ELEMENTS DISTRIBUTION FOR THE UPPER SANDSTONE MEMBER OF THE ZUBAIR FORMATION IN ZUBAIR OIL FIELD, SOUTHERN IRAQ

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ABSTRACT

The upper sandstone member (Z/2) is one of the most important reservoirs in the Zubair Oilfield, south of Iraq. It belongs to the upper part of the Zubair Formation, the Lower Cretaceous age, and deposited in deltaic environments. The upper sandstone member consists of several sandstone units which are isolated by the shale units. Major trace and rare earth elements (REEs) of the upper sandstone member in Zubair Formation have been analyzed. Six core samples were used to determine the source of sediments, paleo-environment redox condition and elements concentrations. The geochemical analysis data indicate that the source of sediments rock was influenced by a low to moderate degree of weathering conditions in the Hammar and Safwan Domes. The results have shown that all samples were formed in an oxic environment, with humid paleoclimate. Geochemical analysis data indicate that all rock samples are fundamentally derived from rhyolitic and andesitic rocks more a felsic source. The results show that the samples are mainly of marine organic matters input. The values of Chemical Index of Alteration in the Hammar Dome range from 13.05 to 24.37, while from 23.72 to 77.22 in the Safwan Dome. These results may attribute to fine and medium clastic sedimentary rocks in the H sandstone unit, with a low degree of weathering in the Hammar Dome, and high to medium with slightly higher abundance of clayey silts in the Safwan dome.

Keywords: Rare earth elements; Zubair Oilfield; Zubair Formation; Safwan Dome

INTRODUCTION

The chemical compositions of the sedimentary rocks are the products of many factors such as

transport, weathering conditions, provenance, diagenesis and climate (Johnsson and Basu, 1993). Geochemical analysis of major and trace elements can provide a detail of the sediment composition, origin of the sedimentary rocks, and paleo-weathering conditions (Nesbitt and Young, 1982; Taylor and McLennan, 1985). Zubair Oilfield is located in southern Iraq, approximately, 20 Km southwest of Basrah city. It is located between 47° 32'– 47°45' Latitude and 30° 42'–30° 05' Longitude. It covers an area of about 1170 km². It is bounded from the north by the Nahran Umr Oilfield, and from the west by the Rumaila Oilfield and from the south by the Kuwait-Iraq borders (Fig.1). The Zubair Oilfield consists of three domes, Safwan, Rafidiyah and Shuaiba-Hammar Domes from the south to the north respectively (ZFOD, 2016) (Fig. 1).

The average thickness of the Zubair Formation ranges 380–400 m. It is an alternation of shale, siltstone and sandstone. Zubair Oilfield was first discovered in 1949 and has been operating since 1951. This field is one of the most important oilfields in Iraq after Rumaila and West Qurna Oilfields. Based on the sand/shale ratio, Zubair Formation is divided into five members (Abbo and Saffar, 1967). The upper sandstone member (Z/2) is one of Zubair Formation's members, and has been divided into 11 units including H sandstone unit (ZFOD, 2016) (Tables 1 and 2). (Awadh et al., 2018) studied the geochemical indicator of the Paleoredox environment of the Zubair Formation in some oilfields, south of Iraq. (Awadh, 2018) studied the geochemical reaction between the brines and rocks in the Zubair Formation and effect of the brines composition on the reservoir chemistry. (Al-Jafar and Al-Jaberi, 2019) mentioned that the Zubair Formation delta is deposited through sea regression followed by sea progression. In this study, the major, trace elements, and REEs of the Zubair Formation were studied. The main objectives are comparison of chemical composition, revealing the source rocks of sediments, paleo redox conditions, paleo climate, and chemical weathering intensity for the H sandstone unit between Hammar and Safwan Domes in the Zubair Oilfield.

ZUBAIR OILFIELD STRATIGRAPHY

Owen and Nasr (1958) found the typical section of the Zubair Formation in Zubair area, in Well Zb-24; its thickness is 362.9 m which appears at depth of ranges 3523.66–3160.76 m. Based on sand/shale ratio, this formation is subdivided into 5 members, lower shale member (Z/6), lower sandstone member (Z/5), middle shale member (Z/4), upper sandstone member (Z/2) and upper shale member (Z/1) from the bottom to the top (Abbo and Saffar, 1967) (Table 1) (Fig. 2). Upper sandstone member (Z/2) consists of an alteration of sandstone and shale with a total thickness of

110 m, while the thickness of the units that contain the oil is about 55 m. Z/2 consists of eleven different units, but the main reservoir units are five; A, B, H, L and N in terms of oil reserves, the present study focuses on H sandstone unit.

