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## Geochemistry of Oil and Oil–Source Rock Correlation in Kareem–Rudeis Formations in the Central Gulf of Suez, Egypt

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**ABSTRACT**

The present study focuses on organic geochemical studies of source rock and crude oil in Kareem and Rudeis rocks in GG85-1, WFA-1 wells in the central Gulf of Suez. The objectives of this study are the correlation between the two crude oil samples from Kareem Formation and Rudeis Formation and their extracts. The physical and geochemical studies revealed that the generated oil from Kareem and Rudeis formations are classified as mature and paraffinic oils generated from mixed organic source under suboxic depositional conditions. Meanwhile, their extracts show different maturity level and organic source. Both the geochemical and chemometric analyses (HCA) reveal no affinity between the generated oils of Kareem and Rudeis formations and their organic matter. This indicates that the oils reservoirized in Kareem and Rudeis formation originated from another source rock. Rudeis and Kareem formation are not the effective source rock in the central Gulf of Suez.

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**Introduction**

Gulf of Suez is located at the intersection of the African and Arabian plates trending an NNW-SSE direction. Geomorphologically, it is known as the clysmic rift. It is bounded by Sinai massive on the east and Red Sea hills of the Eastern Desert on the west. It contains more than 80 oil fields in reservoirs that vary from the Precambrian to Quaternary in age (stratigraphically). And it is considered the most producer oil rift basin in the Middle East and Africa [1, 2]. The area lies between longitudes 33° 11' 47.39 and 33° 11' 47.49 E and latitudes 28° 43' and 28° 34' N in the central Gulf of Suez (Figure 1). The sedimentary sequence in the studied area ranges in age from Lower to middle Miocene, located in south October block. (Figure 2) shows a generalized stratigraphic column of the central part of Gulf of Suez. The Gulf of Suez has 3 major sedimentation episodes; pre-rift, syn-rift and post-rift sediments. Many authors evaluated The Gulf of Suez source rock [3-5]. The organic abundance, kerogens category and thermal progress from some wells in central Gulf of Suez were investigated to ascertain the probabilities of hydrocarbon generation [6]. Detailed oil-source rock and oil-oil correlations study provide information about the genetic origin of the oils, the prospective area of the effective source rock and optimizing the conventional hydrocarbon exploration in the study area. In this study, we investigated the geochemical characteristics of Kareem and Rudeis oils and correlated it with Kareem and Rudeis source rocks based on biomarker and chemometric studies to define oil origin and identify the role of Kareem and Rudeis formation in the hydrocarbon generation in the central Gulf of Suez.



