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RESEARCH ARTICLE

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TECTONIC SETTING OF FERRUGINOUS SANDSTONE EVIDENCES FROM PETROGRAPHY AND GEOCHEMISTRY, WEST ED DEBBA, SUDAN

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Abstract
Ed Debba ferruginous sandstones are important for sedimentary iron ore. Petrography and geochemistry (major and trace elements) of sandstones, Wadi Milk Formation, west Ed Debba, have been investigated to understand their provenance and tectonic setting. Petrographic analysis suggests that they are matured quartz arenite and arkose, mainly interior Cratonic sediments, granitic composition and metamorphic (psammatic) rocks origin of humid climate. Major and trace elements geochemistry support the petrographic results. The geochemical data interpretation on the basis of discriminate diagrams reveals they are quartz arenite, sub lithic arenite and Fe- sandstone and reflect their maturity on humid climate, the source materials were derived from varied tectonic setting, but dominantly passive margin, due to heterogeneous of source area.

Key Words: ferruginous sandstones, Wadi Milk Formation, quartz, arenite, arkose

INTRODUCTION

The sandstone of study area located about 80Km west of Ed Debba, as a part of Wadi Milk Formation and host large amount iron ore (Fig.1). Geochemical and provenance studies of clastic sedimentary rocks used to understand the composition and geological evolution of the sediment source areas and to construct the tectonic setting of the depositional basin. The key relations between provenance and basin are governed by plate tectonics, which thus ultimately controls the distribution of different types of sandstones [11]. Sedimentary petrography for provenance studies is a standard method in Sedimentology and basin analysis. Discrimination Diagrams, based framework composition as quartz, feldspar and rock fragments, have been used to construct tectonic settings of ancient sandstone (e.g. [11]; [16]; [32]; [10]). The tectonic setting of a depositional environment influences composition of sediment ([24]; [8]). Transport mechanism and mixing of materials from diverse source area may obscure the original signatures and thus prevent reconstruction of the paleogeography from geochemical analysis [26]. The usefulness of major ([8]; [27]; [21]; [5]; [4]; [15] & [36])

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and trace ([7]; [12]) elements geochemistry discrimination diagrams to infer the tectonic setting of sedimentary rocks. The sediments (sandstone and mudstone) in Dongola and wadi Muqaddam areas are placed in the Wadi Milk Formation, which is Albian-Cenomanian age, and unconformable overlies granitic basement in Wadi Milk and Dongola [30].The Area between western Bayuda desert and Wadi Howar -North Kordofan Block represent a semi outliers composed of Nubian Sandstone (belong to Wadi Milk Formation?). The sandstone is moderate to poorly expose as inselberge, hilly outcrop scattered in sea sand. They consist of fine to coarse-grained with pebble, sub rounded to sub angular shape, poorly to moderate sorting, massive, cross-bedded originates from fluvial environment and brownish to dark color, so these color may be due to ferruginous. The sandstone intercalated with mudstone, which undergone by iron oxide replacement. The sandstone and mudstone are cemented dominantly by iron oxide (hematite), argillaceous material and locally siliceous. the study area affected by Post-Nubian Fault in two systems one is directed to320° (NW) and second to 040° (NE), which are appeared as liner feature, silicification, but the later (NE) as same direction of wadi milk fault (WMF).

The aim of this paper is to attempt to reconstruct the provenance and tectonic setting of ferruginous sandstones (iron ore?) of Ed Debba using integrated petrographical analysis and major, trace elements geochemistry.

