Abiogenic origin of petroleum hydrocarbons: Need to rethink exploration strategies

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The origin of petroleum hydrocarbons is a matter of debate since its discovery[1]. Nevertheless, during the last several decades it was firmly believed that the origin of petroleum hydrocarbons is 'biogenic' (fossil fuel), a hypothesis that was first proposed in 1757 by the Russian scientist Mikhail Vasilyevich Lomonosov[2]. Consequently, all the worldwide strategies used organic content of sedimentary rocks as a proxy during hydrocarbon exploration. The logic behind this proposition is the compositional similarity between petroleum hydrocarbons and that of organic matter presently being formed and deposited. In fact, during our investigations in the northern Indian Ocean, we also proposed few areas for intense hydrocarbon exploration[3–5] based on preservation of organic matter in surface sediments.

Nowadays there is a growing belief that the origin of petroleum is not 'biogenic', but 'abiogenic'[2]. The Russian geologist Nikolai Alexandrovitch Kudryavtsev was the first to propose[2] the modern abiotic theory of petroleum in 1951. Although it prevailed for long[6], this theory generated interest in the West only after the publication of 'The Deep Hot Biosphere' by Thomas Gold[7] in 1999. Gold's version of the hypothesis was partly based on the existence of thermophile bacteria in the earth's crust, which perhaps resulted in the existence of certain biomarkers as 'contaminants' in extracted petroleum.

Abiogenic origin of hydrocarbons

This abiogenic theory suggests that natural petroleum was formed from deep carbon deposits, possibly dating to the formation of the earth, which is supported by an increasing body of evidences.

Meteorites are believed to represent the major composition of materials from which the earth was formed, and some meteorites such as carbonaceous chondrites contain carbonaceous material. The ubiquity of hydrocarbons in the solar system is taken as evidence to infer that there may be much more petroleum on the earth than commonly thought. Theoretically, the second law of thermodynamics permits the genesis of natural petroleum only at depths more than 100 km at pressures of above 30 kbar well into the mantle of the earth and at higher temperatures consistent with that environment[8]. Further, the statistical mechanical model predicts that methane compressed to 30–40 kbar (pressure at depths around 150–200 km) at 1000°C (conditions in the mantle) yields hydrocarbons having properties similar to petroleum[8]. It is suggested that this petroleum of primordial material of deep origin at high pressure is transported via 'cold' eruptive processes into the crust of the earth until it escapes to the surface or is trapped by impermeable strata, forming petroleum reservoirs. Proponents of 'abiogenic' petroleum origin contend that deep microbial life is responsible for the biomarkers that are generally cited as evidence of biogenic origin. In this regard it must be noted that the microbial life has been discovered 4.2 km deep in Alaska and 5.2 km deep in Sweden[2].

The abiogenic theory on the origin of petroleum seeks to explain the origin of commercial accumulations of petrochemicals via chemical mechanisms such as serpentinite catalysis. Lipid components in hydrothermal sulphide deposits from the active Rainbow vent field (Mid-Atlantic Ridge at 36°N) revealed the presence of methane and possibly a minor amount of the alkanes anticipated to be of 'abiogenic' origin[9]. A recent study has shown the occurrence of low-molecular-weight hydrocarbons in natural hydrothermal fluids, which has been attributed to abiogenic production by Fischer–Tropsch-type (FTT) reactions based on concentration, and the presence of stable radiocarbon isotopes of hydrocarbons dissolved in hydrogen-rich fluids venting at the ultramafic-hosted Lost City Hydrothermal Field[10]. These findings illustrate that the abiotic synthesis of hydrocarbons in nature may occur in the presence of ultramafic rocks, water, and moderate amounts of heat.

The presence of vast quantities of methane hydrate (methane clathrate) within deep pelagic oozes in the oceans of the earth, is cited as evidence for abiogenic methane generation from serpentinization of the oceanic crust. This is supported by continuous methane upwelling through gas chimneys (gas vent) in oceans forming pockmark features, cold seeps, methane-related diagenetic carbonates, benthonic ecosystems such as cold-water corals, methane flares, shale diapirs, submarine and terrestrial mud-volcanoes. Most of the times, the isotopic data of upwelling methane have misled regarding the origin of hydrocarbons as 'biogenic', despite the fact that these are mainly abiogenic. This discrepancy has been sorted out by an explanation that the bacterial reworking of primordial methane which comes from great depths yields biogenic methane at shallow levels in the crust[11]. This inference is attested by common association of biologically inert helium with hydrocarbons, mainly with methane and nitrogen gas fields, which can be explained only by the abiogenic origin of petroleum deposits.