**Figure 1:** Location map of the studied area, central Gulf of Suez, Egypt.

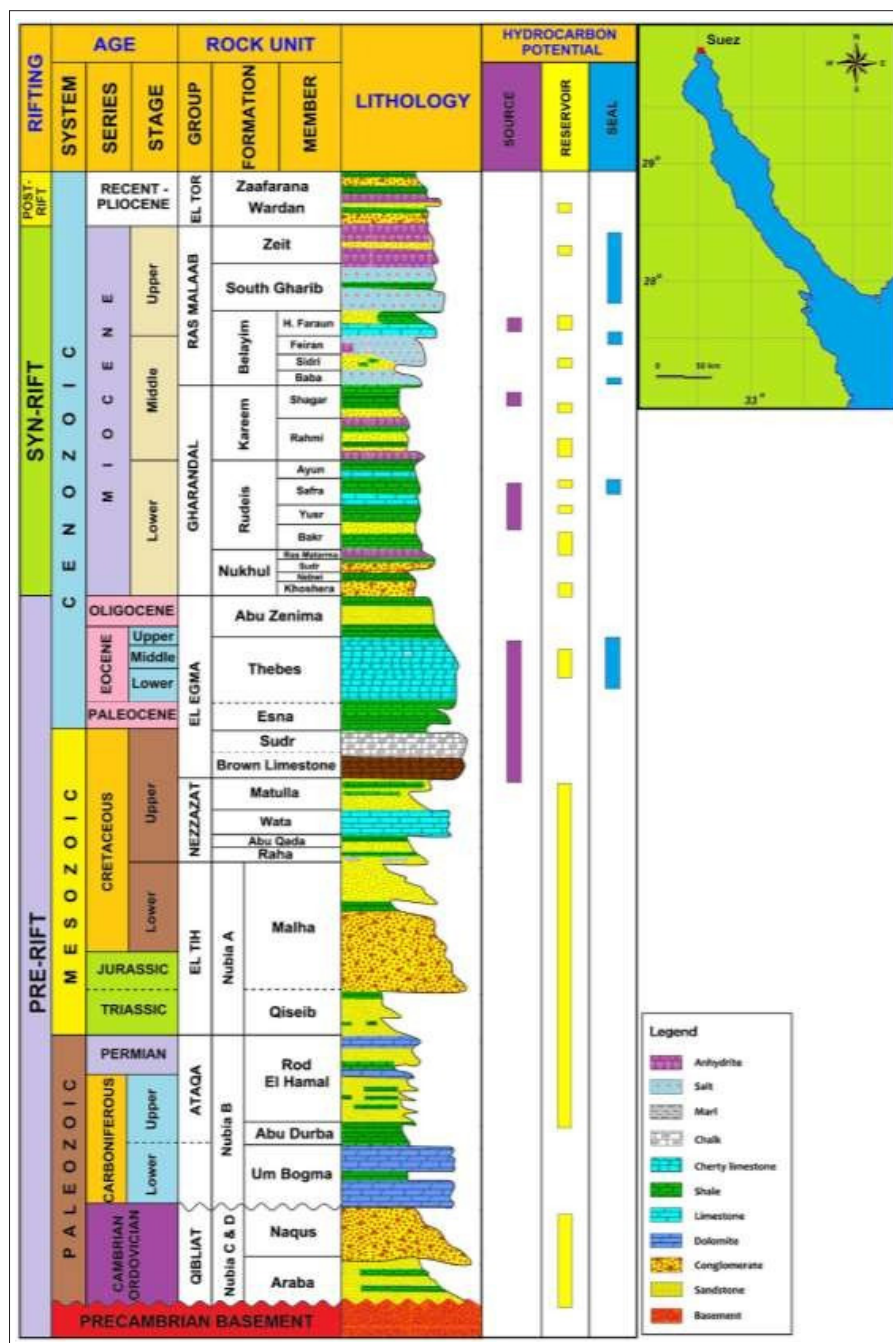


Figure 2: Generalized stratigraphic column of the central Gulf of Suez (El Diasty et al. 2019)

### Geologic Setting

Gulf of Suez province is made up of a thick sedimentary succession that spans the Paleozoic to Cenozoic and was formed by 3 main tectonic rifting episodes from the Cambrian up to Recent. These successions vary in thickness, hydrocarbon potential, lithology, areal spreading and sedimentation environment. The pre-Miocene sediments comprise Paleozoic to Lower Cretaceous Nubian sandstones capped by upper Cretaceous to Eocene carbonates and minor clastics. The two major lithologic units represented in the overlying Miocene sediments are clastic sequence overlain by a series of evaporites. Many reservoirs are considerable in the pre-Miocene sediments. The majority of the oil in the Gulf of Suez comes from the Miocene clastics unit which provides both source rocks and pay horizons, while the middle of Miocene evaporites deposits ensure a respectable seal for the traps developed through rifting juncture [7]. There are several potential source rocks alternating from upper Cretaceous to Miocene. Numerous source rock suggestions fit the complex geological setting of Gulf of Suez rift region, in which sediments subjected to diverse geological circumstances, including deepness of burying, lithology and facies variations, richness and depositional environments. The Gulf of Suez is segregated with two accommodation zones (Zaafarana and morgan accommodation zones) in to three massive hydrocarbon territories with alternating polarity of strata dip direction (Figure 3) The central one (Belayim province) is the most productive hydrocarbon province in Egypt. It providing a promising future oil exploration in this region [8]. According to geophysical and geological evidences, the central and northern parts of it contain numerous elongated, narrow depositional troughs. Gulf of Suez is dissected by a complex pattern of faults: N-S to NNE-SSW in addition to E-W trending normal faults at the rift borders and within the rift basin and NE trending

