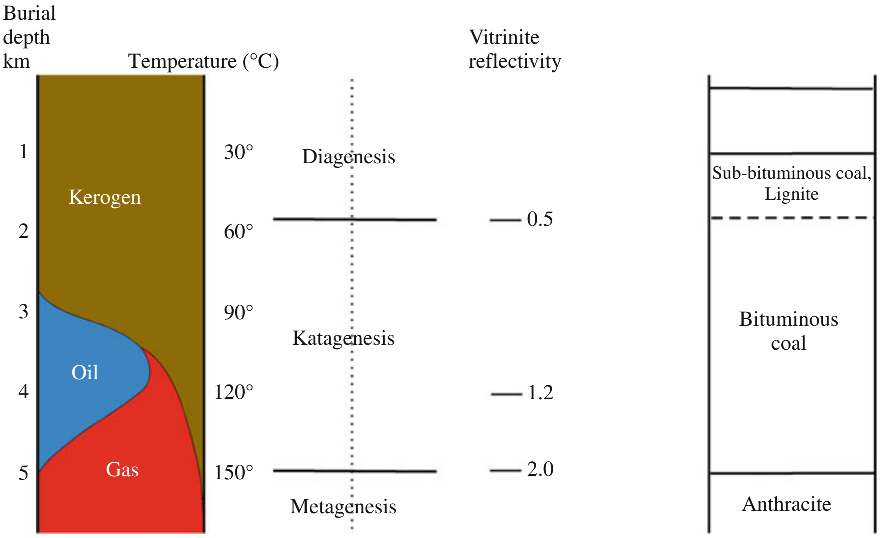

Fig. 1.7 Alteration (maturation) of organic matter and generation of oil and gas as a function of temperature. The maturation is also a function of time and this can be determined by measuring the vitrinite reflectivity. Coals become more shiny and have higher reflectivity with increasing temperature. The depth (temperature) range where oil is generated is called the "oil window". At higher temperatures oil will be altered into gas by cracking

Fig. 1.8 Kimmeridge Clay (Upper Jurassic) unconformably overlain by the lower Chalk (Upper Cretaceous). This is a very good source rock and equivalent shales are the main source rocks for oil and also much of the gas in the North Sea basin and also further North in mid Norway (Haltenbanken) and the Barents Sea. A layer of red Chalk marks the transition from black shale facies to carbonate facies. From South Ferriby, Yorkshire, England

1.8 Hydrocarbon Traps

Traps consist of porous reservoir rocks overlain by tight (low permeability) rocks which do not allow oil or gas to pass. These must form structures closed at the top such that they collect oil and gas, which is lighter than water. We can think of an oil trap as a barrel or bucket upside down (Fig. 1.9) which can then be filled with petroleum which rises through the water until it is full. The point where the petroleum can leak from this structure is called the *spill point*. *The closure* is the maximum oil column that the structure can hold before leaking through the spill point (Fig. 1.10).

The cap rock may not be 100% effective in preventing the upward flow of hydrocarbons, but these will still accumulate if the rate of leakage is less than the rate of supply up to the trap. *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.

Traps can be classified according to the type of structure that produces them. We distinguish between:

(1) *Structural traps* that are formed by structural deformation (folding, doming or faulting) of rocks.

(2) *Stratigraphic traps* which are related to primary features in the sedimentary sequences and do not require structural deformation like faulting or folding. This may be sandstones pinching out in shales due to primary changes in facies (Fig. 1.11).