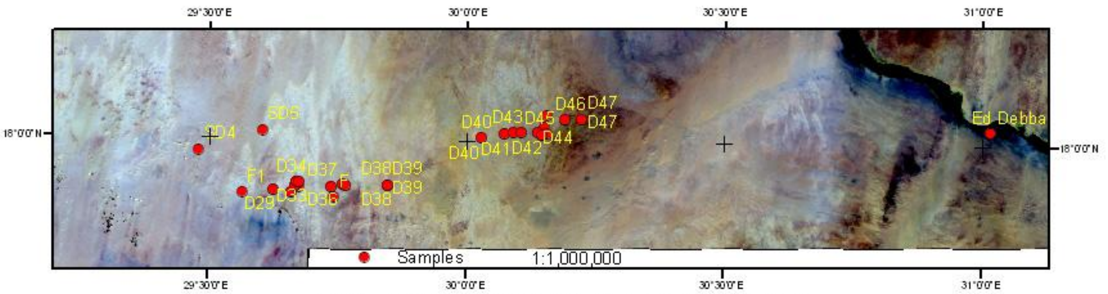

Fig.1: Landsat Image shows study area

GENERAL GEOLOGY

Generally, the crustal evolution of the NAS is mainly one of Continental margin/island arc are development and related syn-to post-tectonic magmatism. West of the ANS a series of scattered basement areas in North/Central Sudan formed a structural entity known as Nile Craton. The area between Uweinat Block and the Nile in North/Central Sudan is invaded by numerous, voluminous granites of Late Pan-Africa Age. The western part of Bayuda desert contains high grade poly-metamorphic rocks [28]. The predominant rocks in Wadi Howar-North Kordofan Block are high-grade granitoid gneisses which contain minor inliers of high-grade metasediments and which are intruded by voluminous granitoid. The basement inliers are predominantly of Pre-Pan-African origin. They were reworked during the Pan-African and intruded Late Pan-African granitoid [28]. The sandstone is dominated clastic series have a wide horizontal distribution in the area around Khartoum and towards the north and northwest to the Dongola region of the northern Sudan. These sediments have been delineated as Nubian Sandstone Formation, give Cretaceous age based on a few mega plant fossils [22]. Tertiary Basalt , trachyte, have been found within Nubian sandstone as lower patches shape less than 20m diameter.

MATERIAL AND METHODOLOGY

Twenty one samples were collected from outcrops of ferruginous sandstone and siltstone west Ed Debba of Wadi Milk Formation Twenty one thin sections were examined with a petrographic microscope, (6) samples selected for modal composition and other petrographical features. Each thin section of the six; minimumly 300 points were counted using Gazzi-Dickinson method [16] and (15) samples for visual estimation and classification. Chemical analysis of (21) samples were performed by X-ray fluorescence at the OMAC chemical lab.

RESULTS

Petrography: The analyzed samples are medium to coarse grained, sub rounded to sub angular, moderate to poorly sorted. The framework grains of sandstone are composed of monocrystalline (Qm) and polycrystalline (Qp) quartz, feldspar (F) and lithic fragments (L). The main mineralogical constituents are quartz with very little amount of feldspar and lithic fragment (quartzitic). The quartz (Qm &Qp) occurs throughout the samples, they range between 90% and more than 95% for total quartz (Fig.2). The Qm is greater than Qp in its amount, commonly rounded to sub angular. The contacts between the (Qp) sub-grain are straight to suture, the first occurs more commonly, the sub-grain size is variable, even within a single composite grain of Qp.

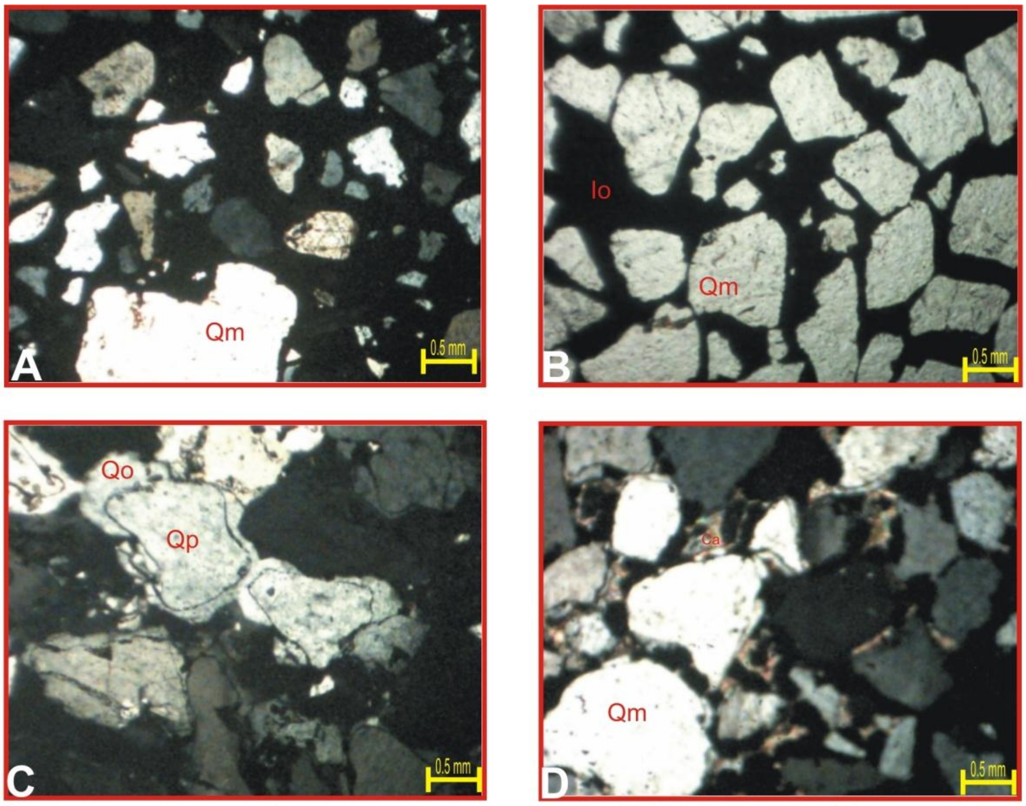

Fig.(2): Photomicrographs of Ed Debba sandstone showing:Quartz arenite; (A) monocrystalline quartz(Qm) .(B) iron oxide; haematite (Io).(C);polycrystalline quartz(Qp) and quartz overgrowth(Qo). (D):secondary carbonate (Ca).