strike-slip faults, which cross the Gulf basin [9-11]. Interpreted the extension of the Gulf of Suez rift basin due to the interaction of 4 major fault trends during Late Oligocene-Early Miocene. Successions of the Miocene age (Gharandal-Ras Malaab groups) are shallow to open marine environments, mainly affected by the structure framework developed through the Early-Middle Miocene time [12]. Organic-rich source rocks and good quality reservoir rocks found in the Lower Miocene Gharandal Group's sediments. Gharandal sediments is superimposing the Ras Malaab Group which, comprises mostly of evaporite, salt and anhydrite sediments. It was formed during the Middle-Upper Miocene and providing excellent regional cap rocks for Miocene reservoir rocks from pre-rift and syn-rift periods [13]. Through the initiating of Langhian time (Kareem Formation), open marine conditions were registered along Gulf of Suez. The prevailing marine circumstances lead to deposition of a tinny anhydrite bed at the lower segment (Rahmi member) of the Kareem Formation [14]. The Miocene section consists of two main groups. The lower is the Early Miocene clastics (Gharandal Group) and having the Nukhul, Rudeis and Kareem formations. This followed by Middle Miocene evaporites (Ras Malaab Group). Belayim, South Gharib and Zeit

formations represented as this upper group. The Gharandal clastics represent the lower part of the Miocene sequence in the Gulf of Suez area. It consists of sandstones, shales, limestones and minor anhydrite beds. It varies greatly in thickness from place to another and represented by the following formations arranged from base to top: Nukhul Formation represents shallow marine clastics, and changes in areas to marls, limestone of shallow to partly open marine environment at the upper units [15]. It reflects a continuous subsidence of the basin and changes into open and deep marine conditions during the deposition of the overlying Rudeis Formation. Nukhul sediments unconformably overlie the Eocene rocks and are mainly composed of limestone, sandstone and shale. Anhydrite forms an important lithological component of Nukhul in the southern half of the Gulf of Suez, but it is absent in the northern half. This possibly suggests more open marine environment at the northern half, compared to the restricted shallow depositional environment at the southern half of the Gulf Suez. The four members of Rudeis Formation are Bakr, Yusr, Safra, and Ayun. The first two represent the lower Rudeis open marine marl and shale, while the other two represent the upper Rudeis coarse clastics (mostly sandstones).

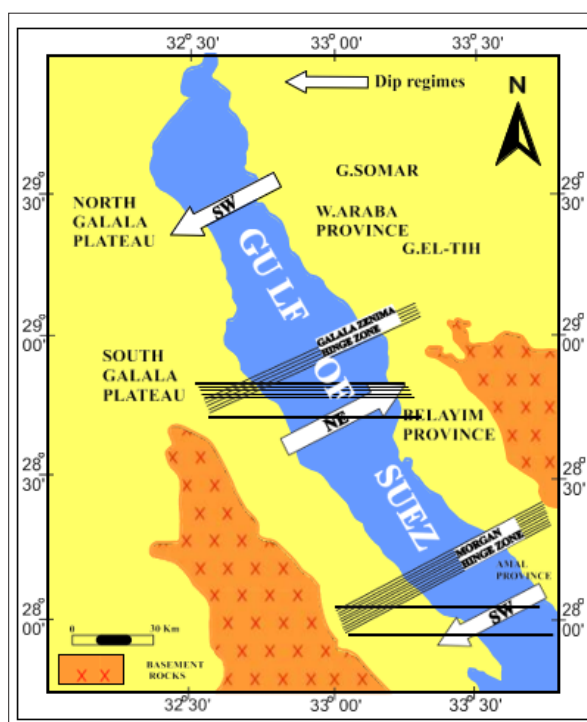


Figure 3: Generalized Gulf of Suez massive tectonic provinces (Modified after moustafa, 1976).

