Economic Geology with reference to Palaeobotany

Economic geology is a scientific discipline concerned with the distribution of mineral deposits, the economic considerations involved in their recovery, and an assessment of the reserves available. Economic geology deals with metal ores, fossil fuels (e.g., petroleum, natural gas, and coal), and other materials of commercial value, such as salt, gypsum, and building stone. It applies the principles and methods of various other fields of the geologic sciences, most notably geophysics, structural geology, and stratigraphy. Its chief objective is to guide the exploration for mineral resources and help determine which deposits are economically worthwhile to mine. Specialists in economic geology often assist in the extraction of the mineral commodities as well.

Economic geology is concerned with earth materials that can be used for economic and/or industrial purposes. These materials include precious and base metals, non-metallic minerals, construction-grade stone, petroleum, natural gas, coal, and water. Economic geology is a sub-discipline of the geosciences; according to Lindgren (1933) it is "the practical application of geology". Today, it may be called the scientific study of the Earth's sources of mineral raw materials and the practical application of the acquired knowledge. The techniques employed by other earth science or geological disciplines (such as geochemistry, mineralogy, geophysics, petrology and structural geology) might all be used to understand, describe, and exploit an ore deposit.

Mineral Resources

Mineral resources are concentrations of minerals significant for current and future societal needs. Ore is classified as mineralization economically and technically feasible for extraction. Not all mineralization meets these criteria for various reasons. The specific categories of mineralization in an economic sense are:

1. Mineral occurrences or prospects of geological interest but not necessarily economic interest
2. Mineral resources include those potentially economically and technically feasible and those that are not
3. Ore reserves, which must be economically and technically feasible to extract

Ore geology

Ore is natural rock or sediment that contains desirable minerals, typically metals that can be extracted from it. Ore is extracted from the earth through mining and refined, often via smelting, to extract the valuable element or elements. Biological footprints can suggest the presence of a particular ore in an area eg. *Citrobacter* species can have concentrations of uranium in their bodies 300 times higher than in the surrounding environment, so finding it in the soil can indicate Uranium deposits. Geologists are involved in the study of ore deposits, which includes the study of ore genesis and the processes within the Earth's crust that form and concentrate ore minerals into economically viable quantities.

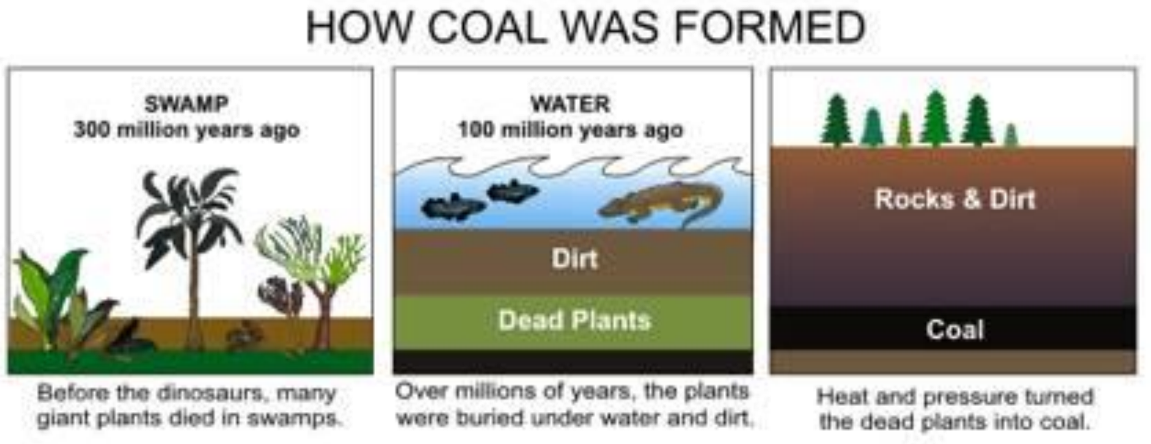
Study of metallic ore deposits involves the use of structural geology, geochemistry, the study of metamorphism and its processes, as well as understanding meta-somatism and other processes related to ore genesis. Ore deposits are delineated by mineral exploration, which uses geochemical prospecting, drilling and resource estimation via geo-statistics to quantify economic ore bodies. The ultimate aim of this process is mining.

Coal and petroleum geology

The study of sedimentology is of prime importance to the delineation of economic reserves of petroleum and coal energy resources.

