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Table of Content

1. Introduction

Hydrocarbon traps form where porous and permeable reservoir rocks (carbonates, sandstones) are covered by rocks with low permeability (cap rocks) that are capable of preventing the hydrocarbons from further upward migration. A trap, therefore, has two functions viz. i) it allows entry of hydrocarbon and ii) it obstructs their escape. Typical cap rocks are compacted shales, evaporites, and tightly cemented sandstones and carbonate rocks. The cap rock need not be 100% impermeable to water, oil or gas. If the upward loss of hydrocarbons is less than the supply of hydrocarbons from the source rocks to the reservoir, hydrocarbons may still accumulate and form a trap.

Since development of a successful petroleum system includes formation of source rock, cap rock and trap all together, it is necessary to understand how a trap forms and what are the different ways a permeability contrast or structural closure can force oil/gas to accumulate in a bed or structure.

1.1 Basic Trap-Fluid Nomenclature: Rocks above (cap rock) and alongside (wall rock) of a trap are commonly impermeable not only for oil or gas but also for water under reservoir pressure condition. Hence, water which originally present in a reservoir get displaced downward with accumulation of oil and gas. This pool of displaced water is referred as 'bottom water'. The pool of water that is bounded laterally is called edge water (Fig. 1). The structurally lowest point in a trap that can retain hydrocarbon is referred to as spill point.

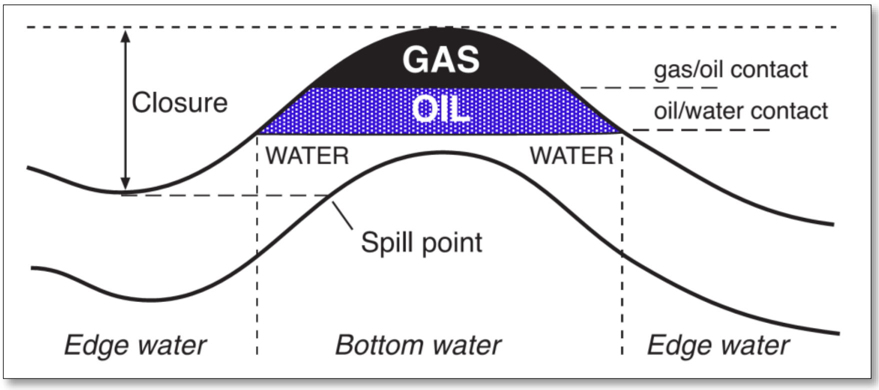

Fig. 1 Anticlinal structural trap with oil-water, oil-gas contact and bottom, edge water shown.

2. Classification of Traps

Traps are usually classified according to the mechanism that produces the hydrocarbon accumulation. The two main groups of traps are those that are formed by structural deformation of rocks (**structural traps**), and those that are related to depositional or diagenetic features in the sedimentary sequence (**stratigraphic traps**).

Many traps result from both of these factors (**combination traps**). A common example is stratigraphic pinch-out (e.g., a sandstone lens wedging into mudstone) that is combined with tectonic tilting (which allows hydrocarbons to pond in the updip part of the sandstone wedge). Other traps result mainly from fracturing (which creates the reservoir porosity) or hydrodynamic processes. There are many classifications of hydrocarbon traps in use, but most have ~90% in common.

