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Millions of years are not necessary for petroleum formation

RICHARD BRUCE

ABSTRACT

There is no need for millions of years to form petroleum. Temperature rather than time is key to the transformation of organic matter to hydrocarbons. There is an exponential increase in hydrocarbon generation with increase in temperature. Realistic conditions in natural settings and in laboratories reinforce rapid petroleum formation. These conditions include the presence of water, high temperatures, convective and advective heat transfer, and the presence of permeable sediments.

INTRODUCTION

Petroleum is a fossil fuel, meaning that it has formed by the decomposition of organic matter. It is a complex mixture of hydrocarbons in liquid, gaseous or solid form. The term is often used for the liquid form, commonly called crude oil, but technically petroleum also includes natural gas and the viscous or solid form known as bitumen.

It is commonly assumed that it takes millions of years for petroleum to form in a sedimentary basin. However, real-time investigations in natural settings and laboratories show that petroleum can be generated in a period of even a few years or less at appropriately high temperatures and in the presence of water.

THE KEY: TEMPERATURE RATHER THAN TIME

The transformation of organic matter to hydrocarbons is influenced more by temperature than by time. For example, the Moscow brown coals (of Carboniferous age and supposedly hundreds of millions of years old) are buried to depths of less than 200 metres and are relatively cool. They have never reached a more advanced stage of coalification. This is in contrast with the Carboniferous black coals of Pennsylvania and England which were buried deeper and reached higher temperatures. The influence of temperature is exponential (Tissot and Welte 1984), and this is confirmed by natural seafloor hydrothermal systems and laboratory studies.

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MODERN SEAFLOOR HYDROTHERMAL SYSTEMS

High-temperature natural seafloor hydrothermal systems, such as in the Gulf of California and the Red Sea (Figure 1), are locations where there is efficient instantaneous and simultaneous petroleum generation, expulsion and migration (Simoneit 1990). Hot vent water encountering organic-rich seafloor mud converts the organic matter to hydrothermal petroleum which usually migrates rapidly upward into seawater where it is biodegraded.

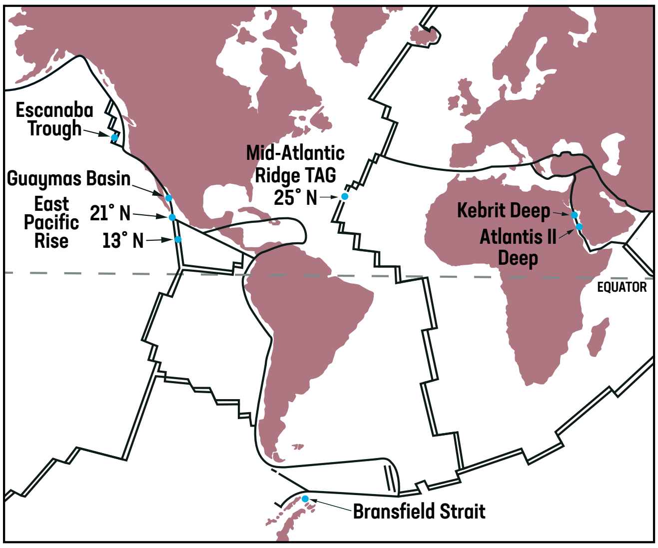

Figure 1. Location map of some modern seafloor hydrothermal systems discussed by Simoneit (1990).

LABORATORY STUDIES

Laboratory hydrous pyrolysis is a method for simulating natural petroleum formation. It involves pyrolysis (i.e. heating in the absence of oxygen) of petroleum source rocks or their isolated organic matter in the presence of liquid water. In contrast, anhydrous pyrolysis means heating without water. Water is present in sedimentary basins and so hydrous pyrolysis is more realistic to natural sedimentary systems. Water can reduce the time for petroleum generation by orders of magnitude.

With higher temperatures the peak of bitumen generation moves towards decreasing time of heating (Figure 2). After several days with temperatures in the vicinity of 300 °C significant bitumen can be generated, and this may occur near igneous intrusions (Reeckmann and

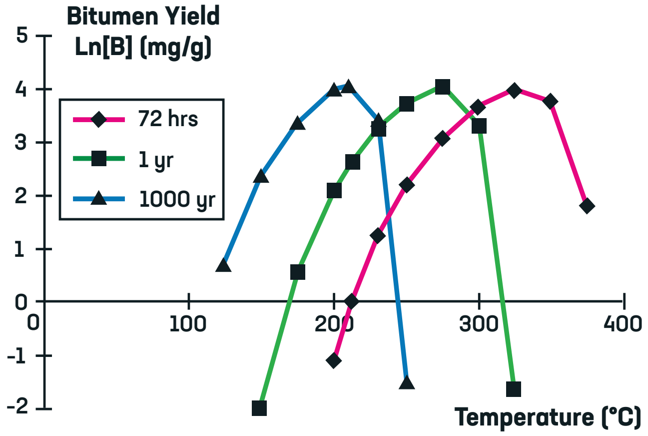

Figure 2. Bitumen yield versus temperature for various times of heating based on the kinetic model of Nielsen and Barth (1991).

