

= Oil shale geology =

Oil shale geology is a branch of geologic sciences which studies the formation and composition of oil shales ? fine @-@ grained sedimentary rocks containing significant amounts of kerogen , and belonging to the group of sapropel fuels . Oil shale formation takes place in a number of depositional settings and has considerable compositional variation . Oil shales can be classified by their composition (carbonate minerals such as calcite or detrital minerals such as quartz and clays) or by their depositional environment (large lakes , shallow marine , and lagoon / small lake settings) . Much of the organic matter in oil shale is of algal origin , but may also include remains of vascular land plants . Three major type of organic matter (macerals) in oil shale are telalginite , lamalginite , and bituminite . Some oil @-@ shale deposits also contain metals which include vanadium , zinc , copper , uranium .

Most oil shale deposits were formed during Middle Cambrian , Early and Middle Ordovician , Late Devonian , Late Jurassic , and Paleogene times through burial by sedimentary loading on top of the algal swamp deposits , resulting in conversion of the organic matter to kerogen by diagenetic processes . The largest deposits are found in the remains of large lakes such as the deposits of the Green River Formation of Wyoming and Utah , USA . Oil @-@ shale deposits formed in the shallow seas of continental shelves generally are much thinner than large lake basin deposits .

= = Classification and varieties = =

Oil shale belongs to the group of sapropel fuels . It does not have a definite geological definition nor a specific chemical formula , and its seams do not always have discrete boundaries . Oil shales vary considerably in their mineral content , chemical composition , age , type of kerogen , and depositional history and not all oil shales would necessarily be classified as shales in the strict sense . Their common feature is low solubility in low @-@ boiling organic solvents and generation of liquid organic products on thermal decomposition .

There are varying classifications of oil shales depending on their mineral content , type of kerogen , age , depositional history , and organisms from which they are derived . The age of the oil shale deposits ranges from Cambrian to Tertiary age . Lithologies range from shales to marl and carbonate rocks , all of which form a mixture of tightly bound organic and inorganic materials .

Oil shales have been divided into three categories based on mineral composition ? carbonate @-@ rich shale , siliceous shale and cannel shale . Carbonate @-@ rich shales derive their name from the large amount of carbonate minerals such as calcite and dolomite . As many as twenty carbonate minerals have been found in oil shale , the majority of which are considered authigenic or diagenetic . Carbonate @-@ rich oil shales , particularly that of lacustrine @-@ sourced deposits , have usually the organic @-@ rich layers sandwiched between carbonate @-@ rich layers . These deposits are hard formations that are resistant to weathering and they are difficult to process using ex @-@ situ methods . Siliceous oil shales are usually dark brown or black shales . They are not rich in carbonates but rather in siliceous minerals such as quartz , feldspar , clay , chert and opal . Siliceous shales are not as hard and weather @-@ resistant as carbonate @-@ rich shales , and may be better suited for extraction via ex @-@ situ methods . Cannel shales are usually dark brown or black shales , which consist of organic matter that completely encloses other mineral grains . They are suitable for extraction via ex @-@ situ methods .

Another classification according to the type of kerogen , is based on the hydrogen , carbon , and oxygen content of oil shales ' original organic matter . This classification is known as the " van Krevelen diagram " . The most used classification of oil shales was developed between 1987 and 1991 by Adrian C. Hutton of the University of Wollongong , adapting petrographic terms from coal terminology . According to this classification , oil shales are designated as terrestrial , lacustrine (lake @-@ bottom @-@ deposited) , or marine (ocean bottom @-@ deposited) , based on the environment where the initial biomass was deposited . Hutton 's classification scheme has proven useful in estimating the yield and composition of the extracted oil .