### Materials and Methods

Two rock samples and two oil samples from Kareem and Rudeis formations were collected from WFA- 1 and GG85-1 wells in central Gulf of Suez. Routine analyses including API, Sulfur, Vanadium and Nickel measurements were performed on oil samples. Vanadium and Nickel were measured using atomic absorption spectroscopy. About 20-30 60 g of rock samples was extracted for 72 h in a Soxhlet apparatus using chloroform. The extracts and oil samples were deasphalted by n-pentane. The saturated hydrocarbons (SAT), aromatic hydrocarbons (ARO), and NSO compounds were isolated from the deasphalted fraction by column chromatography using sequential elution with n-hexane, benzene and chloroform, respectively. The GC-MS analyses of the saturated hydrocarbons were performed on an Agilent 6890 Series equipped with a flame ionization detector (FID). Oven temperature was raised from 100°C to 300° C at a fixed rate of 3 °C per minute with HP-1 fused silica capillary column (60 m, 0.53 mm, 0.5 lm).

Three chemometric analyses (e.g., Hierarchical clustering analysis (HCA), factor analyses and Star plot) were performed using different biomarker ratios by using IBM SPSS statistical software (Table 1 & 2) [16].

## Results and Discussion

### Physical Characteristics of Oils

The physical properties of studied oil samples are presented in Table 1 including Sulfur, Vanadium, Nickel and API gravity. The studied oil samples have moderate API gravities with values 28.45° and 35.14° in Kareem and Rudeis oils respectively, indicating that these oils are normal oils [17,18]. These samples show low sulfur content with values ranging between 0.07-0.09 wt % suggesting that these oils are mainly Paraffinic or Paraffinic-naphthenic oils generated in high maturity levels [19]. Plotting the relation between API gravity and Sulfur content indicating that the studied oils were generated from type II low sulfur kerogen (Figure 4). Vanadium (V) and Nickel (Ni) contents provide a good implication on the depositional conditions of organic matter [20]. (Table 1). The studied oils have high V/Ni ratio in the range of 1.1 and 1.6 indicating marine-transitional environments during the deposition of organic matter [21]. The relation between sulfur content and V/Ni ratio confirmed this result (Figure 5).

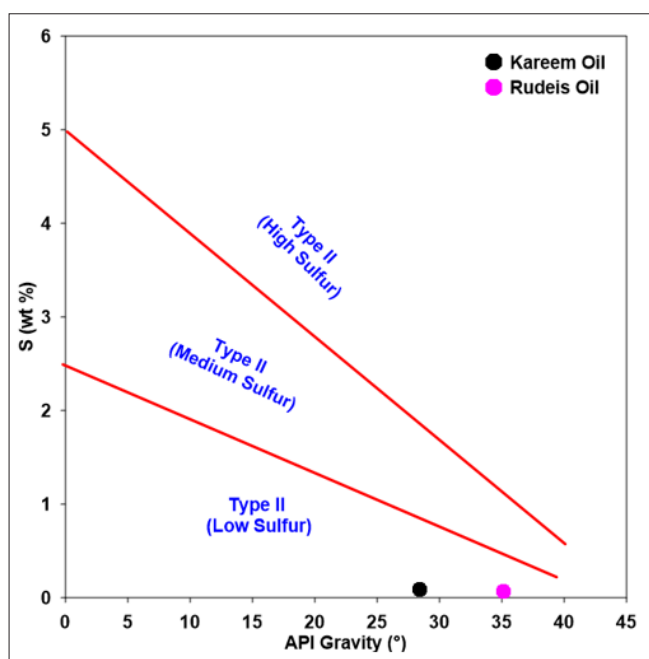


Figure 4: Cross plot of the API gravity versus sulphur content (Orr,2001).