Mebberson 1984). Within realisable temperatures in sedimentary basins, generation of significant bitumen can occur after 1000 years. In other words, hydrous pyrolysis indicates that significant volumes of petroleum may be generated at temperatures in the vicinity of 200 °C, if maintained for the order of 1000 years.

Laboratory hydrous pyrolysis provides evidence for *simultaneous* oil generation and expulsion from source rocks. Kerogen is the solid, insoluble organic matter found in sedimentary rocks and its typical constituents are algae and woody plant material. Upon heating, kerogen decomposes to an expanding tarry bitumen. The expansion causes the rock bedding plane to fracture, and this allows liquid oil to be expelled (Lewan 1991). Laboratory studies show organic matter can be extensively converted to hydrocarbons at temperatures less than 300 °C and with heating times of a few years or less, from oil shale or brown coal (Saxby et al. 1986). Modelling by Middleton indicates that after 1000 years, peak bitumen generation can occur within temperatures realisable in sedimentary basins (about 200 °C or about three kilometres depth) (Bruce et al. 1996).

A HYDRODYNAMIC CONCEPTUAL MODEL

A conceptual model (Figure 3) was developed by Middleton (Bruce et al. 1996). In geological terms, this model essentially describes the case where hot fluid is flowing, under pressure and from a deep source, through a thin, very porous and permeable layer which is overlain by a thick and less permeable shaly layer. The main fluid flow passes through the porous layer and then upward along a brecciated fault zone. Such flow of hot brines is well known to exist in sedimentary basins. The much slower flow through the shaly unit above the hot permeable layer was considered, along with a source bed 200 metres above the hot layer and buried three kilometres deep.

Reference to Figure 2 shows that if the source bed is maintained near 200 °C for periods of greater than one year, then significant volumes of hydrocarbons can be generated. Indeed, the model shows that for a heating period of 1000 years with a temperature of 200 °C, the bitumen concentration is at its peak value. Thus,

