BHARATHIDASAN UNIVERSITY

Tiruchirappalli - 620 024
Tamil Nadu, India

Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Petroleum Geology
Course code : MTIGT 0701

UNIT – II
Diversity in Occurrences - Traps

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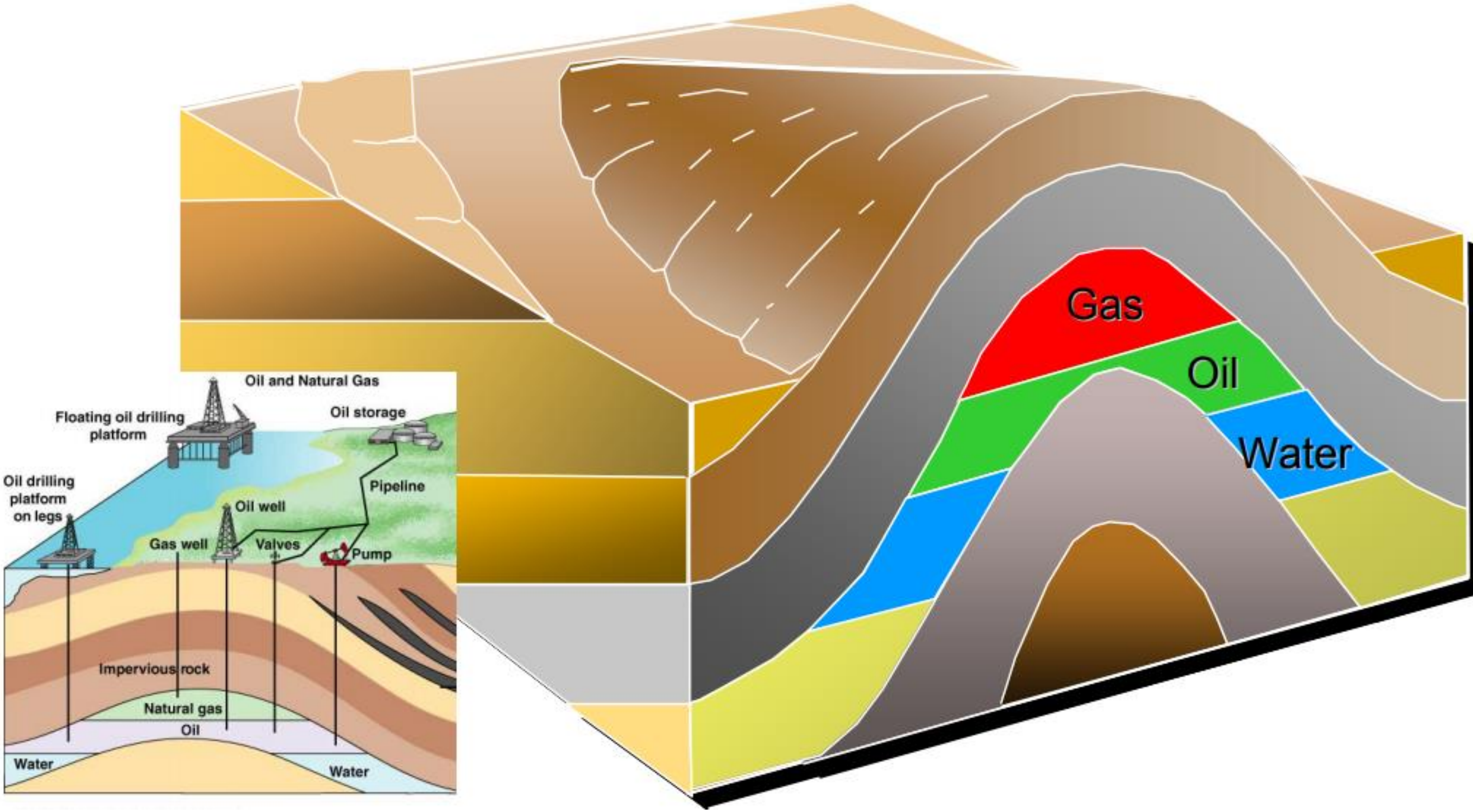
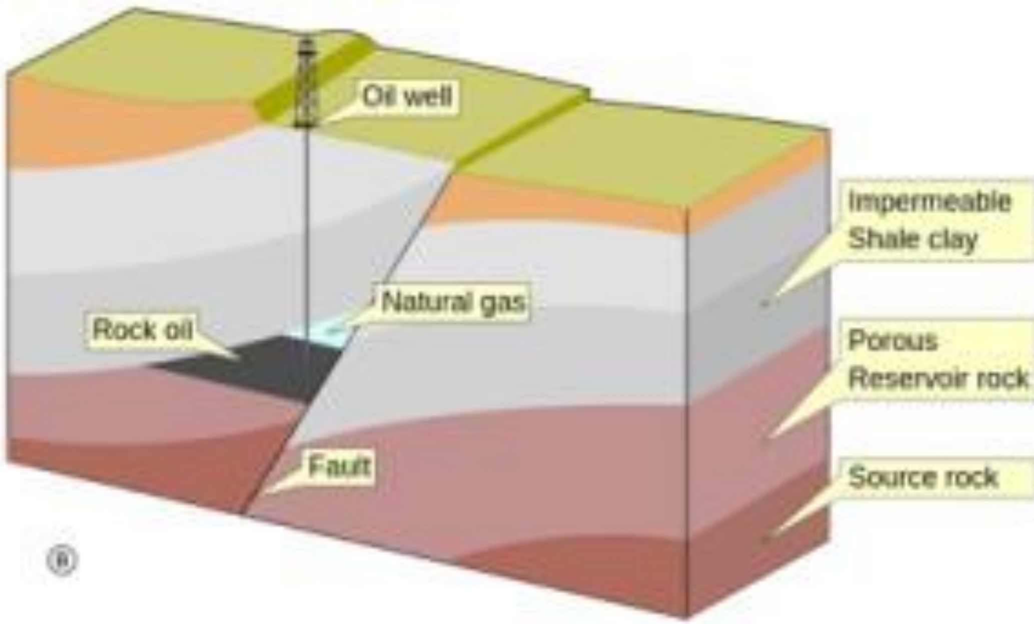
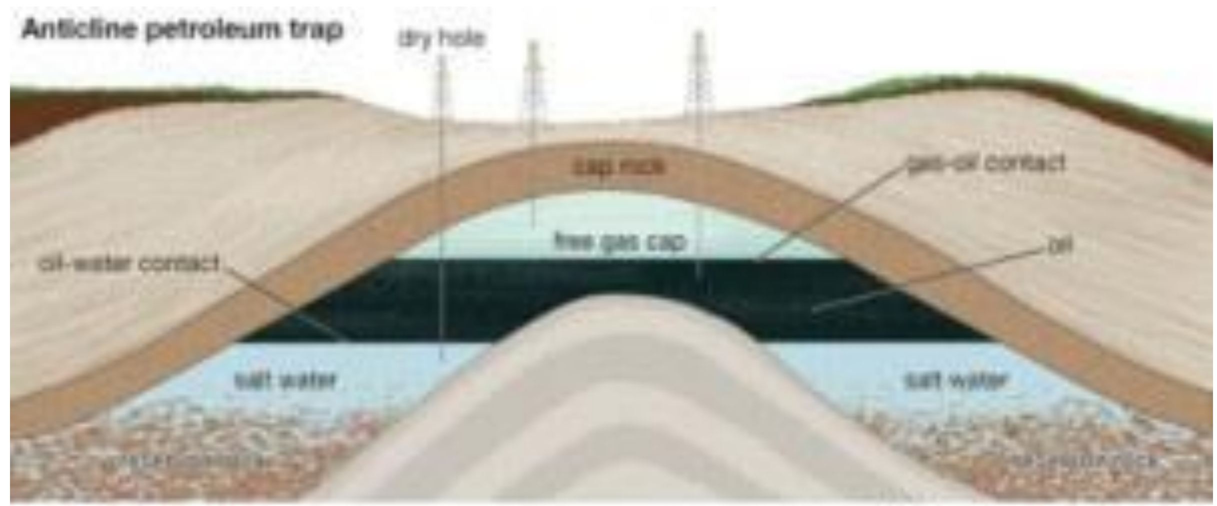
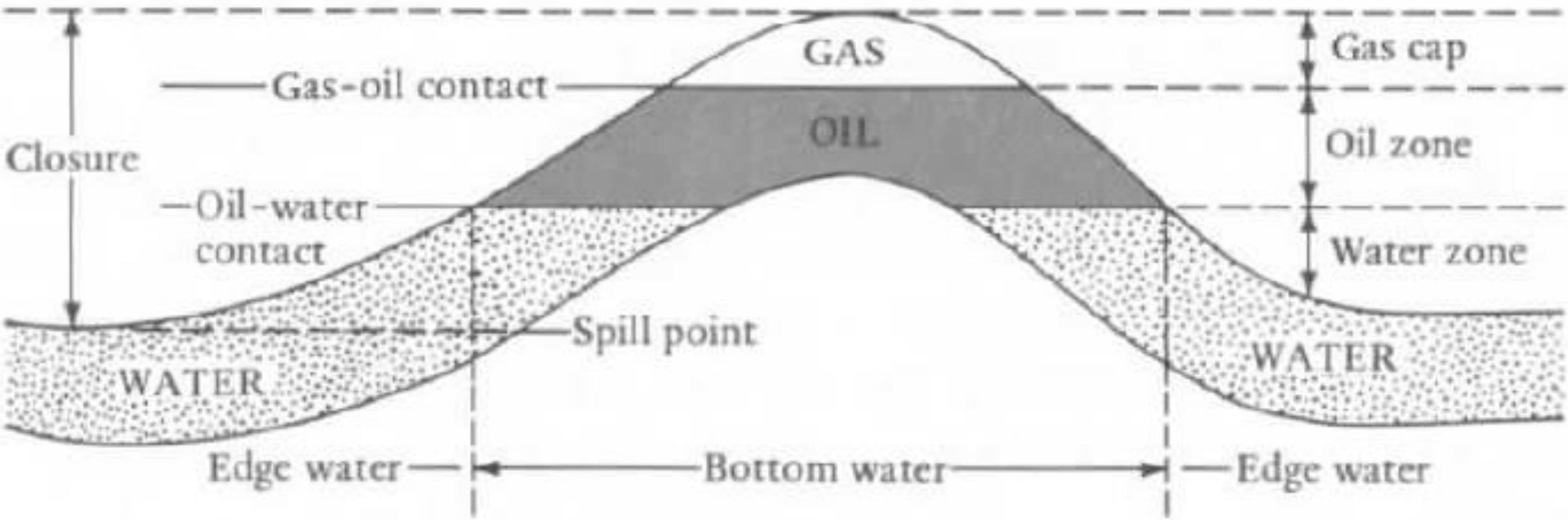
Petroleum Accumulates in Structural Closure




Oil well
Impermeable
Shale clay
Natural gas
Rock oil
Porous
Reservoir rock
Fault
Source rock
®


Anticline petroleum trap
dry hole
cap rock
gas-oil contact
free gas cap
oil-water contact
oil
salt water
salt water



Cross-section through a simple anticlinal trap.

A trap typically is the final place where oil and gas end up. The most important job for exploration geologists therefore is to find the traps.

Traps consist of porous reservoir rocks overlain by tight (low permeability) rocks (seals) which do not allow oil or gas to pass (cap rocks).

Cap rocks are usually not totally impermeable with respect to water, but may be impermeable to oil and gas due to capillary resistance in the small pores.

The classification divides the traps broadly into three basic types:

(1) Structural traps; (2) Stratigraphic traps; (3) Combinations traps

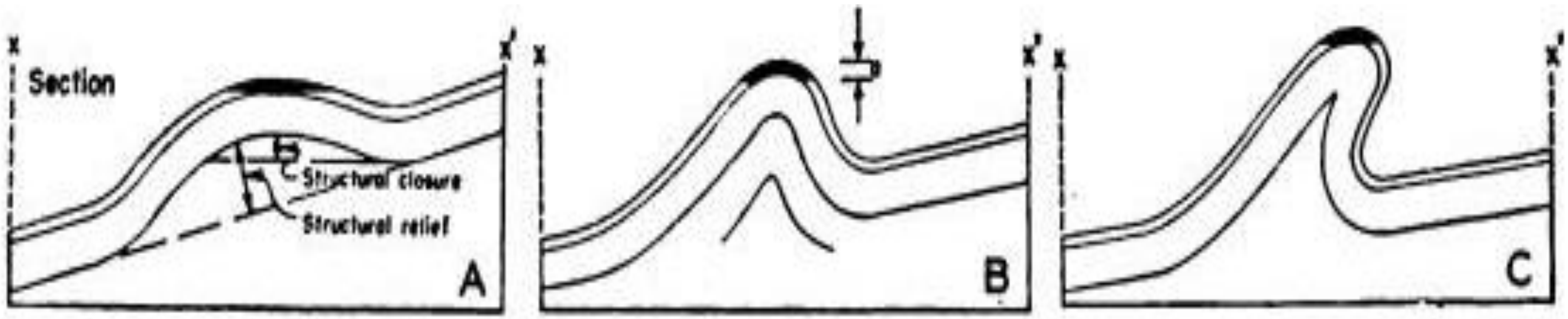
Structural traps are formed by tectonic deformation, such as **(1) folding; (2) faulting (3) fracturing; (4) intrusion of a plug, usually of salt; (5) combinations of the above.**

The two major mechanisms in forming structural traps are arching through a variety of processes (folding, differential compaction, draping, uplifting of salt or mud domes) and faulting, again in many different ways (extensional, compressional / thrusting, wrench-faulting, rollover faulting). It is very common for arching to be associated with faulting.

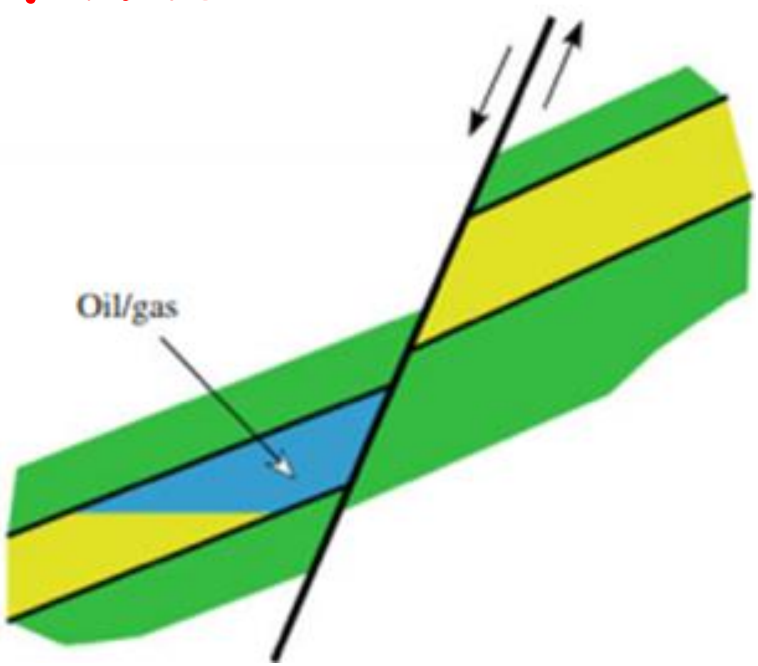
The most typical traps, where 80-90% of the oil is trapped, are anticlines which are structural traps.

Traps Caused by Folding

Structural traps that result chiefly from folding are of widely varied shapes; they include everything from low, narrow anticlines, which may be symmetrical or asymmetrical or even overturned.