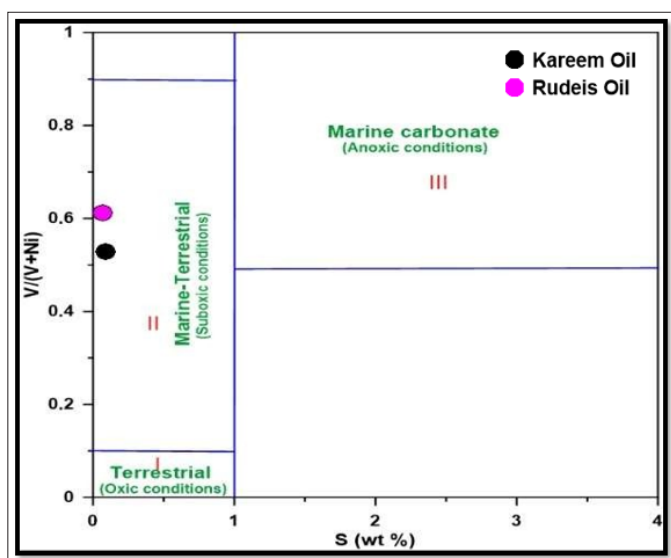


Figure 5: V/(V+Ni) ratios versus sulfur content for the oil samples, central Gulf of Suez, Egypt (After Lewan, 1984).

### Gross Composition of Oils and Extracts

The bulk chemical composition of the studied oils displays the dominance of the saturated fractions than other fractions (57.9-62.1 %) followed by aromatics and NSO compounds and asphaltenes. In contrast, Kareem and Rudeis extracts show high abundance of NSO compounds and asphaltenes (49.68%-70.34%) relative to saturate and aromatic fractions (Table 2). Based on Tissot and Welte ternary plot of bulk composition, the studied oils are classified as paraffinic oils, meanwhile the extracts belong to Paraffinic-naphthenic oils (Figure 6) [19].

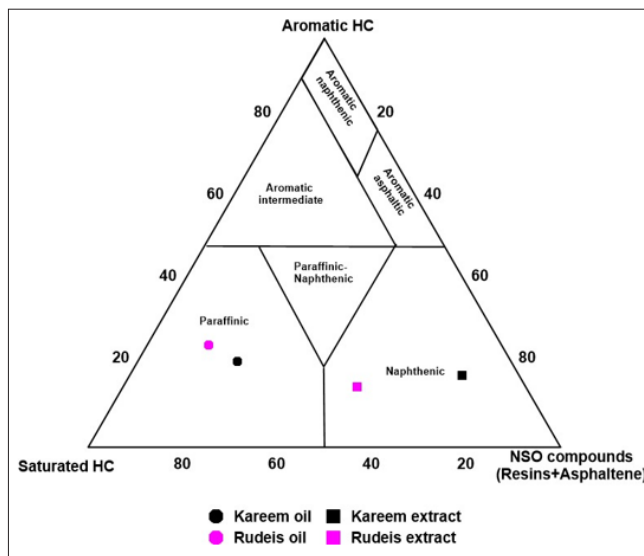
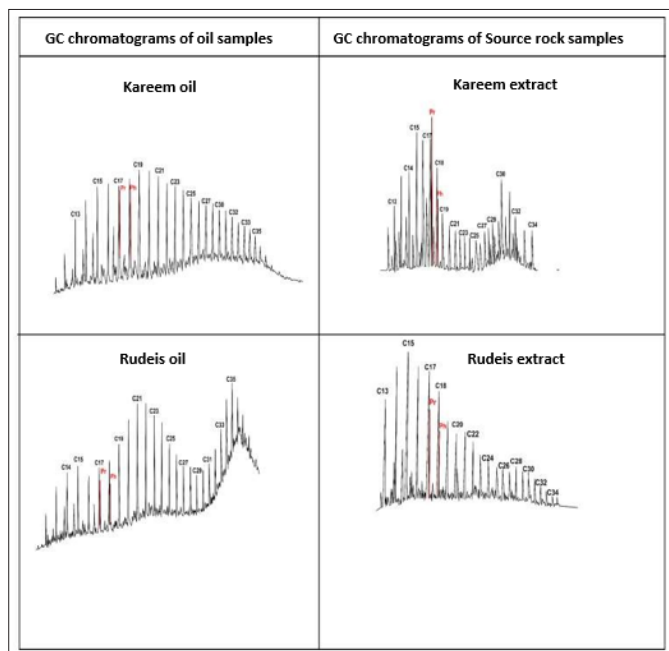