Pressure inclusion is present in quartz grain. Fractures filled with iron oxides, iron oxide rims are commonly present with the development of quartz overgrowth (Fig.2C). Clay material are very little amount, replaced by the hematite and carbonate (Fig.2D). Lithic fragments were found in little amount in sandstone as metamorphic rock fragment (Quartzite). Sandstone, siltstone are cemented by ferruginous, which is dominant and argillaceous, siliceous. Due to the nature of sand grains the source rock which is providing the sediments are granitic composition and metamorphic (psammatic) rocks origin and may fluviatile sand [1].

Classification: Petrographic investigation based on mineral composition and texture to identify composition and classification of sandstones using [13] scheme, which indicates that they are mainly fine to coarse-grained, rounded to sub angular shape, poorly to moderately sorting, they are quartz arenite, arkose and siltstone.

Provenance and tectonic setting: Modal composition for (6) samples are revealed that they are quartz arenite Q99.7F0.3L0.3. On a QFL diagram [10], the Ed Debba sandstones plot in the field of a craton-interior source, indicating that they were derived from igneous source rocks [10] (Fig.3). QFRF ternary diagram of [32], indicate a metamorphic source rock in a humid climate (Fig.4).

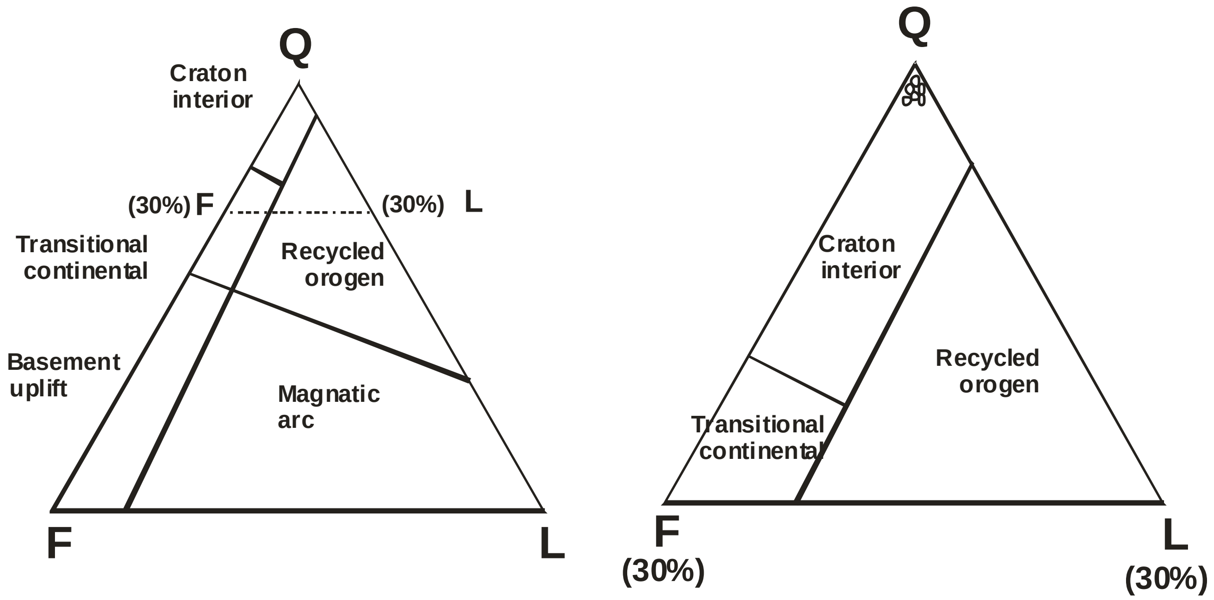

Fig.(3): QFL ternary diagram for Ed Debba sandstone (Dickinson et al.,1983).