Fig. 1. A. Location map of the Zubair Oilfield (modified after Al-Ameri *et al.*, 2009)
B. Upper sandstone surface map of selected wells in the Zubair Oil field

Table 1. The members of the Zubair Formation (Owen and Nasr, 1958)

Member	Average Thickness (m)	Lithology
Upper Shale Member Z/1	85-95	Shale with two units of sandstone contains the secondary amount of shale
Upper sand Member Z/2	95-110	Sandstone with few amounts of shale
Middle shale Member Z/4	65-75	Black shale with few amounts of Sandstone
Lower sand Member Z/5	50-60	Fine to very fine Sandstone with few amounts of shale
Lower shale Member Z/6	60-70	Fissile, gray to black Shale, with a zone of sandstone

Fig. 2. Location and stratigraphy of the study area. (a) Location of the Zubair Oilfield, (b) Middle Jurassic to Upper Cretaceous stratigraphic column of SE Iraq (after Haq *et al.* 1988), (c) The typical well from South Iraq modified after (Wells *et al.*, 2017)

Table 2. Upper sandstone unit (Member Z/2) of the Zubair Formation (ZFOD, 2016)

Basrah Oil Company (BOC) Units	Zubair Field Operating Division (ZFOD) Units Revision 2	Zubair Field Operating Division (ZFOD) Units Revision 3	Lithology
U SS Mb	AB	A	Sandstone
U sand C	C	B 0	Shale
U sand DJ	H3	B	Sandstone
U sand J2	H2	C	
U sand J1	H1	D	
U sand K	K	K	Shale
U sand L	L3	E	Sandstone
U sand L2	L2	F	
U sand L1	L1	G	
		H	
U sand M	M	H0	Shale
U sand N	N	H1	Sandstone

MATERIALS AND METHODS

The core samples of the upper sandstone member in the Zubair Formation were studied in several methods and techniques. Six core samples were collected from H3, H2, and H1 units for Hammar and Safwan Domes. The first three samples in the Hammar dome were collected from the well Zb-201 at depths of 3256.90m, 3267.78 m, and 3277.50 m respectively. While the other three samples collected from well Zb-184 in Safwan Dome at depths of 3194.88 m, 3201.38 m, and 3207.50 m respectively, as shown in Figure (1B). Bulk geochemical analysis; major, trace and rare earth elements (REEs) were conducted by inductively coupled plasma-mass spectrometry (ICP-MS) analysis in the laboratory of ALS, Spain. The concentrations of major and trace elements were compared against the values of the Upper Continental Crust (UCC) and the Post Archain Australian Shale (PAAS) (McLennan, 2001). The REEs were normalized according to the values of Chondrite according to McDonough and Sun (1995). The chemical indicators, such as chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), and Parker Weather Index (WIP) were used to determine the intensity of weathering (Parker, 1970). This is further supported by calculation of the Chemical Index of Weathering (CIW) (Harnois, 1988), Plagioclase Index of Alteration (PIA) and Index of Compositional Variability (ICV) (Cox et al., 1995). McLennan (1989) proposed formula was used to calculate Eu anomaly (Eu/Eu*) with REE patterns provide an additional support to identify the type of rock components. Statistical analyzes were performed using SPSS Statistics 23. The values recorded below the limits of detection were removed. The correlation coefficient was used to find the relationship between the elements and extent of the compatibility with each other.

RESULTS AND DISCUSSION

Major Oxides

The concentrations of SiO₂ are slightly high in the north part of the Hammar Dome, while it recorded high in the south part of the Safwan Dome. While the amount of Al₂O₃ was higher in the Safwan Dome as compared to the Hammar Dome. Furthermore, Al₂O₃ seems to be higher in the Safwan Dome this could be due to increase clay minerals such as kaolinite, illite, and siltstone. Relatively, the Fe₂O₃, MgO, CaO, K₂O, MnO, and LOI concentrations are higher in the Safwan than the Hammar Dome as shown in Table (3). On the contrary, Na₂O and SO₃ in the Safwan Dome are lower than the Hammar Dome. However, TiO₂ and P₂O₅ concentrations are relatively similar in both Domes, as shown in Tables (3 and 4).