Traps caused by faults

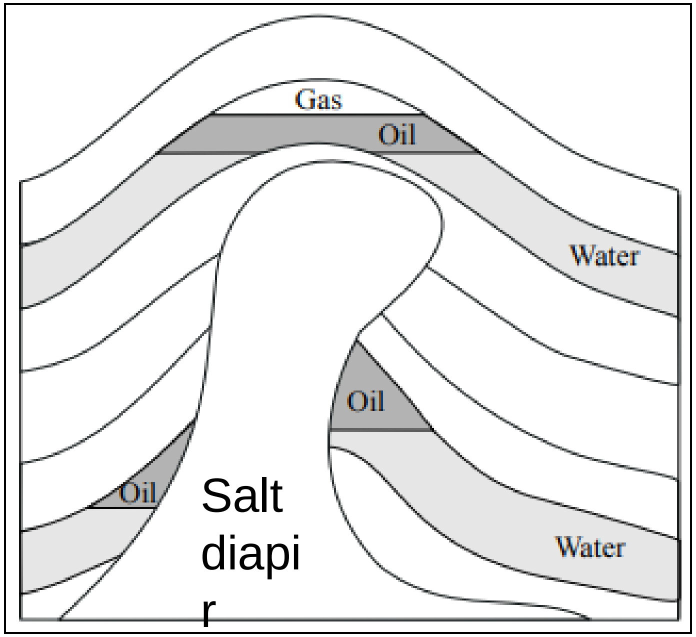


These types of traps are formed when reservoir rock is split along a fault line. Between the walls of the split reservoir, clay traps oil and prevents it from leaving the trap. Other times there exists a pressure differential across the two sides of the fault that prevents the fluids from migrating. The fault plane must therefore be sealing for vertical flow.

The displacement along faults can be both vertical (normal faults) and horizontal (strike slip faults). Reverse faults are faults where the hanging wall is moved upwards relative to the footwall below the fault plane.

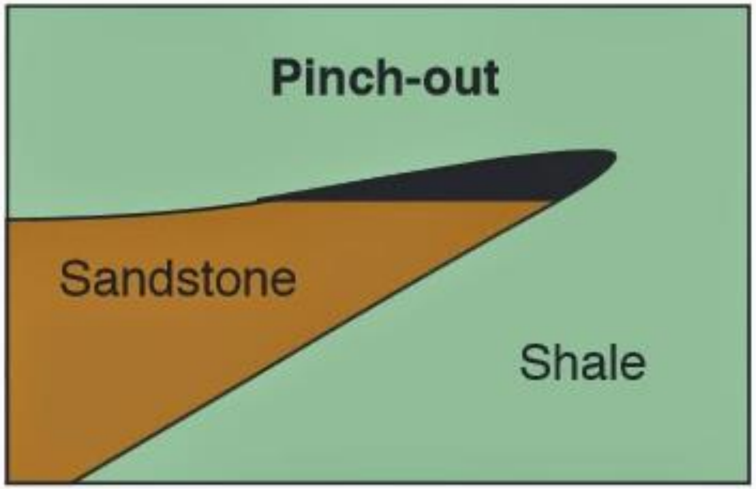
Traps caused by Salt Domes

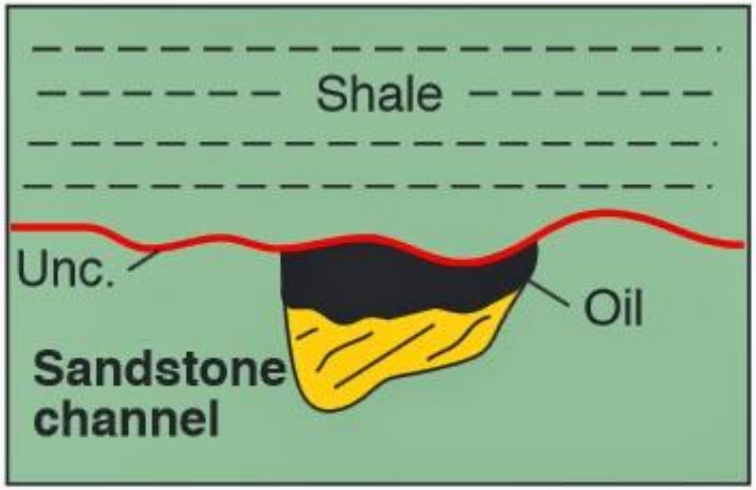
Salt domes are formed because salt is lighter than the overlying rocks, and the salt therefore "floats" up due to buoyancy and forms a salt dome (diapir). The quantitatively most important salt minerals are **Halite** (NaCl - density 2.16 g/cm3), **Gypsum** (CaSO4. 2H2O - density 2.32 g/cm3). **Anhydrite** (CaSO4 - density 2.96 g/cm3) is too dense to contribute to the formation of diapers.

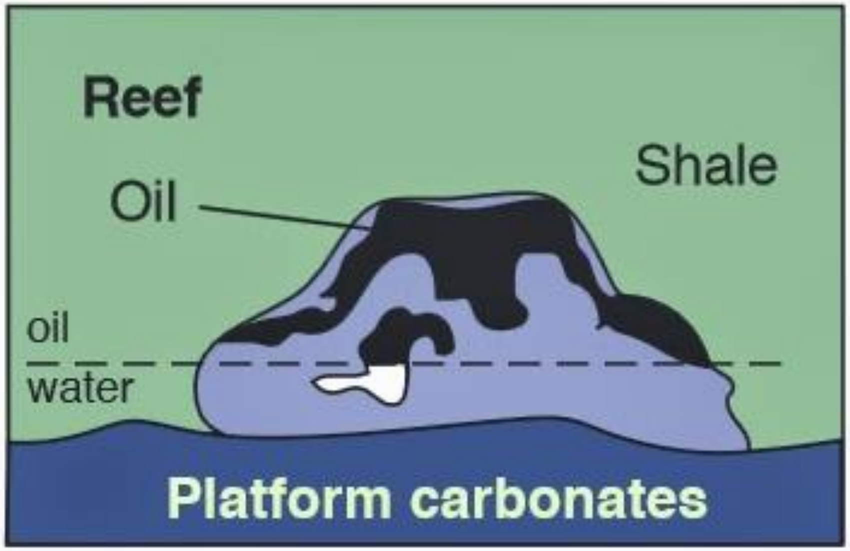


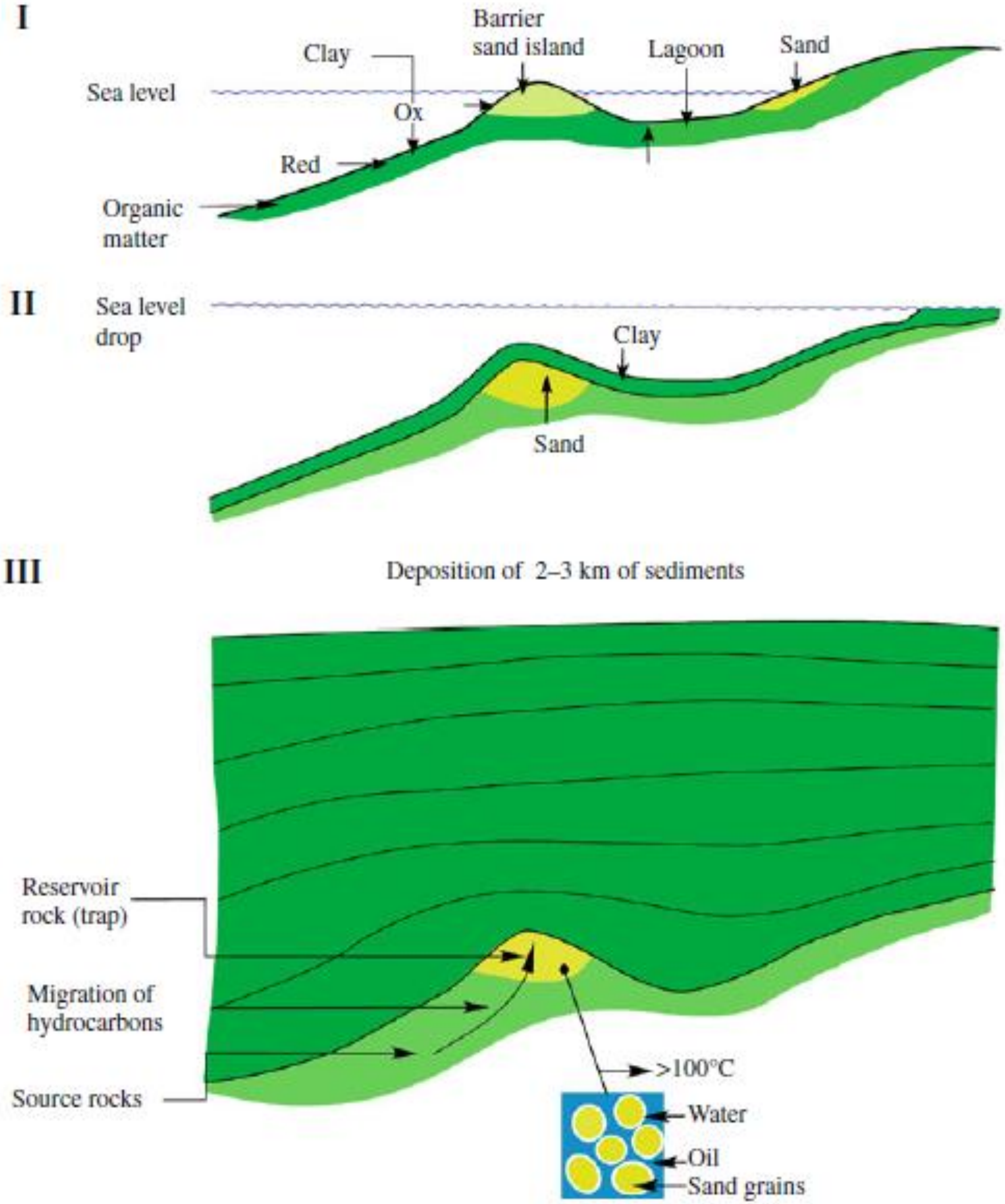
In order for the salt to move upwards and form a salt dome, salt beds must be at least 100 - 200 m thick. The rate of salt movement is extremely slow and a dome may take several million years to form.

Stratigraphic traps, which mainly has to do with the way the sediments have been deposited (related to unconformities, lithofacies change) and do not require structural deformations like faulting or folding. Examples of this type of trap are an **unconformity trap, a lens trap** and **a reef trap**.

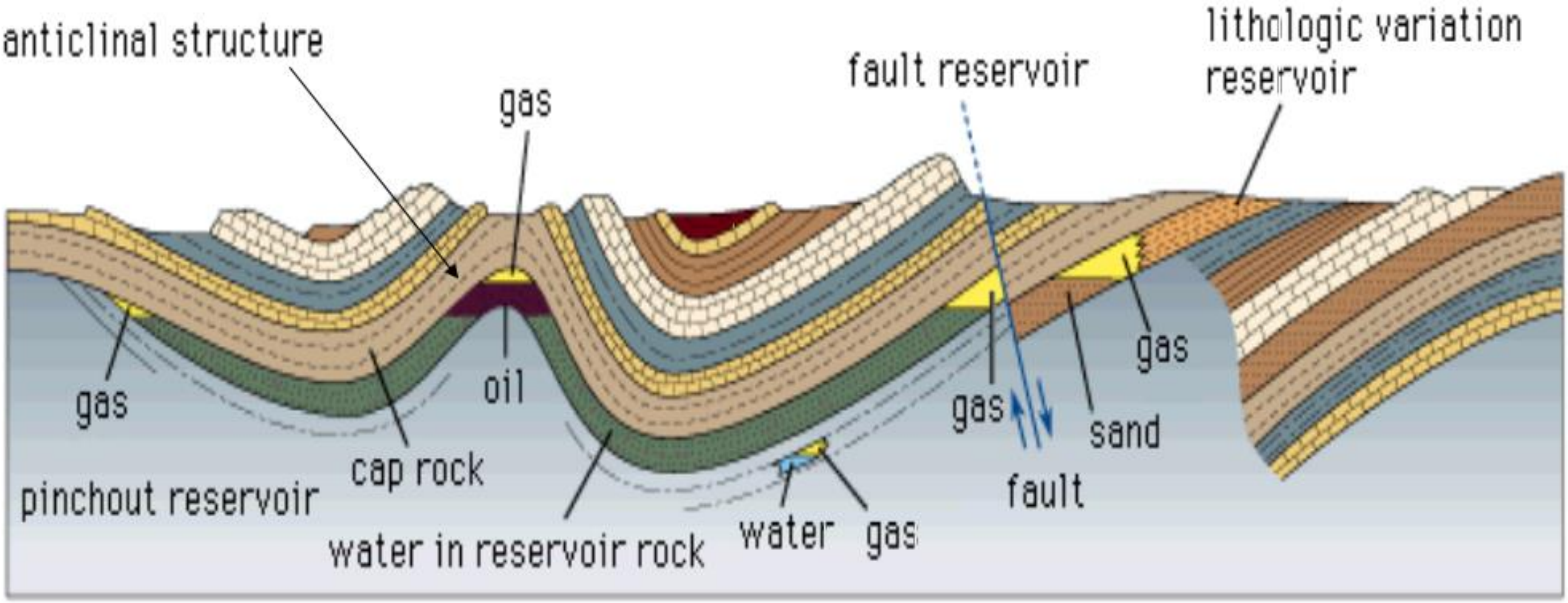




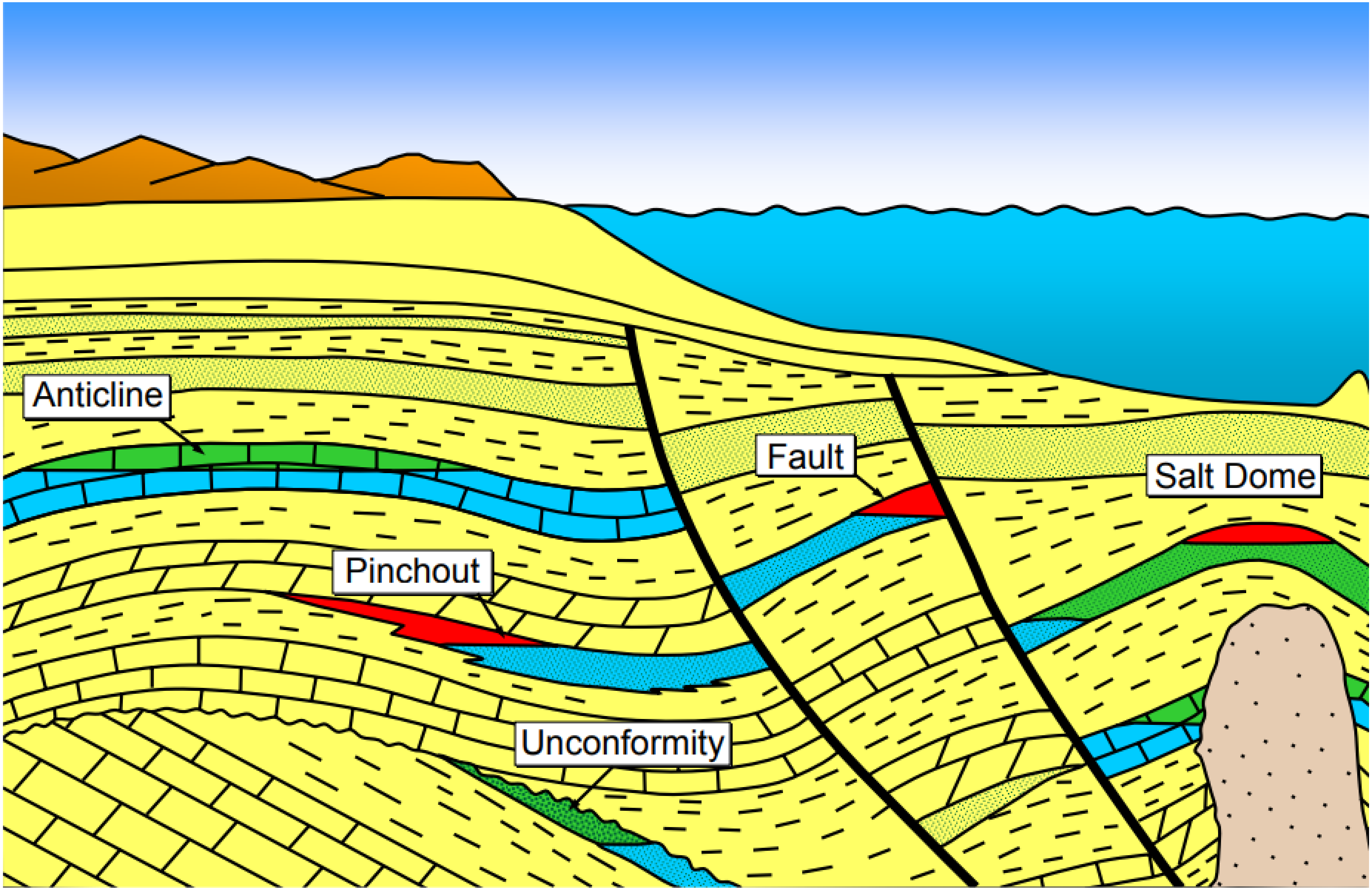



I
Clay
Barrier
sand island
Lagoon
Sand
Sea level
Ox
Red
Organic
matter
II
Sea level
drop
Clay
Sand
III
Deposition of 2–3 km of sediments
Reservoir
rock (trap)
Migration of
hydrocarbons
Source rocks
>100°C
Water
Oil
Sand grains

Trap types



The pinchout and lithologic variation reservoirs are examples of stratigraphic traps


Anticline
Fault
Salt Dome
Pinchout
Unconformity

Other Types of Trap

More unusual kinds of trap can be encountered. If the pore water in a sedimentary basin has sufficiently strong flow of water into the basin, the oil/water contact may diverge markedly from a horizontal plane due to the hydrodynamic stresses and are called hydrodynamic trap.

