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Research paper

# Geochemical characterization of source rocks and oils from northern Iraq: Insights from biomarker and stable carbon isotope investigations

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A B S T R A C T

The origin of oil in the Cretaceous–Tertiary reservoirs of northern Iraq remains controversial. Consequently, a detailed geochemical study, including Rock-Eval pyrolysis, gas chromatography–mass spectrometry, and carbon isotope analysis was conducted on 65 source rock core and cuttings samples from the Najmah, Chia Gara, and Balambo formations, northern Iraq. Twenty-four crude oils were also analyzed to provide new insights into source organic matter, depositional environment, and correlations between crude oils and their probable source rocks.

Bulk geochemical analysis of candidate source rock samples indicates that the Najmah Formation has more petroleum potential than the Chia Gara and Balambo formations. These three candidate source rocks were deposited in slightly different environments and have different organic matter types as determined by screening analysis and biomarker data. The Najmah Formation contains organic-rich (TOC up to 4.2 wt%) oil-prone type I-II kerogen deposited under anoxic conditions. The Chia Gara and Balambo formations contain mixed type II-III and type-III kerogens, oil- and gas-prone, deposited under less reducing conditions with more terrigenous organic matter input. Unfortunately, most of the rock samples contain less than 2.5 wt% TOC, which likely excludes them as source rocks, but more deeply buried equivalents may contain more organic matter.

Biomarker and stable carbon isotope compositions suggest that Cretaceous- and Miocene-reservoired oils from the northern Iraq basins, although predominantly derived from marine carbonate organic matter, constitute five genetically distinct oil families. Based on age-specific biomarkers, the oils were probably derived from three active petroleum systems in northern Iraq: Jurassic, Jurassic–Early Cretaceous, and Early to mid-Cretaceous. Biomarker maturity parameters indicate that most of the oils were generated in the early oil window, similar to the extracts.



## 1. Introduction

Iraq is a long-standing petroleum-producing country in the Middle East and a founding member of the Organization of Petroleum Exporting Countries (OPEC). The current proven reserves of 133 billion barrels of oil and 110 trillion cubic feet of gas are assigned to three petroleum systems: Paleozoic, Jurassic, and Mesopotamian Cretaceous–Tertiary (Ahlbrandt et al., 2000; Verma et al., 2004).

Most of the petroleum that has been discovered in Iraq is believed to originate from Jurassic rocks and is trapped in Cretaceous and Tertiary reservoirs in the Mesopotamian Basin and Zagros Fold Belt (Alsharhan and Nairn, 2003; Jassim and Goff, 2006; Aqrawi et al., 2010; Al-Ameri et al., 2011; Al-Ameri and Zumberge, 2012). Northern Iraq lies within the northern part of the Zagros Fold Belt and is estimated to contain about 45 billion barrels of Iraq's 115 billion barrels of oil reserves, making Iraq the sixth largest oil reserve in the world (Jassim and Al-Gailani, 2006).

Alsharhan and Nairn (2003) and Pitman et al. (2004) proposed that the principal source rocks were deposited during the Late Jurassic to Early-Middle Cretaceous, and the weight of evidence suggests that these two sources are responsible for the bulk of the Iraqi oil reservoirs. For this reason, the present study is aimed to 1) assess the nature and petroleum potential of the Upper Jurassic–Lower Cretaceous source rocks and their depositional paleoenvironments; 2) provide bulk and molecular characterization of

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oils discovered in the Mesozoic–Tertiary reservoirs in northeastern Iraq; and 3) classify the oils into genetic families on the basis of oil–oil correlation and determine their source rocks.

## 2. Geologic background

The tectonic framework and paleostructural elements of Iraq have exerted fundamental control on basin evolution and petroleum geology, e.g., source, reservoir and seal distribution as well as structural style and trapping mechanism (Jassim and Goff, 2006; Aqrawi et al., 2010; English et al., 2015). The Arabian Plate can be subdivided into the Arabian Shield and the Arabian Shelf. The Arabian Shelf in northern Iraq can be divided into a stable shelf and a folded zone or unstable shelf (Jassim and Buday, 2006). The opening of the southern Neo-Tethys in the Late Jurassic strongly affected subsidence of the unstable shelf. The unstable and stable shelves together comprise five tectono-physiographic zones that are generally bounded by major faults that represent deep-seated structural elements. These tectonic zones include 1) the thrust zone, 2) the folded zone, 3) the Mesopotamian Basin, 4) the Salman zone, and 5) the Rutbah-Jezira zone (Ameen, 1992; Jassim and Buday, 2006; Jassim et al., 2006). The study area is related to the low folded/foothill region of the folded zone in which mainly Cenozoic rocks are exposed (Ameen, 1991, 1992).

All significant hydrocarbon discoveries in northern and northeastern Iraq occur in compressional structures formed during the Zagros orogeny. The large-scale Zagros anticlines in Iraq probably formed by a combination of thick-skinned deformation involving the basement and thin-skinned deformation above a detachment near the base of the lower Paleozoic (McQuarrie, 2004).