Table 3. The concentrations of major oxide in the study area

Location	Formation	Units	Concentration of major oxides %											LOI	Total %
			SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	P ₂ O ₅	SO ₃	MnO	TiO ₂		
Hammar Dome	Zubair - Upper sandstone member	H1	92.00	0.06	0.04	4.15	0.01	0.02	0.21	0.01	1.30	0.03	0.01	2.08	97.91
		H2	93.51	0.08	0.04	2.30	0.04	0.02	0.12	0.002	0.60	0.02	0.01	3.26	96.74
		H3	92.67	0.09	0.10	3.73	0.01	0.02	0.23	0.01	0.97	0.03	0.02	2.01	97.95
Mean			92.75	0.08	0.07	3.22	0.02	0.02	0.17	0.01	0.95	0.03	0.01	2.45	97.54
Safwan Dome	Zubair - Upper sandstone member	H1	90.31	0.13	0.06	2.62	0.14	0.05	0.09	0.01	1.32	0.02	0.01	5.41	94.59
		H2	81.93	0.38	1.06	7.29	0.08	1.38	0.13	0.01	0.27	0.12	0.01	7.40	92.49
		H3	87.03	0.40	0.13	2.46	0.13	0.07	0.13	0.05	1.00	0.02	0.01	8.68	91.27
Mean			86.12	0.26	0.09	4.95	0.11	0.71	0.11	0.03	0.80	0.05	0.01	7.16	92.78

Table 4: Correlation coefficient of major oxide in the study area

	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	Na ₂ O	P ₂ O ₅	SO ₃	TiO ₂	LOI
SiO ₂	1										
Al ₂ O ₃	-.839*	1									
CaO	-.931-**	0.65	1								
Fe ₂ O ₃	-0.78	0.39	.911*	1							
K ₂ O	0.56	-0.71	-0.31	0.05	1						
MgO	-.926-**	0.62	.998**	.910*	-0.32	1					
Na ₂ O	0.32	-0.37	-0.18	0.18	.857*	-0.21	1				
P ₂ O ₅	-0.16	0.65	-0.13	-0.32	-0.46	-0.17	-0.12	1			
SO ₃	0.59	-0.46	-0.77	-0.58	0.17	-0.76	0.23	0.13	1		
TiO ₂	0.32	-0.48	-0.03	0.12	0.6	-0.06	0.56	-0.53	-0.19	1	
LOI	-.862-*	.939**	0.66	0.36	-.871-*	0.66	-0.63	0.49	-0.44	-0.58	1

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

Trace Elements

The presence of trace elements in rock-forming minerals depends on the type of crystallographic structure. The behaviour of trace elements is complicated during sedimentary processes controlled by many factors such as sorting, weathering, origin, adsorption, and transformation processes (Al-Mayyahi *et al.*, 2018). The concentrations of some elements such as B, Ta, Te and Pt recorded low values in all core samples of this study area. As well as, Re, In, and Ge recorded concentrations below the limits of detection for some core samples, particularly in the Safwan Dome. The mean concentrations of trace elements are higher in the Hammar than the Safwan Dome, except for Co, Rb, Ga, Sn, Y, Sr, Nb, Zr, Sr, Ba, V, Sc, Cs, Pb and Th. Cr, Mo, Zn, and Ni (Table 5), while Ba and Cr are observed in the Hammar Dome at the highest concentrations in the H2 unit compare to the Safwan Dome.

Table 5. A comparison of the geochemical analyses data of this study with the global concentration rates

Oxides and elements	Average concentrations Oxides in % and Trace elements in ppm		UCC	NASC	PAAS	Taylor, 1995 and McLenne, 2001
	Hammar Dome	Safwan Dome				
SiO ₂	96.91	95.90	66.00	64.80	62.80	57.10
Fe ₂ O ₃	2.37	2.88	5.00	5.65	7.22	9.10
Al ₂ O ₃	0.04	0.16	15.20	16.90	18.90	15.90
TiO ₂	0.01	0.01	0.50	0.70	1.00	0.90
CaO	0.04	0.30	4.20	3.63	1.30	7.40
MgO	0.01	0.30	2.20	2.86	2.20	5.30
Na ₂ O	0.14	0.09	3.90	1.14	1.20	3.10
K ₂ O	0.02	0.11	3.40	3.97	3.70	1.30
Ba	90.97	637.33	700.00	636.00	650.00	250.00
Co	1.59	1.88	25.00	26.00	23.00	29.00
Cr	24.48	17.07	35.00	125.00	110.00	185.00
Cs	0.03	0.07	4.00	5.00	15.00	1.50
Ga	0.38	0.72	17.00	N/A	N/A	18.00
Hf	0.07	0.08	5.80	6.30	5.00	3.00
Nb	0.09	0.07	25.00	13.00	19.00	8.00
Ni	4.98	4.36	20.00	58.00	55.00	105.00
Pb	5.75	11.43	112.00	125.00	160.00	37.00
Sr	8.14	18.20	350.00	142.00	200.00	260.00
Th	1.39	1.64	10.50	12.30	14.60	4.20
U	0.16	0.14	2.50	2.66	3.10	1.10
V	5.17	5.60	60.00	130.00	150.00	230.00
Zr	2.68	3.05	240.00	200.00	210.00	100
Sc	0.19	0.75	10.00	14.90	16.00	30.00
Y	1.06	1.21	22.00	35.00	27.00	19.00
La	2.25	1.72	30.00	31.10	38.20	20.00
Ce	8.18	4.02	64.00	67.03	79.60	43.00
Pr	1.07	0.45	7.10	N/A	8.83	4.90