Basin and its types :

a low area / depression in the Earth's crust, of tectonic origin, in which sediments accumulate.

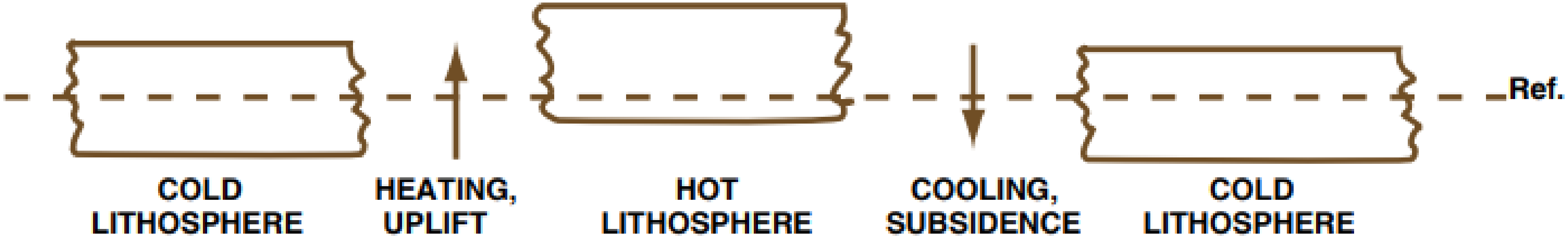
Sedimentary basins range in size from as small as hundreds of meters to large parts of ocean basins. The essential element of the concept is tectonic creation of relief, basin classification depends upon the locations in which they occur rather than the type of sedimentation.

Basin can occur within the continents, continental margins and oceanic locations.

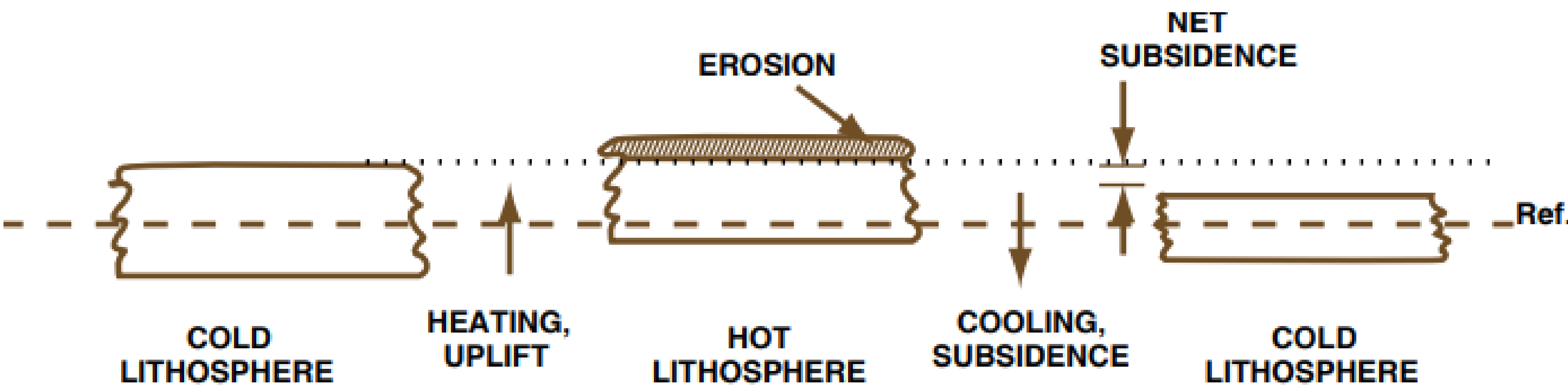
Local : On a small scale, hundreds to thousands of meters laterally, fault movements can create relief of hundreds to thousands of meters, resulting in small but often deep basins (some of these are called intermontane basins). Relief of this kind is on such a small scale that it tends not to be isostatically compensated.

Regional : Basin relief can be created mechanically on a regional scale in two very important ways: **thermally** or **flexurally**, or by a combination of those two effects).

Thermal : If the lithosphere is heated from below, it expands slightly and becomes less dense. This less dense lithosphere adjusts isostatically to float higher in the asthenosphere, producing what we see at the Earth's surface as crustal uplift. If the lithosphere cools back to its original temperature, there's isostatic subsidence back to the original level.



But, if erosion took place while the crust was elevated, and when the crust cools again it subsides to a position lower than where it started, thus creating a basin available for filling by sediments.



Flexural

Another important way for basin formation is placing a large load on some area of the lithosphere. The new load causes the lithosphere to subside by isostatic adjustment. But because the lithosphere has considerable flexural rigidity, the area adjacent to the load is bowed down also.

The region between the high-standing load and the lithosphere is thus depressed to form a basin. This model has been very successful in accounting for the features of foreland basins, which are formed ahead of large thrust sheets that move out from orogenic areas.

GEOSYNCLINES

The concept of geosynclines was developed in the last century to deal with the existence of thick successions of sedimentary rocks in what we would today call orogenic belts.

A geosyncline is a large basin like down warping of the crust in which thick sedimentary and volcanic rocks got accumulated. Usually, but not always, such accumulations are deformed during a later phase of the same geological cycle in which they were deposited.

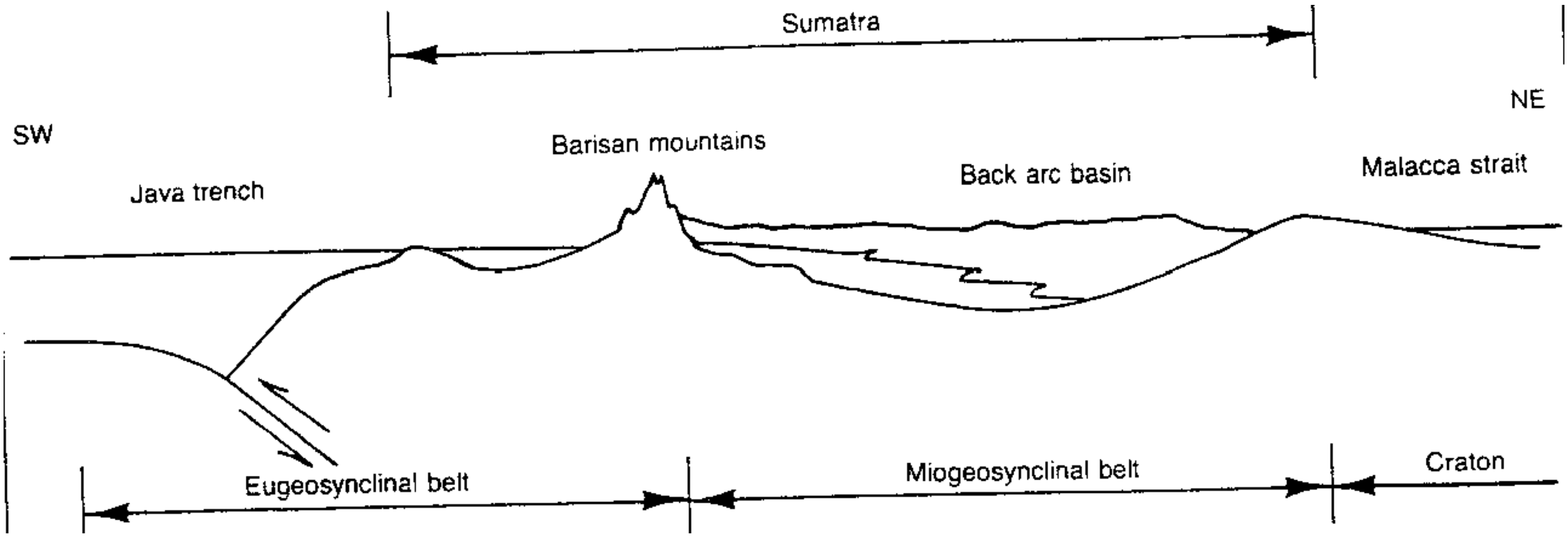
Geosysnclines subside slowly as they receive sediments and remain active for a long periods of geological time. Marine sediments are characteristics of geosynclines. Modern geosynclines occur along the zones of subduction where the sea floor moves under continental crust.

Trenches are places where rapid and chaotic sedimentation occurs and this part is known as **eugeosyncline**. The sediments in eugeosyncline are deposited in deep water and are heterogeneous and usually not considered no good source rocks.

On the landward side of the geosynclines, marine sediments were deposited in more calmer conditions than in the eugeosyncline and are known as **miogeosyncline**.

Miogeosyncline represents shelf of the continent and has less sediment thickness than eugeosyncline. It consists of sandstones, shale and carbonates and considered prospective for hydrocarbon accumulation.

Cross section of Indonesian geosyncline



Basin Formation Mechanisms

*a. **Thermal Contraction** - cooling and subsidence of Earth's crust and upper Mantle*

Ex. cratonic sags- intracratonic basins

*b. **Crustal Extension** - crustal stretching and thinning*

Ex. i. Rift basins , ii. Strike-slip basins

c. Crustal Compression

Ex. i. subduction-related fore arc basins

d. Crustal Loading - isostatic subsidence

Ex. i. sediment loading on crust results in isostatic subsidence into asthenosphere

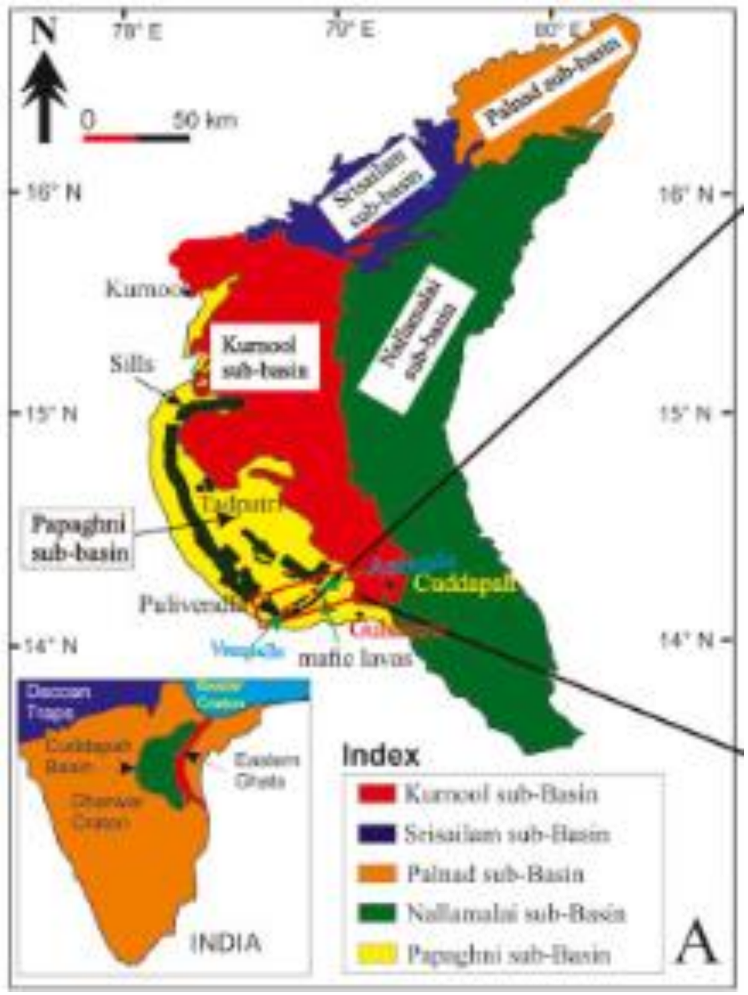
1. thrust belt forebulge

2. passive margin loading

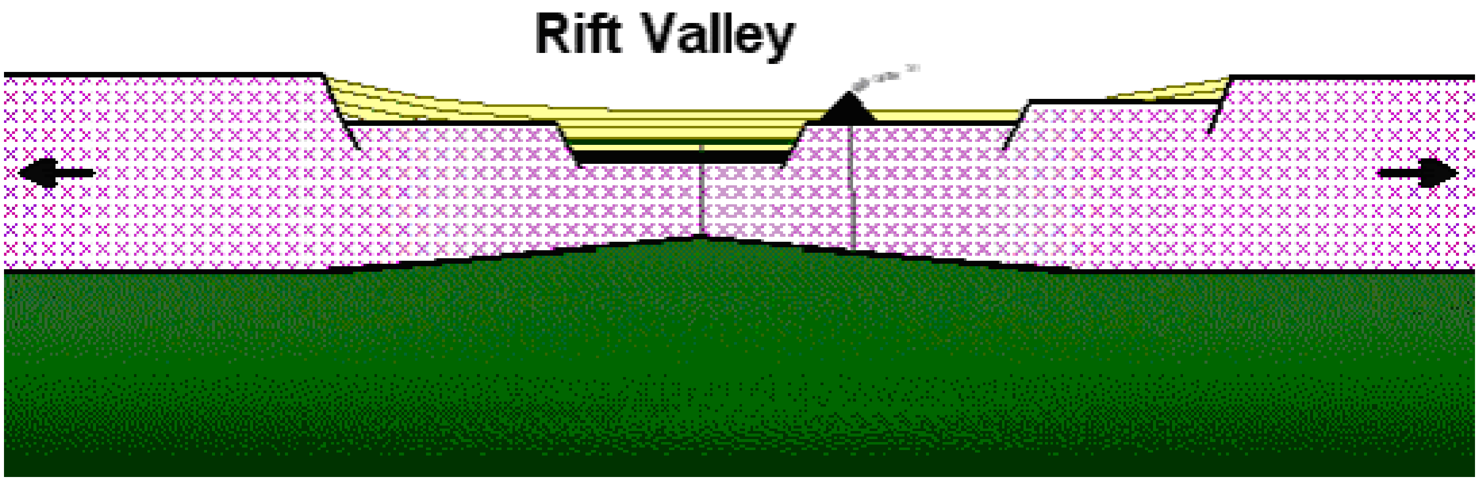
Intracratonic basins form within stable continental interiors. Intracratonic basins are areas on the craton, at some distance from the craton margin, undergoing differential subsidence relative to the surrounding area of cratonic basement.