This is the branch of geology that has the greatest economic importance worldwide as it includes the study of fossil fuels (coal, oil and natural gas): they form by diagenetic processes that alter material made up of the remains of organisms. The places where the original organic material forms can be understood by studying depositional processes, but the formation of coal from plant material and the migration of volatile hydrocarbons as oil and gas require an understanding of the diagenetic history of the sedimentary rocks where they are found.

Coal-forming environments



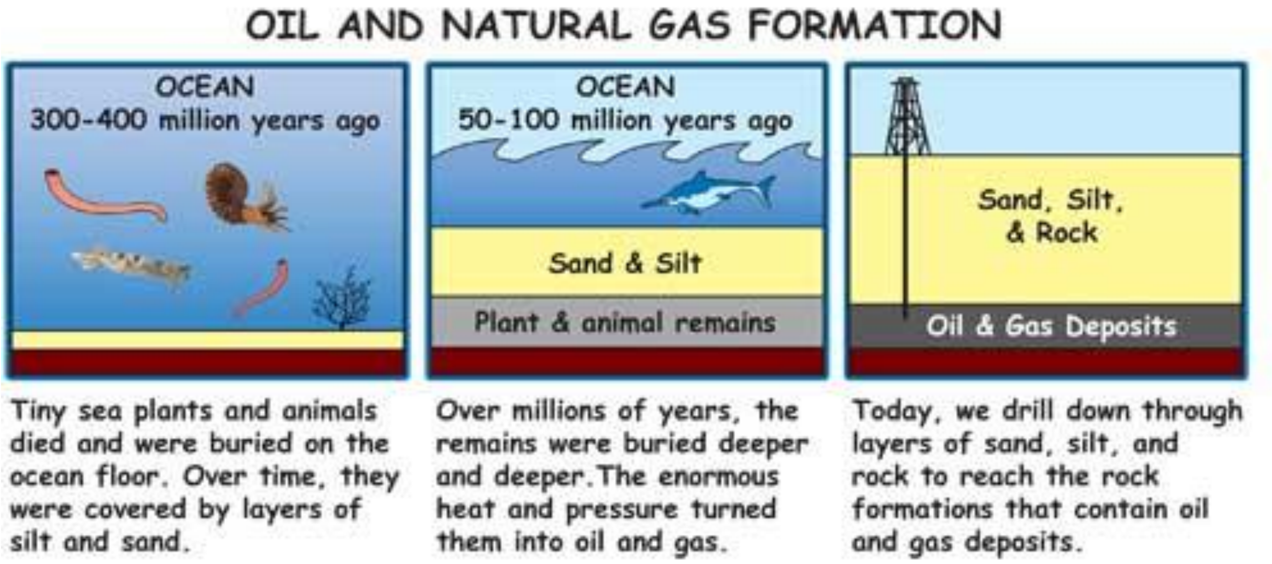
Vegetation on the land surface is usually broken down either by grazing animals or by microbial activity. Preservation of the plant material is only likely if the availability of oxygen is restricted, as this will slow down microbial decomposition and allow the formation of peat, which is material produced by the decay of land vegetation. In areas of standing or slowly flowing water conditions can become anaerobic if the oxygen dissolved in the water is used up as part of the decay process. These waterlogged areas of accumulation of organic material are called mires, and are the principal sites for the formation of thick layers of peat. Mires can be divided into two types: areas where most of the input of water is from rainfall are known as ombotrophic mires or bogs; places where there is a through-flow of groundwater are called rheotrophic mires or swamps. In addition there are also rheotrophic mires that have an input of clastic sediment, and these are referred to as marshes, or salt marshes if the water input is saline.

The significance of these different settings for peat formation is that these environmental factors have a strong influence on the quality and economic potential of a coal that might subsequently be formed. Bogs tend to have little clastic input, so the peat (and hence coal) is almost pure plant material: the peat can be many metres thick, but is usually of limited lateral extent. Swamp environments can be more extensive, but the through-flowing water may bring in clay, silt and sand particles that make the coal impure (it will have a high ash content). Also, if the water is saline, it will contain sulphates and these lead to the formation of sulphides (typically iron pyrite) in the coal and give the deposit a high sulphur content: this is not desirable because it results in sulphur dioxide emissions when the coal is burnt. The ash and sulphur content are the two factors that are considered when assessing the coal grade, as the lower they are, the higher the grade. A wet environment is required to form a mire and therefore a peat, so environments of their formation tend to be concentrated in the wetter climatic belts around the Equator and in temperate, higher latitudes. In warmer climates plant productivity is greater, but the microbial activity that breaks down tissue is also more efficient. Both plant growth and microbial breakdown processes are slower in cooler environments, but nevertheless the fastest rates of peat accumulation (over 2mm yr 1) are from tropical environments and are ten times the rate of peat accumulation in cooler climes. Coals that originate as peat deposits are known as humic coals, but not all coals have this origin. Sapropelic coals are deposits of aquatic algae that accumulate in the bottoms of lakes and although they are less common, they are significant because they can be source rocks for oil: humic coals do not yield oil, but can be the origins of natural gas.