Nd	4.87	1.93	26.00	30.40	33.90	20.00
Sm	0.88	0.52	4.50	5.98	5.55	3.90
Eu	0.13	0.11	0.88	1.25	1.08	1.10
Gd	0.52	0.59	3.80	5.50	4.66	3.30
Tb	0.05	0.07	0.64	0.85	0.77	0.60
Dy	0.25	0.31	3.50	5.54	4.68	3.60
Ho	0.05	0.05	0.80	N/A	0.99	0.78
Er	0.13	0.12	2.30	3.28	2.85	2.10
Tm	0.02	0.01	0.33	N/A	0.41	0.32
Yb	0.09	0.08	2.20	3.11	2.82	2.20
Lu	0.01	0.01	0.32	0.46	0.43	0.30
La/Th	1.52	1.05	2.62	2.80	2.53	4.76
Th/Sc	7.28	2.19	0.91	1.07	0.83	0.14
Eu/Eu*	0.35	0.23	0.65	0.67	0.65	0.66
La/Lu _{cn}	6.16	5.89	9.73	N/A	9.16	N/A
La/Sm _{cn}	0.54	0.70	4.20	N/A	4.33	N/A
Gd/Lu _{cn}	1.41	2.01	1.48	1.50	1.34	N/A
ΣLREE/HREE	12.08	8.02	9.54	7.06	N/A	N/A
Th/Yb	15.27	21.07	4.77	3.95	5.18	1.91
La/Sc	11.71	2.29	3.00	2.09	2.39	0.67
Gd/Yb	0.16	0.27	1.73	1.77	1.65	1.50
Sm/Nd	0.18	0.27	0.17	0.20	0.16	0.20

Rare Earth Elements

The total REEs recorded the highest value in the Hammar Dome (10.77-110.79ppm; avg. 44.74ppm), with high amount of REE in one sample in H3 unit 110.79ppm, while the range was low in the Safwan Dome (14.09-37.63ppm; avg. 27.31ppm). The light rare earth elements (LREE) ranged largely from 3.66 to 43.73 with an average of 17.24 in Hammar Dome, and 4.85 to 10.56 with an average of 8.64 in Safwan Domes as shown in Tables (6 & 7). The LREE/HREE ratio shows that the content of LREE is significantly higher than heavy rare earth elements (HREE), it ranges from 9.01, 9.22, and 18.00 in Hammar Dome, and 5.08, 9.36 and 9.60, respectively in Safwan Dome. The LREE content comprises of 90% of the total REEs in this study, this is further evidence that gives a clear perception of the absence of ferromanganese and heavy minerals, and abundance of SiO₂ indicates a more felsic component (Ingri and Ponter, 1987) (Fig. 3). The geochemical properties of REEs are very similar and could not be easily fractionated during the sedimentary processes (McLennan and Taylor 1989). The average of LREE/HREE ratio is higher in Hammar Dome than Safwan Dome (Table 6) with (La/Yb)_n = 11.9 ppm and HREE (Gd/Yb)_n = 2.6 ppm, and insignificant Eu anomaly (0.35ppm) as shown in Tables (5 and 8). There are no systematic differences in REE patterns between H units of Hammar Dome. The H sandstone unit in Safwan also showed variations in concentrations of

REEs which has almost similar ratios of LREE/HREE in Hammar Dome (8.02ppm) with $(La/Yb)_n = 12.3$ ppm; $(Gd/Yb)_n = 4.49$ ppm and $Eu/Eu^* = 0.23$ ppm.