They are thus distinguished from platform areas by significantly greater thicknesses of sedimentary cover, e.g. > 4.5 km of strata in the Michigan basin, compared to ~1 km of strata on the surrounding platform area.

Important intracratonic basins in India : Vindhyan, Cuddapah, Chattishgarh.

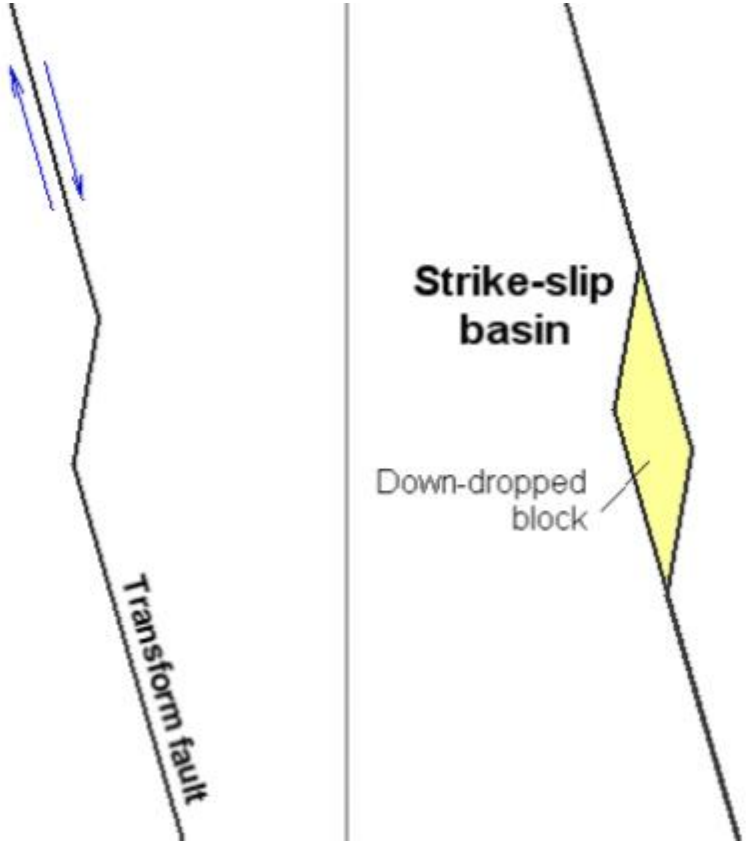

N
0
50 km
16° N
15° N
14° N
Palnad sub-basin
Srisailam sub-basin
Kurnool sub-basin
Nallamalai sub-basin
Sills
Tadpatri
Papaghni sub-basin
Cuddapah
Pulivendla
mafic lavas
Deccan Traps
Cuddapah Basin
Dharwar Craton
Eastern Ghats
INDIA
Index
Kurnool sub-Basin
Srisailam sub-Basin
Palnad sub-Basin
Nallamalai sub-Basin
Papaghni sub-Basin
A

Rift Basin : The down-dropped basin formed due to stretching and thinning of the continental crust. Rifts are elongate depressions overlying places where the lithosphere has ruptured in extension. Where filled with sediments they may contain exploitable quantities of oil and gas. Ex. East African rift.



Arabian Peninsula
Red Sea
Afar Lowlands
Gulf of Aden
EAST AFRICAN RIFT
Eastern Branch
Western Branch
Lake Victoria
Mt. Kenya
Mt. Kilimanjaro
Indian Ocean
Africa
?

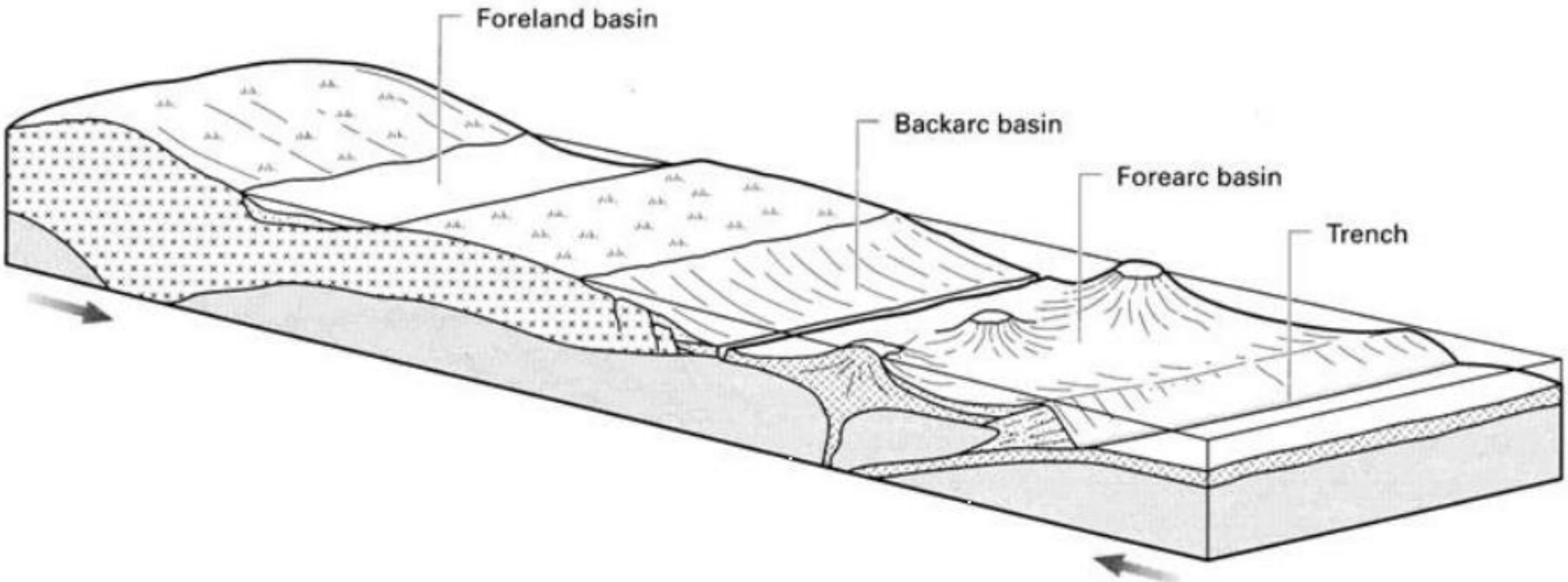
Pull-apart or strike-slip basins form along major transform faults where they bend, or between fault splays. They tend to be deep and narrow, and are characterized by very fast subsidence. There are some good examples along the San Andreas fault zone.



Basin along San Andreas fault zone

Crustal Compression

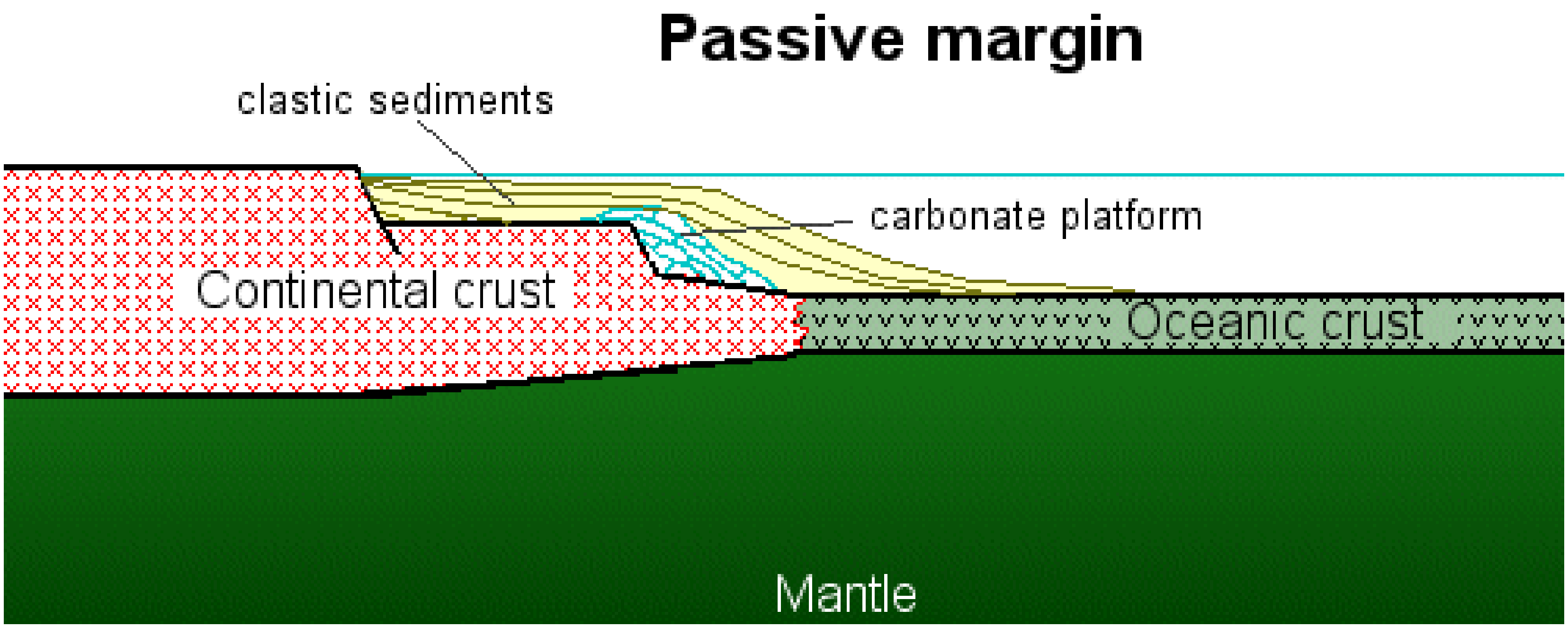
Basins formed at plate convergence - Trench, forearc, foreland and backarc basins form at active subduction boundaries



Foreland basin *develops adjacent and parallel to a mountain belt. Foreland basins form because the immense mass created by crustal thickening associated with the evolution of a mountain belt causes the lithosphere to bend, by a process known as lithospheric flexure.*

The width and depth of the foreland basin is determined by the flexural rigidity of the underlying lithosphere, and the characteristics of the mountain belt. The foreland basin receives sediment that is eroded off the adjacent mountain belt, filling with thick sedimentary successions.

Passive margin basins *form along continental-ocean margins where no subduction is taking place. Examples include the east coast of India, eastern coasts of North and South America etc. PMBs can accommodate sediment accumulations as much as 20 km thick.*



Classification of Sedimentary Basins vs. Tectonic Setting

a. Cratonic Basins - not located at plate boundaries

*i). **Intracratonic Sag** - thermal contraction and subsidence in plate interiors*
e.g. Cuddapah basin

*ii). **Passive Margin Coastal** - marginal marine sediment loading and isostatic subsidence e.g. Atlantic Coast, USA, east coast of India*

b. Convergent Tectonic Basins - subduction related, compressional

i). Forearc Basins

1. *sediment loading and subsidence between subduction trench and volcanic arc*
2. *complex accretionary tectonics*

ii). Backarc Basins

1. *back arc extension and sedimentation; inboard of volcanic arc*

iii). Thrust Belt – foreland basins

e.g. Himalayan foreland

c. Divergent Tectonic Basins - rifting related, extensional

i. Rift Basins - e.g. Red Sea, East African Rift, Rio Grande

1. fault bounded basins with down-dropped blocks

2. elongate shapes common

3. symmetric/asymmetric grabens

ii. Aulacogens - failed rift basins

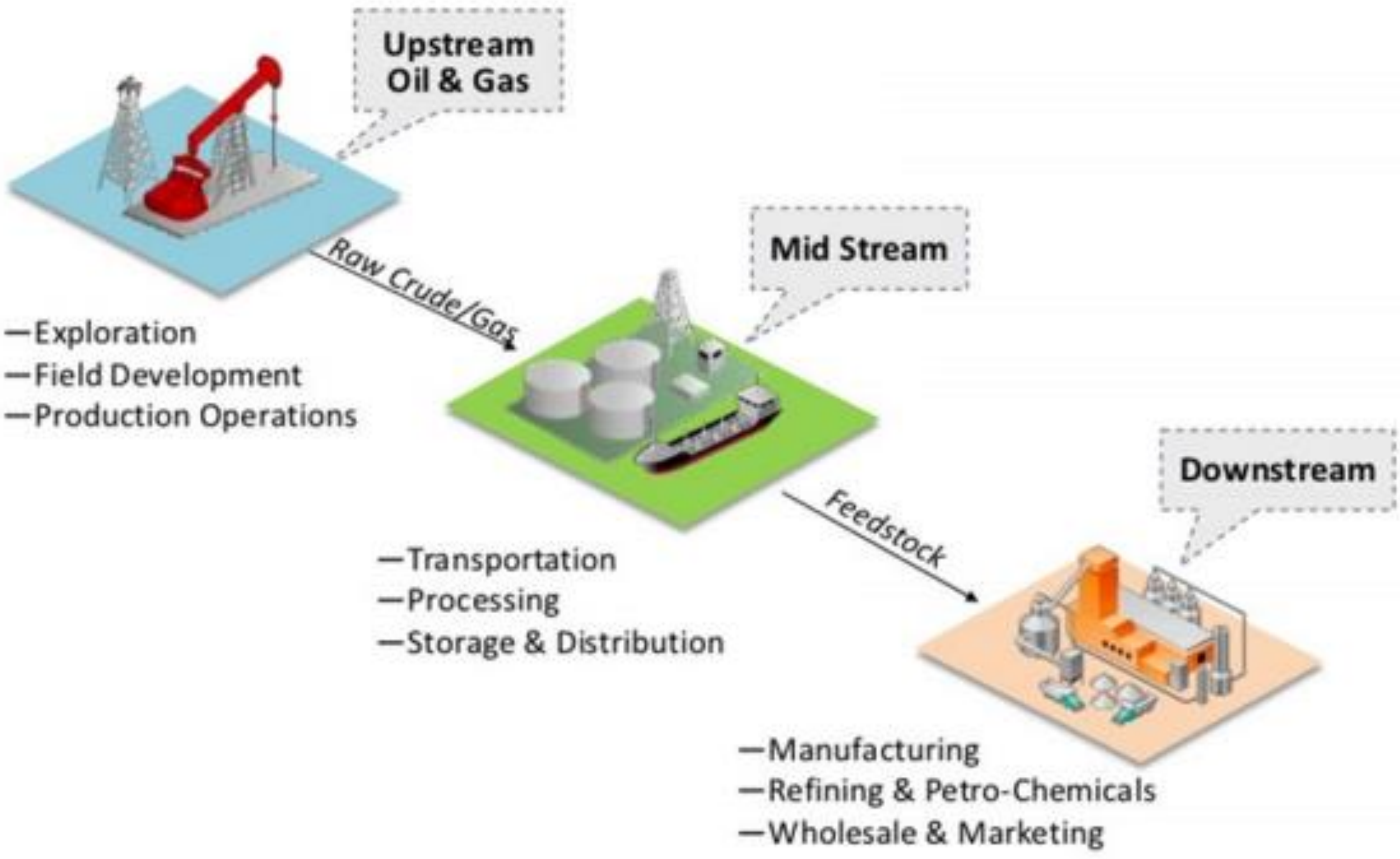
1. e.g. Godavari graben

d. Transcurrent Tectonic Basins - transform, strike-slip tectonics

i. Transtensional tectonics, rift-like faulting between strands of strike-slip fault zones

ii. e.g. Ridge Basin, California, San Andreas

Hydrocarbon Exploration



The Exploration techniques for Petroleum can be separated into two ways : ***Surface geology*** *and* ***Subsurface geology.***

Surface geology

- Direct Indications:

When we explore for oil and gas, we will observe on many indications especially on oil and gas that upon the ground through the seep along fault trace, porous rock, oxidation of petroleum reduces that volatile constituents and some plant forms.