Cannel coal (also called candle coal) is a type of terrestrial shale , which is hydrogen @-@ rich

brown to black coal , sometimes with shaly texture , composed of resins , spores , waxes , cutinaceous and corky materials derived from terrestrial vascular plants as well as varied amounts of vitrinite and inertinite . Lacustrine shales consist of Lamosite and Torbanite . Lamosite is a pale @-@ brown and grayish @-@ brown to dark @-@ gray to black oil shale whose chief organic constituent is lamalginite derived from lacustrine planktonic algae . Torbanite , named after Torbane Hill in Scotland , is a black oil shale whose organic matter is telalginite derived from lipid @-@ rich Botryococcus and related algal forms . Marine shales consist of three varieties , namely Kukersite , Tasmanite , and Marinite . Kukersite , named after Kukruse in Estonia , is a light @-@ brown marine oil shale whose principal organic component is telalginite derived from the green alga , Gloeocapsomorpha prisca . Tasmanite , named after Tasmania , is a brown to black oil shale whose organic matter consists of telalginite derived chiefly from unicellular tasmanitid algae of marine origin . Marinite is a gray to dark @-@ gray to black oil shale of marine origin in which the chief organic components are lamalginite and bituminite derived from marine phytoplankton with varied admixtures of bitumen , telalginite , and vitrinite .

= = Composition = =

As a sapropel fuel , oil shale differs from humus fuels in its lower content of organic matter . The organic matter has an atomic ratio of hydrogen to carbon of about 1 @.@ 5 ? approximately the same as that of crude oil and four to five times higher than coals . The organic matter in oil shales forms a complex macromolecular structure which is insoluble in common organic solvents . It is mixed with varied amounts of mineral matter . For commercial grades of oil shale , the ratio of organic matter to mineral matter is about 0 @.@ 75 : 5 to 1 @.@ 5 : 5 .

The organic portion of oil shale consists largely of prebitumen bituminous groundmass , such as remains of algae , spores , pollen , plant cuticles and corky fragments of herbaceous and woody plants , and cellular debris from other lacustrine , marine , and land plants . While terrestrial oil shales contain resins , spores , waxy cuticles , and corky tissues of roots and stems of vascular terrestrial plants , lacustrine oil shales include lipid @-@ rich organic matter derived from algae . Marine oil shales are composed of marine algae , acritarchs , and marine dinoflagellates . Organic matter in oil shale also contains organic sulfur (about 1 @.@ 8 % on average) and a lower proportion of nitrogen .

Three major types of organic matter (macerals) in oil shale are telalginite , lamalginite , and bituminite . Telalginite is defined as structured organic matter composed of large colonial or thick @-@ walled unicellular algae such as Botryococcus and Tasmanites . Lamalginite includes thin @-@ walled colonial or unicellular algae that occur as distinct laminae , but display few or no recognizable biologic structures . Under the microscope , telalginite and lamalginite are easily recognized by their bright shades of yellow under ultraviolet / blue fluorescent light . Bituminite is largely amorphous , lacks recognizable biologic structures , and displays relatively low fluorescence under the microscope . Other organic constituents include vitrinite and inertinite , which are macerals derived from the humic matter of land plants . These macerals are usually found in relatively small amounts in most oil shales .

Mineral matter in oil shale contains fine @-@ grained silicate and carbonate minerals such as calcite , dolomite , siderite , quartz , rutile , orthoclase , albite , anorthite , muscovite , amhipole , marcasite , limonite , gypsum , nahcolite , dawsonite and alum . Some oil @-@ shale deposits also contain metals such as vanadium , zinc , copper , uranium among others .

= = Formation = =

Most oil shale formations took place during mid @-@ Cambrian , early and middle Ordovician , late Devonian , late Jurassic and Paleogene periods . These were formed by the deposition of organic matter in a variety of depositional environments including freshwater to highly saline lakes , epicontinental marine basins and subtidal shelves and were restricted to estuarine areas such as oxbow lakes , peat bogs , limnic and coastal swamps , and muskegs . When plants die in such an

anaerobic aquatic environment , low oxygen levels prevent their complete bacterial decay .

For undecayed organic matter to be preserved and to form oil shale , the environment must remain uniform for prolonged periods of time in order to build up sufficiently thick sequences of algal matter . Eventually , the algal swamp or other restricted environment is disrupted and oil shale accumulation ceases . Burial by sedimentary loading on top of the algal swamp deposits converts the organic matter to kerogen by the following normal diagenetic processes :

Compaction due to sediment loading on the coal , leading to compression of the organic matter .

With ongoing heat and compaction , removal of moisture in the peat and from the intracellular structure of fossilized plants , and removal of molecular water .