Formation of coal from peat

The first stage of peat formation is the aerobic, biochemical breakdown of plant tissue at the surface that produces a brownish mass of material. This initially formed peat is used as a fuel in places, but has a low calorific value. The calorific value is increased as the peat is buried under hundreds of metres of other sediment and subjected to an increase in temperature and pressure. Temperature is in fact the more important factor, and as this increases with depth (the geothermal gradient) the peat goes through a series of changes. Volatile compounds such as carbon dioxide and methane are expelled, and the water content is also reduced as the peat goes through a series of geochemical changes. As oxygen, hydrogen and nitrogen are lost, the proportion of carbon present increases from 60% to over 90%, and hence the calorific value of the coal increases. Differences in the degree to which the original peat has been coalified are described in terms of coal rank. Transitional between peat and true coal is lignite or brown coal, which is exploited as an energy source in places. Going on through the series, low-rank coal is referred to as sub-bituminous coal, middle rank is bituminous and the highest rank coals are known as anthracite. In the process of these reactions, the original layer of peat is reduced considerably in thickness and a bed of bituminous coal may be only a tenth of the thickness of the original layer of peat.

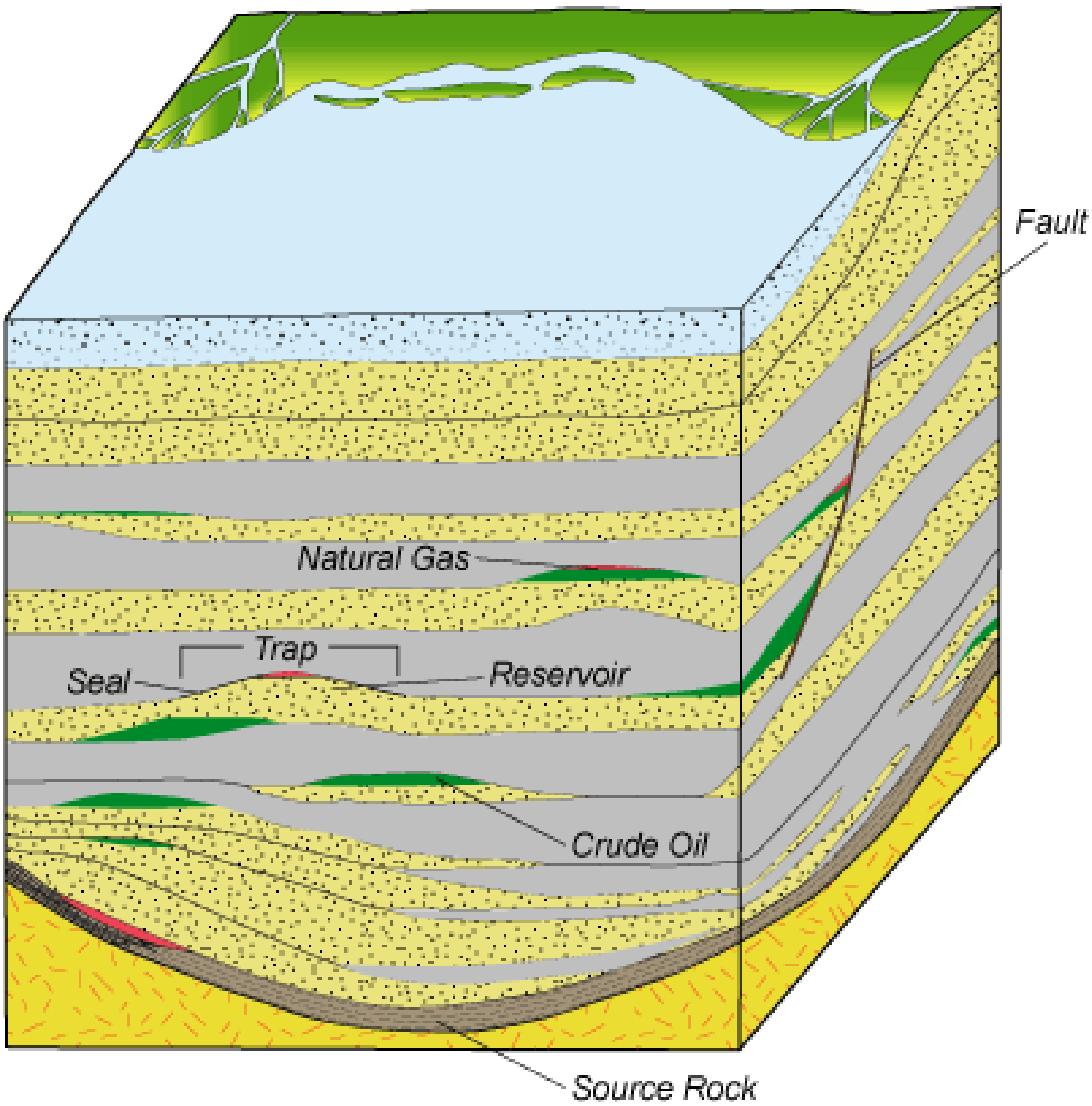
Formation of oil and gas



Naturally occurring oil and gas are principally made up of hydrocarbons, compounds of carbon and hydrogen: petroleum is an alternative collective term for these materials. The hydrocarbon compounds originate from organic matter that has accumulated within sedimentary rocks and are transformed into petroleum by the processes of hydrocarbon maturation. This takes place in a series of stages dependent upon both temperature and time. The first stage is biochemical degradation of proteins and carbohydrates in organic matter by processes such as bacterial oxidation and fermentation. This eogenesis eliminates oxygen from kerogen, the solid part of the organic matter that is insoluble in organic solvents.
Three main types of kerogen are recognised:

- Type I is derived from planktonic algae and amorphous organic material and is the most important in terms of generating oil.
- Type II consists of mixed marine and continental organic material (algae, spores, cuticles) which forms gas and waxy oils.