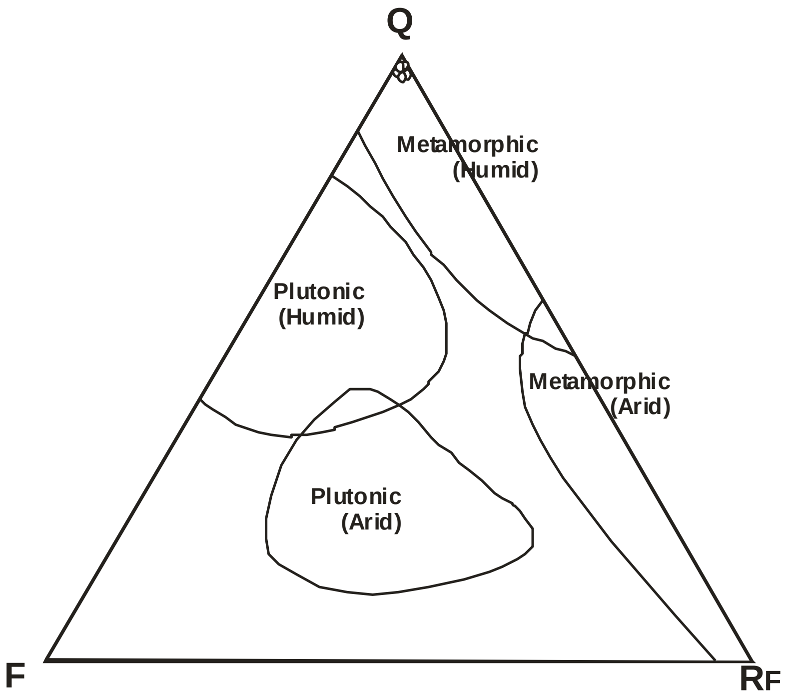

Fig.(4): The effect of source rock on composition of Ed Debba sandstone using diagram of Suttner et al. (1981).

Geochemistry: The major and trace element concentrations of Ed Debba sandstones are listed in tables 1-4, respectively. Major elements undergo some changes during sedimentary processes; the SiO_2 is enriched, Na_2O and K_2O are depleted in sandstones compared with the source rock composition [8]. Ed Debba sandstone revealed relatively high SiO_2 (52.89-91.3, av.66%) and very low of K_2O (0.005-0.55, av.0.1%) and Na_2O (0.025-0.1, av. 0.029%) and high Fe_2O_3 (1.02-35.47, av. 21.01%).

Chemical classification: Ed Debba sandstones are classified geochemically using major elements classification diagrams of [24]; quartz arenite, sub lithic arenite and sub arkoses [14]; quartz arenite, sub lithic arenite and Fe-sandstone (Fig.5), and trace element (log Co ppm vs. log Ga ppm) diagram of [35] to separate quartz arenite from arkose and sub arkose, all sample classified as quartz arenite

Table (1): major oxide values(wt.%) of Ed Debba sandstones

Sample	D29	D30	D32	D33	D34	D35	D36	D37	D38	D39	D40
SiO_2	80.04	69.67	58.63	62.71	60.64	68.07	62.81	70.31	64.63	75.12	56.58
TiO_2	0.2	0.64	0.08	0.03	0.07	0.16	0.05	0.02	0.48	0.06	0.16
Al_2O_3	1.81	2.66	0.41	1.24	0.63	2.02	0.59	0.31	2.38	0.45	0.8
Fe_2O_3	12.06	18.39	35.47	16	33.16	23.45	30.46	16.18	27.33	18.01	35.34
MnO	0.31	0.12	0.05	10.41	0.16	0.2	0.66	5.66	0.11	0.28	0.09
MgO	0.16	0.25	0.1	0.07	0.14	0.19	0.08	0.07	0.11	0.14	0.07
CaO	1.13	2.61	0.11	0.15	0.21	0.81	0.21	0.08	0.19	1.34	0.34
Na_2O	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
K_2O	0.04	0.03	0.32	0.32	0.02	0.02	0.03	0.06	0.01	0.02	0.01
P_2O_5	0.114	0.172	0.377	0.168	0.29	0.303	0.359	0.231	0.537	0.055	1.002
LOI	3.51	4.93	5.13	5.04	4.94	4.95	4.88	3.67	4.75	4.53	5.76
$log(SiO_2/Al_2O_3)$	1.645629	1.418164	2.155336	1.703915	1.983419	1.527604	2.027177	2.355655	1.433857	2.222543	1.849573
$log(k_2O/Na_2O)$	0.20412	0.079181	1.10721	1.10721	-0.09691	-0.09691	0.079181	0.380211	-0.39794	-0.09691	-0.39794