Methanogenesis ? similar to treating wood in a pressure cooker ? results in methane being produced , removing hydrogen , some carbon , and some further oxygen .

Dehydration , which removes hydroxyl groups from the cellulose and other plant molecules , resulting in the production of hydrogen @-@ reduced coals or oil shales .

Though similar in their formation process , oil shales differ from coals in several distinct ways . The precursors of the organic matter in oil shale and coal differ in a sense that oil shale is of algal origin , but may also include remains of vascular land plants that more commonly compose much of the organic matter in coal . The origin of some of the organic matter in oil shale is obscure because of the lack of recognizable biologic structures that would help identify the precursor organisms . Such materials may be of bacterial origin or the product of bacterial degradation of algae or other organic matter .

Lower temperature and pressure during the diagenesis process compared to other modes of hydrocarbon generation result in a lower maturation level of oil shale . Continuous burial and further heating and pressure could result in the production of oil and gas from the oil shale source rock . The largest deposits are found in the remains of large lakes such as the deposits of the Green River Formation of Wyoming and Utah , USA . Large lake oil shale basins are typically found in areas of block faulting or crustal warping due to mountain building . Deposits such as the Green River may be as much as 2 @, @ 000 feet (610 m) and yield up to 40 gallons of oil for each ton (166 l / t) of shale .

Oil @-@ shale deposits formed in the shallow seas of continental shelves generally are much thinner than large lake basin deposits . These are typically a few meters thick and are spread over very large areas , extending up to thousands of square kilometers . Of the three lithologic types of oil shales , siliceous oil shales are most commonly found in such environment . These oil shales are not as organically rich as lake @-@ deposited oil shales , and generally do not contain more than 30 gallons per ton of oil shale . Oil shales deposited in lagoonal or small lake environments are rarely extensive and are often associated with coal @-@ bearing rocks . These oil shales can have high yields ? as much as 40 gallons per ton (166 l / t) of oil shale . However , due to their small areal extent , they are considered unlikely candidates for commercial exploitation .

= = = Formations in the United States = = =

The United States has two significant oil @-@ shale deposits which are suited for commercial development due to their size , grade and location . The Eocene Green River Formation covers parts of Colorado , Wyoming and Utah ; the second significant deposit is Devonian oil shales in the eastern United States . In both places , there are sub @-@ basins varying in volume and quality of the reserves . Oil shale in the Green River Formation is found in five sedimentary basins namely , Green River , Uinta , Piceance Creek , Sand Wash and Washakie . The first three have undergone some significant exploration and attempts to commercialize the oil shale reserves since the 1960s . The Green River Formation includes deposits from two large lakes which covered an area of over 65 @, @ 000 square kilometres (25 @, @ 100 sq mi) during early to middle Eocene period . These lakes were separated by the Uinta uplift and the Axial Basin anticline . For significant periods during their 10 Ma life , the lakes became closed systems allowing many changes in size , salinity and sediment deposition . Oil shale is a result of abundant blue @-@ green algae that thrived in the lakes .

The oil shale that underlies almost 750 000 square kilometres (289 000 sq mi) in the eastern United States was formed in a marine depositional environment very different from the Green River Basins . These deposits have also undergone commercialization attempts ; they are also resources for natural gas and have been mined for low grade oil shale . These oil shales were formed during the Late Devonian and Early Mississippian periods . During this time , much of the eastern United States was covered by a large shallow sea . The oil shale is thought to have been the result of slow deposition of planktonic algae. under anoxic conditions . In parts of the basin close to the shoreline , the organic mixture that helped form the oil shale contains organic rich sediment from the rising Appalachian mountains .

== Formations in Brazil ==

Brazil has nine significant locations of oil shale deposits . The size , location and quality of oil shale deposits in the Paraiba Valley and the Irati Formation have attracted the most attention . These two contain an estimated 1 4 billion barrels of in situ shale oil with total resources as much as more than three billion barrels . While the " Irati formation " deposit is the smaller of the two , containing an estimated 600 million barrels in situ compared to 840 million in the Paraiba valley formation , the former is more economically viable .