Field Geology

-traditional method of finding oil
-mapping the surface geology and studying the relationship to geological units
-to predict and understand the types of rock in the subsurface

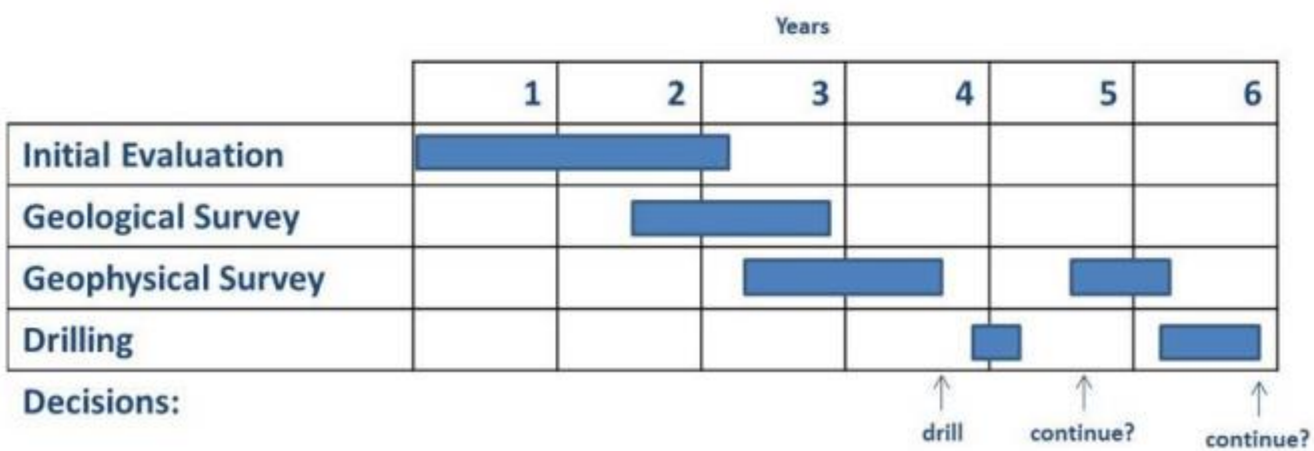
Essential when rock appear at the surface. Geologists search on many important things such as Geological mapping that plot geologic data on the map, their thicknesses and distribution that are essential in an exploration area, correlation of geological sections that make us know the information of the rock sections, photogeological interpretations and search on cross-sections including stratigraphy, structure, porosity, lithology, and thickness of important formations all of these will help one in exploration.

Upstream | Petroleum Exploration

The role of exploration is to provide the information required to exploit the best opportunities presented in the choice of areas, and to manage research operations on the acquired blocks.

An oil company may work for several years on a prospective area before an exploration well is drilled and during this period the geological history of the area is studied and the likelihood of hydrocarbons being present quantified.

Stages of a typical exploration program



Exploration is a risk activity and the management of exploration assets and associated operations is a major task for oil companies. The risk cannot be eliminated entirely but can be controlled and reduced by adopting conceptual and technological innovations.

When it's been decided to start up with an exploration project in a basin or in a larger area containing several basins, the quantity and quality of available data must be acquired and evaluated like geological / geophysical data, production of existing fields (if any), etc.

Basin assessment/evaluation is the first step to the study of the area under interest. Technological development has provided oil companies with Basin Modeling – which is a numerical simulations that allows the temporal reconstruction of the history of a sedimentary basin and the associated evolution of the processes related to the formation of petroleum accumulations.

On the basis of data and evidences collected from the preliminary studies, the company management, in the light of the possibilities and the probabilities of a discovery based on G&G data, may decide to move to the following stage, which is the acquisition (through direct negotiations or by taking part in bids, etc.) of the legal right to perform prospecting in the selected area/block.

Goal of exploration is to identify and locate a prospect, to quantify the volume of hydrocarbon which might be contained in the potential reservoirs and to evaluate the risk inherent the project itself.

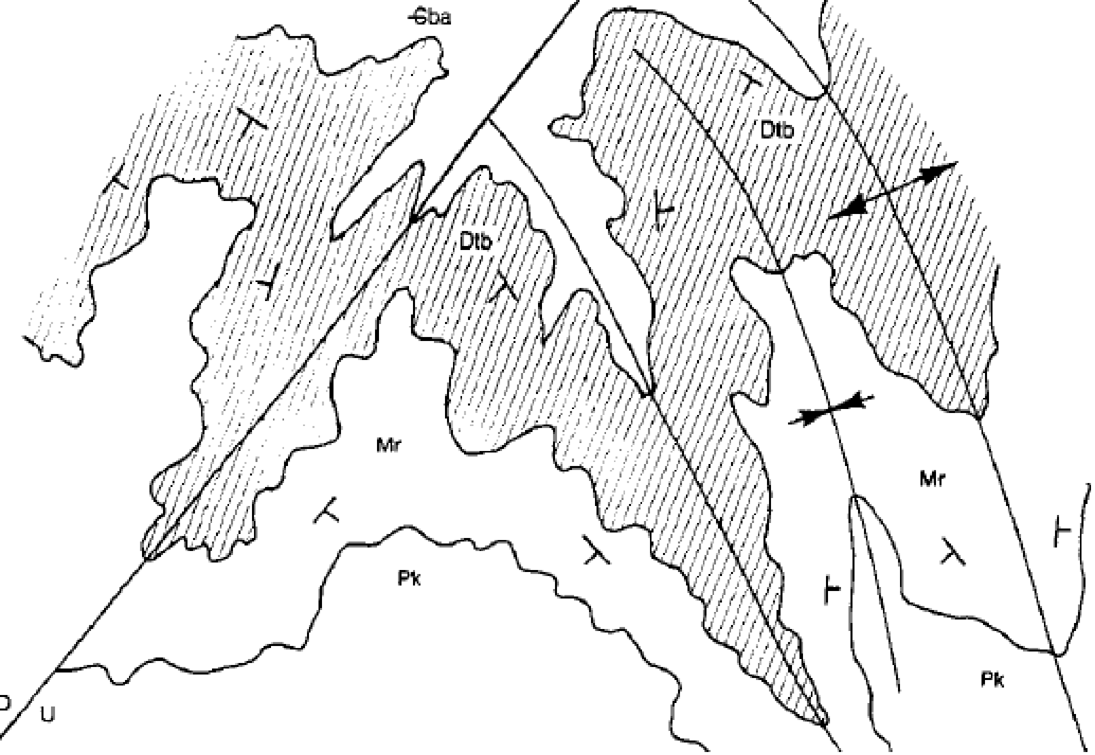
A prospect is a viable target evidenced by geological and geophysical indications that is recommended for drilling an exploration well.

Geological mapping and prospecting

Geological mapping and prospecting are valuable techniques in an petroleum exploration. Geological mapping It is basically a technique which allows a graphical presentation of geological observations and interpretations.

Geological prospecting make use of geological disciplines such as petrography, stratigraphy, sedimentology, structural geology, geochemistry. Such disciplines are used to achieve different targets but it must be stressed that their integration is fundamental to depict a picture of reality.

Identify the source and reservoir rocks, their distribution and thickness, correlation of the geological units, creation of cross section and identification of structure, stratigraphy and thickness of the beds etc.


-Єba
Dtb
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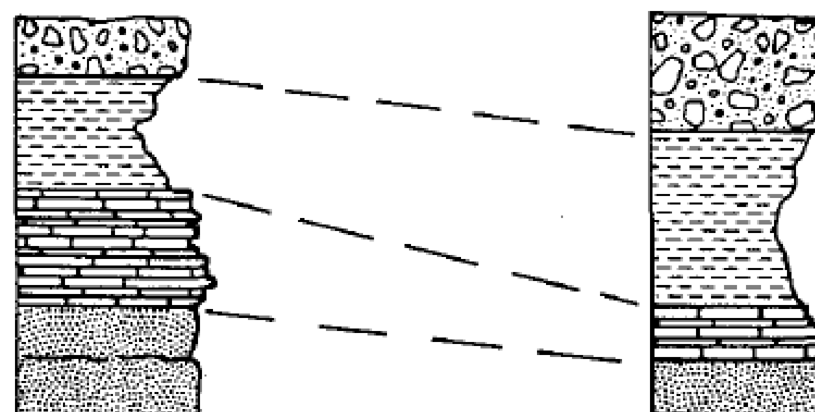


Surface geophysical techniques determine density, magnetic, and acoustical properties of a geologic medium. Three geophysical methods used in petroleum exploration comprise magnetic, gravimetric, and seismic (including refraction/reflection) techniques.

The magnetic and gravity methods are used only in primary surveys where little is known of the subsurface geology and/or the thickness of sediments of potential prospective interest.

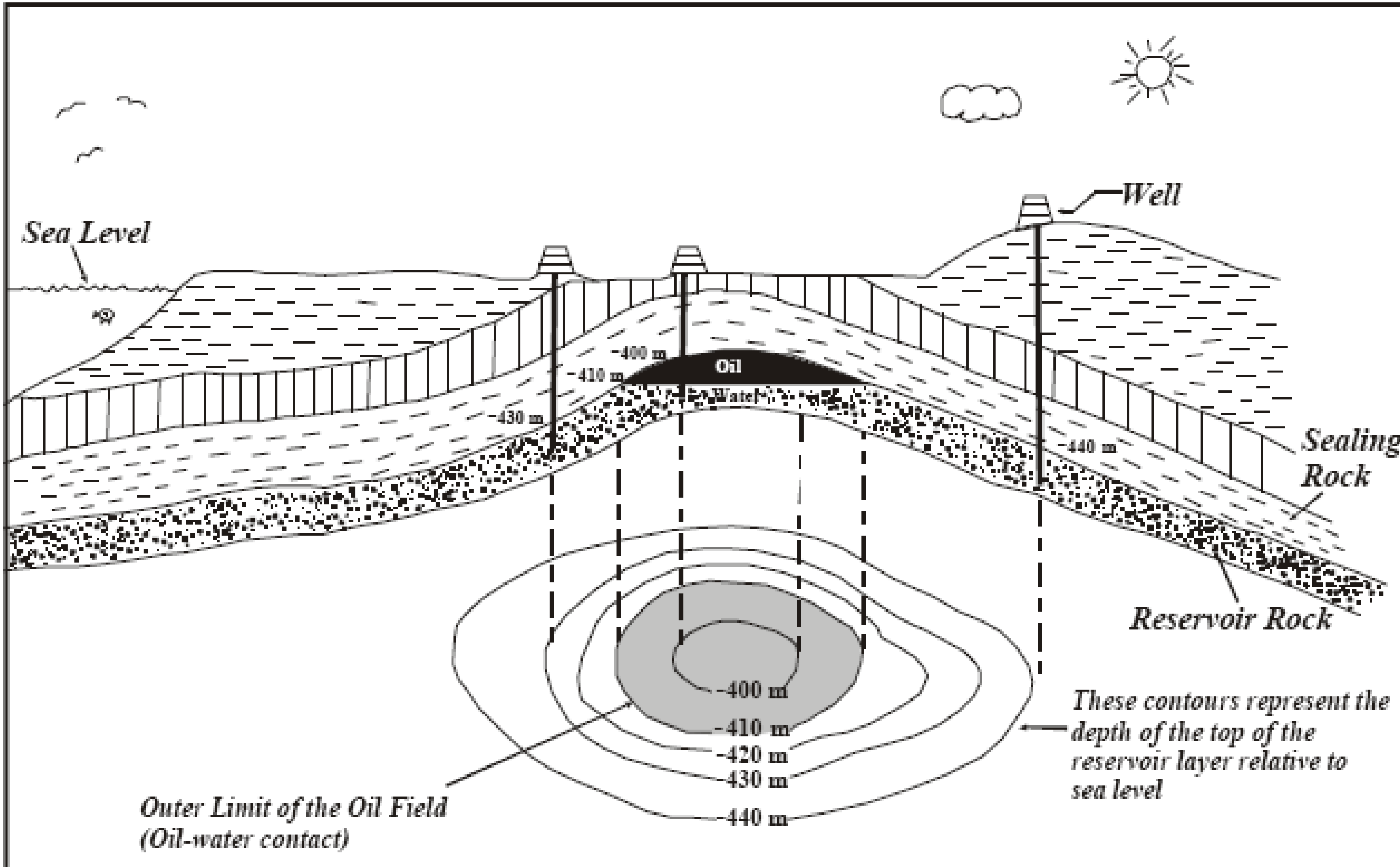
The seismic reflection method is universally used for determining the underground geological structure of a reservoir rock in a certain area. The method(s) selected will depend on the type of information needed, the nature of the subsurface materials, and the cultural interference.

Petroleum Exploration - Contour Mapping

Contour maps are one of the most effective means of displaying information about the geologic structure (i.e., the degree of buckling and faulting of the layers) of an area.

A contour is a line on which every point is at the same level above or below a chosen reference surface. In most maps the reference surface is sea level. If a contour line represents an elevation on the surface of the ground, it is a ***topographic*** *contour. A map showing topographic contours for an area would be called a* ***topographic map****.*

If such a contour represented an elevation of a rock stratum (layer), then it is called a ***structure*** *contour. A map showing structure contours for a certain rock layer throughout an area would be called a* ***structure contour map****. Such maps are used to illustrate the size, shape and location of geologic structures.*

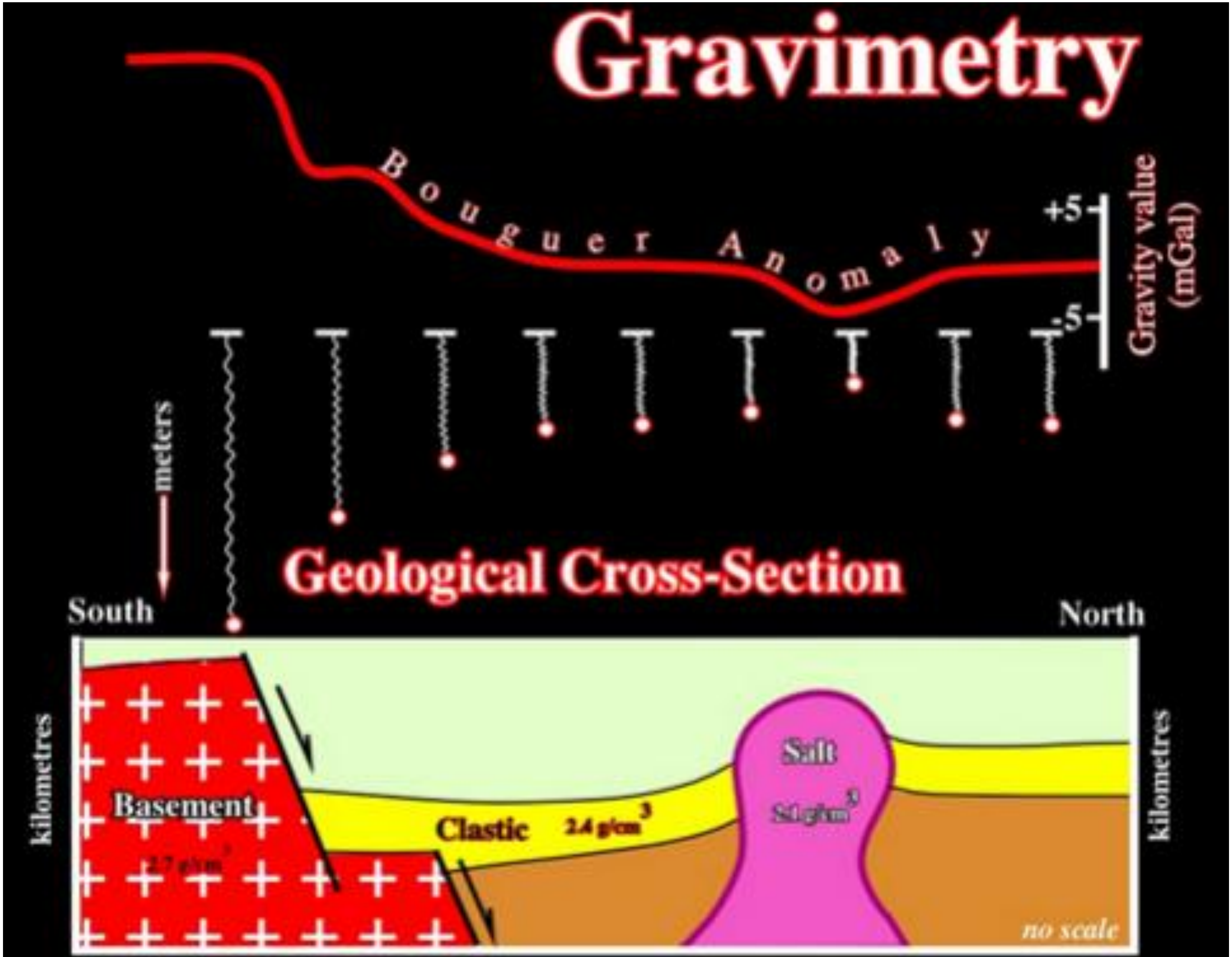


Subsurface Structure Contour Map

Gravimetric prospecting (Gravity survey)

Gravimetric prospecting is a geophysical technique which is able to identify anomalies in the gravity acceleration generated by contrasts in density among bodies in the subsurface.