Table (2): major oxide values(wt.%) of Ed Debba sandstones

Sample	D41	D42	D43	D45	D46	D47	SD1	SD5	SD6	SD7
SiO_2	91.31	63.63	81.5	62.83	52.89	54.28	57.49	61.97	67.88	65.35
TiO_2	0.02	0.03	0.16	0.09	0.005	0.04	0.1	0.06	0.11	0.47
Al_2O_3	0.17	0.69	0.32	0.52	0.54	1.08	1.38	0.44	0.76	1.22
Fe_2O_3	6.02	29.58	14.27	30.54	4.66	4.91	1.02	31.49	26.41	26.47
MnO	0.04	0.96	0.1	0.19	18.83	21.07	22.26	0.08	0.12	0.1
MgO	0.06	0.1	0.06	0.19	0.04	0.05	0.06	0.13	0.07	0.14
CaO	0.1	0.21	0.1	0.68	0.1	0.13	0.14	0.47	0.63	1.18
Na_2O	0.025	0.025	0.025	0.025	0.025	0.025	0.1	0.025	0.025	0.025
K_2O	0.02	0.03	0.02	0.005	0.17	0.38	0.55	0.02	0.02	0.03
P_2O_5	0.063	0.223	0.127	0.205	0.213	0.266	0.121	0.334	0.212	0.041
LOI	1.2	4.88	2.3	4.75	5.33	5.26	5.1	4.82	4.5	5.07
$log(SiO_2/Al_2O_3)$	2.730069	1.964813	2.406008	2.082164	1.99098	1.701216	1.619713	2.148729	1.950928	1.728886
$log(k_2O/Na_2O)$	-0.09691	0.079181	-0.09691	-0.69897	0.832509	1.181844	0.740363	-0.09691	-0.09691	0.079181

Table (3): Trace element values (ppm) of Ed Debba sandstones

Sample	D29	D30	D32	D33	D34	D35	D36	D37	D38	D39	D40
Ba	505	117	117	11598	219	232	1097	12091	158	56	156
Co	80	11	13	4192	59	41	87	343	21	86	26
Cr	40	39	35	33	27	59	152	22	51	31	25
Cu	72	18	17	507	22	24	83	52	8	45	6
Ga	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
La	7	21	5	9	7	22	9	6	12	5	5
Nb	<5	5	<5	<5	<5	<5	<5	<5	6	<5	<5
Ni	110	23	32	1107	52	47	142	213	41	98	84
Sc	4	7	4	6	<1	3	1	<1	4	4	<1
Sr	21	23	11	38	15	221	25	59	279	8	15
Th	<5	15	<5	18	<5	<5	<5	14	6	<5	<5
V	71	94	47	284	41	41	115	70	98	193	42
Y	16	15	18	96	38	29	62	60	5	13	7
Zr	27	42	10	6	10	30	15	11	48	9	16

Table (4): Trace element values (ppm) of Ed Debba sandstones

Sample	D41	D42	D43	D45	D46	D47	SD1	SD5	SD6	SD7
Ba	35	1191	63	37	41709	36422	34812	38	41	126
Co	14	108	50	36	4485	1720	3366	43	43	31
Cr	38	32	47	28	42	39	38	25	45	30
Cu	<2	25	16	12	432	206	584	44	17	31
Ga	2.5	6	2.5	2.5	2.5	2.5	2.5	8	2.5	2.5
La	4	12	17	12	14	24	27	4	6	13
Nb	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	43	241	184	105	260	235	228	85	136	59
Sc	<1	4	1	2	3	2	7	3	3	2
Sr	4	11	9	13	51	200	62	10	9	15
Th	<5	<5	<5	<5	51	46	44	<5	<5	6
V	7	88	36	53	356	135	374	107	61	58
Y	5	13	16	6	134	66	101	11	8	12
Zr	9	12	10	9	7	10	16	10	10	27

(Fig.6). Based on major oxide ratios of [19], Ed Debba sandstones are classified ; nineteen samples are consistent with quartz arenite (log (SiO_2/Al_2O_3) ≥ 1.5), their ratios value are range from 1.5 to 2.7 with average 2 and two samples are arkoses (SiO_2/Al_2O_3) <1.5), the value 1.41 and 1.43[2].

