Mineralogy and Geochemistry of Yamama Formation
(Late Beirussian-Early Valanginian), Southern Iraq

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ABSTRACT

A total of 138 core samples were collected from six subsurface sections of Yamama Formation. These sections were randomly distributed in West Qurna and Nahr Ulya oilfields. The collected samples were analyzed for Ca, Mg, Fe, Na, Mn, Sr, Pb and insoluble residue using wet chemical analysis, in addition of representative samples were examined by X-ray.

X-ray diffractograms revealed that the bulk samples consist of calcite, dolomite, and subordinate dolomitic quartz. Whereas, the clay fractions of insoluble residue consist of kaolinite, illite, illite-montmorillonite mixed-layer. The kaolinite percentage shows a marked increase in Nahr Ulya Field (i.e. towards the palaeoshoreline).

The concentration of V, Mg, and Pb progressively increases in water salinity increases. The Fe and Mn concentrations are function of the clay content of the sediments, while the concentration of Sr is largely controlled by the fossil debris. Regarding Pb no systematic trend in its distribution was noted, i.e. it has an erratic distribution.

Ca/Mg, Mn/Ca, and Fe/Mn atomic ratios proved that Yamama Formation were deposited in a shallow marine-lagoonal-Mackenzie environment.

جمهوريماتی و معنیت تكوین الپاسه (البریحیان المنظر-الفلاحیان المیکری)

جغرافی العراق

لtypescript

تم جمع 138 نمونة نباتية من منطقة هادف تحت سطحية من تكوين الپاسه. هذه النماذج موزعة
عندما تلقي الپاسه ودرودة في المحمية. بلغت نماذج المجموع إلى عناصر الالمنيوم والمعادن
الحديد والصوديوم والفلور والهنفياتوم والفسانس والاصطناعات غير الپاسه، كما أن 10% من مجموع
النماذج تم تفكيكها بالأشعة السينية لحالة
INTRODUCTION

The stratigraphic column of southern Iraq is characterized by rich oil reservoir assemblages with important hydrocarbon accumulations within many formations. Yamama Formation represents one of the most widely distributed reservoirs in Iraq and neighboring areas (Fig. 1). It also forms one of the most important oil production reservoirs, in southern Iraq that extends from Late Berriasian to Early Valanginian within the main regressive depositional cycle (Berriasian-Aptian) south of Iraq. Yamama Formation was first described by (Weisske and Hazanbamp, 1952), citing in (Van Bellen et al., 1959), from the type locality at Yamama area, Saudi Arabia as a member of Yamama Group, beside, Sahna and Rebi Formations. Yamama Formation in this area is composed of fragmental limestones. There is no any surface exposure for Yamama Formation is expected in Iraq and the reference section for this formation has been selected by (Rezabak, 1952), citing in (Van Bellen et al., 1959), in Rashid well no.1, at depth interval (3065-3854 ft). It consists of dense limestones with carbonate development. The Formation is conformably overlain and underlain by the Rashid and/or Sahna Formations respectively (Buday, 1950).

Yamama Formation was laid down in a depositional basin of a wide geosynclinal belt. It covers a large area, south-central Iraq and extend inward to central and northern parts, where it is replaced by Zagara and Grai Formations. Zagara Formation consists of thinly bedded limestones and clayey limestones whereas Grai Formation consists of algal lime and dolomitic limestones (Al-Awely, 1985). In Kuwait, Yamama is replaced by equivalent Khangah Formation (Robelathan, 1979), cited in (Mathlith, 1999).

Yamama Formation has been studied by many workers owing to its economic importance. There studies have dealt with stratigraphic, sedimentologic and micropalynologic aspects. The purpose of this work is to through more light on these micropalynologic and geochronological characteristics of this formation in order to consider its depositional and diagenetic conditions.

METHODLOGY

A total of 138 samples were collected from six subsurface sections of West Qurna (WQ) and Nasrida (N) field, southern Iraq (Fig. 2). The distribution of samples are as follows: 29, 30 and 31 from N-2, N-3 and N-5 Samples 32, 33 and 34 from WQ-12.
WQ-14 and WQ-15 respectively. The uneven distribution of the samples throughout the boreholes is attributed to the lack of some cores in some boreholes. The petrographical

Fig. 1: The stratigraphic column of southern Iraq and neighboring areas (Van Belle et al., 1999).
Fig. 2: Location map.
characteristics of Yamama Formation have been discussed previously by (Al-Mohamed, 2002). Therefore, only the geochemical and mineralogical studies are given here. The collected samples were firstly cleaned by washing using distilled,터리와 염화수를 사용하여 처리한 후, 합성식으로 모델화되었다. 즉, 초기 침전물을 통해 나타난 투명한 고분자질산(AS), 카르고 스트립과 Mg는 질소로 끓여진 후, 무온실에서 분석하였다. 그 결과, 원측의 모델화된 침전물은 치명적인 결과로 파악되었다.