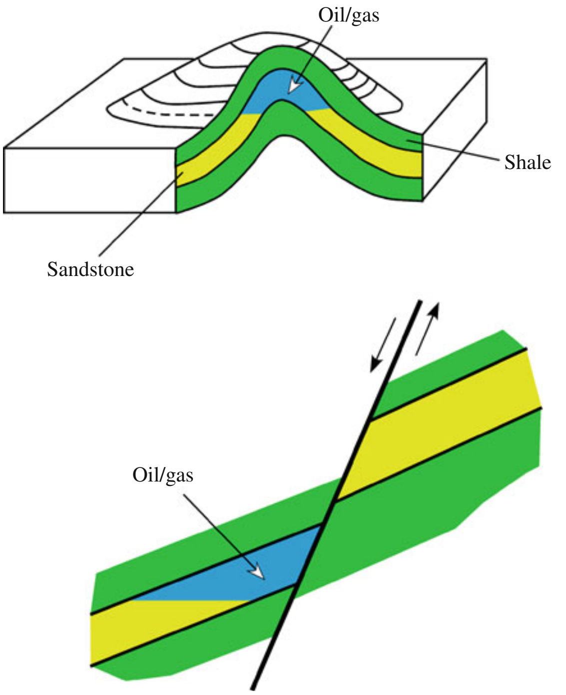

Fig. 1.9 Examples of structural traps. Simple anticlinal trap and a fault-controlled trap

Carbonate reefs tend to form primary structures which function as stratigraphic traps.

There are also combinations between stratigraphic and structural traps (Fig. 1.12).

It is important to establish when structural traps were formed in relation to the migration of the petroleum. Structures formed after the main phase of source rock maturation and associated migration will not be effective traps. In some cases traps formed late can collect gas which normally is generated and migrates later than oil.

Stratigraphic traps, by contrast, have been there all the time, and the timing of the migration is not so important. They may however depend on slight tilting of the strata involved.

1.8.1 *Structural Traps*

(a) Anticlinal Domes

Domes formed by diapirism or other processes may form closures in all directions (four-way closure). A simple anticline is not sufficient to trap oil. Anticlines with an axial culmination are needed to provide four-way closure. This means that the fold axis must be dipping in both directions (Fig. 1.9).

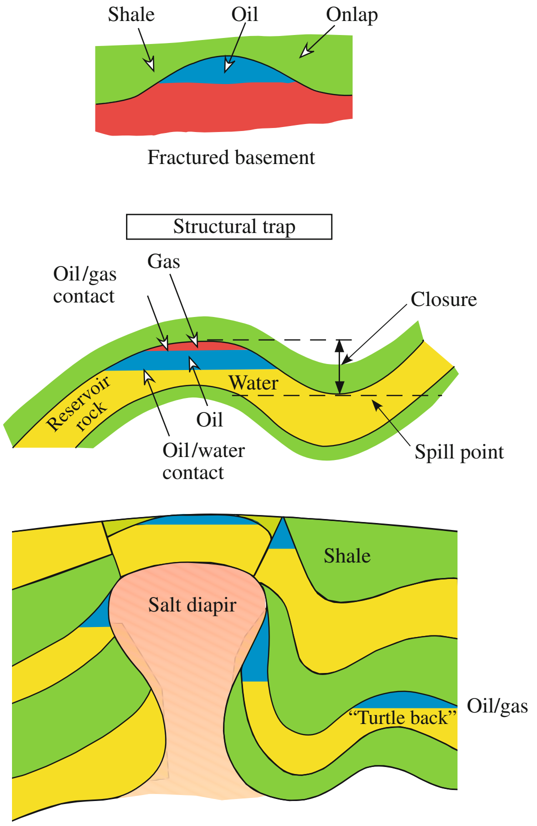

Fig. 1.10 Structural traps related to salt domes and anticlinal folds. A basement high can also be a trap when it is covered by a black shale (source rock). The basement may have some porosity due to fractures or a thin sediment cover

Anticlinal traps can form in association with faulting. This is especially true in connection with growth faults (roll-overs) (see below), but also with thrust zones.

