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NECESSARY CONDITIONS *FOR PETROLEUM GENERATIONS*

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Abstract

The presence of organic-rich sediments in sedimentary basins forms the basis for petroleum generation. The remains of decayed plants and animals within the soil layers are termed organic matter, in which phytoplankton; zooplankton, higher plants, and bacteria are the most important contributors. The production, accumulation, and preservation of ungraded organic matter are pre-requisite for the existence of petroleum source rocks.

Petroleum source rock is fine grain sediments that, in its natural setting, has generated and released enough hydrocarbons to form a commercial accumulation of oil, gas, or both. Source rocks are usually shales and limestone. The organic matter in the source rocks is disseminated and insoluble in normal petroleum solvents such as carbon bisulfide. This is known as "kerogen". Chemical, kerogen consists of carbon, hydrogen, and oxygen, with minor amounts of nitrogen and sulphur. The three basic kerogen types are type I-algal, type II liptinitic, and type III-humic.

Temperature plays an important role in kerogen maturation, in which the rate of increase in temperature in the earth with depth is termed as "geothermal gradient"; at this gradient, petroleum is released from kerogen during catagenesis, with the first oil and later gas being released.

INTRODUCTION

Production, accumulation, and preservation of ungraded organic matter are pre-requisite for the existence of petroleum source rocks. A source rock is fine-grained sediment that, in its natural setting, has generated and released enough hydrocarbons to form a commercial accumulation of oil, gas, or both.

The emergence of photosynthesis as a worldwide phenomenon is a noteworthy historical event with respect to the formation of potential source rocks. Photosynthesis is represented by the following equation.

$$6CO_2 + 12H_2O = C_6H_{12}O_6 + 6H_2O + 6O_2$$

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Photosynthesis is the basis of mass production of organic matter. Approximately two billion years ago, in the Precambrian era, photosynthesis emerged as a worldwide phenomenon. The foundation for its food pyramid and the evolution of higher forms of life was laid here. The enrichment of molecular oxygen in the atmosphere of the earth is a direct consequence of photosynthesis and the mass production of organic matter.

During the earth history and on a global scale, the average preservation rate of primary organic production expressed as organic carbon is estimated to be less than 0.1% (minimum). The upper limit of the preservation rate of organic carbon found in certain deficient environments favourable for the deposition of source rock-type sediments is approximately 4% (maximum).

METHODOLOGY

The research work involves the collection and collation, of various literature from different authors. These literature were studied, and all the information relevant to the research work was extracted and reviewed and incorporated into the write-up.

PRODUCTIVITY AND PRESERVATION OF ORGANIC MATTER

The amount of organic matter buried in sediments is related to the ratio of organic productivity and destruction. Generally, organic matter is destroyed on the Earth's surface, and only minor amounts are preserved. The deposition of organic-rich sediment is favoured at a high rate of organic matter production and high preservation potential. These two factors are now discussed. Determining production and preservation for the present day is relatively easy, but extrapolating back in time is harder, this production-destruction ratio of organic matter is largely related to the growth of land plants. Therefore, marine and continental environments should be considered separately.

Starting in the Precambrian period until the Devonian, the sole primary producer of organic matter was marine phytoplankton. Since the Devonian Period, an increasing amount of primary production is also contributed by higher terrestrial plants. At present, marine phytoplankton and higher terrestrial plants are estimated to produce approximately equal amounts of organic carbon. Quantitatively, the four most important contributors to organic matter in sediments are *PHYTOPLANKTONS, ZOOPLANKTONS, HIGHER PLANTS and BACTERIAS*. Higher organized animals, such as fish, contribute on average very little to organic matter in sediments, so they can be neglected in practice.

According to the laws of the food chain, zooplanktons show a tendency to be high in areas with high phytoplankton productivity, and heterotrophic bacteria are abundant where organic matter is available as a source of food.

The biological productivity of marine environments is mainly control by light, temperature, and mineral nutrients, such as phosphate and nitrates. The larger part of biological production is concentrated in the upper 60–80 m water column. The biological productivity of coastal waters is, on average, approximately twice as high as that of the open ocean. The most productive areas are areas with water up-welling, such as in certain parts of the western continental shelf.

In addition, organisms are composed of the same chemical constituents of lipids, proteins, carbohydrates, and lignin in higher plants. However, there are very characteristic differences with respect to the relative abundances of these compounds and their detailed chemical structures. With respect to the formation of petroleum, the lipids are most important. Lipids encompass fat substances, waxes, and lipid-like components, such as oil-soluble pigments, terpenoids, steroids, and many complex fats. A prominent building block of many of these components is the (isoprene) unit, which contains 54 C-atoms in sequence and one methyl side chain.