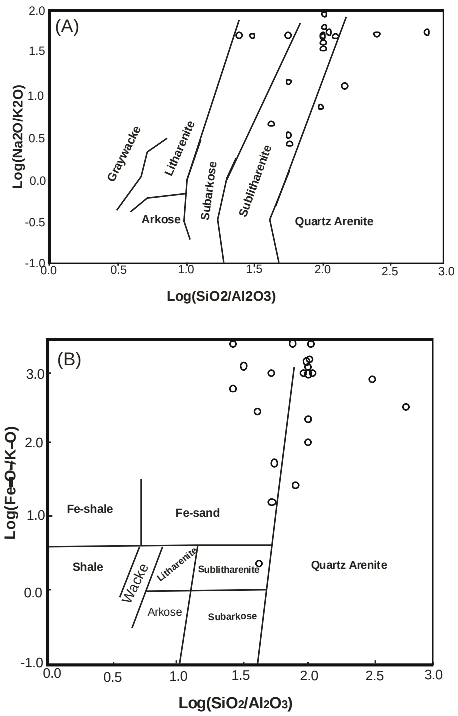

Fig.(5): Chemical classification Ed Debba sandstone (a) log(SiO_2/Al_2O_3) vs log(Na_2O/K_2O) diagram of Pettijohn,(1972), and (b) Log(SiO_2/Al_2O_3)vs log (Fe_2O_3/K_2O) diagram of Herron,(1988).

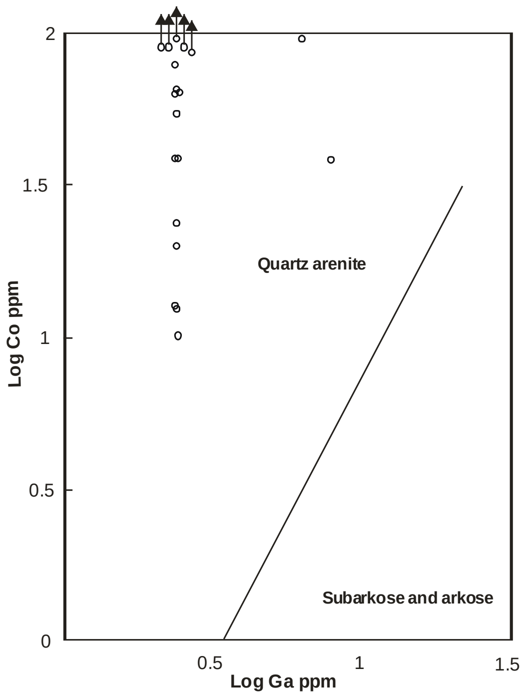

Fig.(6):chemical classification of Ed Debba sandstone log Co ppm vs log Ga ppm diagram of Vine and Tourtelot, (1973)

A bivariant plot of SiO_2 vs. Al_2O_3 + K_2O + Na_2O proposed by [31] was used in order to identify the maturity of Ed Debba sandstones as a function of climate (Fig. 7). This plot revealed the humid climatic conditions for the samples investigated.

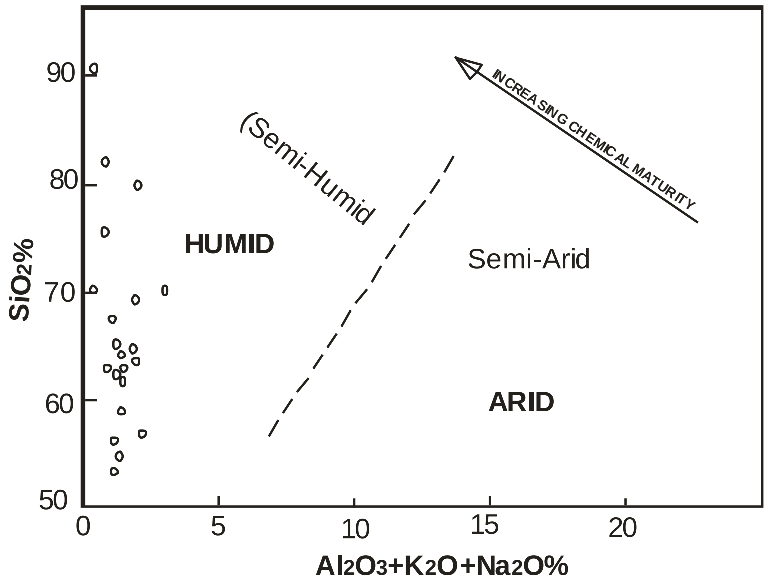

Fig.(7):Chemical maturity of Ed Debba sandstone Suttner and Dutta,(1986).

Provenance and Tectonic setting: Many types of discrimination diagrams of tectonic settings that use major element chemistry have been proposed for clastic sediments ([8]; [27]). The K_2O/Na_2O vs. SiO_2 binary tectonic diagram of [27] discriminates between oceanic island arc (OIA), active continental margin (ACM) and passive margin (PM) tectonic setting, this diagram classified Ed Debba sandstone into active continental margin and oceanic island arc (Fig.8). The (SiO_2/20)-(K_2O+Na_2O)-TiO_2+Fe_2O_3+MgO) ternary diagram of [18], all Ed Debba sandstone samples classified as passive margin (Fig.9). Immobile trace elements in detrital sediments have also been used successfully in discrimination diagrams of palaeotectonic settings [34], these elements probably are transferred quantitatively into clastic sediments during weathering and transportation, reflecting the signature of the parent material [6]. The La-Sc-Th and Th-Sc-Zr/10 ternary diagrams [7] have been used to differentiate between oceanic island arc, continental island arc, active continental margin and passive margin settings. These diagrams divided Ed Debba sandstone into continental island arc, active and passive continental margin tectonic environments (Fig.10).