(b) Salt Domes

Salt domes are formed because salt (specific gravity c.1.8–2.0) is lighter than the overlying rock, and the salt therefore "floats" up due to buoyancy. The quantitatively most important salt minerals are halite (NaCl – density 2.16 g/cm^3), gypsum ($CaSO_4 . 2H_2O$ – density

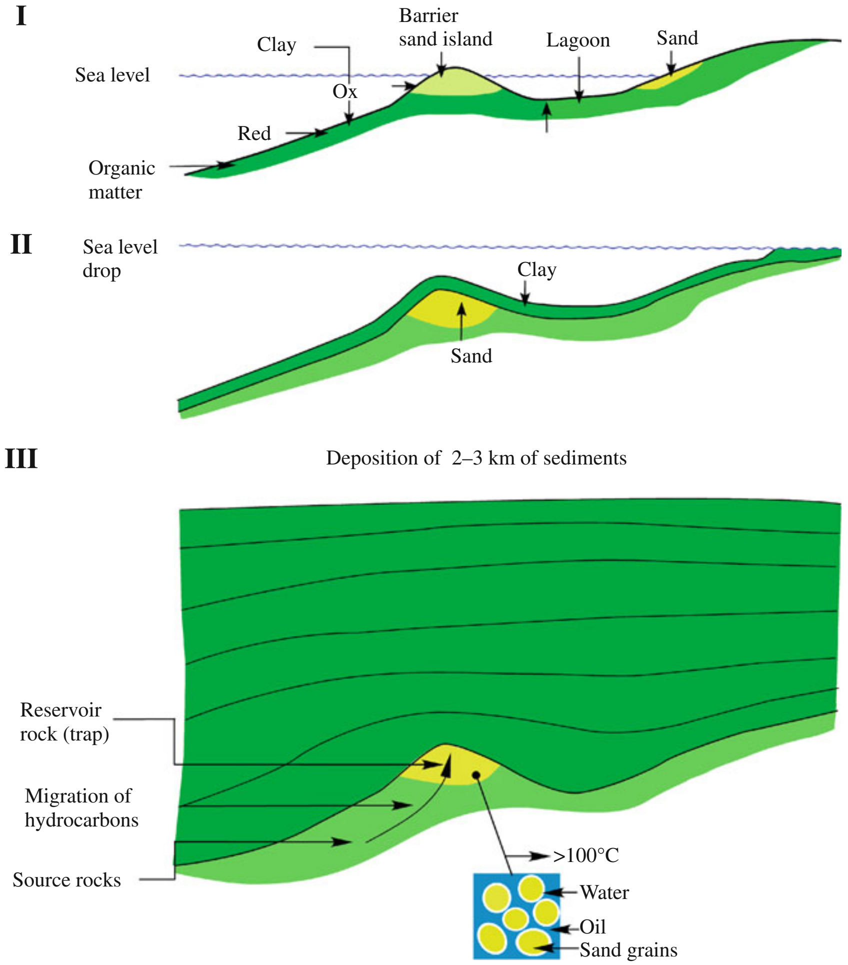

Fig. 1.11 Examples of stratigraphic traps. A barrier island forms a separate accumulation of sand where the associated mudstones (shales) may represent both source rocks and cap rocks

2.32 g/cm^3). Anhydrite ($CaSO_4$ – density 2.96 g/cm^3) is too dense to contribute to the formation of diapers.

In order for the salt to move upwards and form a salt dome, a certain thickness of overburden is required and the salt beds themselves must be at least 100–200 m thick. The upward movement of salt through the overlying sequence, and the resultant deformation of the latter, is called halokinetics or salt tectonics.

The rate of salt movement is extremely slow and a dome may take several million years to form. Movements of the earth's surface may, however, also be recorded in recent history as is the case onshore Denmark. Salt may break right through the overlying rocks and rise to the surface, or form intrusions in younger sediments. If gypsum has been deposited, this will be altered into anhydrite at about 1 km burial depth, with a consequent 40% compaction and the increase in density will remove the buoyancy relative to the surrounding sediments. A comparable expansion occurs when rising anhydrite comes into contact with groundwater and reverts to gypsum.

Traps may be created (1) in the layers above the salt dome, (2) in the top of the salt dome (cap rock), (3) in the beds which are faulted and turned up against the salt structure and (4) through stratigraphic pinching out of beds round the salt dome. Reservoirs may form by solution and brecciation at the top of salt domes.

