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Geochemical characteristics and genetic types of the crude oils from the Iranian sector of the Persian Gulf

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ABSTRACT

Comprehensive geochemical study shows genetic relationships among 33 crude oils from Iranian sector of the Persian Gulf and suggests the ages and paleoenvironments of their source rocks. The samples were collected from Jurassic to Tertiary reservoirs of 17 developed oil fields where about 15 billion barrels of recoverable oil have been reserved. The oil density varies in rather wide range, between 12.2° and 39.2° API. Asphaltene contents ranged from 0.8–18.5%, and the maltene fractions are dominated by saturated HCs (29.3–70.9%) with subordinate proportions of aromatic HCs (22.30–38.30%) and polar compounds (7–15.70%). Pristane to phytane (Pr/Ph) ratios are variable (0.67–1.41). Sulfur content in crude oil samples are highly variable (0.65–3.7%). According to the Tissot and Welte's classification, most of the oils can be classified as "high sulfur" oils. Statistical and geochemical results indicate that the studied oils belong to four main genetic groups:

Group I oils (Jurassic to Early Cretaceous reservoirs of the Dorood, Kharg, Aboozar and Foroozan oil fields in the NW part of the Persian Gulf) originated from Jurassic or older carbonate rich source rocks deposited in an anoxic environment.

Group II oils (Jurassic to Early Cretaceous reservoirs of the Salman, Resalat, Reshadat and Balal oilfields in the eastern part of the Persian Gulf) were sourced from Jurassic or older, carbonate source rocks deposited in a relatively oxic environment;

Group III oils (Late Cretaceous to Tertiary reservoirs of the Aboozar, Bahregansar, Souroush, Nowrouz, Dorood and Kharg oilfields in the north/north-west part of the Persian Gulf) were probably sourced from Middle Cretaceous calcareous shales.

Group IV oils (Late Cretaceous reservoir of the Sirri A, Sirri C, Sirri D, Sirri E, Resalat and Reshadat oilfields in the eastern part of the Persian Gulf) probably originated from mid to Late Cretaceous source rock.

1. Introduction

In terms of hydrocarbon resources, the Persian Gulf Basin is the richest region of the World, holding 57% (715 billion barrels) of the world's crude oil reserves and sizeable reserves (2462 tcf) of natural gas, accounting for 45% of total proven world gas reserves (Rabbani, 2007). More than 51% of recoverable liquid hydrocarbons are located in Cretaceous reservoir rocks whereas up to 50% of the gaseous hydrocarbons were discovered in Permo-Triassic. More than 80% of oil reserves are contained in carbonate rocks and just 20% are confined to sandstones. For gas reserves, up to 90% of its volume is concentrated in limestone and dolomites; sandstone is the reservoir rock for the other 10% (Alsharhan and Nairn, 1997).

There are many parameters which make the Persian Gulf and its coastal areas one of the world's largest single source of crude oil and hydrocarbon accumulations. The presence of repetitive, extensive and rich source rock beds, excellent reservoirs accompany with impermeable regional seals and huge anticlinal traps lead to make the richest region in the world. The regional geology and some of the most important factors contributing to the petroleum systems of the Persian Gulf and surrounding areas have been discussed in numerous publications (e.g. Murris, 1980; Alsharhan and Nairn, 1997; Sharland et al., 2001; Pollastro, 2003; Rabbani, 2008; Bordenave and Hegre, 2010). However, the probable active petroleum systems in the region, their impacts on charging the reservoirs and relevant extents have not been determined yet. This is due in part to the contribution of different source rocks in charging the reservoirs caused by long distance migration from hydrocarbon generation kitchens towards large-scale low relief regional highs (especially in the NW) and salt related structures (especially in

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the SE) and vertical migration, remigration caused by the severe tectonics in the region as well as lack of data. Genetic relationship investigation could be used in order to classify crude oil samples into generic families (oil–oil correlation) to define their numbers and respective extents, both regionally and stratigraphically, inferring depositional environment, lithology, organic matter input, age and maturity of the probable source rocks that the samples are originated from as well as the area where these source rocks have been effective.

The objectives of this geochemical study were to use high-resolution geochemical analysis and statistical methods (HCA and PCA), to evaluate genetic relationships among 33 crude oil samples collected from Jurassic to Tertiary reservoirs of 17 oilfields in the Iranian sector of the Persian Gulf, their probable source rock age, lithology, paleoenvironment and their relative thermal maturity.

2. Geology of the Persian Gulf

The Persian Gulf Basin is located at the junction of Arabian and Eurasian lithospheric plates. Several structural elements originated at the end of Paleozoic in the basin, including Gotnia Trough in the north (Iraq and Syria), Arabian Trough in the central part of the basin (Saudi Arabia, northern branch of the Persian Gulf and Bahrain), and Rub-Al-Khali in the United Arabian Emirates (U.A.E.) (Fig. 1). The importance of these restricted intra-shelf basins are due to their impacts on the petroleum systems of the region. Most of the petroleum in Saudi Arabia and Iraq is sourced from cyclically bedded Jurassic shales and carbonates accumulated in these basins formed on the passive margin platform of the Tethys sea (Ayres et al., 1982). At the early Late Cretaceous (Turonian) the series of events resulting in the closure of Tethys ocean at the Mesozoic/Cenozoic boundary have occurred (Ziegler, 2001). This series of events led to the formation of Mesopotamian Foredeep which consist of the Zagros Basin (Lurestan, Dezful, and Khuzestan provinces in Iran and adjacent areas in Iraq), the Fars Block (Fars Platform) in the southwest of Iran, the northern slope of the Qatar Arch and the most part of the Persian Gulf area, including the Rub-Al-Khali Basin. At the end of the Early Miocene (later stage of collision), the Zagros block was thrust over the eastern edge of the Arabian plate (Konyuhov and Maleki, 2006).