Table 6. Distribution of LREE to HREE ratio of the Zubair Upper member

Location	Units	Σ LREE	Σ HREE	Σ (LREE+HREE)	Σ LREE/HREE	Avg. Σ (LREE+HREE)	Range Σ LREE/HREE	Avg. Σ LREE/HREE
Hammar Dome	H1	3.66	0.41	4.07	9.01	18.34	9.012-18.003	12.08
	H2	4.33	0.47	4.8	9.22			
	H3	43.73	2.43	46.16	18			
Safwan Dome	H1	4.85	0.52	5.37	9.36	9.87	5.079-9.602	8.02
	H2	10.52	1.1	11.61	9.6			
	H3	10.56	2.08	12.63	5.08			

Table 7. The rare earth elements concentration in the study area

	Unit	Rare earth elements (ppm)															
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
Hammar Dome	H1	0.80	1.75	0.18	0.77	0.16	0.03	0.16	0.02	0.10	0.02	0.05	0.01	0.04	0.01	0.15	0.53
	H2	0.95	2.10	0.22	0.89	0.18	0.03	0.15	0.02	0.12	0.03	0.07	0.01	0.06	0.01	0.15	0.66
	H3	4.99	20.7	2.8	12.95	2.29	0.31	1.24	0.10	0.52	0.09	0.25	0.03	0.17	0.02	0.27	1.98
	Av.	2.25	8.18	1.07	4.87	0.88	0.13	0.52	0.05	0.25	0.05	0.13	0.02	0.09	0.01	0.19	1.06
Safwan Dome	H1	1.09	2.36	0.26	0.94	0.21	0.03	0.18	0.03	0.13	0.03	0.08	0.01	0.06	0.01	0.26	0.63
	H2	2.34	5.08	0.53	2.11	0.45	0.07	0.44	0.06	0.29	0.05	0.13	0.02	0.11	0.01	1.56	1.26
	H3	1.73	4.63	0.56	2.75	0.89	0.23	1.14	0.13	0.51	0.07	0.14	0.02	0.07	0.01	0.43	1.75
	Av.	1.72	4.02	0.45	1.93	0.52	0.11	0.59	0.07	0.31	0.05	0.12	0.01	0.08	0.01	0.75	1.21

Fig. 3. Distribution of REEs and a comparison between the LREE to HREE in the study area

The total REEs were higher than NASC values, whereas, they are almost similar to those of UCC. It is due to high quartz concentration and lower amount of heavy minerals. However, it observed that the highest Σ REE abundances resulted in Hammar Dome as shown in Tables (5 and 6). This can suggest that the sediments are derived from sources that have comparatively depleted in HREE, also it indicates that more felsic rocks like rhyolite and andesite than mafic rocks. The most noticeable evolutionary pattern of sedimentary REEs patterns is for Eu/Eu*. Archean sedimentary rocks are not anomalous or only slightly anomalous with respect Eu anomaly (Eu/Eu* = 1), while post-Archean sedimentary rocks on average show a significant and constant depletion in Eu (Eu/Eu* = 0.65). This break in composition corresponds to the Archean-Proterozoic boundary (Taylor and McLennan, 1985). All the sandstone of the core samples in the present study showed Eu/Eu* in a narrow domain with an average of 0.35 for the Hammar Dome and 0.23 for the Safwan Dome and it less than UCC as shown in Table (5). La and Th concentrations are increased in the felsic rocks. While, Sc increases toward the mafic rocks. The concentration of Sc was less than 2 ppm in all examined samples, which gave indicator for a more felsic component. As well as, the high ratios of La/Sc and Th/Sc indicate the origin of the felsic rocks (Cullers et al., 1988; Wronkiewicz and Condie, 1987).

Table 8. Distribution of the geochemical ratios in the study area

Dome	Units	Geochemical ratios											
		Eu/ Eu*	Ce/ Ce*	Sm _N /Nd _N	La _N / Lu _N	La/Th	Th/Yb	La/Sc	Nb/Y	Cr/Ni	Th/Sc	La _N / Yb _N	Gd _N /Yb _N
Hammar	H1	0.03	1.08	0.57	16	1.21	2.7	5.3	0.14	5.43	4.37	10.2	2.12
	H2	0.04	1.23	0.56	13.5	1.65	1.78	6.26	0.13	3.86	3.8	9.16	1.51
	H3	0.99	2.08	0.48	21.7	1.69	3.09	18.3	0.06	5.03	10.8	16.3	4.17
	Av.	0.35	1.46	0.54	17.1	1.52	2.52	9.94	0.11	4.77	6.33	11.9	2.6
Safwan	H1	0.04	1.37	0.61	18.1	1	3.49	4.22	0.15	3	4.22	10.9	1.88
	H2	0.13	2.1	0.58	19.5	1.26	3.17	1.5	0.04	6.18	1.19	12.5	2.42
	H3	0.51	1.51	0.88	17.3	0.87	4.94	4.03	0.03	2.88	4.61	13.5	9.19
	Av.	0.23	1.66	0.69	18.3	1.05	3.87	3.25	0.07	4.02	3.34	12.3	4.5