2.1 Structural Traps: Structural traps are primarily the result of folding and (or) faulting, or both.

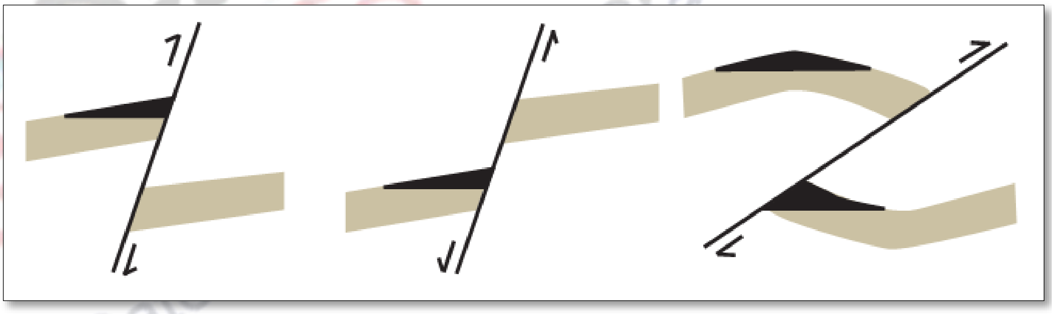

Fig. 2 Examples of structural trap: Reverse fault, Normal fault and faulted limb of an anticline.

2.1.1 Anticlinal (fold) and dome traps: Necessary conditions: An impervious cap rock and a porous reservoir rock; closure occurs in all directions to prevent leakage (i.e. four-way closure necessary for a dome).

- *Simple fold traps* (anticlinal) with axial culmination (fold axis dipping in two or more directions). The simplest type of trap is formed when a sandstone bed that is overlain by tight (i.e. low permeability) shale is folded into an anticline. A simple anticline, however, may not necessarily be a trap. The crest of the anticline must have an apical culmination (i.e. a peak) somewhere along the fold axis so that hydrocarbons can be trapped. Closure is defined as the height to the crest of a structure above the spill point of a trap. Anticlinal traps are commonly detected by seismic reflection. In mature oilfields, most of these simple traps have probably been found, but many anticlinal traps remain to be discovered offshore and in new prospective areas.

- *Salt domes*: Strata around the salt dome curve upward creating traps against the sealing salt layers (see below for more details).
- *Growth domes:* Domes or anticlines form *during* sedimentation when one area subsides more slowly than the surrounding areas. Their formation is concurrent with sedimentation (i.e. they form during deposition), and not due to later (tectonic) folding. Growth anticlines may form due to differential compaction over salt domes or other upward-projecting features in the substrate (topographic highs on the buried landscape).

2.1.2 Fault traps: The fault plane must have a sealing effect so that it functions as a fluid migration barrier for reservoir rocks. There are several common types of fault trap:

- *Normal faults*- commonly associated with graben (rift) structures. b) *Strike-slip faults*- these may not be sealed due to incremental movements, but basement-controlled strike-slip faults commonly produce good anticlinal structures in overlying softer sediments.
- *Thrust faults*- commonly associated with compressional tectonics (e.g., the Front Ranges in Alberta).
- *Growth faults*- Growth faults typically form in sediments that are deposited rapidly, especially at deltas. Faulting occurs *during* sedimentation (i.e. syndepositionally), such that the equivalent strata

on the downthrow side will be thicker than on the upthrow side. The throw between corresponding strata declines upwards along the fault plane. Minor fault planes with an opposite throw (antithetic faults) may also form in the strata that curve inward towards the main fault plane. The fault plane is commonly sealed, preventing further upward migration of oil and gas. Fault traps may also form when sandstone beds are offset against the fault plane. Some petroleum traps, however, form in "roll-over" anticlines on the down-faulted block. Growth faults may reduce porewater circulation in sedimentary basins; consequently, undercompacted clays, which may develop into clay diapirs, are often associated with growth faults.

Some general points about fault traps…

The *geometry* and *timing* determine whether faults will be effective in forming fault traps:

- *Dead faults* that predate basinal sediments only affect the underlying basement – they play no direct role in hydrocarbon trapping in the younger sedimentary pile.
- *Continuously developing faults (growth faults)* — these are active during sedimentation and are major petroleum traps (e.g., Niger Delta).
- Young (late) faults —these form late during sedimentation; depending on their initiation and growth, they may or may not be effective as traps. 4. Late regenerated faults —these are new movements on old faults — they are more likely to destroy than form traps, but may be effective.

