented on structure maps as a single line, a normal fault with a low-dipping plane invariably results in a zone where the datum surface is absent. This zone is called a datum gap. The breadth of the datum gap is determined by the degree of dip in the strata, the dip of the fault plane, the amount of throw, and the relationships between the dip and strike of the strata and the fault plane.



Subsurface Structure Map: Faults

Datum gap



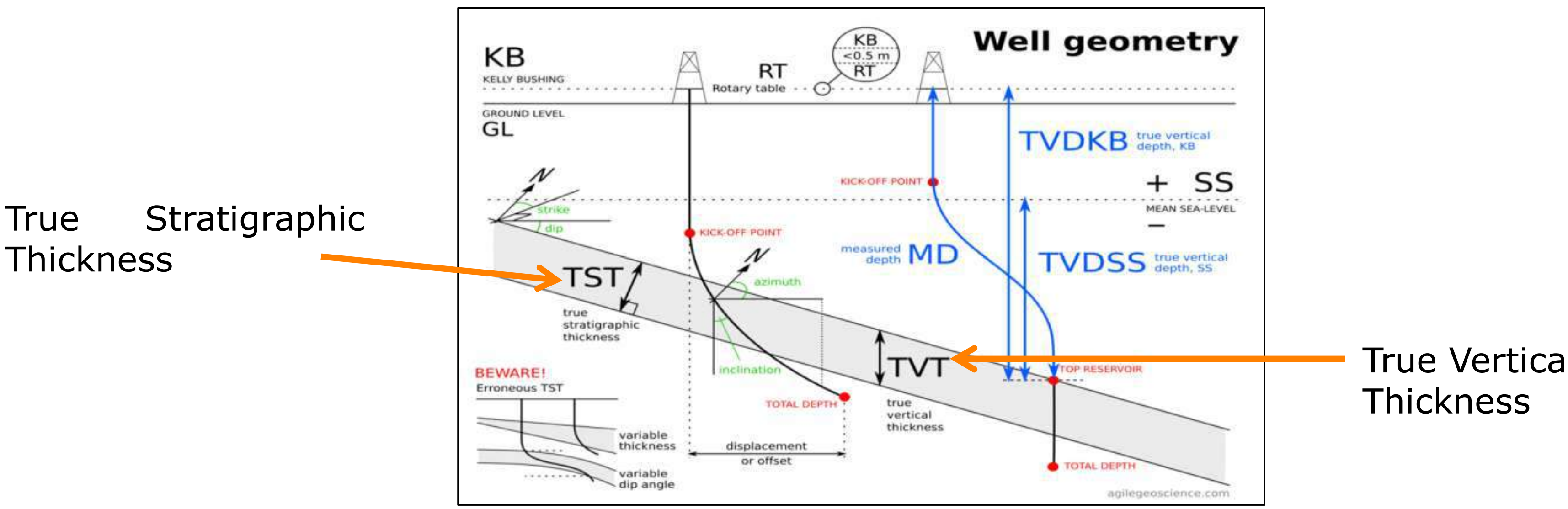
Thickness maps

They are maps that show by means of contours the variations in stratigraphic thickness of a stratum, formation, or group of formations.

There two types of thickness maps:

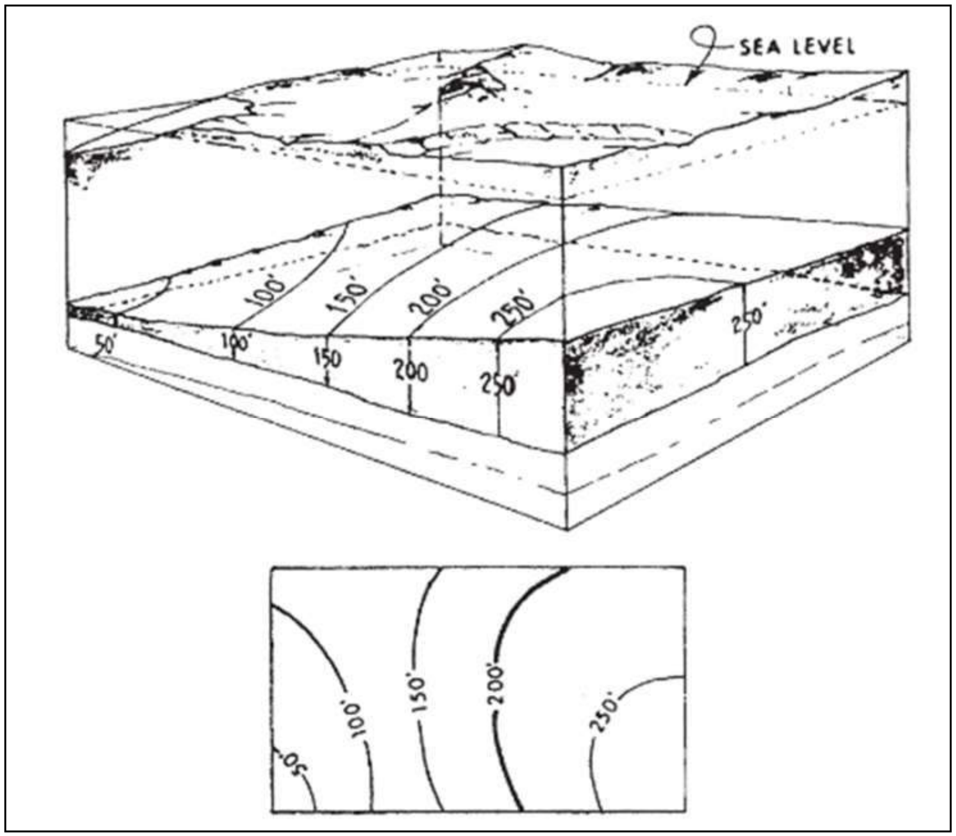
1-Isopach map displays lines of equal thickness in a layer where the thickness are measured perpendicular to the layer boundaries. Isopach maps in geology are also referred to as True Stratigraphic Thickness (TST) maps .