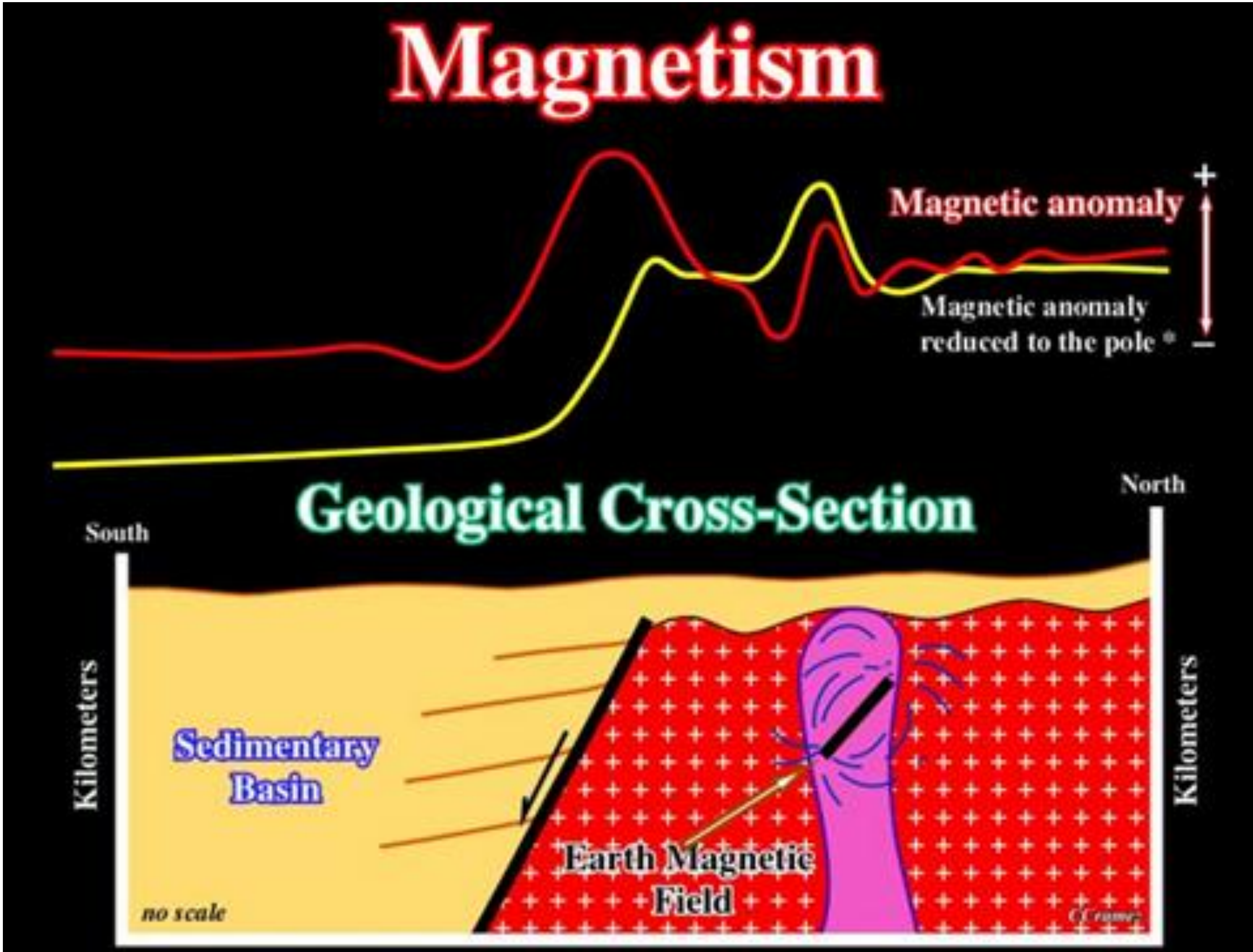
Gravimetric prospecting is used to reconstruct of the main structural elements of sedimentary basins such as: extension, thickness, salt domes, intrusive plutons and dislocations or faults.


Gravimetry
Bouguer Anomaly
+5
-5
Gravity value (mGal)
meters
Geological Cross-Section
South
North
kilometres
kilometres
Basement
2.7 g/cm³
Clastic
2.4 g/cm³
Salt
no scale

Magnetic survey & prospecting

This method involves measuring local anomalies in the Earth's magnetic fields.

The method enable acquisition of data on structural characteristics and depth of the susceptive basement and therefore, indirectly, on the thickness of sedimentary overburden and identifies the presence, depth and extension of volcanic or plutonic masses within the sedimentary sequences.


Magnetism
Magnetic anomaly
+
Magnetic anomaly
reduced to the pole *
−
Geological Cross-Section
South
North
Kilometers
Kilometers
Sedimentary
Basin
Earth Magnetic
Field
no scale

For example, a geologist working in a given area knows that approximately 500 meters below the surface there is a porous and permeable sandstone layer overlain by a thick impermeable shale. And suppose that somewhere in the area the sandstone was arched up in the shape of a dome or anticline.

you would say, this is a perfect candidate for a hydrocarbon trap. But now you must somehow construct a structure contour map to determine the size and exact location of the anticline. You will need to know this so that you can acquire petroleum rights for all of the land overlying the structure before you drill it and also to determine the best drilling location.

But how can you determine the elevations of a sandstone layer that is buried under 500 meters of rock?

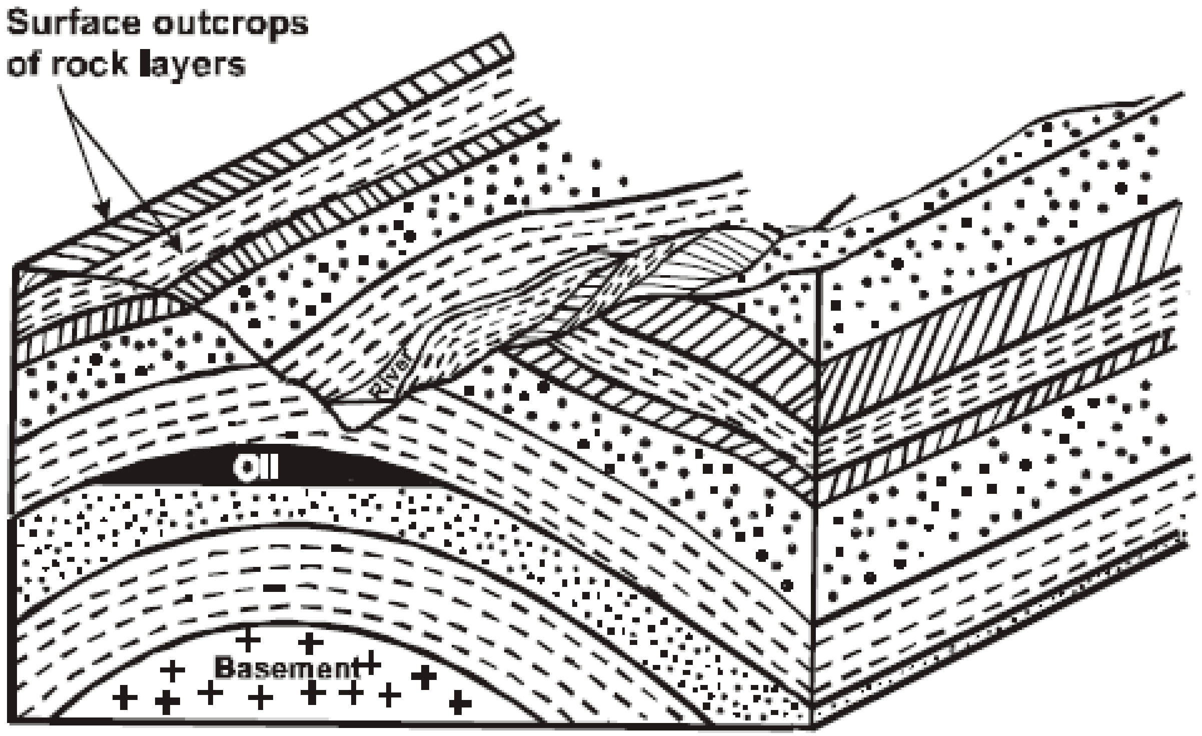
Imagine that you can shovel off the 500 meters of rock and walk around on top of the sandstone layer. Suppose you found that the top of the dome was at an elevation of – 400 meters (the minus sign indicates that an “elevation” below sea level). Then, if you walked 10 meters down the dome to an elevation of – 410 meters and started painting a line on the surface of the sandstone at that elevation, you'd find you would paint a line clear around the dome and end up back where you had started painting. The line you had painted would be the – 410 meter contour on the sandstone layer. Drop down another 10 meters and paint the – 420 meter contour.

You will have a longer walk and use more paint this time. Nevertheless, keep dropping down and painting a line at each ten-meter elevation until the whole structure has been contoured. You will know that you have completed contouring the structure when the line you are painting no longer "closes" or in other words no longer comes back to the point at which you started painting it.

Surface Mapping

In some areas, the presence of subsurface structures, especially anticlines, is evident at the surface. In such a case, geologists can search for anticlines by studying topographic maps and aerial photographs, and by going into the field and studying the rock layers that are exposed (i.e. outcrops) at the surface. Anticlines are not, however, always represented as ridges or hills on the surface. Land surface is a product of erosion and may not reflect the underlying structure. Sometimes the crest of an anticline is represented by a topographic low such as a river valley.

To determine the subsurface structure from the surface geology, the field geologist must study every possible outcrop in the area and determine the angle and direction at which the formations or layers are dipping to acquire the precious data points that are needed to construct a contour map



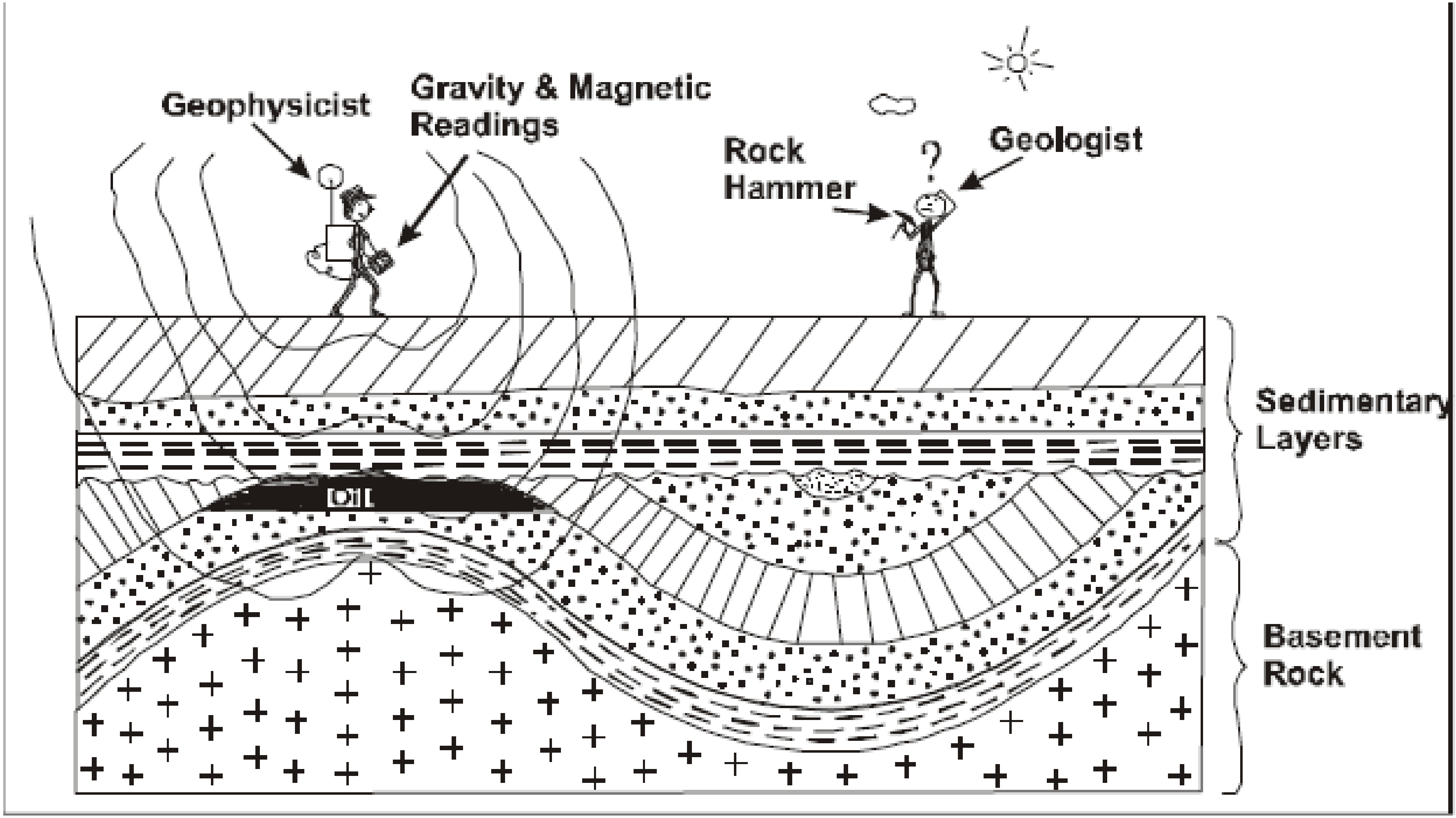
Eroded Anticline

Sometimes geologists can estimate the subsurface structure by studying the rock layers that "outcrop" on the surface. The subsurface does not always match the surface topography. In this example, a topographic low (river valley) overlies a subsurface high (an anticline).

Geophysics

In most areas, the subsurface structure cannot be determined from studying the surface alone. In such areas, the formations may have been eroded and then covered by thick layers that do not parallel the underlying beds; or the area may be covered by swamps or may even be under the ocean.

Fortunately, in such situations geophysics will be of immense help. The geophysicist uses physical phenomenon such as magnetic attraction, the pull of gravity, the speed of sound waves through different types of rocks, and the behavior of electric currents to determine the subsurface structure.



In many areas there are no clues to the subsurface structure visible at the surface. Geophysical methods must be utilized to estimate subsurface structure in such areas. Here the geophysicist is recording gravity and magnetic measurements to determine the topography of the basement rocks. Hydrocarbon traps are often formed over basement highs as shown here.