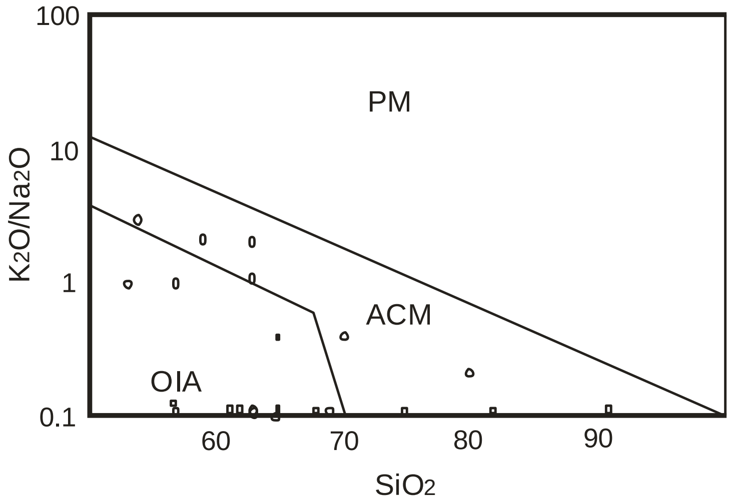

Fig.(8):Discrimination diagram of Ed Debba sandstone K_2O/Na_2O vs SiO_2 Roser and Korsch, (1986). Tectonic fields are oceanic island arc (OIA), active continental margin (ACM)and passive margin (PM).

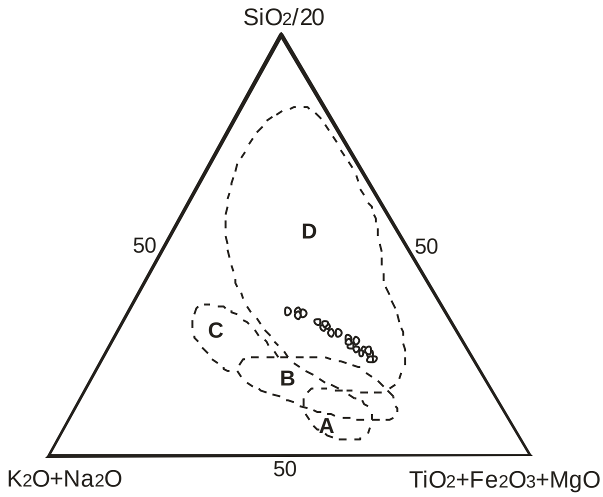

Fig.(9):Tectonic discrimination diagrams for Ed Debba sandstone (Kroonenberg,1994).A:Oceanic island Arc, B: Continental island Arc, C: Active continental margin, D: Passive margin.

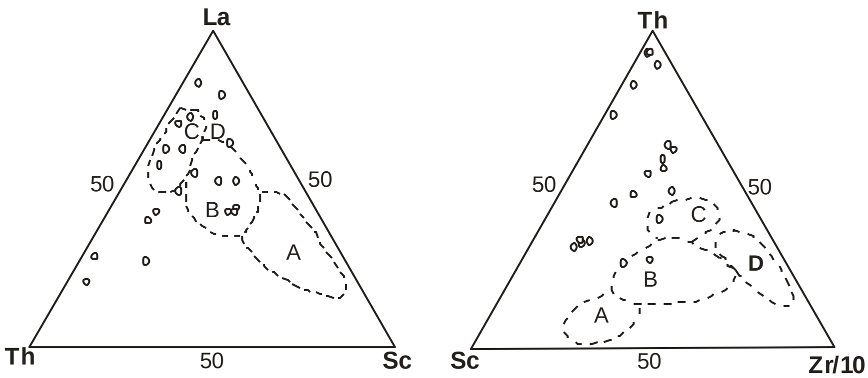

Fig.(10): Tectonic discrimination diagram of Ed Debba sandstone La-Th-Sc and Th- Sc-Zr/10 (Bhatia and Crook, 1986).