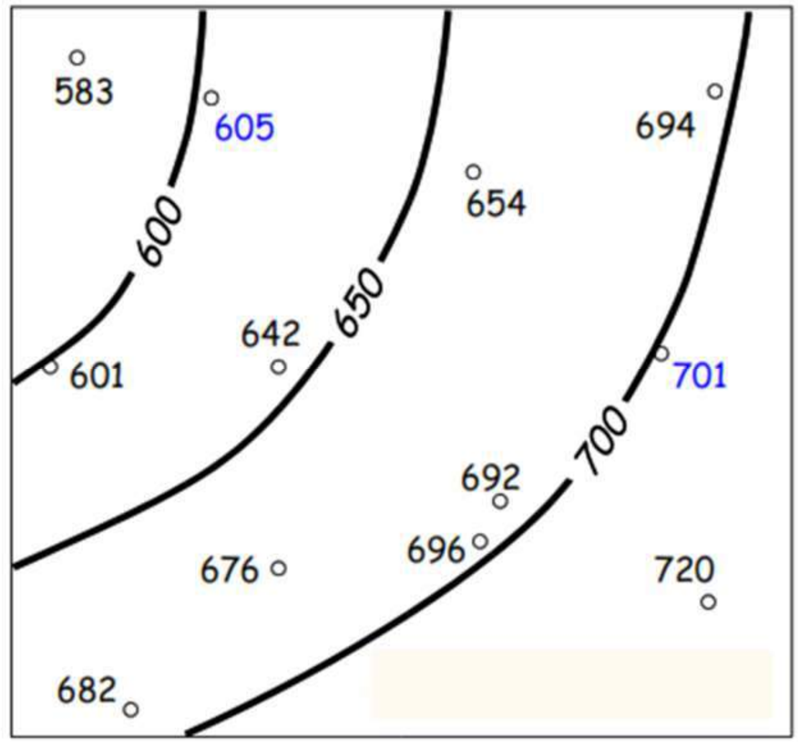
2- An isochore map displays lines of equal thickness in a layer where the thicknesses are measured vertically. Isochore maps in geology are also referred to as True Vertical Thickness (TVT).



Thickness maps

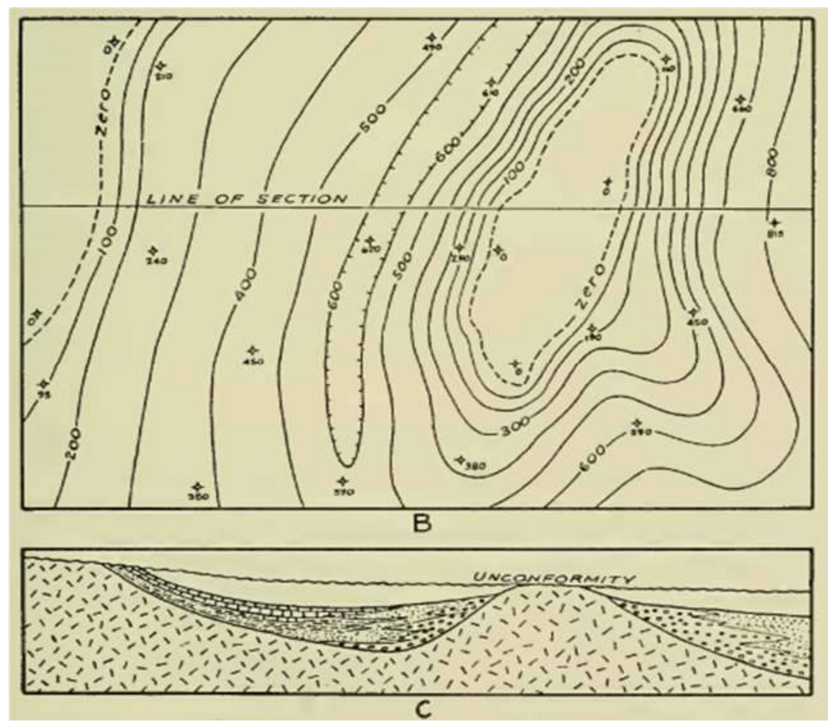
To construct a thickness map from wells, one locates the top and bottom of the stratigraphic unit on a given log, subtracts the lesser depth from the greater, and plots the resulting thickness on a map. Repetition for each of the available logs generates the data that are then contoured on the map.