There are more than 36 formations (Cambrian–Quaternary) in the Persian Gulf stratigraphic column. This study focused on Mesozoic–Cenozoic petroleum systems and corresponding formations (Fig. 2).

Jurassic and Cretaceous horizons are of immense importance because of the remarkable richness of hydrocarbons in the Persian Gulf carbonate platform. On the northern margin of the Arabian plate, an immense passive margin developed during the Jurassic through Late Cretaceous which led to the deposition of ideal sequence of petroleum system elements. The thick Callovian–Kimmeridgian Surmeh/Arab formation is considered as the most important carbonate reservoir rock in the Jurassic (Bordenave, 2002). The Hanifa-Tuwaiq and Diyab formations extended on both side of the Qatar Arch in Arabian and Rub-Al-Khali basins, respectively, and are the main feeders of the Late Jurassic to Early Cretaceous petroleum system (Pollastro, 2003). It seems that the Diyab as well as the Hanifa-Tuwaiq Formation, mostly located outside of Iran, have contributed to charging some of the Iranian oil fields in the east and west of the Qatar Arch, respectively.

Approximately 16% of the world's hydrocarbon reserves accumulated in the Cretaceous carbonate (Scott et al., 1988) which consists of Fahliyan (Yamama), Gadvan and Dariyan (Shuaiba) formations. These reservoirs are mostly sealed by regionally continuous marine shales or anhydrites. The lower part of Kazhdumi Formation and its equivalent Nahr-Umr shale acts as a major regional seal for the Lower Cretaceous reservoirs.

Throughout the Persian Gulf region, Upper Cretaceous Ilam-Sarvak (Mishrif) formations and Oligo-Miocene Asmari/Ghar Formation are the most important and proliferous reservoirs. These reservoirs are probably charged by the two main source rocks of the Albian Kazhdumi Formation and Paleocene Pabdeh Formation. Moreover, there is a locally extended source rock, Ahmadi Member of the Sarvak Formation (Cenomanian), which is considered as the third source rock for the Middle Cretaceous to Early Miocene petroleum system. Most of the hydrocarbons generated by these source rocks have migrated vertically through fractured layers toward the reservoirs capped by the thick evaporites of Early Miocene Gachsaran Formation (Bordenave and Hegre, 2005).

3. Material and methods

The following methods were conducted on the 33 oil samples collected through the Iranian part of the Persian Gulf.

The oils were analyzed for API gravity with an Anton Paar DMA5300M density meter and for sulfur content with a Leco SR-12 analyzer. Before the deasphalting, oils were topped under nitrogen (for 5 h) at 60 °C. The asphaltene fraction was precipitated with *n*-hexane. The remaining maltenes were then separated into compositional fractions of saturated hydrocarbons, aromatic hydrocarbons and resins by column chromatography, using alumina:silica gel (2:1 v:v) columns (0.8 × 25 cm). The fractions were eluted with *n*-hexane, toluene and toluene:methanol (1:1 v:v), respectively. Oils and their individual fractions for the measurement of stable carbon isotope composition were combusted in an on-line system. The stable carbon isotope analyses were performed using the Finnigan Delta Plus mass spectrometer. The stable carbon isotope data are presented in the δ notation relative to V-PDB standard (Coplen, 1995), with the analytical precision estimated to be ±0.2‰.

High resolution gas chromatography was used in order to analyze the whole oil. For this purpose 1 μl of sample diluted in CS_2 was introduced into a splitless injector of a Hewlett Packard 5890 series II GC held at a temperature of 300 °C. From there the sample passes through a 50 m × 0.2 mm Agilent DB1 column (0.5 μm film thickness) using a constant flow 0.3 ml/min of nitrogen as the carrier gas. The column oven was programmed to hold at 30 °C for 5 min and then to increase to 320 °C at 3 °C/min, at which point it was held for 20 min. Components eluting the column were detected by a flame ionization detector (FID) held at 325 °C.

The isolated saturated hydrocarbon fractions from the oils were diluted in isooctane and analyzed by GC–MS for determining biomarkers. The 5β-cholane was used as internal standard. The analysis was carried out with the Agilent 7890A gas chromatograph equipped with the Agilent 7683B automatic sampler, an on-column injection chamber and a fused silica capillary column (60 m × 0.25 mm i.d.) coated with 95% methyl/5% phenylsilicone phase (DB-5MS, 0.25 μm film thickness). Helium was used as the carrier gas. The GC oven was programmed: 80 °C held for 1 min, then increased to 120 °C at the rate of 20 °C/min, then increased further to 300 °C at the rate of 3 °C/min and finally held for 35 min. The gas chromatograph was coupled with a 5975C mass selective detector (MSD). The MS was operated with an ion source temperature of 230 °C, the ionization energy of 70 eV, and a cycle time of 1 s in the mass range from 45–500 Da. In the selected ion mode (SIM) the dwell time was set to 30 ms for each ion.

The aromatic hydrocarbon fractions of the oils were diluted in toluene spiked with terphenyl standard and analyzed by the GC–MS using the same equipment as for the saturate hydrocarbon