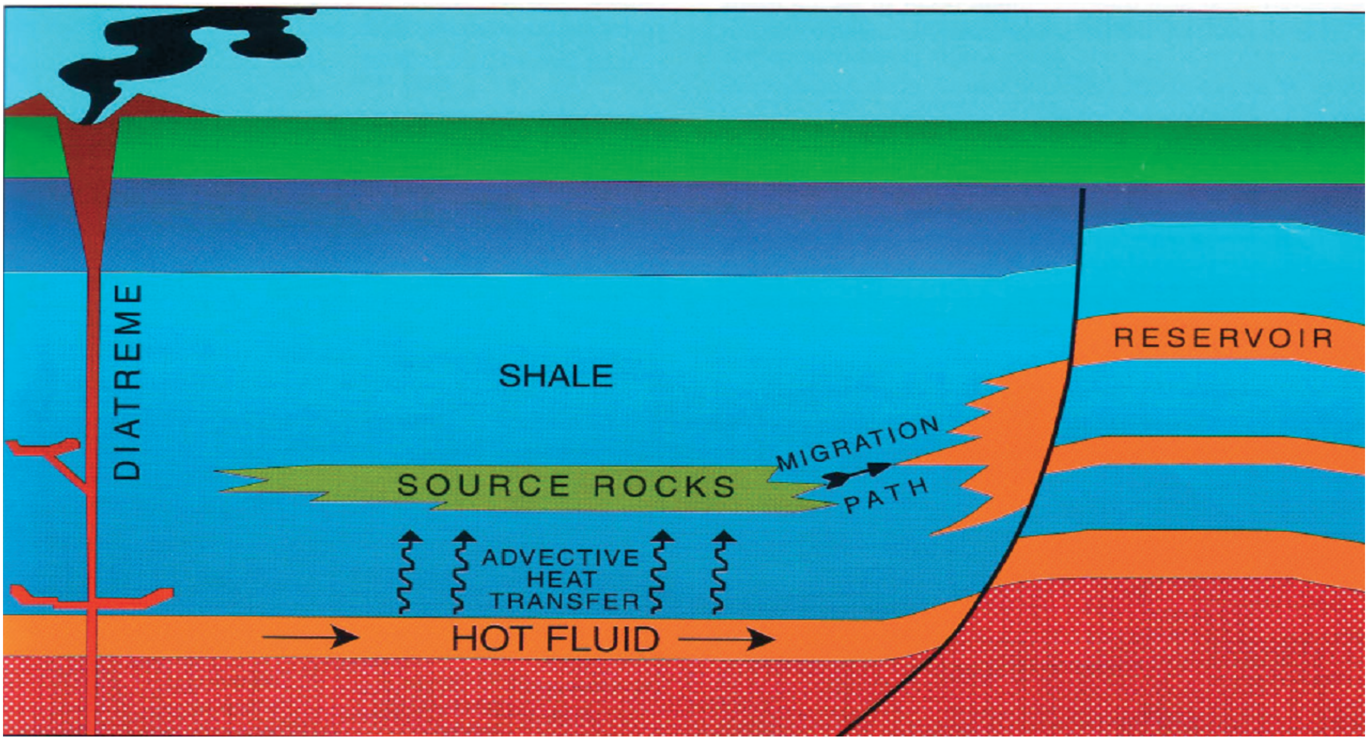

Figure 3. Schematic diagram showing conceptual model of hydrocarbon generation in a hydrothermally affected basin (Bruce et al. 1996).

economic volumes of hydrocarbons can be generated in short periods of time (circa 1000 years) in sedimentary basins that have experienced hot-fluid flow for similar durations and advective velocities in the range of 0.315 to 1.58 metres/year.

significant hydrocarbon generation can occur in geologically short periods of time

The widespread occurrence of lead-zinc (Pb-Zn) mineralisation in hydrocarbon-prone basins (Rickard et al. 1979; Lindblom 1982) provides strong coincidental support for the hypothesis that significant hydrocarbon generation can occur in geologically short periods of time as a result of hot-fluid flow (Cathles and Smith 1983) in such basins.

PURELY BURIAL MODEL UNREALISTIC

In the past a 'burial' model was favoured for petroleum generation and it gave very long generation times, even millions of years. In this model, heat rose up vertically from within the Earth and the heat transfer was by conduction (transfer of heat energy through direct contact), and thus exceedingly slow. Relatively low values of permeability (ability for fluids to flow) were used, and fractures were not considered. In contrast, a model that is more realistic to natural systems is the hydrodynamic (moving fluids) model. Heat transfer is by convection (circulation of heated water) or by advection (movement of heated water in a particular direction). The water flows laterally as well as vertically and more realistic permeability values are used, including fracture permeability.

Thermal conduction has been a major parameter in quantitative maturation studies. However, it would be more realistic to take into account permeable sediments. These provide excellent pathways for convective (and advective) heat transfer by flowing fluids and enable preferential heating of regions at rates much higher than those provided by conduction alone (Lerche 1990). Even a shale can have fluid flow and much more so a good aquifer. Permeable sediments provide excellent pathways for heat transfer by flowing fluids. Purely conductive heat flow is very slow and likely to be rare in basins.

Laboratory measurements of the permeabilities of rocks of hand specimen scale give values much lower than the effective permeabilities found in actual field reservoirs where larger fractures are found. Natural fractures allow greater fluid flow since they enhance effective permeability. Even hard rock systems such as mid-ocean ridge basalts have heat transfer by fluids flowing through fractures.

Data on the permeability of various rocks within hydrothermal systems are presented in Figure 4. A to J were commonly modelled permeabilities, whereas 1 to 10 are actual observed system permeabilities in modern hydrothermal systems. Permeability values three to six orders of magnitude lower than average crustal permeabilities, or observed permeabilities of present-day analogues, have been commonly used in modelling of hydrothermal systems. Consequently, rates for hydrothermal ore formation and hydrothermal reaction rates described in the literature have been lower by the same magnitude (Holyland 1988).

SOME SEDIMENTARY BASIN EXAMPLES

Convective and advective heat flow has probably been present in more sedimentary basins than previously recognised. The following provides some examples.

In the Swiss and French Molasse Basin, second order variation in vitrinite reflectance has been related to a regional discharge of warm fluids controlled by tectonic structures (Schegg and Moritz 1993). In the German Molasse Basin, generally gas fields are closer than oil fields to the Alpine front (Bachmann and Müller 1991). These examples are considered to reflect the temperature distribution of fluids as they flowed into these basins.

The Bowen Basin, Queensland has evidence for heat transport away from igneous intrusions by laterally