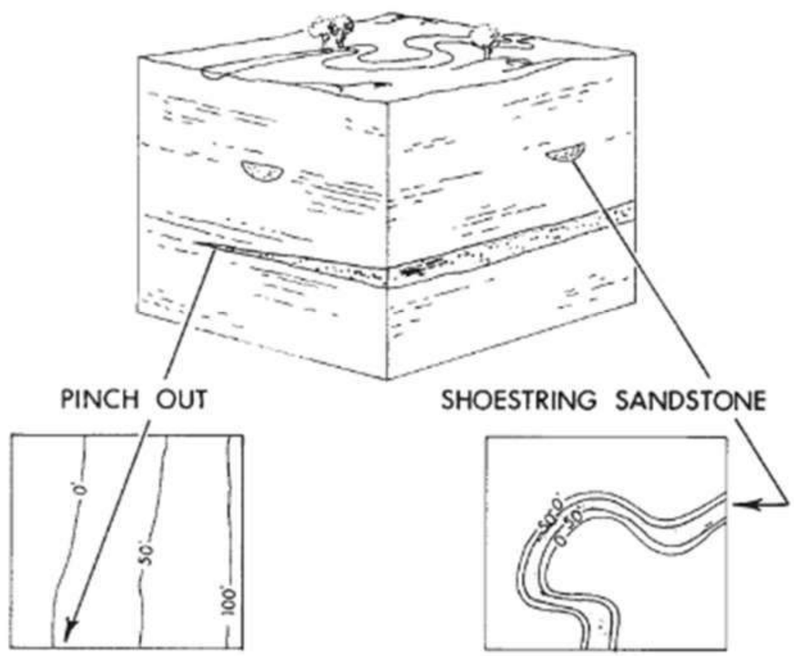
Uses of Isopach map:

-Isopach maps may be made to show minor details of oilfields, or may be made for regional studies covering thousands of square miles.
-particularly useful in determining the time of faulting and folding.
-Isopach maps bring out the distinction between the subsiding basin and its adjacent shelf area.
-To calculate the volume of oil in a formation.
-To locate buried structures in regions where formation habitually become thinner over structural crests.



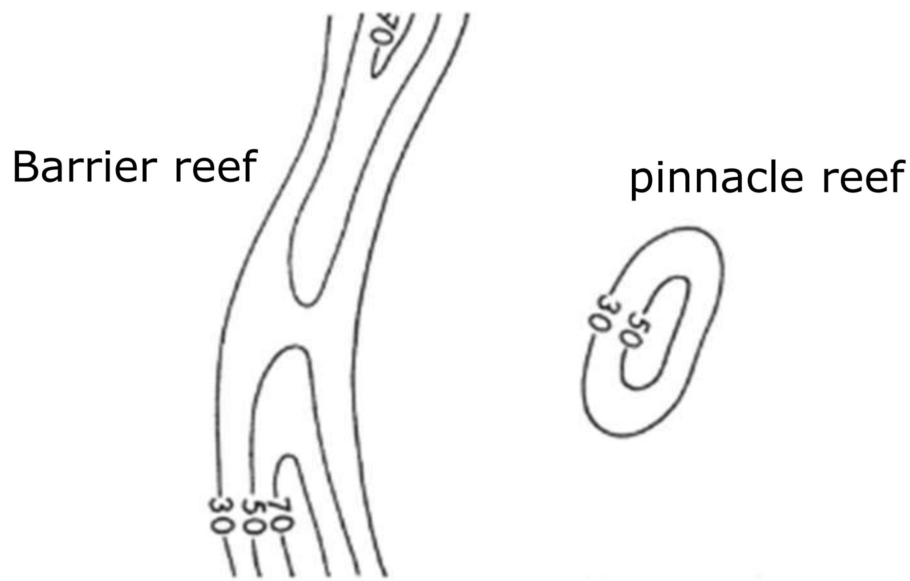
Uses of Isopach map:

-An isopach map can be used in exploration to delineate a sandstone pinch-out where the isopach contour line becomes zero. The aerial patterns of beach and river channel sandstones are seen on an isopach map.