UCC Normalization

Major oxides and trace elements were normalized versus UCC (Fig. 4). The concentration of major oxides is low compared to UCC, except SiO₂. The concentration of Mo and Se have high values in all the studied samples, while W is enriched in samples of the Hammar Dome and Ba are enriched in samples of the Safwan Dome. The concentrations of Al₂O₃, K₂O, MgO, CaO, Ba, Sr, and Rb of the Hammar Dome were low, while MnO, Fe₂O₃, TiO₂, Zr, Sn, Cr, Se, Ni, V, and

Pb showed disparity values between the samples. SiO₂, Se, and Mo have been unified enriched, compared with the UCC in all the samples.

Fig. 4. UCC-normalized pattern of major and trace element in the Hammar and the Safwan Dome

REEs Normalization

Rare earth elements that corrected for Chondrite-normalized are presented in Figure (5 A&B). The patterns showed increasing in LREE values with negative Eu anomaly in all of studied samples, with positive Ce anomaly as shown in Tables (8 and 9). This indicates that compatibility with zircon causes anomalies, and observed that oxidation increases to the upper direction. The most common method to normalized the rare earth elements is normalized versus chondritic meteorites (Nakamura, 1974).

Table 9. Rare earth elements (normalization) with chondrite values

Location	Units	Rare Elements (normalization) in (ppm)													
		La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Hammar Dome	H1	2.5	1.94	1.4	1.34	0.77	0.43	0.52	0.37	0.33	0.23	0.25	0.28	0.24	0.16
	H2	2.95	2.33	1.67	1.56	0.87	0.42	0.49	0.39	0.41	0.39	0.34	0.31	0.32	0.22
	H3	15.6	23	21.5	22.7	10.9	4.22	3.98	2	1.73	1.24	1.21	0.97	0.96	0.72
	Av.	7.02	9.09	8.2	8.54	4.18	1.69	1.66	0.92	0.82	0.62	0.6	0.52	0.51	0.36
Safwan Dome	H1	3.39	2.62	1.96	1.65	1	0.41	0.58	0.51	0.44	0.35	0.39	0.28	0.31	0.19
	H2	7.31	5.64	4.1	3.7	2.15	0.99	1.41	1.16	0.95	0.68	0.61	0.53	0.58	0.38
	H3	5.39	5.14	4.3	4.82	4.25	3.05	3.68	2.51	1.69	0.97	0.64	0.47	0.4	0.31
	Av.	5.36	4.47	3.45	3.39	2.47	1.48	1.89	1.39	1.03	0.67	0.55	0.43	0.43	0.29
Average Chondrites		0.32	0.9	0.13	0.57	0.21	0.07	0.31	0.05	0.3	0.07	0.21	0.03	0.18	0.03

Fig. 5. REE chondrite normalized of the Hammar and the Safwan Domes
Sm/Nd, La/Sm_N and Gd/Yb ratios

Sm and Nd are moving during weathering, REE bearing mineral and the differential weathering for component mineral, for example, removing minerals that are less resistant to weathering, such as feldspar (Viers and Wasserburg, 2004). It will significantly change Sm/Nd ratio (Feng, 2010). The present study shows that Sm/Nd and Gd/Yb ratios were 0.18 and 0.16 in the Hammar Dome, whereas in the Safwan were 0.27 for both ratios (Table 5) (Fig. 6). Gd/Yb ratio was present a fractionation pattern characterized by a continuous increase in LREE from La to Sm ($La/Sm_N = 0.4$ to 1.1), followed by a negative anomaly in Eu ($Eu/Eu^* = 0.35$ and 0.23) (Tables 5 & 7) (Fig. 7) and a regular distribution of HREE from Gd to Yb ($Gd/Yb = 0.19$ to 0.41) which indicate highest felsic content.

Fig. 6. A comparison of geochemical ratios between Sm/Nd and Gd /Yb

Fig. 7. A comparison of geochemical ratios between La/Sm_N and Gd /Nd

Distribution of Trace Elements in the Kerogen

The concentration of vanadium (V) ranges from 3.4-8.7 ppm with an average of 5.60 ppm in the Safwan Dome, while it ranges from 1.8-7.1 ppm with an average of 5.17 ppm in the Hammar Dome (Table 5). The Ni, Co, and Mo concentrations were 4.36, 1.88, and 1.14 ppm respectively in the Safwan, while it was 4.98, 1.59, and 2.02 ppm respectively in the Hammar Dome. The trace elements distribution shows that V was the highest concentration, while Co is the lowest (Fig. 8). The change in the concentrations of these elements may provide evidence for determining type of the sedimentary environment. Therefore, concentrations of the variable

elements were observed from one layer to another as a result of sea level change. It is known that the relatively high concentrations of vanadium than nickel give an indicator of the marine organic matter input, while on the contrary indicators for terrestrial organic matter (Lewan 1984; Akinlua et al., 2007a; Galarraga *et al.*, 2008). The high V/Ni ratio in the present study refers to marine organic matter input.