The identification of clay minerals in the obtained effluent fractions was based mainly on the first basal reflection and according to the method of (Ghose, 1987) and (Carr, 1970). Furthermore, the bulk samples were also examined by XRD. The XRD analyses were carried out using Philips PW 1850 X-ray spectrometer using Cu-Kα radiation source and Ni filter.

To ensure the reproducibility of the analytical results, the precision of the chemical analyses was determined following the methods of (Watanabe, 1969), (Maxwell, 1968) and (Rosenthal et al., 1979). And were within the acceptable value at both 95% confidence level, the applied methods were of high analytical accuracy (1-2%).

The resulting raw data were statistically treated. The range, mean and standard deviation (S.D.) for the components together with their correlation coefficients were calculated (Table 1). Furthermore, Frequency histograms were constructed using long-normal intervals according to the method suggested by (Cepheus, 1969).

MINERALOGY

The mineral contents in the Yamama Formation samples could be categorized into two groups:

1. Carbonaceous minerals. The XRD analyses (diffraction patterns) (Fig. 3) depict the occurrences of the following minerals according to their abundance: low Mg calcite, dolomite with trace amounts of pyrite (Fig. 4).

2. Clay minerals. Kaolinite, illite, and illite-muscovite interstratifications. All these minerals were previously recorded in the Iraq carbonate oil reservoirs (Al-Vanswenti and Al-Hamoud, 2004).

Kaolinite in carbonate rocks is usually of detrital origin whereas illite may be of detrital or diagenetic origin (Patton, 1975); however, in carbonate rocks in the study area could be the result of illite transformation into smectite in units and subsequent incorporation into marlstone basins (Plagel, 1982). Mixed-layered clay minerals could be either detrital (Carr, 1970) or diagenetic (Carringer and Posner, 1986).

Kaolinite forms the major part of clay minerals that encountered within the IR of Yamama Formation. The dominance of kaolinite with well-crystallized form reflect the near-shore environment (Plagel, 1982), and the detrital origin, wet climate and low topographic relief of the neighboring area (Mullot, 1976). Moreover, the amount of kaolinite shows a marked increase in Nasib field, i.e., towards the palaeoshoreline.
Table 1: Minimum, maximum, mean and standard deviation of the studied components in West Qurna (WQ) and Nassaria fields and their correlation coefficient.

<table>
<thead>
<tr>
<th>Component</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Qurna Field</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
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Fig. 3: X-ray diffractogram of the Yamana carbonate bulk sample.
Fig. 4: X-ray diffractions of clay minerals within LR.
Illite-montmorillonite mixed layers constitute the minor part of the detectable clay minerals. IIllite seems to be of diagnostic origin formed by the addition of smectite layers to the ordinary sheets of illite, as shown by the elongation in 10 A' peaks together with the weakening or disappearance of the secondary reflections. Based on (Jubb, 1981), the present illite-montmorillonite mixed layer represents a transition stage in the smectite to illite transition (with increasing depth in clay bedrocks) which involves the incorporation of K ions into the smectite structures and loss of interlayer water, this process is largely depth and temperature dependent.

GEOCHEMISTRY

The geochemical characteristics of Yamama Formation have been discussed according to the distribution of major and trace components as well as the inter-elemental relationships.

The average of CaO and MgO concentrations in Yamama Formation in WQ and Ns-fields were 31.73%, 3.38%, 34.76% and 0.57% respectively (Table 1), which are less than those reported by (Dejiab, 1992) and (Helal, 1992) (Table 2). The low Mg content reflects low degree of dolomitization which could be attributed to:

1. The relative low salinity of dolomitizing solution.
2. The depletion of the available Mg throughout the anhydrite-law Mg calcite inversion.

Table 2: The average concentration of the selected components of Yamama Formation in comparison with other carbonate rocks.

<table>
<thead>
<tr>
<th>Component</th>
<th>Major Oxides %</th>
<th>Trace element ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CaO MgO FeO K2O Na2O Mn Sr Pb</td>
<td></td>
</tr>
<tr>
<td>Bast, 1953</td>
<td>45.67 7.9 2.54 3.05 508 - -</td>
<td></td>
</tr>
<tr>
<td>Enk, 1989</td>
<td>53.35 4.7 3.33 2.94 1000 830 7</td>
<td></td>
</tr>
<tr>
<td>Mesopotamia, 2001</td>
<td>41.25 0.69 2.34 9.66 151 356 -</td>
<td></td>
</tr>
<tr>
<td>Present study</td>
<td>WQ</td>
<td>31.73 0.18 0.06 0.66 25 282 35</td>
</tr>
<tr>
<td></td>
<td>Ns</td>
<td>34.76 0.17 0.06 0.66 25 282 35</td>
</tr>
</tbody>
</table>

The Fe content varies from 33 to 2244 ppm. with an average value of 1671 ppm in WQ, whereas it varies from 25 to 3581 ppm, with an average of 189 ppm in Ns-field. A comparison between (Bast, 1953) and international carbonate composition is shown in (Table 2).