Uses of Isopach map:

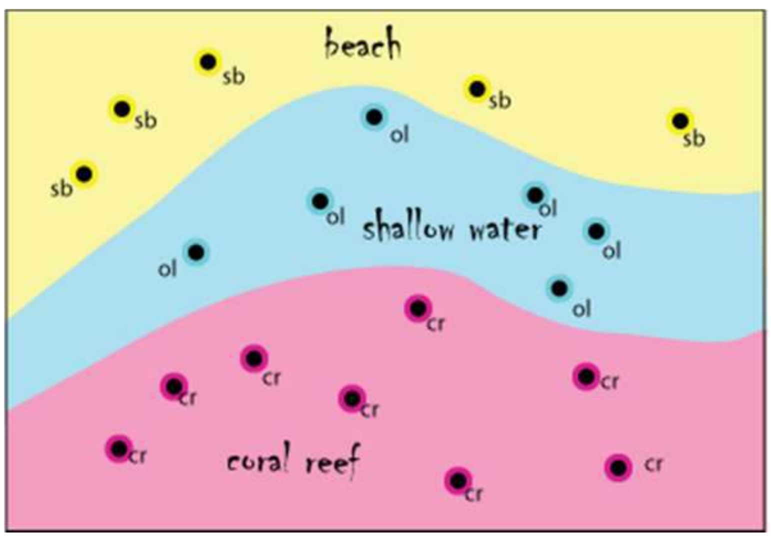
-Isopach maps of limestone layers can also be used to locate a reef. A reef is a mound and is shown by thick contour lines. Barrier reefs that are long can be distinguished from pinnacle reefs that are circular.



Facies Map

It is a stratigraphic map indicating distribution of sedimentary facies within a specific geologic unit. If it is based on numerical stratigraphic data (percentages, relative thicknesses, and rate of lithologic components) it is called **lithofacies map**.

Nearly every formation or group of formations lies within definite stratigraphic boundaries but within these boundaries one rock type may grade laterally into another and a lithofacies map is designed to show the nature and the direction of gradation.



Facies Map

Facies maps may show specific character like distribution of coarse clastic sediments toward certain direction to distinguish the land mass that furnished the sediments.

Comparison with respect to amount and distribution of formation of clastic origin with those of chemical origin is frequently of use in regional studies. The maps that show the result of such comparisons are called " **Clastic Ratio Maps** " The clastic ratio at a given point is the ratio of the total thickness of the clastic to that of the noncalstic at that point and is expressed as :

$$\text{Clastic ratio} = \frac{(\text{ conglomerate } + \text{ sandstone } + \text{ shale })}{(\text{ Limestone } + \text{ dolomite } + \text{evaporite})}$$

Facies Map

Variations of clastic ratio maps are sand-shale ratio maps and **clastic – shale ratio maps.** These ratios are expressed as follows:

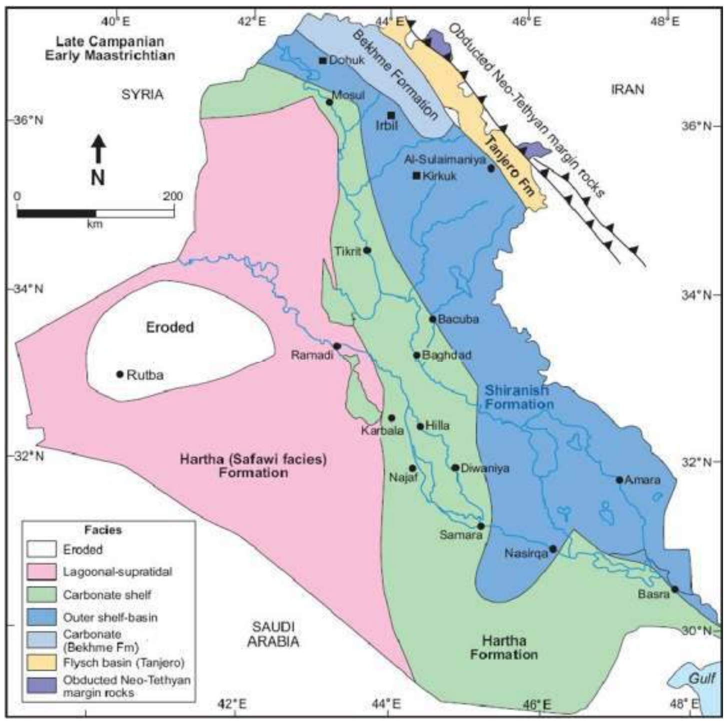
$$\text{Sand} - \text{ shale ratio } = \frac{\text{conglomerate } + \text{ sandstone}}{\text{shale}}$$

$$\text{Clastic} - \text{ shale ratio } = \frac{\text{sandstone} + \text{clastic limestone}}{\text{shale}}$$

A **clastic ratio map** shows the variations in the clastic ratio from place to place and other maps show corresponding variations in other ratios. Contour lines may be drown to connect points of equal ratio.

Paleogeographic Maps:

Paleogeographic maps show the locations of ancient lands and sea, geography of selected portions of the earth's surface at specific times in the geologic past; environments of sedimentation (e. g. deltas, reefs, deserts, or deep-sea basins); and areas undergoing uplift and erosion or subsidence and deposition.



Subsurface cross sections

-Subsurface cross sections are geologic diagrams, which shows the subsurface as if it were cut open and seen from the side. They show the geology of a vertical plane below the earth's surface, and represent important tools for understanding and visualizing geologic structures and stratigraphic relationships. Subsurface cross sections fall into two general groups, structural and stratigraphic.

