

Petroleum Traps and Seals

I. Overview / Definitions

- a. Trap - geometric juxtaposition of impermeable "seal" strata over permeable reservoir strata
- b. Spill point - lowest elevation at which hydrocarbons can be contained in trap
- c. Closure - highest elevation at which the trap is sealed
- d. Fluid Distribution
 - i. Density-driven buoyancy and vertical fluid segregation: water, oil, gas in ascending order; presence or absence of any fluid a function of diagenetic history, geologic construct, and thermal maturation/migration process
 - ii. OWC: "oil-water contact"
 - iii. "Cap Gas"
 - iv. Formation Waters
 1. Bottom water - water directly beneath oil, below OWC
 2. Edge Water - formation water in subjacent strata
 - v. Tar Mat - dense, asphaltic hydrocarbon accumulations at the OWC

II. Seals and Cap Rocks

- a. Seal - impermeable sediments or rock material that prevents migration of hydrocarbons
 - i. common - shale and crystalline evaporites
 1. high compaction and induration of shales increase brittle rheology, > fracture potential
 - ii. seals may or may not have high porosity, requisite is impermeable
 - iii. Leaky Seals - fracture degradation of cap

III. Classification of Traps

- a. Structural Traps
 - i. Fold traps
 1. anticlines (compressional stress)
 2. drape anticlines (compactional folding)
 3. drag folds (fault induced)
 4. roll-over anticlines (compactional folding)
 - ii. Fault traps
 1. Strike-Slip Faults (wrench faults) (transtensional stress)
 2. Thrust Faults / Reverse Faults (compressional stress)
 3. Normal Faults (extensional stress)
 4. Growth Faults (syndepositional faulting)
- b. Diapiric Traps - density-driven flow of rock materials, under pressure
 - i. Salt Diapirs
 - ii. Mud Diapirs
- c. Stratigraphic Traps
 - i. Depositional
 1. marine marine transgression/regression cycles
 - a. stratigraphic pinchout - interfingering
 - b. barrier island bars
 - c. reefs
 2. fluvial-deltaic
 - a. channel sands/sandstones encased in overbank deposits
 - ii. Unconformity
 1. angular / truncation

- 2. On lap
- iii. Diagenetic Traps - low-permeability seal zones created by diagenetic alteration
 - 1. preferential cementation
 - 2. clay alteration
 - 3. dolomitization
- d. Hydrodynamic Traps
 - i. Pressure-induced blockage of fluid flow
- e. Combination Traps - complex associations involving two or more trapping mechanisms

IV. Structural Traps

- a. Fold traps
 - i. Tectonic (compressional)
 - 1. anticlinal folds
 - a. common in convergent tectonic settings e.g. Zagros Mountains
 - b. transtensional folding e.g. San Andreas
 - 2. drag folds (fault induced)
 - a. transtensional folding in strike-slip fault zones e.g. San Andreas
 - b. thrust-fold belts e.g. Wyoming
 - ii. Compaction (extension)
 - 1. drape anticlines (compactional folding)
 - a. upfolds caused by draping and compaction of sediment deposited over high relief basement discontinuity
 - b. upfolds caused by differential compaction during burial
 - 2. roll-over anticlines
- b. Fault traps - fracture zones juxtaposing rocks of varying mechanical properties + avenue of fluid flow in subsurface
 - i. Strike-Slip Faults (wrench faults) (transtensional stress)
 - 1. wrench faulting = transverse faulting = strike-slip faulting
 - 2. rotation / ball-bearing deformation (right-lateral or left lateral)
 - 3. transpression/transtension zones
 - a. e.g. strike slip basins of San Andreas
 - b. complex fault-fold relations
 - c. vertical fault splays = "flower structures"
 - ii. Thrust Faults / Reverse Faults (compressional stress)
 - iii. Normal Faults (extensional stress)
 - iv. Growth Faults (syndepositional faulting)
 - 1. amount of offset or "throw" increases in downward direction along fault plane
 - 2. sedimentary strata thicken across the growth fault zone
 - 3. syndepositional faulting, progressive accumulation of deformation over time
 - a. e.g. Gulf Coast Texas, Niger delta

V. Diapiric Traps - density-driven flow of rock materials, under pressure and buoyancy

- a. Salt Diapirs - "salt intrusives"
 - i. salt density avg. $\sim 2 \text{ g/cm}^3$; less than surrounding sediments after compaction
 - ii. density contrasts + compaction result in buoyant upwelling of salt deposits in solid state

- 1. enhanced by seismic activity as catalyst
 - iii. up-doming and deformation of overlying and surrounding sediments via "salt intrusion"
 - 1. folding-normal faulting above
- b. Mud Diapirs
 - i. common in over-pressured sediments
 - ii. associated with tectonic compression, convergent tectonics

VI. Stratigraphic Traps - trap scenarios caused by depositional variations in lithology due to environment of deposition, base level changes or post-depositional diagenetic alteration over time.

- a. Depositional
 - i. pinchout traps
 - 1. interfingering of sand and muds in marginal marine environments
 - 2. "shoestring" sands
 - 3. basin subsidence results in uptilting of interfingering sands, buoyant fluid trapping maximized in reservoir
 - ii. barrier island traps
 - 1. barrier islands - marine marginal sand accumulations highly sensitive to transgressive/regressive sea level fluctuations
 - 2. juxtaposition of sand reservoir sediments to offshore muds/shales
 - 3. geometry - elongate, migrating sheets, offer high potential for reservoir continuity along depositional strike
 - 4. e.g. San Juan Basin, Colorado
 - iii. reef traps
 - 1. reefs - carbonate build-up that may either be elongate or domal in nature
 - 2. complex porosity-permeability relations depending on diagenetic history and depositional setting
 - 3. influenced by transgressive/regressive processes in association with offshore muds or back reef tidal environments
 - iv. channel traps
 - 1. fluvial channels in non-marine or deltaic environments
 - 2. facies juxtaposition of sand/gravel in channels with muds in overbank floodplain environments
 - 3. complex interbedded relationships result from basin subsidence, channel migration, and base level changes over time
 - 4. 3-D sand geometry
 - a. ribbons (elongate meandering systems)
 - b. sheets (braid plain systems)
- b. Unconformity
 - i. Superunconformity traps - impermeable sediments on top of reservoir materials
 - 1. angular / truncation
 - 2. paraconformities
 - ii. On lap transgressive relations
 - 1. landward migration of beach environments = erosive due to wave zone
 - 2. complex erosion/juxtaposition of offshore muds over near-shore or non-marine sands
- c. Diagenetic Traps - low-permeability seal zones created by diagenetic alteration
 - i. preferential cementation

- ii. clay alteration
- iii. dolomitization
- iv. solution zones

VII. Hydrodynamic Traps

- a. Pressure-induced blockage of fluid flow
- b. upward buoyant migration of hydrocarbon counterbalanced by downward pressure from subsurface groundwater

VIII. Combination Traps - complex associations involving two or more trapping mechanisms