Geophysical methods

Passive:

- *Method using the natural fields of the Earth, e.g. gravity and magnetic*

Active:

- *Method that requires the input of artificially generated energy, e.g. seismic reflection*

The objective of geophysics is to locate or detect the presence of subsurface structures or bodies and determine their size, shape, depth, and physical properties (density, velocity, porosity…) + fluid content

Basement Rocks

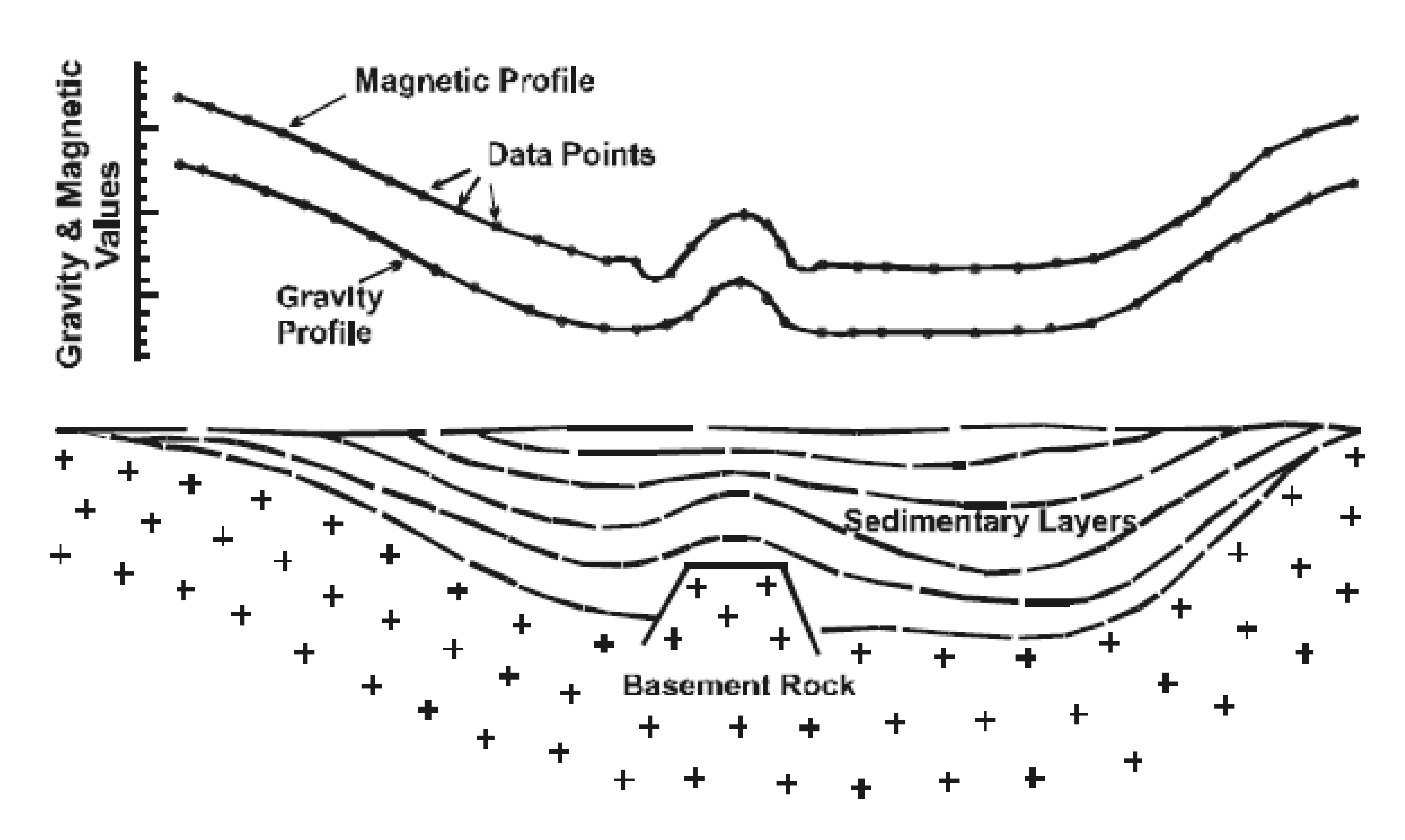
A sedimentary basin is normally underlain by igneous and / or metamorphic basement rocks These basement rocks have two important properties that distinguish them from sedimentary rocks in the eyes of a geophysicist.

(1) They are more magnetic than sedimentary rocks; and
(2) They are more dense than sedimentary rocks.

These two differences provide the basis for two very useful geophysical techniques; magnetic surveying and gravity surveying.

The magnetic properties of basement rocks create distortions and anomalies in the earth's magnetic field. The magnitude of these anomalies as measured at the surface, is proportional to the depth of burial of the basement rocks.

In other words, when the basement rocks are close to the surface, the magnetic distortions are stronger. When the basement rocks are buried deeper, the magnetic distortions seen at the surface will be weaker. The geophysicist, by taking magnetic measurements throughout an area, can estimate the geologic structure of the basement rocks, as well as the thickness of the sedimentary cover rocks.



Gravity and Magnetic Profiles

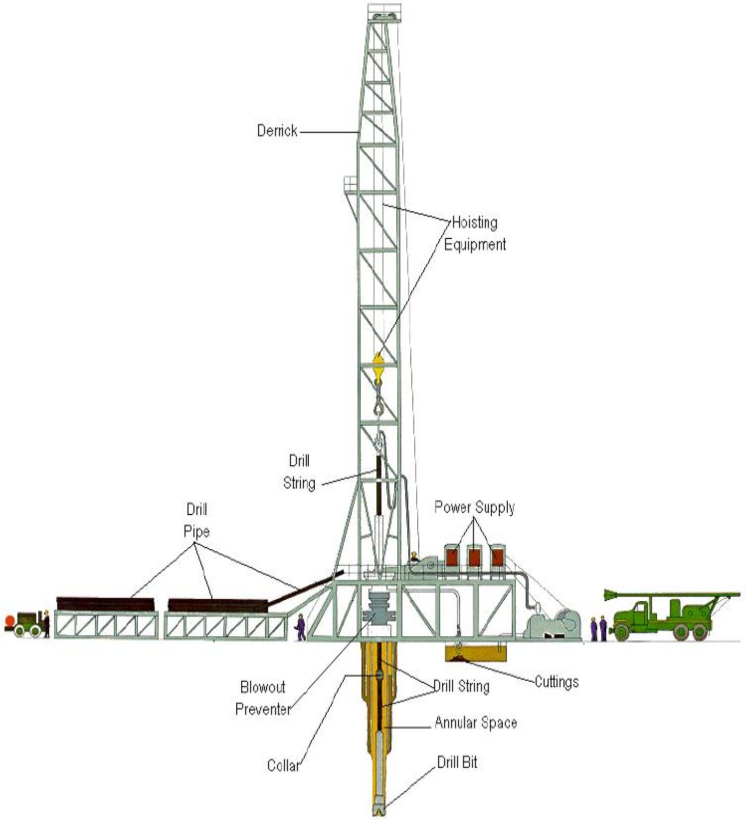
This simplified schematic shows how gravity and magnetic measurements taken at the surface can pin-point the location of a subsurface anticline.

Magnetics

- Magnetic surveying aims to investigate the subsurface geology by measuring the strength or intensity of the Earth's magnetic field.
- Lateral variation in magnetic susceptibility give rise to spatial variations in the magnetic field
- It is expressed in so called *magnetic anomalies*, i.e. deviations from the Earth's magnetic field.
- The unit of measurement is the *tesla* (T) which is volts·s·m-2 In magnetic surveying the *nanotesla* is used (1nT = 10-9 T). The magnetic field is a vector
- Natural magnetic elements: iron, cobalt, nickel, gadolinium. Ferromagnetic minerals: magnetite, ilmenite, hematite, pyrhotite
- Reconnaissance tool for Surface & Subsurface structure
- Oil/Hydrocarbon migration to top – Chemical reaction – induce / create magnetic anomaly – May be deducted by low flying aircrafts.

DRILLING TO CONFIRM

- Only when a structure is rated as prospective in terms of trap, seal, migration and source,
- it is drilled. A chance of success (COS/POS) of 20 to 35 % is considered risk worthy.
- Only 1 in 3 to 5 exploration wells find oil/ gas Drilling is expensive, risky and tough.
- Coring, logging, testing are part of drilling ops.



Gravity Surveys

Since basement rocks have a higher density than sedimentary rocks, they have a stronger gravitational attraction. The tiny differences in the earth's gravitational field that are measured in gravity surveying are too small to be noticeable to humans. In other words, you would not feel heavier if you were standing in an area where the basement rocks were close to the surface.

These gravitational differences can only be detected using a very sensitive instrument. The principles employed in gravity surveying are very similar to those of magnetic surveying. That is, when basement rocks are close to the surface, the gravitational distortions will be greater; when the basement rocks are deeply buried, the gravitational distortions will be less pronounced.

Once again the geophysicist, using the gravity meter, takes hundreds or even thousands of measurements throughout an area. The values are plotted on a map at the appropriate locations and then, after making a number of mathematical corrections, the geophysicist is able to make a map that will show the structure of the basement rocks which may be thousands of meters below the surface.

Seismic Exploration

Geophysical surveys can generally be classified into two categories: **reconnaissance surveys**, which are run to define broad areas of interest that contain the thick sedimentary layers that have the potential to contain hydrocarbon traps; and **detailed surveys** which are conducted to locate individual geologic structures which can then be drilled.

The gravity and magnetic surveys would generally be classified as reconnaissance type surveys. Magnetic surveys are often done from an airplane flying a grid pattern over a large area. These "aeromagnetic" surveys define the areas where sedimentary rock is thick enough to warrant further, more detailed work.

Gravity and magnetic surveys are also frequently done from ships to find sedimentary basins in offshore areas. Once again, these surveys would be followed up by a more detailed type of survey before well locations could be chosen. The most common geophysical technique for obtaining the detailed geologic structural information needed to pick well locations is, however, the **seismic survey**.

The Seismic Survey

The most accurate and widely used means of finding good drilling locations is the seismic survey. Seismic surveying involves sending sound waves down into the ground and recording the echoes that bounce back off the various sedimentary layers.

The sound or shock waves are generated by;

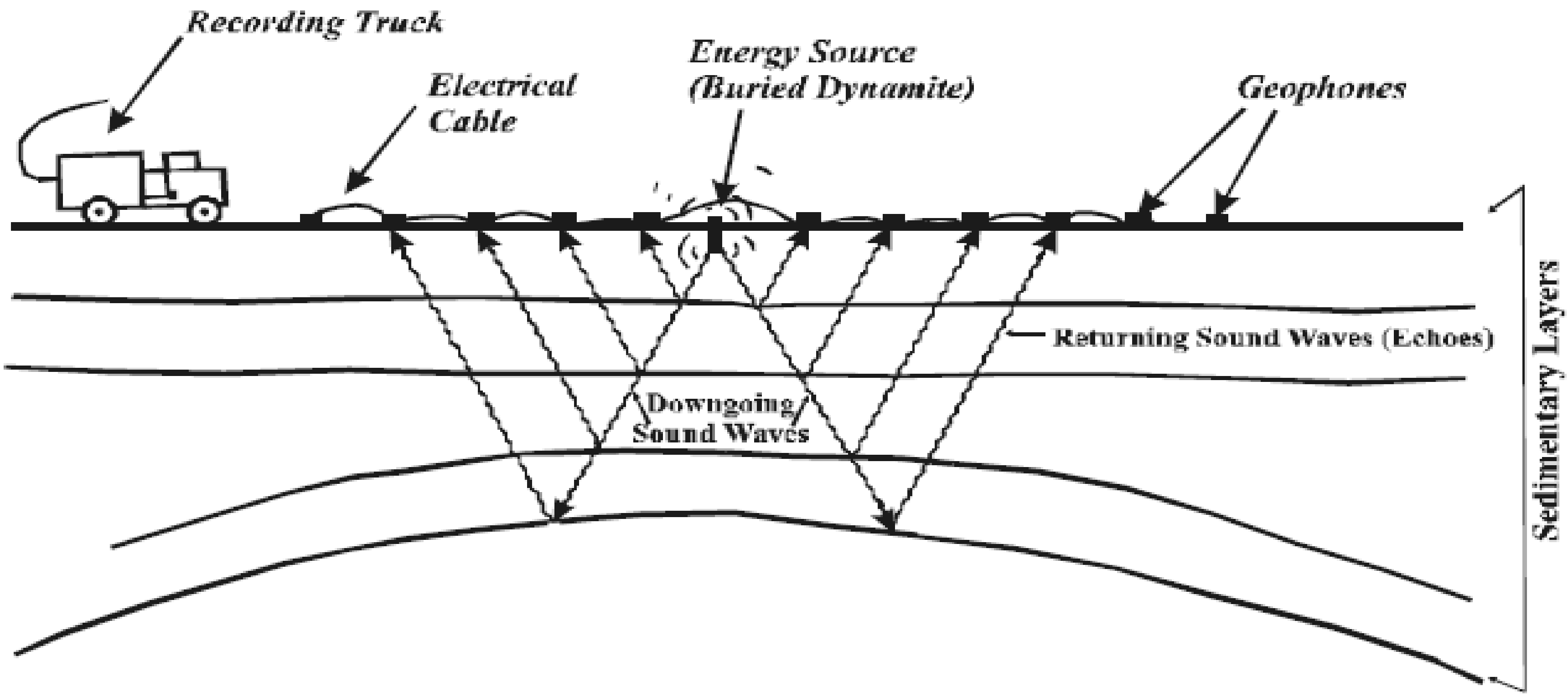
- setting off small explosive charges just below the surface;
- hitting the ground with a heavy weight;
- or shaking the ground using large vibrator trucks.

The echoes returning from the subsurface are detected by sensitive instruments called geophones which are strung out along the ground in a straight line. The geophones are connected by electrical cable to a recording system. The recording system precisely records, to the nearest one thousandth of a second on magnetic tape, the time it takes for the echoes to return to the surface. By knowing the amount of time it takes for a sound wave to reach a certain layer and then bounce back to the surface, as well as the speed of sound through the rock layers in between, the geophysicist is able to determine the depth to that layer at that location. By determining the depth at a large number of points along the seismic line, the geophysicist is able to create a profile of the underground layers along the line.

A good analogy to the seismic method is the sonar system used on ships to determine water depth. The sonar system works by sending a small sound wave downward from the ship, which bounces off the seabed. The time it takes for the echo to return indicates the water depth.