-A contour map depicts the horizontal plan view configuration of a single attribute of a stratigraphic unit, such as structure, thickness, and percent porosity. In contrast, a cross section depicts the configuration of many units as typically viewed in a *vertical plane*. Since a map or cross section alone cannot represent the complete subsurface geological picture, both must be used to conduct a complete and detailed study.

-If a cross section is oriented perpendicular to the strike of the structure, it is termed a *dip section*. If the section is oriented parallel to the strike of the structure, it is called a *strike section*. Finally, if the orientation is oblique to the structural axis, it is termed an *oblique section*.

Uses of subsurface cross sections

Geological cross sections constitute a very important geological exploration and exploitation tool. They are useful in all phases of subsurface geology as well as in reservoir engineering. Cross sections are used for solving structural and stratigraphic problems in addition to being employed as finished illustrations for display or presentation. Used in conjunction with maps, they provide another viewing dimension that is helpful in visualizing a geological picture in three dimensions.

Data of subsurface cross sections

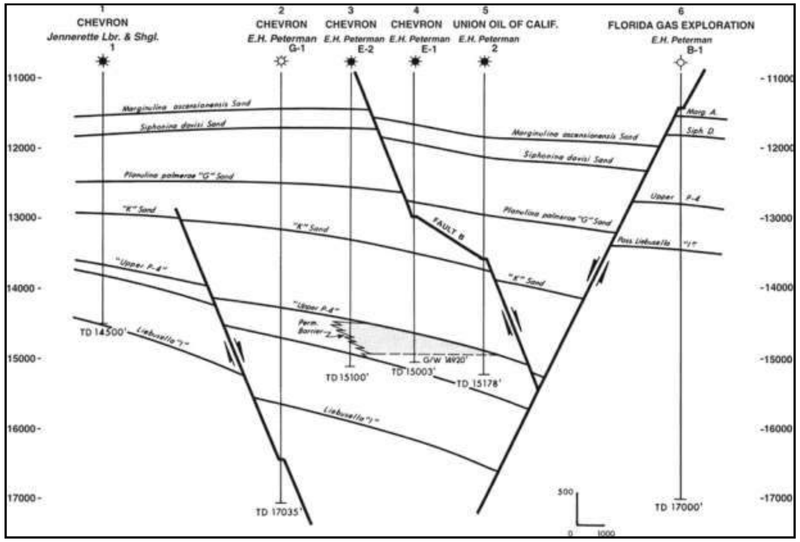
Various data can be used to construct a vertical cross section. It can be based on surface data (dips), electric well log data (markers, unit tops and bases, dips, and faults), seismic data, or entirely from completed subsurface maps.

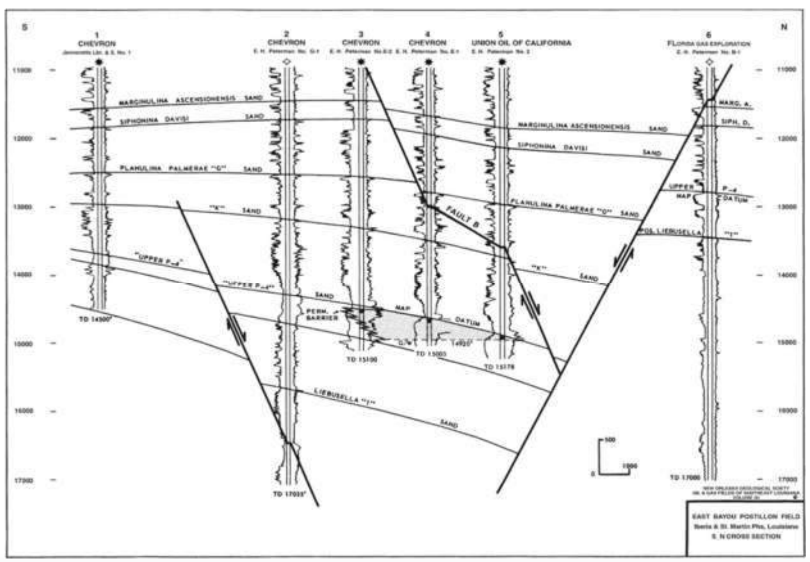
Structural Cross Sections

Structural cross sections illustrate structural features such as dips, faults, and folds. They enabling geologist to visualize the subsurface structure in a vertical plane. Structural cross-sections use present-day elevation as a datum (below or above sea-level). Electric well logs can be used in the construction of structural cross sections. Other data must be used, such as drill-time logs, core data, and lithologic logs prepared from cuttings descriptions.

-If a cross section is oriented perpendicular to the strike of the structure, it is termed a *dip section*. If the section is oriented parallel to the strike of the structure, it is called a *strike section*. Finally, if the orientation is oblique to the structural axis, it is termed an *oblique section*.