Many petroleum fields are closely linked to faulting, but traps that result from faulting alone are less common.

There are three common fault – petroleum pool associations:

- The fault itself makes the trap without an ancillary trapping mechanism such as a fold — normal faults are the most common examples.

- The fault creates another structure (e.g., a fold or horst) that in turn forms the main trap.
- The fault may be a consequence of another structure that forms the main trap- e.g., the extensional crestal faults that form above some anticlines.

Important point: Faults are highly ambiguous features. They may leak, acting as permeable conduits for fluid flow (including oil and gas migration), but more commonly act as seals unless they are rejuvenated after petroleum has pooled. They form seals because of fault gouges or differential pressures either side of the fault plane (Fig. 3):

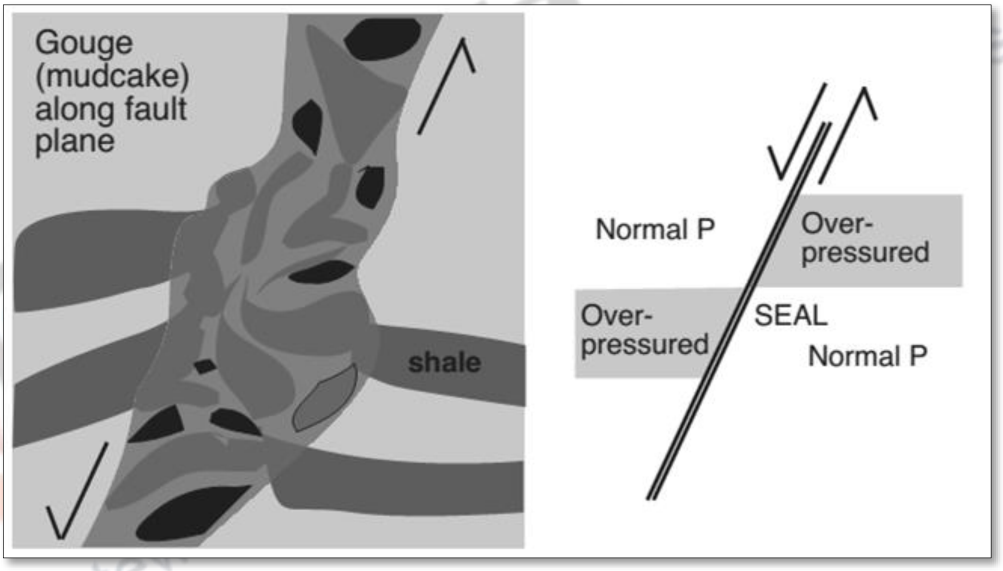

Fig. 3 Model of a fault zone with formation of fault gouze. A fault may create lateral seal for a trap.

SALT DOME RESERVOIRS

Salt domes form when salt is less dense than the overlying rock, and the salt moves slowly upwards due to its buoyancy. For this to happen, there must be a minimum overburden and the thickness of the salt deposits must be more than ~100 m. Upward movement of salt through the sedimentary strata, and associated deformation is termed halokinetics or salt tectonics. Movements may continue for several hundred million years.

Traps may form (1) in the strata overlying the salt dome, (2) in the top of the salt domes (the cap rock - caused by brecciation and dissolution), (3) in the strata that curve upward against the salt intrusion, (4) due to stratigraphic pinch-out of strata around the salt dome (Fig. 4). Salt dome reservoirs produce major oilfields where basinal sediments contain thick salt deposits. Salt deposits are common in Permian-Jurassic sediments around the Atlantic Ocean. Examples include the Gulf of Mexico, where there is Permian and Jurassic salt, the Permian Zechstein salt in NW Europe and the North Sea.