The " Irati formation " consists of two oil shale beds separated by 12 metres (40 ft) of limestone and shale . The upper layer is thicker (9 metres (30 ft)) but the thinner lower bed (4 metres (10 ft)) is of greater value ; the weight percent of shale oil yield is around 12 % for the lower layer as compared to 7 % for the upper one . The oil shale yield varies laterally , and may be as little as 7 % for the lower layer and 4 % for the upper layer . The formation is a very fine grained and laminated deposit ranging in color from dark gray to brown to black . While 60 - 70 % of the shale consists of clay minerals , the balance is made up of organic matter .

No consensus has been reached on the exact depositional nature of the Irati oil shale . One theory suggests that the organic material in the Irati oil shale originated from algae deposited in a lacustrine environment with salinity varying from that of freshwater to brackish water . Other theory suggests that the organic sediment may have been deposited in a shallow , partially restricted marine environment . Hutton 's classification describes it as a marine source oil shale .

== Formation in Estonia ==

The kukersite oil shale of Ordovician age in Estonia is part of the Baltic oil shale basin and was deposited in shallow marine basins . The deposit is one of the world 's highest grade deposits with more than 40 % organic content and 66 % conversion ratio into shale oil and gas . The oil shale is located in a single calcareous layer 2 - 5 meters in thickness and is buried at depths from 7 to 100 m . The total area of the basin is about 3 000 km² . Oil yield from Kukersite is 30 to 47 % . Most of the organic matter is derived from the fossil green alga , *Gloeocapsomorpha prisca* , which has affinities to the modern cyanobacterium , *Entophysalis major* , an extant species that forms algal mats in inter tidal to very shallow subtidal waters . Matrix minerals include low magnesium calcite , dolomite , and siliciclastic minerals . It is not enriched in heavy metals .

== Reserves ==

As source rocks for most conventional oil reservoirs , oil shale deposits are found in all world oil provinces , although most of them are too deep to be exploited economically . As with all oil and gas resources , analysts distinguish between oil shale resources and oil shale reserves . " Resources " refers to all oil shale deposits , while " reserves " , represents those deposits from which producers can extract oil shale economically using existing technology . Since extraction technologies develop continuously , planners can only estimate the amount of recoverable kerogen . Although resources of oil shale occur in many countries , only 33 countries possess known deposits of possible

economic value . Well @-@ explored deposits , potentially classifiable as reserves , include the Green River deposits in the western United States , the Tertiary deposits in Queensland , Australia , deposits in Sweden and Estonia , the El @-@ Lajjun deposit in Jordan , and deposits in France , Germany , Brazil , China , southern Mongolia and Russia . These deposits have given rise to expectations of yielding at least 40 liters of shale oil per tonne of oil shale , using the Fischer Assay .

A 2008 estimate set the total world resources of oil shale at 689 gigatons ? equivalent to yield of 4 @. @ 8 trillion barrels (760 billion cubic metres) of shale oil , with the largest reserves in the United States , which is thought to have 3 @. @ 7 trillion barrels (590 billion cubic metres) , though only a part of it is recoverable . According to the 2010 World Energy Outlook by the International Energy Agency , the world oil shale resources may be equivalent of more than 5 trillion barrels (790 billion cubic metres) of oil in place of which more than 1 trillion barrels (160 billion cubic metres) may be technically recoverable . For comparison , the world 's proven conventional oil reserves were estimated at 1 @. @ 317 trillion barrels ($209 @. @ 4 \times 10^9 \text{ m}^3$) , as of 1 January 2007 . The largest deposits in the world occur in the United States in the Green River Formation , which covers portions of Colorado , Utah , and Wyoming ; about 70 % of this resource lies on land owned or managed by the United States federal government . Deposits in the United States constitute 62 % of world resources ; together , the United States , Russia and Brazil account for 86 % of the world 's resources in terms of shale @-@ oil content . These figures remain tentative , with exploration or analysis of several deposits still outstanding . Professor Alan R. Carroll of University of Wisconsin ? Madison regards the Upper Permian lacustrine oil @-@ shale deposits of northwest China , absent from previous global oil shale assessments , as comparable in size to the Green River Formation .