Structural Cross Sections

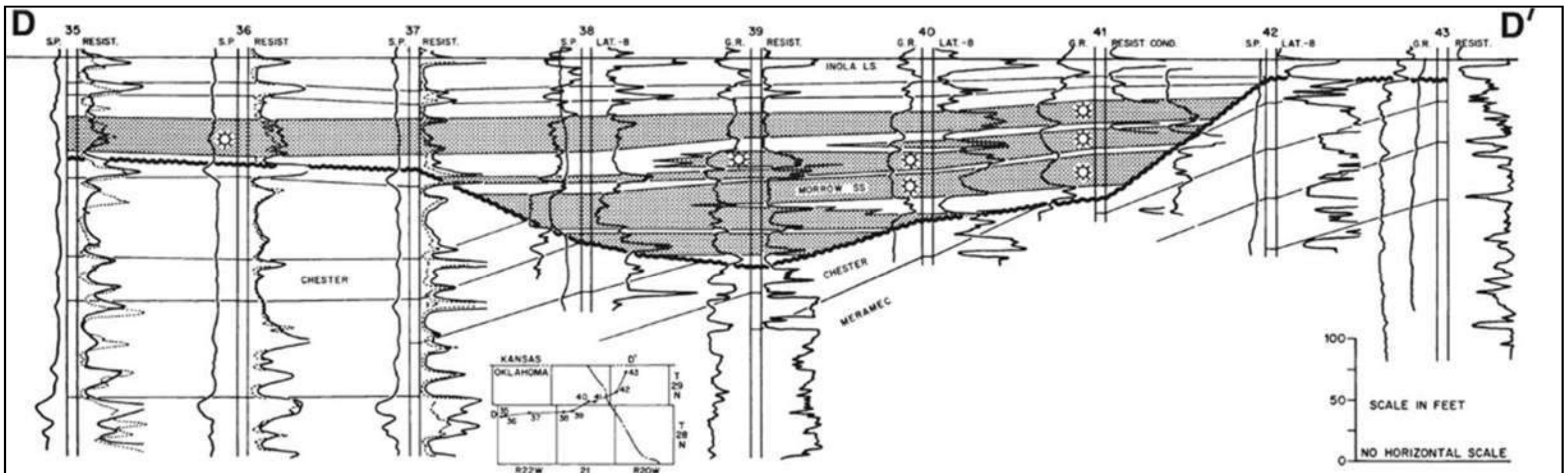




Stratigraphic Cross Sections

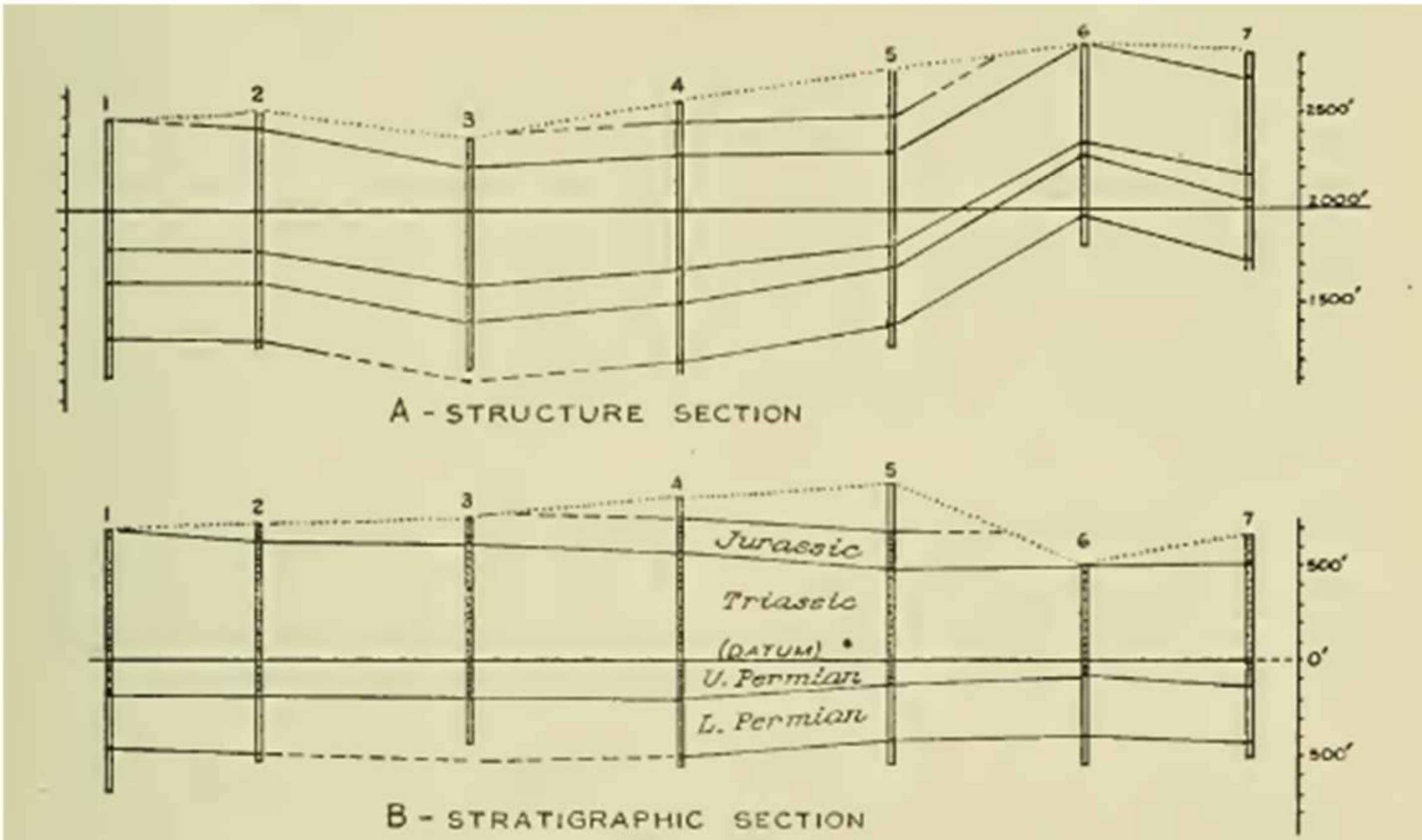
-They are drawn to illustrate stratigraphic correlations, unconformities, permeability barriers, stratigraphic thickness changes, facies changes, and other stratigraphic characteristics.