A balanced optimum condition between the energy level in a body of water and the rate of sedimentation is needed to preserve and concentrate organic matter in sediments. The clay-sized mineral fraction is easily coated with organic matter. This fine-grained fraction and suspended particulate organic matter are of low density and energy level, resulting in quieter water. The deposition of fine-grained sediment limits the access to dissolved molecular oxygen and therefore increases the chances for preservation of organic matter.

However, if the rate of sedimentation is too high, the organic matter is diluted, and a low amount of organic matter is deposited.

Favourable conditions for the deposition of organic matter-rich sediments are found on the continental shelves in areas of quiet waters, such as lagoons, estuaries and deep basins with restricted circulation. Another environment favourable for the accumulation of organic matter is continental slopes. Figure 1 in the Appendix presents the production of organic matter in the present-day world oceans.

EVOLUTION OF ORGANIC MATTER (OGW)

The three main stages of the evolution of organic matter in sediments are stated as follows:

(a) **Diagenesis:** This phase occurs in the shallow subsurface at near-normal temperatures and pressures. This includes both biogenic decay aided by bacteria and abiogenic reactions.

Methane, carbon dioxide, and water are supply in organic matter, leaving a complex hydrocarbon termed kerogen. The net result of the diagenesis of organic matter is the reduction of its oxygen content, leaving the hydrogen; carbon ratio largely unaltered.

(b) **Catagenesis:** This phase occurs in the deeper subsurface as burial continues and temperature and pressure increase. Petroleum is released from kerogen during catagenesis, with the first oil and later gas, the hydrogen: carbon ratio declining, with no significant change in the oxygen: carbon ratio.

(c) **Metagenesis:** This third phase occurs at high temperatures and pressures during metamorphism. The last hydrocarbon generally only methane, are expelled. The hydrogen: carbon ratio decreases until only carbon s left in form of graphite. The porosity and permeability are not negligible.

SOURCE ROCKS

Petroleum source rocks are unique by definition; they either have or have the capability to generate sufficient quantities of hydrocarbon at the appropriate levels of thermal maturity to saturate the pure network of the rock unit and permit oil expulsion, allowing the development of hydrocarbon accumulation.

A source rock can also be defined as a sedimentary rock in which organic material under pressure, head, and time is transformed into liquid or gaseous hydrocarbons. Source rocks are usually shales and limestones.

The work of Ronov (1958) has becomes evident that the ability of a rock to generate and expel hydrocarbons is dependent on the quantity of organic matter present.

While studying the basins of the Siberian platform, Ronov noted that the rocks within petroliferous provinces displayed higher average levels of organic matter enrichment than those of non-petroliferous provinces. He concluded that it was these differences in organic matter that the enrichment determined whether or not petroleum would be present. He further noted that after examining non-reservoir rocks within these basins, it appeared that the threshold of organic enrichment for a petroleum source rock was approximately 1.4 wt% of organic carbon, the average value for shales within the petroliferous provinces. This level of organic enrichment is nearly three times the average 0.5 wt% organic carbon level for shales within non-petroliferous provinces.

It is interesting to note that a lower value of Ronov has commonly been presented as the threshold for effective shale petroleum source rocks (J.M. Hunt, 1979; Tissot & Welte 1984).

Subsequent studies, however, have shown that potential and effective petroleum source rocks contain a minimum of 1.0wt% organic carbon, independent of lithology (Bissada, 1982), thus supporting the original conclusions of Ronov. It was further observed that most source rock units display significant variability with respect to organic enrichment, with some stratigraphic internals within these source rock sequences displaying organic enrichment levels below this obvious threshold value.

In addition, different types of matter can yield different quantities and types of hydrocarbons (Tissot et al, 1974). It became clear that the organic enrichment level was not, by itself, an adequate means of establishing the presence of a petroleum source. A more effective means of establishing hydrocarbon source rock potential is by directly measuring the ability of a rock to generate hydrocarbons through a simulation of the maturation process. This approach was established through the use of various pyrolysis techniques and was standardized through the use of the rock Eval instrument (Espitalie et al 1977). This pyrolysis approach accounted not only for differences in organic enrichment, but also for variations in the mineral matrix effects, including catalysis and retention (Katz 1983).

In addition, hydrocarbon source rocks are characterize by the type of organic matter they contain.

(Tissot et al, 1974) originally identified three primary types of organic matter. Type I organic matter is hydrogen enriched and oil-prone. Hydrocarbon yields from the kerogen can reach as high as 80% by weight. The type I kerogen macromolecule includes a substantial number of long-chained functional groups. Type II organic matter is moderately hydrogen enriched, with primary products being oil and gas. This kerogen mat yields up to 60% hydrocarbons by weight. The type II kerogen macromolecule tends to include more polyaromatic nuclei than type I kerogens and includes a higher proportion of heteroatomic compounds, including ketones and carboxylic acids. Type III organic matter is defined as hydrogen-depleted and gas-prone. These kerogen macromolecules are largely composed of aromatic compounds with short-chained functional groups attached to many of these functional groups oxygenated including phenols, quinines, and acids.