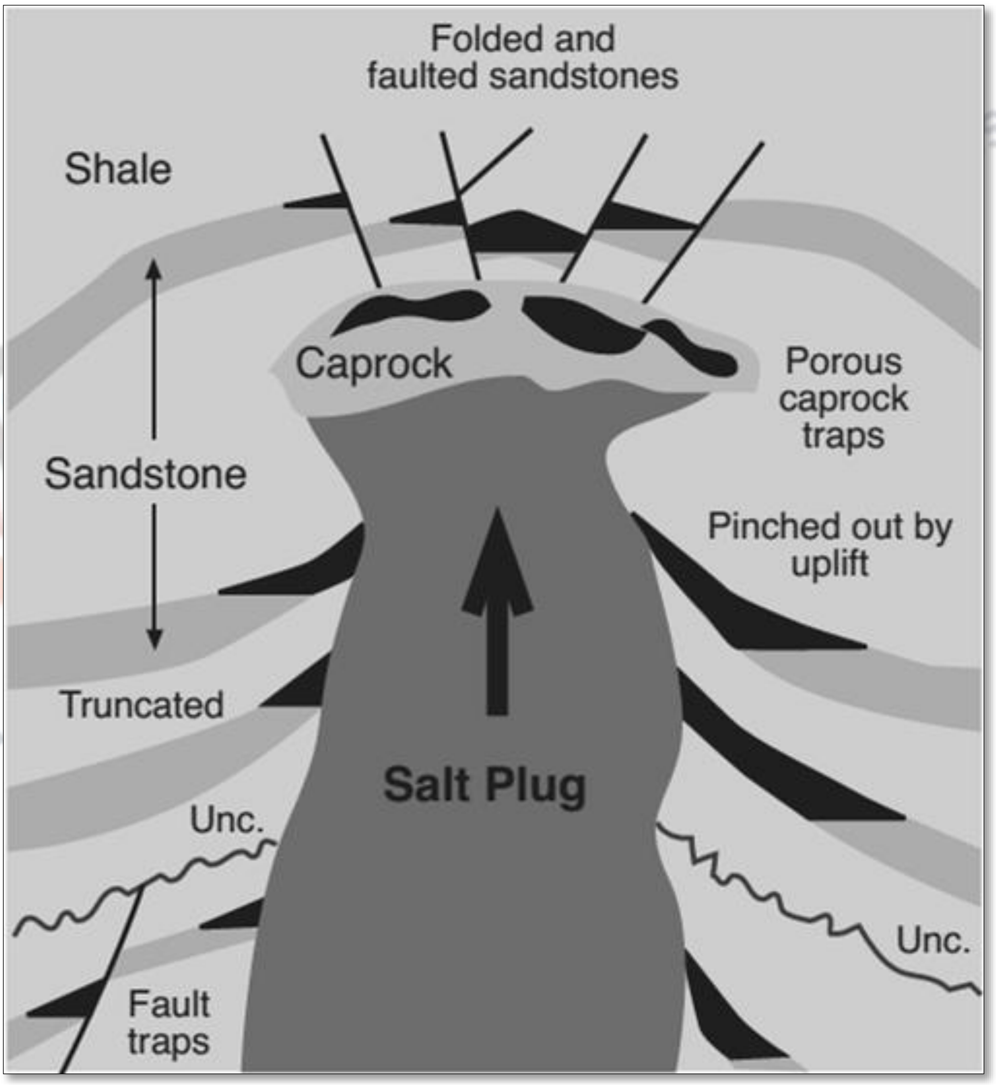

Fig. 4 Ideal salt-dome traps based on examples from U.S. Gulf Coast. Note development of trap at the top, curved strata alongside and because of pinch out.

2.2 Stratigraphic Traps: Stratigraphic traps are created by any variation in the stratigraphy that is independent of structural deformation, although many stratigraphic traps involve a tectonic component such as tilting of strata.

Two main groups can be recognized —

Primary stratigraphic traps result from variations in facies that developed during sedimentation. These include features such as lenses, pinch-outs, and appropriate facies changes.