-The datum for a stratigraphic cross section is normally chosen as some stratigraphic marker with the section set up so that the chosen datum is horizontal. By using a horizontal datum, the distorting effects of structure (folds and faults) are eliminated. This is equivalent to unfolding and unfaulting the strata.



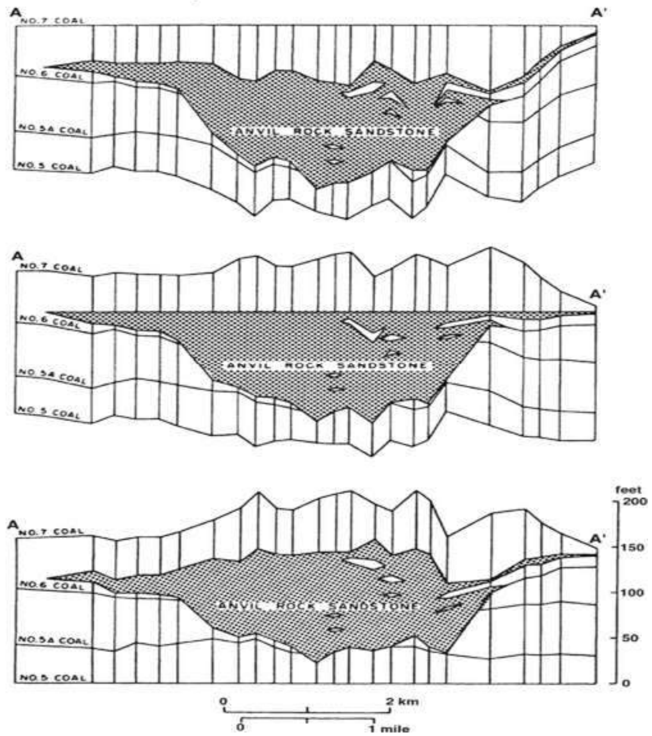
Cross Section D-D′.