Figure 6: Ternary diagram of the gross compositions of studied oils and extracted samples

### Molecular Compositions and Depositional Environment of Oils and Extracts.

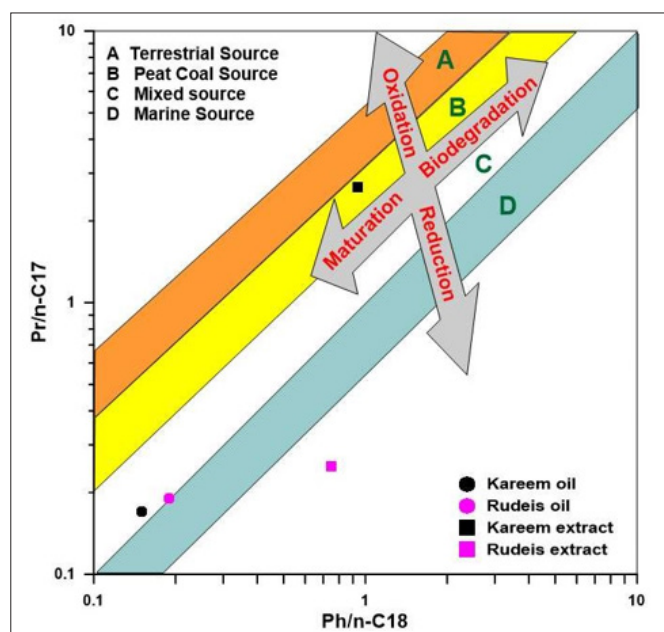
The distribution of n-alkanes in both oil samples and Rudeis extract are dominated by short and medium chains n-alkanes besides the low concentration of long chain (> n-C30) (Figure 7). This distribution is closely related to mixed organic matter sources (substantial marine organic matter) with CPI and OEP values in the range of 1.17, 1.11, 1.31 and 1.08, 1.12 and 1.27 respectively (Table 2). All these parameters show that the studied oils and Rudeis extract are mature and moderately mature, respectively. On the other hand, Kareem extract show bimodal profile of n-alkanes distribution, with abundance of odd carbon numbers displaying high CPI and OEP values equal to 2.84 and 1.86 respectively (Table 2). This indicates that the organic matter of Kareem Formation is originated mainly from less mature terrestrial organic source [22, 23].

Isoprenoid ratio (Pristane/ Phytane) is considered as a good indicator used to determine the source and depositional environment of organic matter [24]. a Pr/Ph ratio less than 0.8 is related to a highly saline and anoxic environment and that ranges from 0.8 -3.0 indicates a suboxic to oxic environment [25].



**Figure 7:** Gas chromatograms of saturated hydrocarbon fractions of oil and extract samples.

The studied oils have high Pr/Ph ratio (2.12-2.14), low Pr/n-C17 (0.17-0.19) and Ph/n-C18 ratios (0.15-0.19) indicating mature oils generated from mature organic matter, and deposited in transitional environments under suboxic conditions (Table 2; Figure 8). Rudeis extract has Pr/Ph, pr/n-C17 and Ph/n-C18 ratios equal to 1.23, 0.25 and 0.75 suggesting marine organic matter deposited in reducing conditions (Table 2; Fig.8). On the other hand, Kareem extract displays high Pr/Ph, high Pr/n-C17 and Ph/n-C18 ratios reflecting terrestrial organic matter deposited in oxidizing conditions (Table 2; Figure 8) [17].