Salt tectonics is of great importance in many oil-bearing regions where there are thick salt deposits in

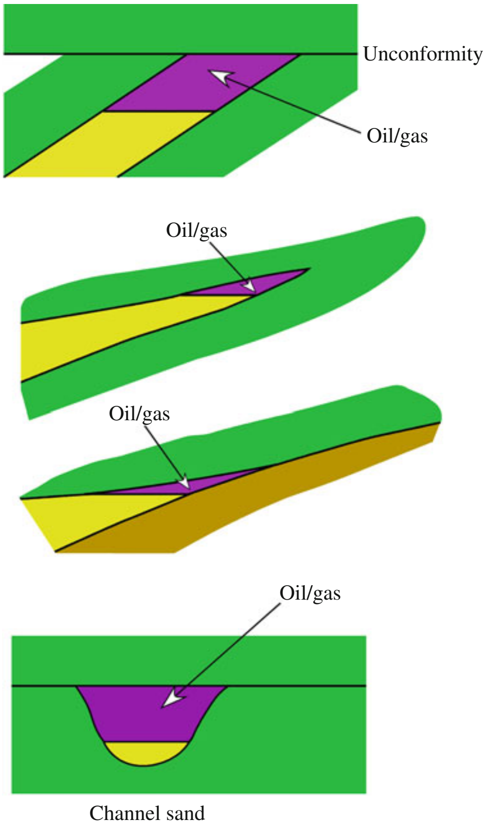

Fig. 1.12 Combination of stratigraphic and structural traps. A reef forms a trap due to the primary relief and also due to later compaction of the mud around the reef

the passive margin sequences of the South Atlantic and the Gulf of Mexico. In the eastern USA we find extensive tracts with Silurian salt, and in Texas and New Mexico we have Permian salt.

Salt layers are the ideal cap rock because of salt's low permeability and ductile properties, which prevent fracturing and leakage.

Salt deposits are particularly common in the Permo-Triassic around the Atlantic. This is because prior to the opening of the Atlantic there were vast areas with fault-controlled basins (rifts) in the middle of a supercontinent (America + Europe, Asia and Africa) with little precipitation. We find similar conditions today around the Red Sea and the Dead Sea. The Permian Zechstein salt in Germany and Denmark continues below the North Sea, and halotectonic movements have formed dome structures in the Chalk, for example in the Ekofisk area.

(c) Growth Anticlines

These are dome-like structures formed when part of a basin subsides more slowly than its surroundings, resulting in least sedimentation on the highest part. The sediment thickness decreases towards the dome centre, which also compacts less than the adjacent thicker sediments and thus contributes to the formation of an anticlinal structure. Growth anticlines form contemporaneously with sediment accumulation, not through later folding.

Growth anticlines can be formed above salt domes, reefs or buried basement highs, through differential compaction.

(d) Fault Traps

In fault traps, the fault plane forms part of the structure trapping the oil and hindering its further upward migration. The fault plane must therefore be sealing for vertical flow in order to function as a barrier and a cap rock for the reservoir rocks. If the reservoir rock is juxtaposed against a sandstone or other permeable rocks the fault must also be impermeable for flow across the fault plane. Most frequently, however, the reservoir rock is faulted against a tight shale or mudrock and the fault is then in most cases sealing (Fig. 1.9). When there is sandstone on both sides of the fault plane, the permeability across it will amongst other things depend on how much clay has been smeared along the junction. At greater depths (>3–4 km) there may be diagenetic changes such as quartz cementation, which can make the fault plane tighter.

There are many different types of faults:

Normal faults – often in connection with graben (rift) structures.
Strike-slip faults.
Reverse faults formed by tectonic stress.
Growth faults.

The displacement along faults can be both vertical (normal faults) and horizontal (strike slip faults). Reverse faults are faults where the hangingwall is moved upwards relative to the footwall below the fault plane. These are typical of areas with high horizontal stresses i.e. due to converging plate movements. Growth faults are driven by gravity-sliding