Fig. 8. Distribution of trace elements in the study area

Weathering and Mobility

It is possible to calculate the intensity of the source region by using the alkaline cations and Al_2O_3 remains. Increasing the intensity of the weathering reduces alkaline cations and enriches the residual Al_2O_3 in the sediment (Nesbitt and Young, 1982; Selvaraj and Chen, 2006). The chemical indicators such as Chemical Index of Alteration (CIA), the Chemical Index of Weathering (CIW) and the Parker Weather Index (WIP) are usually used to determine the intensity of weathering (Parker, 1970). CaO^* is the CaO content contained in the silicate part, in this study, it is not necessary to correct calcium in carbonates because all the studied samples were lacked carbonate contents. The CIA values were measured in the Hammar Dome from 13.05 to 24.37, while in the Safwan Dome range from 23.72 to 77.22. However, these values are higher than their contents in UCC especially in the Safwan, and lower than PAAS. These results

may attribute to fine and medium clastic sedimentary rocks in the H sandstone unit, with a low degree of weathering in the Hammar Dome, and high to moderate in the dome of Safwan. This is further supported by calculated CIW, PIA, and index of compositional variability (ICV) values. CIW in Hammar Dome range from 19.57 to 33.47, while in the Safwan Dome range from 24.28 to 79. The maximum value of PIA is 100 for the materials that changed completely and weathered plagioclase has a PIA value of 50 (Fedo *et al.*, 1995).

PIA of H sandstone unit ranges from 7.4 to 29.16 in the Hammar and 22.47 to 86.57 in the Safwan Dome, suggested moderate weathering in the source area. Moreover, the sediments with $ICV < 1$ is an immature composition with the first cycle of sediment in active tectonic settings. Otherwise, this index $ICV > 1$ is mature structurally and deposited in a tectonically quiet or cratonic environment with a low tectonic activity that covered by sedimentary rock, where sediment recycling is activated (Cox *et al.*, 1995). ICV values for H sandstone unit ranges from 2.75 to 4.99 for the Hammar and 2.67 to 10.13 for the Safwan Dome. Therefore, the average values of ICV can give an explanation of the upper sandstone member in the Zubair Formation, where it compositionally matures and deposited in the quite tectonic. As well as, ICV values more than 2, can give evidence of quartz enrichment during sedimentation. The mobility of the individual elements differs slightly between the Safwan and the Hammar domes. The concentration of Ca, Sr, and Mg are slightly higher, indicated to higher mobility than larger cations, such as K, Rb, and Cs. However, all values are higher in the Safwan than the Hammar Dome. This might happen due to the occurrence of the very fine sand and mud dominated in the sediments of the Safwan than the Hammar Domes. Mg, K, Rb, and Cs are genuinely related to phyllosilicates when the samples are medium to fine sand dominated, supported by decreasing in the concentrations of alkali minerals and increasing in SiO_2 content against UCC (Fig. 4).

Source of Sediments

Zr/ TiO_2 ratio is 0.021 in the Hammar Dome, and 0.050 for the Safwan Dome. While the Nb/Y ratio is 0.109 in the Hammar, and 0.073 in the Safwan Dome. These values have been plotted on the Pearce's diagram (Pearce, 1996), it gave evidence that the rocks of the Hammar Dome are closing to andesite rocks, while in the Safwan Dome are closing to the rhyolite rocks, it considered more felsic in source rocks of the study area (Fig. 9). The geochemical ratios, such as La/Sc, La/Co, Th/Sc, Th/Co, Cr/Th, $(La/Lu)_{CN}$, and Eu/Eu* of the studied sediments were compared to the sediments derived from the felsic source, UCC and PAAS values (Table 10).