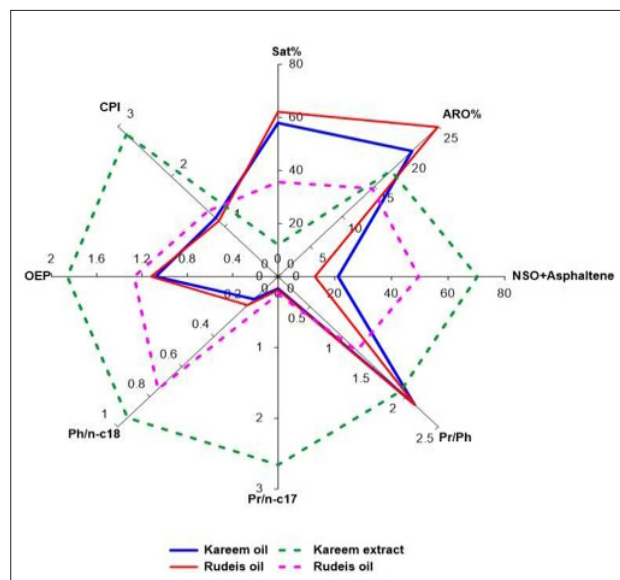


**Figure 8:** Cross plot of Pr/n-C17 vs. Ph/n-C18 for the oils and extracted rock

### Oil/Oil-Source Rock Correlation

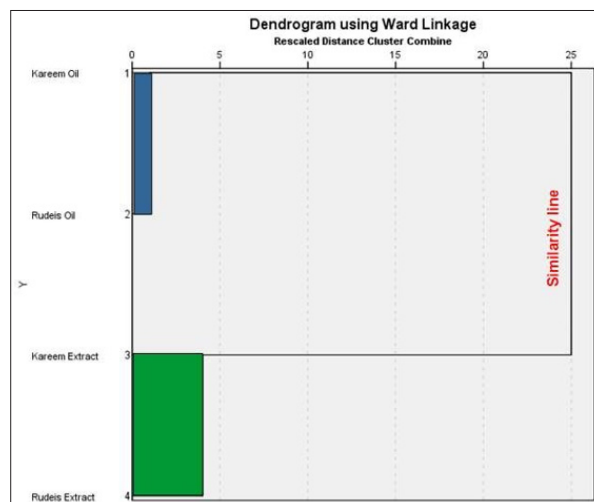
Oil-source rock correlation purposes to find the genetic relationship between source rocks and oils [26]. Based on the chemical compositions, biomarker fingerprints.

The star plot developed by is one of the fast tools for oil-oil or oil-source rocks correlation studies. As shown in Figure 9, the biomarker ratios were plotted on the star plot to assess the similarity or dissimilarity of the studied oils and extracts (Table 2). In star plot, it was noticed that oil samples show similar profiles with regular/significant grouping. Furthermore, oil samples and extracted samples are with different profiles and did not show any regular/significant grouping [27].



**Figure 9:** A polar plot of biomarker ratios to compare oil and rock similarities

Hierarchical cluster analysis (HCA) was applied to correlate oil to its specific source rock. In this study, we have plotted some of the source and maturity diagnostic saturate biomarker parameter in a dendrogram using Wards method. (Table 2). Figure 10 shows that Kareem and Rudeis oils have no link to Kareem and Rudeis extract. No similarities between oils and extracts of Rudeis and Kareem formations in the central Gulf of Suez oils are present [28-31].



**Figure 10:** Result of hierarchical cluster analysis (HCA) of oil and rock samples using the bulk composition and biomarkers.

## Conclusion

The studied oils in Kareem and Rudeis formations are classified as paraffinic and normal mature oils, meanwhile, their extracts belong to Paraffinic-naphthenic, and heavy marginally mature oils.

Kareem and Rudeis oils originated from mixed organic source deposited in suboxic conditions.

Kareem organic matter originated mainly from terrestrial organic matter deposited in oxic conditions.

Rudeis organic matter originated from marine organic matter deposited in reducing conditions

The oil samples show a degree of maturation more than the extracts

No correlation between oils and extracts of Rudeis and Kareem formations in (GG85-1 and in the central Gulf of Suez oils is present indicating that the oil generation of Kareem and Rudeis seems to be migrated from different source rocks.

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