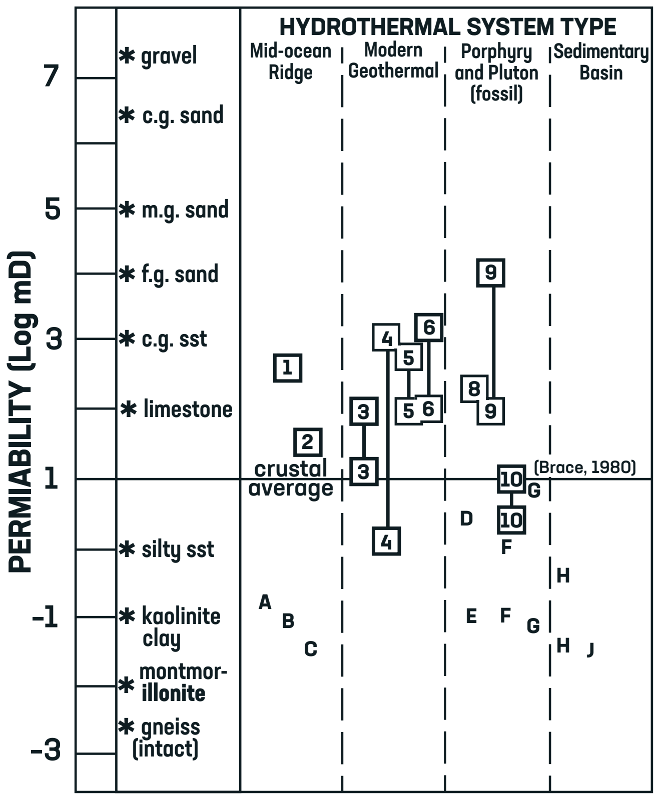

Figure 4. Permeability data for various types of rocks and various hydrothermal system types. 1 to 10 are actual observed system permeabilities. A to J are modelled permeabilities. After Holyland (1988).

flowing aquifers (Uysal et al. 2000). There are irregular variations in coal maturty adjacent to intrusions. Isotopes of strontium (Sr), carbon (C) and oxygen (O) in carbonate veins indicate mixing of magmatic and meteoric waters. Rapid heating approaching 300 °C is indicated by coal with volatiles driven off and excessive bitumen.

The Australian Cooper-Eromanga Basin is not known to be associated with active volcanic centres. However, mathematical modelling of the basin indicates that the subsurface thermal regime and petroleum generation have been markedly affected by a topography-driven groundwater flow system (Eadington et al. 1993; Person et al. 1993). The depth-to-onset of oil generation is some 500 metres shallower than would be expected by just burial depth and conductive heat flow. The groundwater becomes heated at depth and then transmits the heat to petroleum source rocks as it flows along the subsurface topography back up to shallower levels.

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In the United States San Juan Basin, the transport of heat by laterally flowing aquifers can help explain the regional maturation pattern of increasing coal rank towards the hot volcanic centre in the north, and also results in the highest maturation levels being found in sediments that were not at the site of deepest burial (Summer and Verosub 1989). These effects cannot be explained by conductive heat transfer. Overall, volcanism has played a greater role in the thermal maturation of such basins than was formerly assumed.

Studies of the Western Canada Sedimentary Basin (Jessop and Majorowicz 1993) indicate that the assumption of conductive steady state heat flow from the Precambrian basement does not predict vertical temperature profiles that match records from drilling records and logs. A conclusion is that the temperature field within the sedimentary strata has undergone hydrological distortion. The ability of water to flow through permeable aquifers provides a means to transport heat even more effectively than conduction alone.

The northward and northeastward increase of heat flow in the Alberta Basin may demonstrate that regional permeabilities are larger than those estimated from laboratory measurements, because of the existence of fractures (Jessop and Majorowicz 1993). The permeability of hand specimen size samples is measured in laboratories. However, fracture systems are on a greater scale and so not suited to measurement in laboratories.

CONCLUSIONS

Deep time is not necessary for petroleum formation. With realistic parameters in numerous geological settings, formation of petroleum over millions of years may even be considered unlikely.

Hydrothermal processes are significant and should be taken into account when modelling petroleum formation in sedimentary basins. It is more realistic to consider hydrodynamic heat transfer along with hydrocarbon generation modelling incorporating hydrous pyrolysis. There is an exponential increase in hydrocarbon generation with increase in temperature.

There are a variety of scenarios, for example:

1. *instantaneous* generation associated with hydrothermal venting (e.g. Red Sea, Atlantis Deep and Gulf of California seabeds);
2. regions with heat transport away from igneous intrusions by laterally flowing aquifers (e.g. Argentina and Bowen Basin);
3. subsurface situations with temperatures of 200 °C – peak generation can occur in approximately *one thousand years*.

The bottom line is that economic accumulations of oil and gas can be generated in thousands of years in sedimentary basins that have experienced hot fluid flow for similar durations.

DISCLAIMER

The evidence provided in this article is consistent with a young-earth biblical view of Earth history. However, as such, this article is presented in a private capacity only, and not as a representative of my secular employment with a Mines Department in Australia.

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AUTHOR BIOGRAPHY

Richard Bruce has more than 30 years' experience in petroleum and mineral exploration. He has worked in industry, university and government institutions, and currently works as a geologist for a Mines Department in Australia. He has delivered presentations and done field-work in Australia, Asia, North America and the UK. He has qualifications in geology, geophysics and gemmology.