- Type III originates from terrestrial woody matter and is a source of gas only.

Eogenesis occurs at temperatures of up to 408 C and at up to depths of just over 1000 m. At burial depths of between about 1000 and 4000 m and at temperatures of between 408 C and 1508 C, the phase of diagenesis known as catagenesis further transforms the kerogen. This stage of thermal maturation is also known as the 'oil window' because liquid petroleum forms from Type I kerogen under these conditions. With increasing temperature the proportion of gas generated increases. Generation of oil by organic maturation of kerogen is a process that requires millions of years, during which time the strata containing the organic matter must remain within the oil window of depth and temperature. At higher temperatures and burial depths only methane is produced from all kerogen types, a stage known as metagenesis. Formation of oil, which is made up of relatively long-chain hydrocarbons that are liquid at surface temperatures, from sedimentary organic matter requires a particular set of conditions. First, the organic matter must include the remains of planktonic algae that will form Type I kerogen: this material normally accumulates in anaerobic conditions in anoxic marine environments and in lakes. Second, the organic material must be buried in order that catagenesis can generate liquid hydrocarbons within the correct temperature window: if buried too far too quickly only methane gas will be formed. The third factor is time, because the kerogen source rock has to lie within the oil window for millions of years to generate significant quantities of petroleum. Gas consisting of short-chain hydrocarbons, principally methane, is formed from Type III kerogen and at higher maturation temperatures. Burial of coal also generates natural gas (principally methane) and no oil. The methane generated from coal may become stored in fractures in the coal seam as coal bed methane, which is a hazard in underground coal mining, but can also be exploited economically.



Oil and gas reservoirs

The hydrocarbons generated from kerogen are compounds that have a lower density than the formation water present in most sedimentary successions. They are also immiscible with water and droplets of oil or bubbles of gas tend to move upwards through the pile of sedimentary rocks due to their buoyancy. This hydrocarbon migration proceeds through any permeable rock until the oil or gas reaches an impermeable barrier.