Stratigraphic Cross Sections



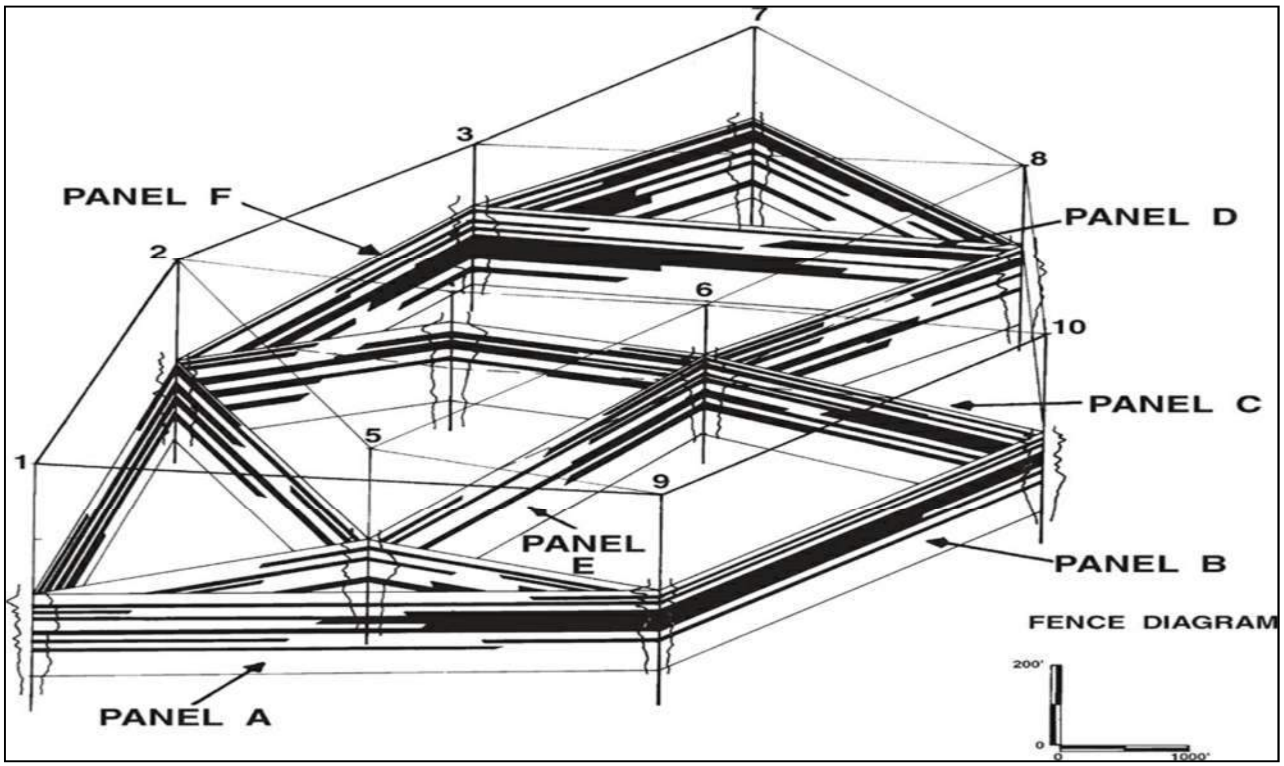
Stratigraphic Cross Sections

Stratigraphic cross-sections use some surface thought to represent a moment in time as a datum such as coal and volcanic ash beds (bentonites) and other event beds, as well as some types of disconformities, which are recognized as sharp contacts. The choice of an appropriate marker bed to use as the datum is extremely important. The choice of a poor datum can pose problems, such as incorrectly illustrating the original configuration of the stratigraphic units under study.



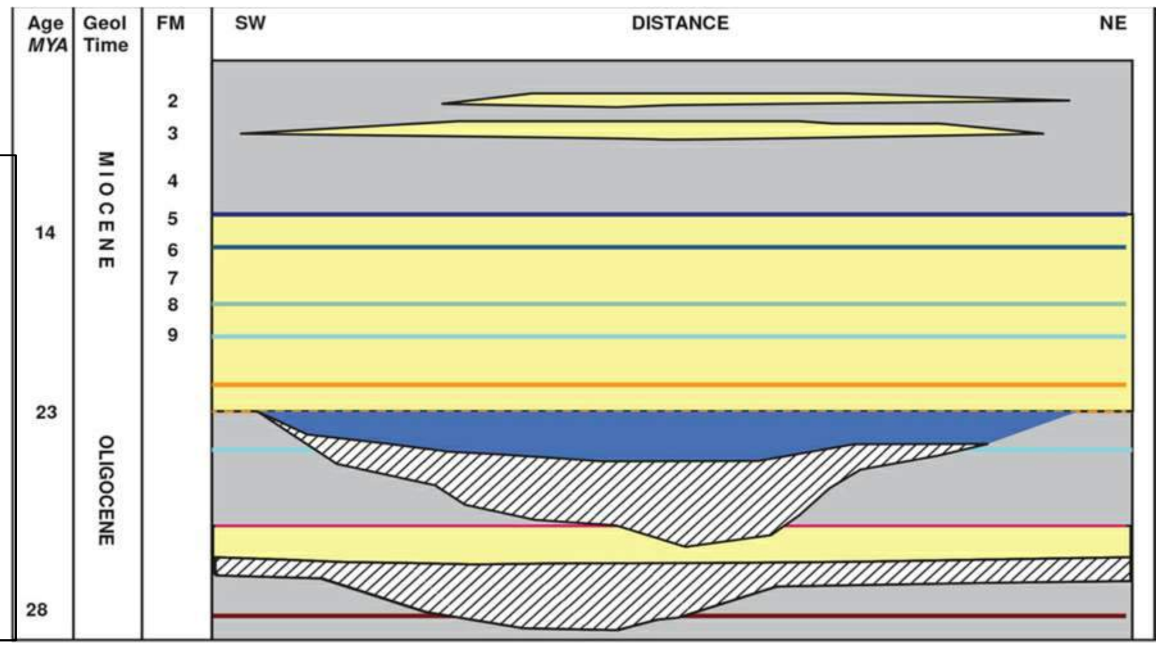
Fence Diagrams

Fence diagrams, also called *panel diagrams*, consist of a 3D network of cross sections drawn in two dimensions. They are designed to illustrate the areal relationship among several wells that are located in close proximity to each other. Fence diagrams can be either structural or stratigraphic.



Chronostratigraphic Sections

Chronostratigraphic sections are plotted with the y-axis in geological time and the x-axis in distance. they are extremely useful in exploration because they *illustrate the history of a basin*. Also important is that the sections can show the distribution of facies across the basin at various times. Source, seal, and reservoir units can be highlighted. Chronostratigraphic sections are usually accompanied with a map that illustrates the line of section.



Generic chronostratigraphic section illustrating the change in lithology with time and along the line of the section. Hachured intervals equal times of erosion and nondeposition.