Fig. 9. Zr/TiO₂ versus Nb/Y plot for the studied domes after (Pearce, 1996)

Table 10. Comparison of the studied elemental ratios with the range of sediments derived from felsic rocks, mafic rocks, UCC and PAAS

Elements ratio	Elements ratio of the Sediments in the present study		Range of Sediments From ^		UCC*	PAAS*
	Hammar Dome	Safwan Dome	Felsic Source	Mafic Source		
La/Sc	5.29 - 18.28, Avg.= 9.94	1.50 - 4.22, Avg.=3.25	2.50-16.3	0.43-0.86	2.21	2.4
La/Co	0.56 - 2.67, Avg.=1.29	0.76 - 1.14, Avg.=0.91	1.80-13.8	0.14-0.38	1.76	1.66
Th/Sc	3.80 -10.81, Avg.= 6.33	1.19 - 4.61, Avg.=3.34	0.84-20.5	0.05-0.22	0.79	0.9
Th/Co	0.39-1.58, Avg.= 0.81	0.83 -0.90, Avg.=0.87	0.67-19.4	0.04-1.4	0.63	0.63
Cr/Th	10.07-46.21, Avg.=26.45	7.44 -13.19, Avg.=10.59	4.00-15	25-500	7.76	7.53
(La/Lu) _{CN}	14.01-22.52, Avg.=17.72	17.91-20.24, Avg.=18.98	3.00-27	1.10-7	9.73	9.22
Eu/Eu*	0.03-0.99, Avg.= 0.35	0.04 - 0.51, Avg.=0.23	0.40-0.94	0.71-0.95	0.65	0.65

^ Cullers *et al.*, (1988) *Taylor and McLennan (1985) and McLennan (2001)

Paleo Redox Situation

The redox-sensitive minerals, such as nickel, chromium, vanadium, and uranium in marine sediments can give strong evidence of local or global palaeo-oceanographic variability (Jones and Manning, 1994). The U/Th ratio is a reliable redox indicator, U/Th ratios below 1.25 indicate an oxic environment of deposition, while values above 1.25 suggest suboxic and anoxic situation (Fig.10). All the core samples in the study area are located in oxic and suboxic conditions. As well as, it showed increasing in oxidation trend from the bottom to the top. Cr is primarily introduced into the sedimentary part of the sediment and may replace Al^{+3} in the clay minerals. V may be bound to organic matter by incorporating V^{4+} in porphyrins, and mostly located in sediments that deposited in reduction environments (Shaw *et al.*, 1990). V/Cr ratio exceeds 2 indicates a state of suboxic, while the values below 2 indicate more oxidizing conditions (Jones and Manning, 1994). In this study, most V/Cr ratio of the samples was less than 2 (Fig. 10). On the other hand, when Ni/Co ratios less than 5, give evidence of oxic environment, while above 5 values refer to suboxic and anoxic environments, this assumption has been suggested by Jones and Manning (1994). In the present study, all samples are located in the oxic condition area. Furthermore, Kimura and Watanabe (2001) suggested that the V/Sc ratios below 9 indicate oxidizing conditions, based on these ratios can provide evidence of the transitional environment in the study area. (Fig. 10).

Fig. 10. The distribution of V/Sc, Th/U, V/Cr, and Ni/Co ratios in the study area

High chemical weathering is associated with warm and humid climates, while a high arid climate is associated with relatively weak chemical weathering (Nesbitt and Young, 1982). Subsequently,

CIA, PIA, ICV, Th/U, and K/Rb of the upper sandstone member in Zubair Formation indicate moderate degree of weathering conditions during the lower cretaceous in the study area. According to $(\text{Al}_2\text{O}_3 + \text{K}_2\text{O} + \text{Na}_2\text{O})$ versus SiO_2 (Fig.11), which provides clear evidence of that the Zubair Formation has been deposited in a humid climate (Fig. 11).

Fig. 11. Paleoclimate of study area after Suttner and Dutta (1986)

CONCLUSIONS

The geochemical composition of the sediments is mainly influenced by the provenance of the source area. SiO_2 was higher compared with the other oxides. Al_2O_3 was recorded higher in the Safwan Dome than the Hammar Dome. The source rock of the upper sandstone member was influenced by more felsic sources. A significant ratio of LREE gives an indicator to lack of ferromanganese and heavy minerals in the study area, low LREE/HREE ratios suggested that fine-grained of sand with clay content in the Safwan Dome as a result present of clay minerals; kaolinite and illite. This study confirms that the upper sandstone member had a high mobility of LREE under humid climate. High Sm/Nd ratios associated with clayey silt presented in the Safwan Dome while low value associated with sandy sediments in the Hammar Dome indicated a strong mobilization of these elements during weathering. V/Ni ratio gives an indicator to marine organic matter input. CIA, PIA, ICV values and Th/U, K/Rb ratios indicate low to moderate degree of weathering conditions influenced by the recycling effect. $\text{Al}_2\text{O}_3 + \text{K}_2\text{O} + \text{Na}_2\text{O}$ with SiO_2 concentrations, indicate a humid climate in the Zubair Formation.

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