KEROGEN TYPES AND STRUCTURES

Kerogen by definition is a 3-dimensional macromolecule consisting 2-4 approximately parallel aromatic sheets made up of approximately 10 aromatic rings with heteroatoms and alkyl chains. Kerogen can also be applied to disseminated organic matter. In sediments insoluble in normal petroleum solvents such as carbon bisulfide. This insolubility distinguishes it from bitumen.

Kerogen consists of carbon, hydrogen, and oxygen, with minor amounts of nitrogen and sulphur.

In immature kerogens, these layers are well spaced and non-parallel, but as the kerogens mature, these sheets get closer together and become more parallel. Simultaneously, kerogens lose many of their hydrogen-rich components, especially the alkly side chains, and constantly become deficient in hydrogen.

Kerogens vary in their composition and thus in their breakdown products, depending on their origins, different chemical structures and different maturation products. One of the methods of differentiating these kerogens is by chemical analysis and subsequently plotting of the atomic H/C and O/C on a Van Krevelen diagram.

The three basic types of kerogen are generally recognizable, the differences are chemical and are related to the nature of the original organic matter, because these three kerogen types generate different hydrocarbons. Their distinction and recognition are important (Tissot et al, 1977). The structures for the three types of kerogen and their oxygen to carbon ratios see **figure1 in the appendix.**

TYPE I KEROGEN: has high H/C ratio and low O/C ratios, is rich in aliphatic material, and has few polyaromatic rings. It has great convertibility to mobile hydrocarbons “often up to 80%” and will produce light, high-quality oil. This type is produced by the accumulation of algal material or by the correct type of microbiological attack on the original organic matter, which already had a high lipid content and high hydrogen to carbon ratio.

TYPE II KEROGEN: (Liptinitic) is the type most commonly found in petroleum source rocks and comprises local marine organic matter deposited in a reducing environment. Organic matter with high lipid content and high H/C ratio. It has relatively high H/C and low O/C ratios, and the resulting kerogen is not so aliphatic rich but contains more aromatic rings and heteroatoms especially sulphur as compared with type I kerogen. It can have convertibility to petroleum by up to 60%.

TYPE III KEROGEN: (Vitrinitic) or Humic has low H/C and high O/C ratios. It is derived from distant terrestrial material containing higher plant and coaly mater, which are often subjected to severe oxidation on land. Organic matter has low lipid content and is rich in hydrogen-deficient structural elements of land plants. Identifiable plant remains are often observed in this type of kerogen. Its convertibility is approximately 40% maximum and while the majority of this would be gas, the oil it produces would be very rich in geochemical fossil wax. However, any significant biological attack on the input organic matter i.e. too long in the oxic zone, will destroy any oil potential it might have had.

MATURATION OF KEROGEN

During the catagenesis phase, the kerogen matures and produces oil and gas. Establishing the level of maturation of kerogen in the source rocks of an area subject to petroleum exploration is vital when kerogen is immature, no petroleum has been generated, and with increasing maturity, first oil and then gas are expelled; when the kerogen is over mature, neither oil not gas remains.

The maturation of kerogen can be measured using several techniques. The maturation rate may be dependent on temperature, time, and possibly pressure.

Some workers have documented an empirical correlation between temperature and petroleum generation (Pusey, 1973a, b, Philippi, 1975, Hunt, 1996). Significant oil generation occurs between 60 and 120^0C and significant gas generation between 120 and 225^0C. Above 225^0C the kerogen is inert and has expelled all hydrocarbons; only carbon remains graphite. The temperatures just mentioned are only the approximate boundaries of oil and gas windows.

GEOTHERMAL GRADIENT

Geothermal gradient is defined as the rate of increase of temperature in the earth with depth. The gradient differs from place to place depending on the heat flow in the region and the thermal conductivity of the rock. The average geothermal gradient in earths approximately crust 25^0C/KM of depth.

The role of temperature in the maturation of source sediments and generation and migration of hydrocarbons has been emphasized.

The geothermal gradient, or rate of increase of temperature with depth, has been measured in most producing areas; the flow of heat through the earth’s upper crust has also been measured in well explored sedimentary basins as well as in otherwise unexplored areas. The world mean head flow rate is taken to be 1.47 HFU (heat flow units) 1 HFU being 10^{-6} cal cm^{-2} S^{-1} (or in SI units approximately 42m Wm^{-2}). If individual volcano and hot spring centers are ignored, the flow is highest over the oceanic ridge and lowest over the oceanic trenches.