DISCUSSION

Geochemical signatures of basin clastic sedimentary rocks provide important sources of information. In particular the use of immobile major and trace elements that are thought to be carried in the particulate load have been found to be useful indicators of source terrain, weathering, tectonic, and environmental evolution. Trace elements such as rare earth elements (REEs) are relatively insoluble and as a result, their original compositions are not upset during the sedimentary processes ([33]; [9]; [23]; [12]). The major element geochemistry of sandstones can be used for drawing inferences related to the provenance type and the plate tectonic setting of ancient sedimentary basins ([6]; [27]). The SiO_2/Al_2O_3 ratio is an approximate indicator of quartz/feldspar ratio [26].The enrichment of SiO_2 over Al_2O_3 may be due to mechanical and chemical processes from source area to basin. Silica (quartz) enrichment is a measure of sandstone maturity, and is a reflection of the duration and intensity of weathering and destruction of other minerals during transport. Silica enrichment also occurs by addition of silica cement, as quartz and opal [19]. The ratios SiO_2/Al_2O_3 and K_2O/Na_2O reflected that Ed Debba sandstones geochemically are matured, also due to diagram of [31]. In comparison on average analysis sandstones with the Upper Continental Crust (UUC) of [20], the abundance of K_2O (0.1%), Na_2O (0.03%) are very low to UUC (3.4%) and (3.9%) (Table5). Also Fe_2O_3+ MgO (21.12%) are very high to UUC (7.23%). These differences are normally due to the different of Ed Debba sandstones which are quartz arenite and the greywacke of UUC. The ferromagnesian trace elements (V, Ni, Co) are so high (113, 186,707) ppm, which are associated with high values ferromagnesian oxides. The high ferromagnesian contents of this sandstone indicate significant contribution from volcanic source; this volcanic component may have been derived from continental shield or from intra-Cratonic volcanic rocks which may have erupted during the rift or grabben stages, before the formation of the passive margin [8]. Based on petrographic analysis the Ed Debba sandstones are classified as dominantly quartz arenites with arkoses, show granitic composition (granite gneiss) and/or metamorphic (psammatic) source. The source area of the sandstone of studied area affected humid climate [32]. The concept that sandstone composition reflects not only the source area but also the tectonic setting of sandstone accumulation has been expressed quite early [29]. Ed Debba sandstones are interpreted as craton interior. The source of interior Cratonic sediments are uplifted terrains of folded and faulted strata from which recycled detritus of sedimentary and meta-sedimentary origin were in put in the basin [11]. Depending on geochemical tectonic discrimination diagrams Ed Debba sandstones suggest varied tectonic setting; passive margin, active continental margin, continental island arc and oceanic island arc ([27]; [18] & [7]), that due to complexity and mixed of income material, add to that location of the area which is bounded by Arabian Nubian Shield in east (Bayuda), Cratonic crust in West (Kordofan block) and generally in east boundary of Saharan meta-craton;(medium to high-grade gneisses, metasediments, migmatites, and smaller outcrops of granulites, but low-grade volcano-sedimentary rocks and granitoids [3].

Table(5):

Chemical composition (major & trace elements) of Ed debba and UCC after McLennan(2001)

mjor oxide(wt.%)	Ed Debba	UCC	trace elements (ppm)	Ed Debba	UCC
SiO_2	66.11	66	Ba	6705.7	550
TiO_2	0.14	0.68	Co	707.4	17
Al_2O_3	0.97	15.2	Cr	42	83
Fe_2O_3	21.01	5.03	Cu	111.1	25
MnO	3.9	0.08	Nb	5.5	12
MgO	0.11	2.2	Ni	167.9	44
CaO	0.52	4.2	Rb	25	112
Na_2O	0.03	3.9	Sc	3.5	13.6
K_2O	0.1	3.4	Sr	52.3	350
P_2O_5	0.26	0.15	Th	11.1	10.7
SiO2/Al2O3	68.15	4.34	U	3.7	2.8
K2O/Na2O	3.33	0.87	V	113	107
Na2O/K2O	0.3	1.15	Y	34.8	22
			Zr	16.4	190
			La	11.5	30
			Th/Sc	3.17	0.79
			Zr/Sc	4.69	13.97

CONCLUSION

Ed Debba sandstones of Wadi Milk formation can be classified as matured quartz arenite and arkose. They are well cemented dominantly by ferruginous and clayey material. Clayey materials are replaced the ferruginous partially or totally. The petrographic analysis suggests that Ed Debba sandstone are mainly interior Cratonic sediments of granitic composition and metamorphic (psammatic) rocks origin of humid climate depend on standard diagram.

On the basis of the geochemistry Ed Debba sandstones are quartz arenite, sub lithic arenite and Fe-sandstone and reflect their maturity on humid climate. Ed Debba sandstones plotted dominantly in passive margin and other field of tectonic provenances, that due to complexity, mixed and heterogeneous of source area.

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