The interesting point is that the Fe content of Yamama carbonates in WQ-field is seven times that of Ns-field. The present high Fe values is related to two main factors:

1. The abundance of clay minerals in the third micritic facies which has a wide distribution in WQ-field (Al-Mohamed, 2002).
2. The presence of pyrite within the 1 R.

Iron has a unimodal distribution in both fields under study but platy bars in WQ and 1-equidimensional in Ns-field as shown in (Fig. 5). This more likely attributed to a unimodal
supply of Fe in WQ depositional basin. Moreover, a negative correlation between Fe-Mg, Fe-O, and Fe-Ca is reported in Na- and WQ-field respectively. These relationships indicate that Fe is mainly associated in dolomite in Na and Mg-calcite in WQ-field. Finally, Fe concentration, which is typical of Na- and WQ-field, illustrates the similarity in geochemical behavior between Fe and Mn as they substitute each other in the carbonate minerals (Faire, 1998).

Regarding Sodium, this element is known to be used as a useful indicator of salinity of depositional and diagenetic solutions (Land and Hoos, 1973). The average Na contents in WQ and Na-field is greater than that reported in barren carbonate rocks (Table 2), which implies that the depositional basin of Yamama Formation ecologically unstable leading to the diversity of lithological microfacies (Al-Munmae, 2002).

Sodium possesses a similar unimodal distribution in both fields (Fig. 4), but WQ-field shows a wide distribution with platylinite whereas Na-field shows leptokurtic peak, which means that Na in the former field was shared among many minerals in comparison with the latter. The absence of any significant correlation between Na and other measured components reflects the independent behavior of this element, which resulted from high Na dissolution rate as well as through diagenetic processes (Anhydrite-Caliche: inorganic and recrystallization), and the rate of deposition (Rio et al., 1998).

The Mn content in the present carbonate sediments is lower than that documented in the barren carbonate rocks (1420 ppm) reported by (Basar and Momen, 1982), (Basar and Momen) (1988). They found that Mn content in carbonate formed under humid climate (average 350 ppm) or under arid climate (average 230 ppm). On the other hand, (Dowiri and Teel, 1974) and (Sauter and Teel, 1983) suggested that Mn content in sediments increases with depth. Therefore, the present Mn content could indicate that Yamama Formation was deposited in a shallow basin developed under arid climate. Moreover, the Mn in the studied carbonate rocks seems to be associated with clay minerals as evident by the direct relationship between Mn and LR in both fields under study; it is worth mentioning that the statistical treatment of Mn data shows that it has a unimodal distribution in WQ and Na-field (Fig. 5). Nevertheless, Mn in WQ-field exhibits wide and homogeneous distribution in comparison with Na-field. This may indicate the systematic detrital supply of terrigenous material for WQ depositional basin.

The structure content in recent carbonate sediments and ancient carbonate rocks varies in a wide range. Generally, its content in recent carbonate is about two times than in ancient carbonate rocks (Siegle, 1984). This variation is attributed to activity, paleogeography and paleo-state of depositional basin as well as the diagenetic processes. The average Sr content of Yamama carbonate sediments in WQ-field (54 ppm) is greater than its average content of (285 ppm) in Na-field. This result is attributed to the following factors.

1. The WQ-field is situated in a deeper part of the depositional basin relative to Na-field.
Fig. 5: Histograms showing the distribution of the studied components in West Qurna (WQ) and Nusaybin (NS).
3. The line of Sr during dolomitization process is more intensive in Na Field in WQ-Field. This conclusion is supported by the work of Shearman and (Shekhram, 1989) cited in Dhar et al. (1986) who found that the dolomitization of limestone occurred at different Sr content at each stage. It is shown from the histograms (Fig. 5) that the Sr distribution in the studied rocks is unimodal. But with a wide peaky aspect distribution in WQ Field and narrow leptokurtic in Na-Field, which probably is related to diversity of Sr environments in WQ field which is related to carbonate sediments, organic debris, and L.F. The inverse relationship between Sr and Na in Na-Field, however, represents the only significant relationship observed (Table 1). This relationship showed that Sr was replaced by Na during dolomitization process, because the structural lattice of dolomite is more suitable for Na with Mg accommodation instead of Sr (Barber, 1974).