Hundreds of measurements collect by Russian Geophysicist F.A. Makarenko indicated that heat flow in petroliferous regions differ by 10-20 percent from the world mean or background value. Because petroleum geologists measure temperatures directly in drill holes, geothermal physics is a much more convenient express for them than heat flow. Geothermal gradients in sedimentary basins generally range from 15-50 $^0CKm^{-1}$ the average value may be taken to be 30^0CKm^{-1} like the access of surface waters. The geothermal gradient of a basin depends largely on the basin's structural style.

Not surprisingly, the highest of all geothermal gradients and heat flow values is sedimentary basins, up to double or even triple the mean, in tertiary back-arc basins associated with the tethyan and circum-pacific volcanic belts.

The central Sumatran basins have a very high gradient of $65\text{-}90^0C\ Km^{-1}$ (heat flow more than 2.0 HFU) in connection with their shallow oil generative window.

The basins of north western and eastern Borneo, geographically next door to Sumatra basins and of the same age, are not back-arc basins, but their geothermal gradients range from 32 to about $50^0C\ Km^{-1}$.

PALEOTHERMOMETERS

Because of the important relationship between temperature and petroleum generation, measuring the maturity of the kerogen is important. It is not enough to be able to answer these questions. Are there organic rich source rocks in the basin? Are they present in large enough volume? Are they oil- or gas-prone? It is also necessary to know whether or not the source rocks have matured sufficiently to generate petroleum or whether they are super mature and barren.

To measure only the bottom whole temperature from the boreholes does not answer the question of kerogen maturity. This measurement only indicates the present-day temperature, which may be considerably lower than that of the past. It is necessary to have a paleothermometer that can measure the maximum temperature to which the source rock can be exposed. Several such tools are available, each varying in efficiency, and each requires expensive laboratory equipment and a considerable degree of technical expertise for the correlation between hydrogen generation, temperature, and some paleothermometers. In general, two major groups of techniques are used for measuring the maximum paleotemperature to which a rock has been heated (Copper, 1977).

CONCLUSIONS

Petroleum-source rocks are mostly from shale and limestone provinces. The variation in the organic matter (kerogen) enrichment determined whether the source rock is higher for petroleum or gas generation with respect to the kerogen type. Source rocks within petroliferous province will have higher average organic enrichment levels than those in the non-proliferous region with respect to kerogen. The three stages of the oil-generating window (OGW) within the sedimentary succession with different depths and geothermal gradients facilitate the breakdown of higher organic molecules at (diagenesis) to smaller molecules at (metagenesis).

The geothermal gradient differs from place to place depending on the heat flow in the region and the thermal conductivity of the rocks. The average geothermal gradient in the earth's crust is approximately $25^0C\ Km^{-1}$ of depth. Paleothermometers are used to measure kerogen maturity because of the important relationship between temperature and petroleum generation.

RECOMMENDATIONS

* It has become apparent that research work to be partially or fully funded is no longer feasible. Therefore, there is a need for that to be Checkmate.

* In our libraries today, most of those books for research are outdated, so we need the latest books, publications, and journals.

* In most organizations, people are fun of extorting money from individuals if they come by looking for research materials; the government has to do something about it.

* Sometimes in life there is need for a sacrifice; people should develop a way of presenting papers even with a little funding, and use the little you have for our educational standard is fallen.

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APPENDIX

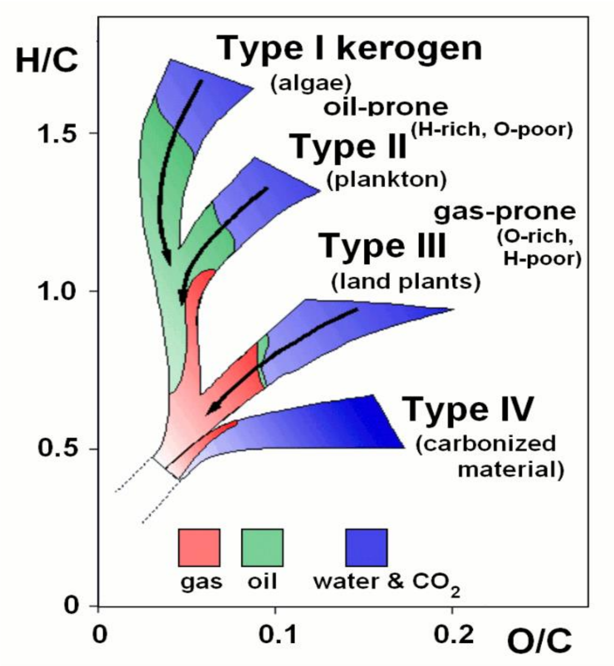

Fig. 1 Kerogene Types