Mass-balance calculations for 'supergiant' oilfields reveal that the calculated source rock could not have supplied the reservoir with the known accumulation of oil, implying deep recharge[2]. Most importantly, throughout the history of the petroleum industry, there have been numerous predictions that the supply of crude oil in the world is being rapidly depleted and would therefore soon be exhausted. In fact, most of such predictions have been proven wrong. To add to this, based on the abiogenic theory, successful exploratory drilling has been undertaken in the Caspian Sea region, western Siberia, and the Dneiper-Donets Basin[12].

Despite the above, recent studies of Lollar *et al.*[13] based on an unusual pattern of $\delta^{13}C$ values among C_1–C_4 alkanes and of δ^2H analysis of gas from the Kidd Creek mine in Ontario, typical of hard-rock mines operating throughout the Canadian Shield, did not provide any evidence of their abiogenic formation. The abiogenic origin of petroleum has been questioned by Glasby[14]. Nevertheless, taking into consideration the strong evidences supporting the abiogenic origin, it is worthwhile to rethink the hydrocarbon exploration strategies in the Indian context.

Exploration strategy: Indian context

The well known on-land liquid and gaseous hydrocarbon deposits in India are associated with sedimentary basins of Assam, Gujarat and the Krishna–Godavari (KG) Basin. Coincidently, these sedimentary basins are highly tectonic regions characterized by the presence of faults and fractures. Presently, it is believed that these faults/fractures act as structural traps for the formation of oil–gas pools. However, going by the abiogenic concept, it is likely that these faults could have acted as conduits for migration of deep-seated hydrocarbons upward to be trapped in shallow pervious sedimentary strata forming oil–gas deposits.

Our studies[3–5,15] in the offshore regions have shown that the organic matter in the Arabian Sea is primarily marine and is of kerogen Type-II, which mainly yields liquid hydrocarbons, whereas in the Bay of Bengal it is terrigenous and is of Type-III kerogen, eventually forming gaseous hydrocarbons. Perhaps such transformations[16] result in the occurrence of liquid petroleum hydrocarbons in the Bombay High offshore Deposits in the Arabian Sea and in the findings of large gas deposits in the Bay of Bengal. These findings are in agreement with the biogenic origin of hydrocarbons. Analysis of fourteen seismic lines by ONGC revealed that that eastern offshore is more favourable compared to the western offshore for gas hydrates and confirms our above-mentioned inferences[17].

The recent gas hydrate exploration in 2007–08 using deep-drilling vessel *JOIDES Resolution* made an interesting discovery[18] of 125 m thick layer of gas hydrate (thickest deposit discovered anywhere in the world) in the KG Basin and confirmed the presence of hydrates in the Andaman Sea and in Mahanadi Basin, giving a boost to the Indian gas hydrate programme. However, no gas hydrate recovery was reported in the deep-sea region off Goa (Konkan–Kerala Basin). Incidentally, all these regions are characterized by the presence of bottom simulating reflectors, a signature of the presence of gas hydrates. It is worthwhile to note that amongst these four regions, the subsurface fault system[19] and the surficial ridge system[20] are prominently associated with the KG Basin, exactly where the gas hydrate discovery was made, an observation consistent with other studies[21,22] involved in the exploration work of the KG Basin. It is known that in recent years several Indian companies have struck gas in this region. Indeed, we have also found that the surficial sediments coinciding with the location of gas hydrate here are fully charged with gases, which has caused the 5 m core barrel of the gravity corer to overflow easily a couple of times[20]. It is likely that the situation here is more favourable for the deep-seated methane to seep through the faults to the subsurface sediments and ultimately get entrapped in water clathedra forming gas hydrates, a situation similar to that found off the shore of Oregon and parts of Canada[21]. The coexistence of faults and gas hydrates in this area supports the possibility of abiogenic origin of hydrocarbons where deep-seated methane could be inorganic.

Conclusion

Thus, the association of the gas–oil deposits and gas hydrate deposits with the fractured crust/tectonically active region in the Indian context affirms the view that hydrocarbon formation could be partially abiogenic. Hence, it is essential that the sedimentary sequences associated with deep-suited faults may be identified and targeted for future hydrocarbon and gas hydrate exploration. In this regard, faults along 85°E and 95°E in the Bay of Bengal[19] are ideal locations. Moreover, the regions characterized by the presence of gas escape features[23], mud diapirs[24] (at West of Swatch of No Ground, Point Calimere and off Saurashtra) and mud volcanoes[25] (Andaman Sea) also should be targeted. Geochemical studies support the presence of abiogenic hydrocarbons in the sediments of the Andaman Sea[26]. We should also look for regions beyond our 'Exclusive Economic Zone' for exploration of hydrocarbons, e.g. deformation zone in central Indian Basin, where our studies[27] have shown the presence of hydrothermally formed hydrocarbons, *n*-alkanes, polyaromatic hydrocarbons and paraffins.

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