The Kirkuk-Hamrin folded subzone to the southeast of the Greater Zab River (Fig. 1) contains long, unbroken anticlines (Ameen, 1992). The Hamrin anticline, for example, contains two separate domes (Nukhaila and Allass) (Fig. 2). These structures are open and simple with few thrusts (Ameen, 1992). Folds generally flatten toward the Mesopotamian Basin where relatively narrow anticlines are separated by wide synclines. The fault-related Hamrin anticline (Fig. 2) is part of a long, high-aspect-ratio system of folds. Its geometry suggests that it is a forced fold above the suspected Zagros foredeep fault zone, which is thought to have been reactivated in the Pliocene to Recent (Jassim and Goff, 2006).

Two major sedimentary basins that border the study area are the Greater Arabian Basin and the Zagros Basin. Each basin is further divided into sub-basins and each of these has its own style and time of origin, which is reflected by differences in thickness and lithology. Stratigraphically, the sedimentary cover of northern and northeastern Iraq contains a thick-carbonate succession in the Mesozoic Jurassic, Cretaceous, and Tertiary (Fig. 3). In this study, we will focus on three stratigraphic rock units: Najmah, Chia Gara, and Balambo formations.

The Najmah Formation is dated as Late Jurassic (Oxfordian–Kimmeridgian). The sequence of alternating fine-grained, recrystallized limestone and oolitic, peloidal packstone/grainstone, coarse dolomites, and thin anhydrites is interpreted as having been deposited in a shallow marine, lagoonal neritic environment. The Najmah Formation unconformably overlies the Sargelu Formation, and unconformably underlies the Lower Cretaceous Yamama Formation. Tectonic activity in the basin in the Late Jurassic was responsible for widespread erosion of the Najmah Formation. The age-equivalent units of the Najmah and Gotnia formations in the high folded and northern thrust zones are the Barsarin and Naokelekan formations (Alsharhan and Nairn, 2003). The Najmah Formation is transitional to the north with the argillaceous and condensed basinal Naokelekan Formation (Buday, 1980).

The geography during the Late Jurassic was controlled by the effects of tectonic activity along the Arabian Plate margin prior to the opening of the southern Neo-Tethys. Differential subsidence led to periodic isolation of the intra-shelf basin from the Neo-Tethys.

The Chia Gara Formation (Middle Tithonian–Berriasian) extends from the Jurassic to the Early Cretaceous. It is underlain by the Barsarin Formation and overlain by the lower Sarmord Formation. The type section of the Chia Gara Formation is located at the Chia Gara anticline, south of the town of Amadiya in the strongly folded zone of northern Iraq (van Bellen et al., 1959). Lithologically, the formation is uniform throughout Iraq, consisting of two basic lithofacies types: thinly bedded limestone and calcareous shale in the lower part of the section and marly limestone and marl in the upper section (Alsharhan and Nairn, 2003).

The Balambo Formation is Valanginian–Turonian (Alsharhan and Nairn, 2003) and can be divided into lower and upper units. The Balambo Formation consists of thin layers of bluish ammonite-rich limestone with interlayered marls and clays, beds of olive green marl and dark blue shale, followed by radiolarian-rich limestone (van Bellen et al., 1959). The upper Balambo Formation was deposited in a deep bathyal environment (Buday, 1980). The lower contact of the formation in the type section seems to be vertically discontinuous, without visible unconformity, and the upper boundary of the upper Balambo Formation is always gradational and conformable. On the other hand, the lower Balambo Formation is homogeneous and consists of thin bedded *Globigerina* limestone, passing down into radiolarian limestone (van Bellen et al., 1959). The Valanginian lower Balambo Formation was deposited in an outer shelf to bathyal environment, in a relatively deep basin situated along the northeast boundary of the Arabian Plate, separated from the southern Neo-Tethys by an intermittently submerged ridge. This ridge has been overthrust by the Zagros Suture units. Toward the west, the Balambo basin was separated from the main shelf basin by the Qamchuqa Ridge situated along the highly folded zone.

## 3. Materials and methods

Sixty-five core and cuttings samples retrieved from the Najmah, Chia Gara, and Balambo formations encountered in the Jambur, Kirkuk, Hamrin, and Zab oil fields, northern Iraq, were analyzed for total organic carbon (TOC), Rock-Eval pyrolysis, solvent extraction for saturated and aromatic stable carbon isotope composition ($\delta^{13}C$), gas chromatography (GC), and gas chromatography–mass spectrometry (GC–MS). All of these bulk and molecular geochemical analyses were conducted by StratoChem Laboratories (New Maadi, Cairo, Egypt) and GeoMark Research Ltd (Houston, Texas, USA).

TOC/Rock-Eval pyrolysis analyses were carried out using a Rock-Eval 6 instrument equipped with a TOC module. The samples were pyrolyzed at 300 °C (hold time 3 min) followed by heating at a rate of 25 °C/min up to 800 °C, held for 5 min. TOC was determined by combustion of the pyrolysis residue at 850 °C as the sum of pyrolyzable and combusted carbon.

For molecular analysis, the samples were extracted using dichloromethane. The extracts were fractionated into saturated and aromatic hydrocarbons, and NSO-compounds (nitrogen-sulfur-oxygen compounds or resins) using column chromatography on silica gel. Thereafter, the extracts were analyzed in the same way as the oil samples, as described below.

The 24 oil samples were collected from six producing oil fields—Hamrin (Hr), Kirkuk (K), Khabbaz (Kh), Bai Hassan (Bh), Jambur (Ja) and Ajil (Aj)—in northern and northeastern Iraq to assess their geochemical characteristics. The studied oil fields, well locations, and oil and rock samples are shown in Fig. 1.