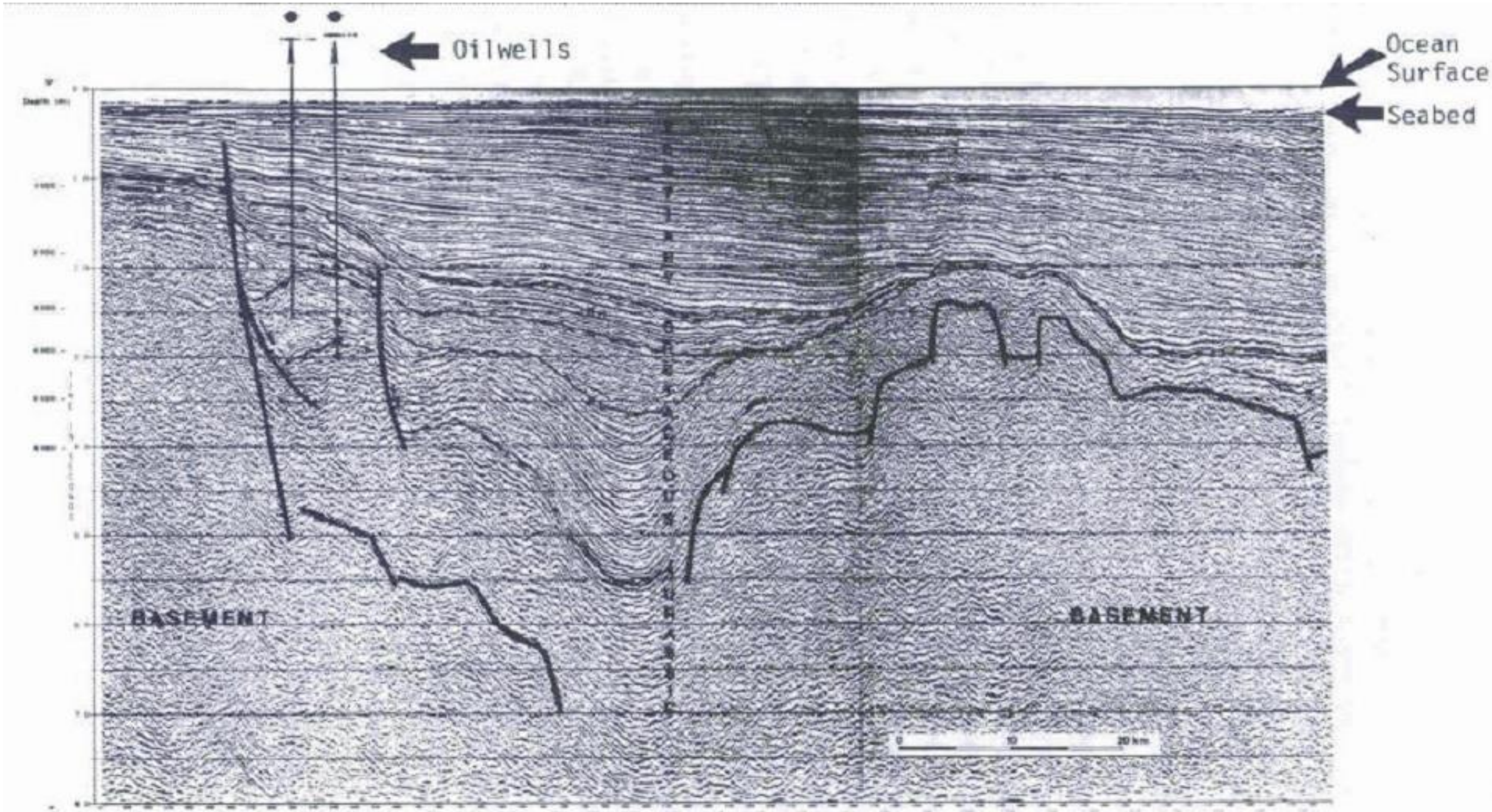
The principal involved is exactly the same as seismic, except that the sonar waves do not penetrate deeply into the seabed to give information about underlying layers. The more powerful seismic waves, on the other hand, can penetrate deeply into the subsurface and bring back information on rock layers tens of kilometers below the surface.

Figure below shows the basic setup used in seismic surveying. Note that many geophones are laid out in a straight line so that the depths for many subsurface points can be determined all at once. Also, notice that all of the energy in a seismic wave does not bounce back from the first layer encountered.



F Seismic Exploration

Some energy bounces back, but some of the energy continues its downward journey to bounce off other, deeper layers. Some rock layers will reflect very little energy back to the surface while others, such as limestone, reflect a lot of energy. It is these strongly reflecting layers that are most useful to the geophysicist in mapping the subsurface structure.

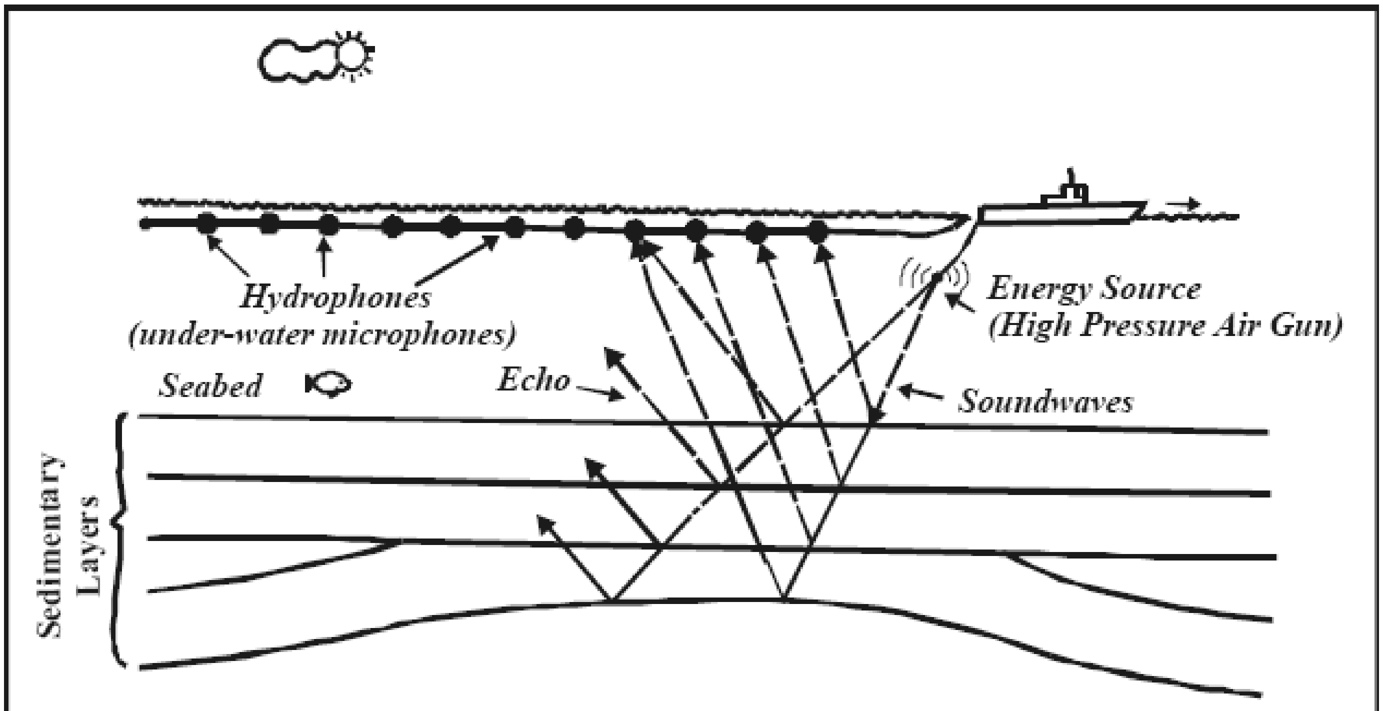


Seismic section across a Sedimentary Basin offshore Newfoundland. The lines on the section show how the geophysicist has interpreted the section. The darkened circles on the well on the left identify the different zones in which oil was discovered.

Note that the oil is contained in a structural trap; an anticline bounded by two faults.

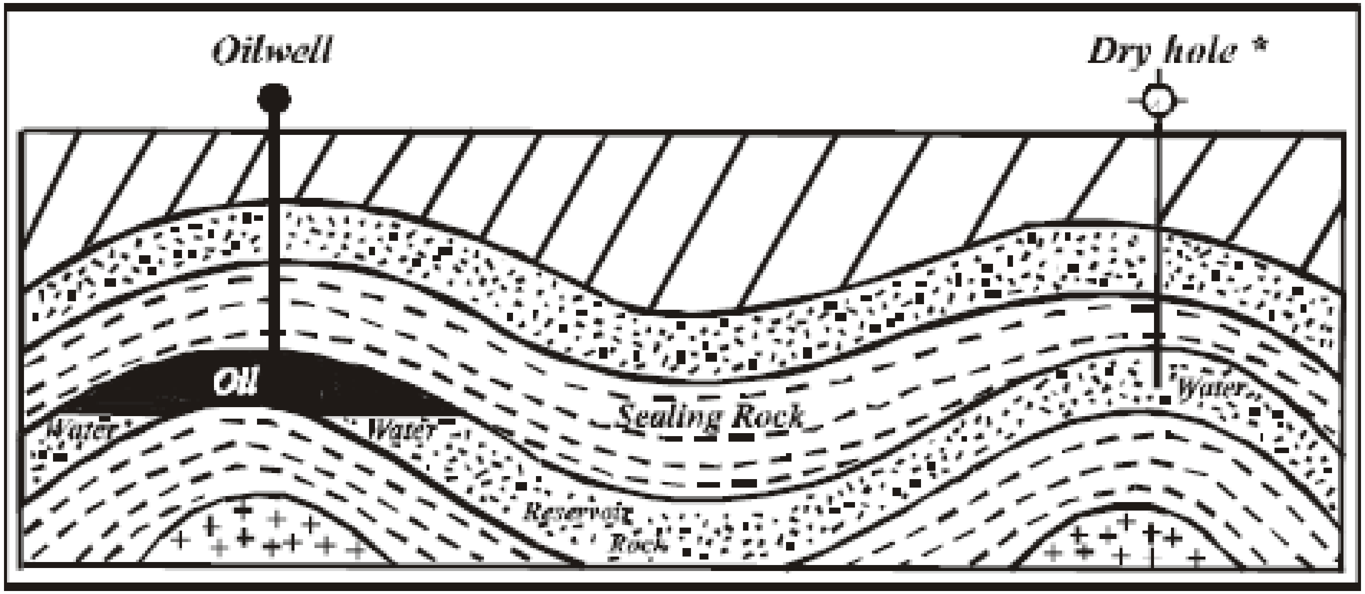
Offshore Seismic

Seismic crew operates in the offshore. In this case, the aquatic equivalent of the geophone, the hydrophone is used to detect echoes returning from the underground layers. The hydrophones, which are essentially underwater microphones, are attached to a buoyant cable and towed behind the ship. The shock waves are generated by a high pressure air gun towed near the back of the ship. Although the equipment used in recording offshore seismic is somewhat different than that used onshore, the principles involved are exactly the same.



Drilling

Now that we have found a promising geological structure and acquired the petroleum rights, it is time to go ahead and drill. Regardless of all the sophisticated geological and geophysical mapping that has been done, the only way to find out if there is any oil or gas present under your land is to drill a well.



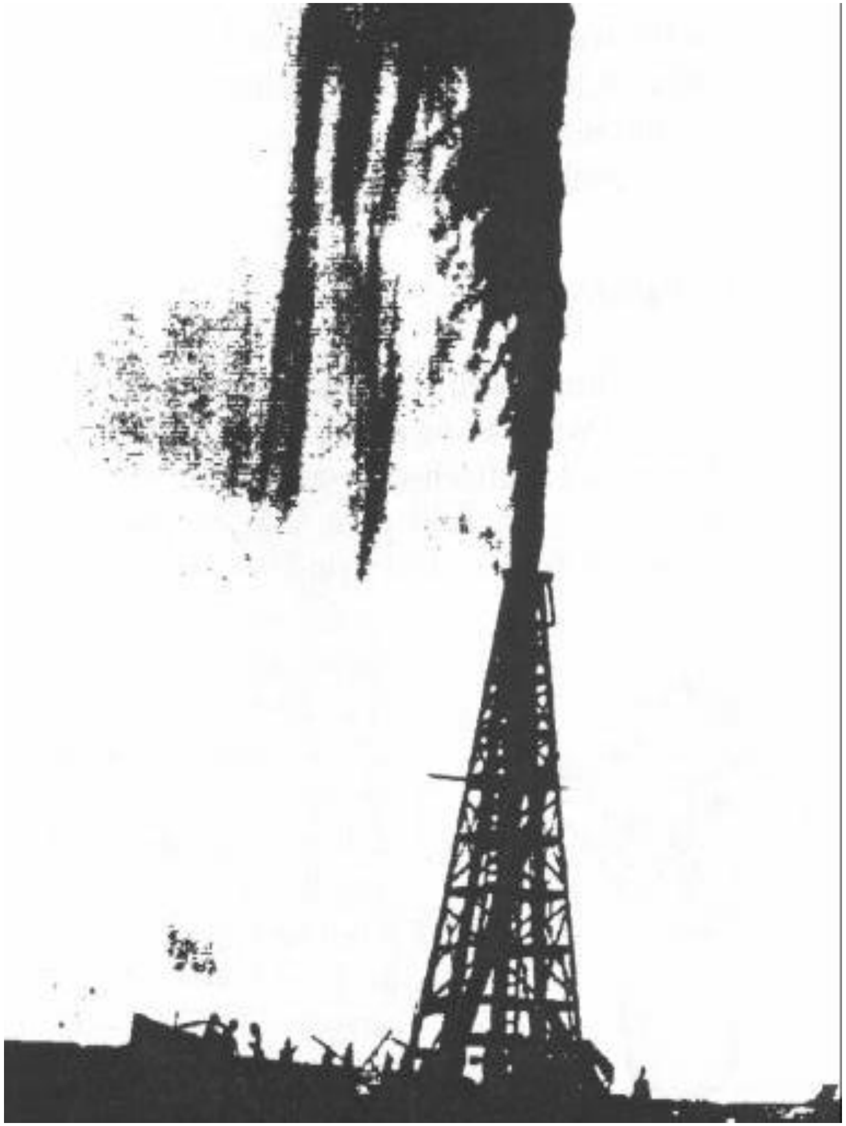
Anticlines and other potential hydrocarbon traps can be located using seismic and other techniques, but the only way to find out if petroleum is present is to drill a well. Here we have two identical geologic structures side by side and only one of them contains oil. Only about one in ten wildcat wells is a discovery.

Wildcat well. drilling into a geologic structure in which no oil or gas has yet been discovered. We will be attempting to discover a new oilfield. If a discovery is made on this geologic structure, we will need to drill more wells (delineation wells) to determine the size of our oilfield. Drilling wells is an expensive and risky business. The costs can run into millions of dollars and the chance of success for wildcats is only about one in ten.

Drilling the Well

Drilling a well involves a whole new cast of characters. The drilling engineer, the driller, the tool pusher, the logging crew and many others. The overall objective of drilling is to bore a hole (the well bore) into the ground until you penetrate a target rock formation, that has been identified by the geologists and geophysicists as having the potential to contain commercial hydrocarbons.

If we were to drill into such a formation without taking the appropriate precautions, the fluids would spew violently out of the hole and we'd have what's called a blowout. Blowouts can be extremely dangerous as well as damaging to the environment. In the early days of the oil industry, before drilling technology had evolved significantly, when a well struck oil it often blew out. These blowouts frequently caught fire, destroyed the rig, and sometimes cost rig workers their lives.



Blowout

The Spindletop Blowout in Texas spewed 50,000 barrels per day for 9 days in 1901 before the well could be controlled. Oil drillers were ill prepared to deal with the pressure in this reservoir as no blowout of this magnitude had ever before been witnessed.

In today's drilling industry, blowouts are very rare. The entire technology of today's drilling industry is focused on the ideal of drilling safely and economically into the pressurized underground formations, without allowing any uncontrolled flow of fluids out of the well.

The well is allowed to flow through a series of valves only under controlled conditions.

- After a well is drilled, it is logged i.e. parametric measurements are taken using electric, nuclear and sonic methods. Porosity, permeability, gas/ water saturation, pressure, salinity are calculated.

- Indicative zones are then drilled to test the flow of gas/oil. Testing certifies a well as discovery or dry.

- Discovery will lead to estimation of likely volume of oil/ gas in the structure.

- Initial estimation determines whether appraisal survey and wells are required.

Appraisal And Development

- Discovery is appraised by additional seismic 2d/ 3d productive zones are mapped for more accurate extent and thickness
- More wells are drilled to calculate the reserve more accurately
- Production level determined
- Production wells are drilled for optimized production
- Once the reserve volume is determined number of wells that can be drilled is estimated.
- Volume of reserve, distribution of reservoir, type of depletion mechanism, economic considerations are guiding factors.

- Each well is designed to produce an optimal volume based on the reservoir condition: porosity, permeability, petrology, saturation etc.

- Over production ignoring rock/ reservoir property will result in reservoir damage, loss of productive sand, water coning, sand infiltration etc.

- Wells may have theoretical capability to produce more than its optimal flow; but it is undesirable to over produce wells to meet demand.

- Over production sustained for long period will cause loss of reservoir, leaving isolated zones that can not be produced; or deplete the field without recovering maximum reserve.