Examples include (Fig. 5):

- Primary pinch out of strata, e.g., strata that pinch out updip in less permeable rocks such as shale;
- Fluvial channels of sandstone that are isolated and surrounded by impermeable clay-rich sediments;
- Submarine channels and sandstone turbidites in strata rich in shale;
- Porous reefs that are surrounded by shale, etc.

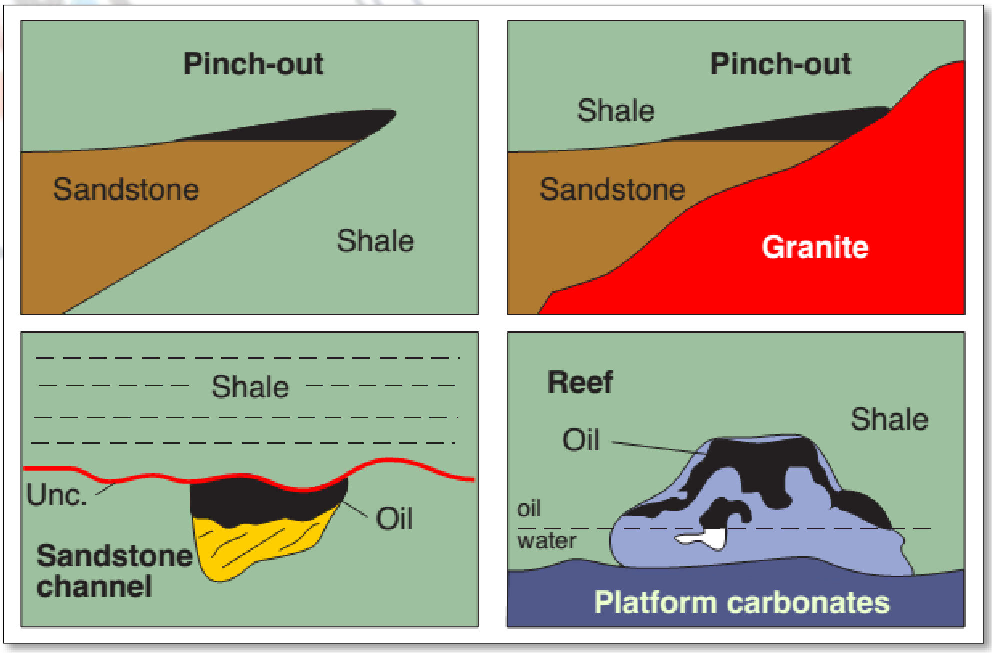

Fig. 5 Examples of stratigraphic traps: Pinch out, Unconformity, platform reefal carbonate.

Secondary stratigraphic traps result from variations that developed after sedimentation, mainly because of diagenesis. These include variations due to porosity enhancement by dissolution or loss by cementation. Paleogeomorphic traps are controlled by buried landscape. Some are associated with prominences (hills); others with depressions (valleys). Many are also partly controlled by unconformities so are also termed unconformity traps.

Combination Traps: Many oil fields around the world are not solely the result of structure or stratigraphy. They are result of combined effects of structural and stratigraphical processes. Pinchout, onlap, truncation traps all require some closure, which is often caused by structural deformation along the strike. Similarly, folded/faulted beds may be sealed by unconformity planes to form trap (Fig. 6).