The lead content ranges from 18 to 43 ppm and from 23 to 48 ppm with an average value of 34 and 35 ppm in WQ and Na-Fields respectively. The closeness of Pb averages, the similar unimodal distributions (Fig. 5), and the absence of any significant correlation between Pb and the other measured components reflects the uniform distribution of Pb within Yarmouk Formation. It is believed that Pb occurs in form of sulphide owing to the available sulphur under reduced conditions of Yarmouk Formation (sedimentary reducing conditions).

The study of L.F. is advanced to be a complementary to the petrographic study because it reflects the subtle or existing conditions of depositional and diagenetic environment (Assir, 1980). In the present study it has been found that all samples contain L.F. ranging from 0.8 to 35.18% with a general trend of increasing from Na (0.8) toward WQ-Field (0.9-0.63). The clay minerals are generally more abundant in the quenched low energy marine environment (Hill, 1977). Therefore, the variation in clay content reflects the different depositional environments of various energy. The frequency distribution of L.F. (Fig. 5) shows that L.F. homogeneously distributed throughout Na-Sequence in comparison with WQ. The direct correlation between Na and L.F. suggests that most of L.F. in Yarmouk Formation is adsorbed by the clay minerals. Eventually the carbonate sediments of Yarmouk Formation were classified in more than one depending on the classification of (Bath et al., 1999) cited in (Peterson, 1975) (Fig. 6).

Elemental Ratios:

CaO/MgO, Sr/Ca, and Fe/Ca ratios were used in this study to provide ample evidence dealing with depositional environment and diagenesis of Yarmouk Formation. The average CaO/MgO molar ratio in WQ and Na-Field is 46 and 44 respectively. The high CaO/MgO molar ratio refers to the less effective of dolomitization process, which clarify that Yarmouk sediments were lithified and stabilized in an environment, in which the dolomitized fluids were not so much effective due to low degree of initial porosity which controlled the rate of dolomitization. Ca/Mg molar ratio was also employed in classifying the studied carbonate rocks using Carters classification (1957). Accordingly WQ and Na-Field carbonate rocks can be grouped into five and three groups respectively (Fig. 7).
Fig. 6: Classification of Yanmar calcareous rocks owing to (Barth et al., 1959) in (Petts, 1978).

Fig. 7: Classification of Yanmar carbonate rocks according to (Chilingar, 1957).
The mean value of Sr/Ca atomic ratio in WQ and Na-fields were 1.53 and 1.147 x 10^{-2} respectively. Owing to (Friedman, 1968), these ratios indicate shallow marine conditions.

According to superimposing of the Ma and Mn data of the present study (Fig. 8) with standard (Friedman, 1968) graph, it is evident that the available data exhibit that the Kurnia Formation is located in a zone extending from marine to lagoonal to brackish sector.

![Graph](image)

**Fig. 8** Superimposing of Sr/Mg relation over Friedman’s graph (1968). Circles for marine carbonates and triangles for lagoonal carbonates.
Vertical Distribution

The chemical components reveal different patterns of vertical distribution throughout the studied sequence (Figs. 9 and 10). Ca and Mg behave in opposite manner, this is due to the substitution of Ca for Mg during dolomitization. Fe and Mn have a similar pattern of distribution as a result of their similar geochemical behavior. Furthermore, Na and Sr vary in reverse way although both of them depending upon the salinity of sea water but they behave in reverse way, which means that the source of the present Sr is the organic carbon remains, while the increase in Na content could be attributed to the variation in salinity of sea water. Finally, no serious changes in Pb contents observed throughout the sequence confirming the independent behavior of this element.

Fig. 9: Vertical distribution of the studied components within Yamama Formation in WU-12.
Fig. 10: Vertical distribution of the studied components within Manzana Formation in Nas 5.
CONCLUSIONS

Based on the geochemistry and mineralogy of Yamama Formation, the following conclusions have been drawn:

1. Low-Mg calcite, dolomitic, albitic, and albite-aragonite mixed layer and pyrite are of diagenetic origin, whereas kaolinite and chlorite are of detrital origin.

2. A detrital influx was inferred to be associated with the Yamama carbonate deposits. This study suggests that such an influx is mainly composed of quartz and feldspar.

3. The abundance of kaolinite and low-Mg calcite showed that the studied carbonates were deposited in a shallow marine environment and suffered from low effective dolomitization.

4. The presence of albitic and interstratified foliation may indicate an authigenic origin. This is because of the possibility of the formation of the two minerals by reaction of K between the layers of kaolinite or montmorillonite during the deposition and/or the diagenesis.

5. The distribution of major and trace elements showed no distinct trend of variations toward upper and lower contacts, which reflects the instability in depositional conditions.

6. The low Mo contents demand within Yamama Formation suggest the shallow depositional environment, and low clay minerals supply because of arid palaeoclimatic conditions.

7. Owing to the insoluble residue and Ca/Mg ratios, it has been found that about 70% and 60% of Yamama carbonate were classified as pure limestone and dolostone, respectively.

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