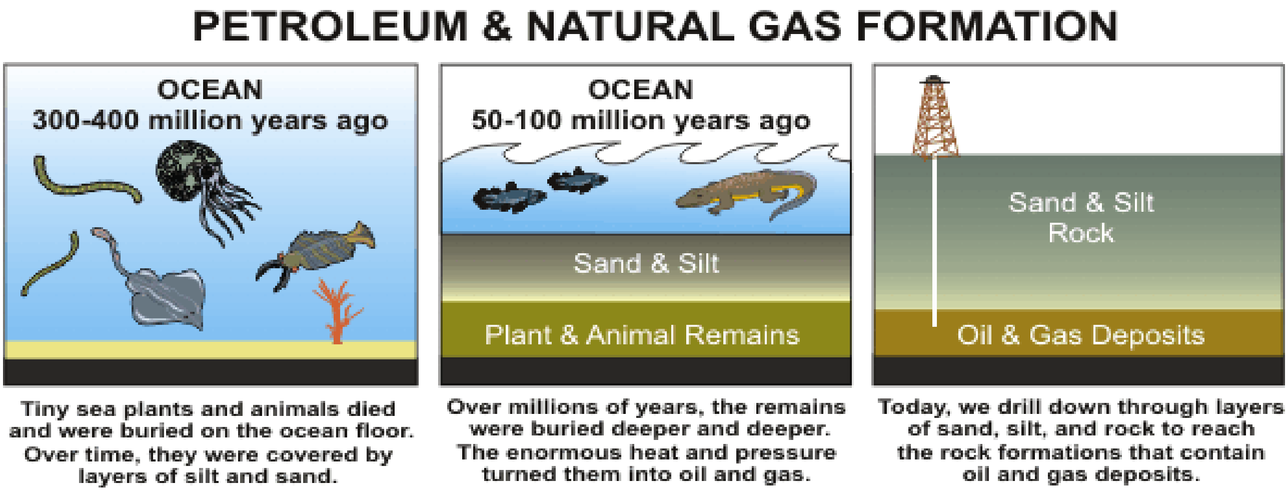
Hydrocarbon traps

Oil and gas become trapped in the subsurface where there is a barrier formed by impermeable rocks, such as well-cemented lithologies, mudrock and evaporite beds. These impermeable lithologies are known as cap rocks. The hydrocarbons will find their way around the cap-rock barrier unless there is some form of hydrocarbon trap that prevents further upward migration. Structural traps are formed by folds, such as anticlines, especially if they are domeshaped in three dimensions, and by faults that seal a porous reservoir rock against an impermeable unit. Other traps are stratigraphic traps, formed beneath unconformities and in places where the reservoir rock pinches out laterally: porous rocks such as limestone reefs that pass laterally into finer grained deposits and where sand bodies are laterally limited and enclosed by mudrocks are examples of stratigraphic traps. The size and shape of the trap determines the volume of oil and/or gas that is contained by the structure, and hence is an important factor in assessing the economics of a potential oil field. In the absence of traps and caps the hydrocarbon reaches the surface and leaks to the atmosphere. Partial release of hydrocarbons from the subsurface as oil seeps and gas seeps can be important indicators of the presence of hydrocarbons.

Reservoir rocks

Almost all oil and gas accumulations occur underground within the pore spaces of beds of sedimentary rocks. In a few rare cases there are accumulations of hydrocarbons in subterranean caverns formed by dissolution of limestone, but the vast majority of reserves are known hosted between grains in sandstones or within the structures of limestones. For a sedimentary rock to be a suitable reservoir unit, it must be both porous and permeable. Porosity is presented as a percentage of the rock volume. Permeability is expressed in darcy units, with a value of 1 darcy representing a very good permeability for a hydrocarbon reservoir. Some of the best reservoir facies are beds of wellsorted sands deposited in sandy deserts and shallow seas, because these contain a high primary porosity. For similar reasons oolitic grainstones can be good reservoirs, and boundstones formed in reefs have a lot of void spaces within the original structure. There are examples of hydrocarbon reservoirs in deposits of many other environments, including rivers, deltas and submarine fans. Limestones may also have important secondary porosity due to dissolution and diagenetic changes. The reservoir quality of a rock is reduced by two main factors. First, the presence of mud reduces both porosity and permeability because clay minerals fill the spaces between grains and block the throats between them. Second, cementation reduces porosity and permeability by crystallising minerals in the pore spaces, sometimes to the extent of reducing the porosity to zero.

Economic oil and gas accumulations



Exploration for economic reserves of hydrocarbons requires knowledge of the depositional history of an area to determine whether suitable source rocks are likely to have formed and if there are any suitable reservoir and cap lithologies in the overlying succession. This analysis of the sedimentology is an essential part of oil and gas exploration. Knowledge of post-depositional events is also important to provide an assessment of the thermal and burial history that controls the generation of hydrocarbons.

Compiled by

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