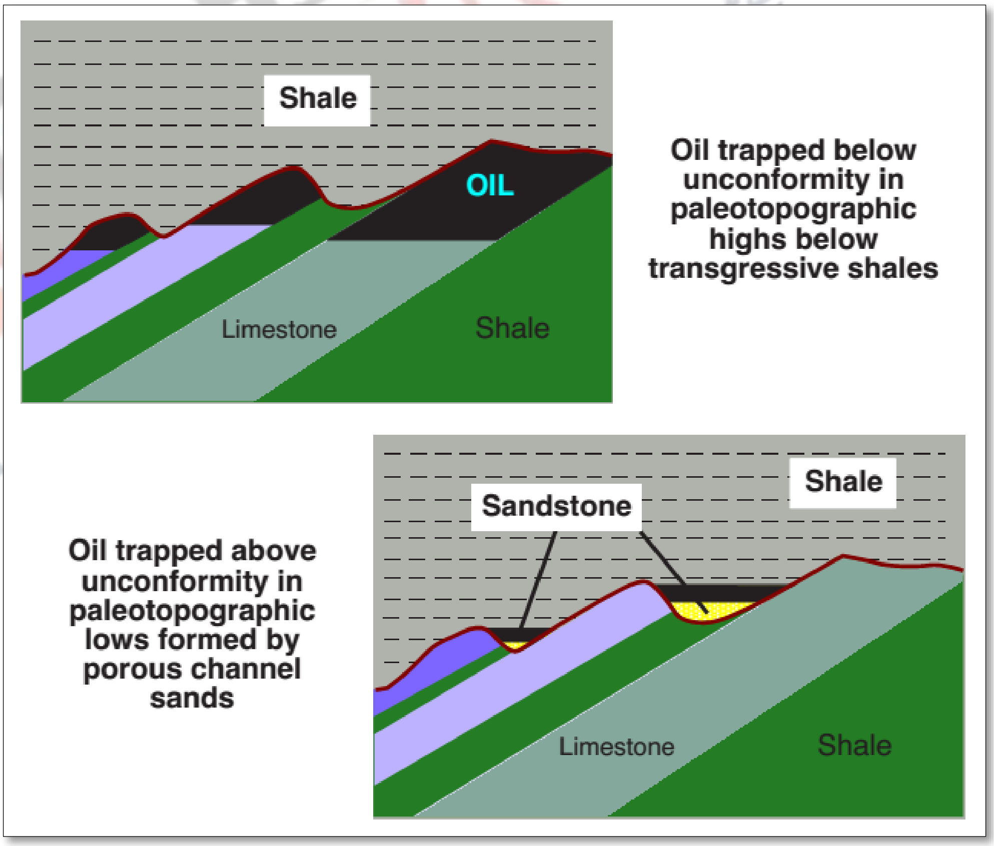

Fig. 6 Trap formation by truncation of folded strata by unconformity plane. Traps can form both below or above the unconformity plane.

2.3 Other Types of Traps

2.3.1 Fractured Reservoirs: Fractured basement rock that projects upward locally into overlying shales can also provide good traps. Fractured, well-cemented rocks (limestones and cherts) along faults may also form good traps of limited lateral extent (Fig. 7).

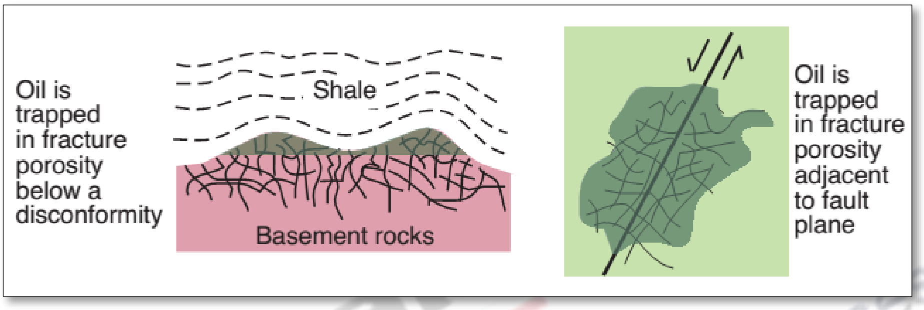

Fig. 7 Trap formation in the basement because of fracture and suitable source rock above in form of shale. Map view on the right.

2.3.2 Hydrodynamic Traps: If pore water flow in a sedimentary basin is strong enough, the oil-water contact may deviate from the horizontal because of the hydrodynamic shear stress that is set up (Fig. 8). In some cases, oil may accumulate without closure. Flow of fresh (meteoric) water down through oil-bearing rocks commonly results in biodegradation of the oil and formation of asphalt, which may then form a cap rock for oil.

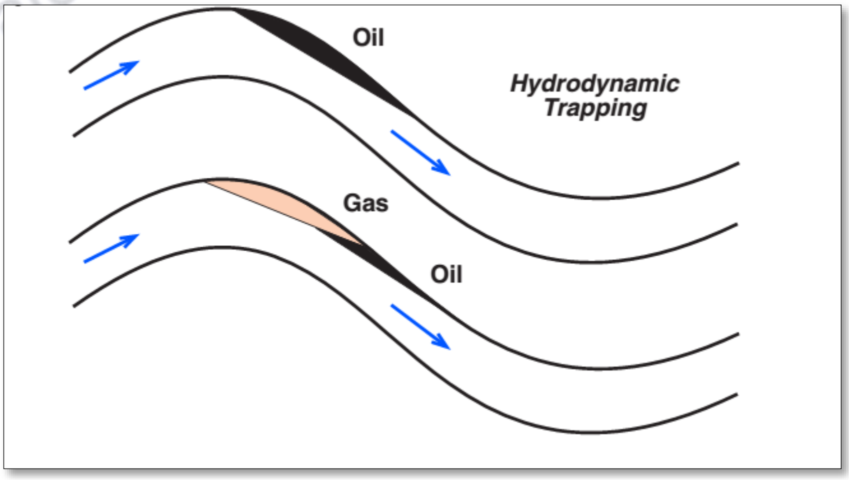

Fig. 8 Hydrodynamic Trap. Oil-water contact deviated from horizontal because of water movement.

5. Summary

Hydrocarbon traps are formed when impermeable/ less permeable strata caps porous and permeable reservoir strata. This typical geological condition allows entry of hydrocarbon within the reservoir but prevents its further migration upward. Displaced water from a reservoir with emplacement of oil/gas forms 'Bottom water' and 'Edge water' in a trap. The lowest structural point up to which a trap can retain hydrocarbon is referred to as spill point for a trap. Broadly, Traps are classified under stratigraphic, structural and combination categories. Both folding and faulting may result in formation of structural trap. Uprise of low-density salt through sedimentary strata and deformations resulted thereby may give way to the formation of varied structural traps. Stratigraphic traps are independent of structural deformation and can be both primary and secondary in nature. Primary stratigraphic traps are result of facies variation in course of deposition whereas secondary stratigraphic traps are those, which are formed in course of diagenetic history. Some other trapping mechanisms include Fracture trap and Hydrodynamic trap.

Frequently Asked Questions-

Short Answer Questions-

Q1. What is a hydrocarbon trap? Discuss how structural deformation help in trap formation?

Q2. With suitable illustrations, discuss different mechanisms of stratigraphic trap formation?

Q3. How salt tectonics help in formation of hydrocarbon trap?

Q4. 'In some cases oil may be accumulated without closure' Justify the statement with reason?

Multiple Choice Questions-

1. Formation of a trap essentially demands

(a) Presence of a reservoir
(b) Presence of a source rock
(c) Presence of a reservoir and cap rock
(d) Only presence of a rock of low permeability

2. Spill point of a Trap refers to

(a) Highest structural point of a Trap
(b) Lowest structural point of a Trap
(c) Lowest structural point of Trap up to which it can retain hydrocarbon
(d) Highest point up to which oil-gas contact can raise

3. Salt Domes often becomes target for search of hydrocarbon trap because

(a) Hydrocarbon preferentially accumulate in salt dome
(b) Halokinetics involved with slow uprise of salt dome generate traps of different variety in adjacent strata
(c) Salt Dome has highest porosity and permeability
(d) Salt domes are commonly found in nature

Suggested Readings:

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