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HEAVY MINERAL ANALYSIS OF THE QUATERNARY SEDIMENTS IN THE SOUTHERN PART OF THE MESOPOTAMIA PLAIN, IRAQ

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ABSTRACT

Heavy mineral data of 87 samples from 51 fully cored boreholes, penetrated the Quaternary fluvial successions of the southern part of the Mesopotamia Plain, have been evaluated using numerical methods. Interpretation relied on the presumption that Quaternary physiography and geological settings of the source regions are comparable to those of today.

Comparative analyses of the present study with the previous work show that the concentration of heavy minerals in the sediments of the studied area coincides with the concentration of heavy minerals in the sediments of the Euphrates and the Tigris Rivers, which have brought pyroxene, hornblende, epidote and garnet-rich sediments from the north and north-east (Turkey and Syria). There is an abnormal increase of concentration of ultrastable minerals (ZTR) in the west bank of the Euphrates River suggesting different sources for the supplied sediments, such sources may be the surrounding formations whose sediments were derived from the Western Desert.

The result of the study reveals volcanogenic hornblende and pyroxene as well as metamorphic epidote and garnet as the dominant minerals of the Quaternary sands. The diversity of the heavy minerals suggests derivation from basic igneous rocks, metamorphic rocks and minor contribution from older sedimentary rocks.

Study of heavy minerals using ZTR index, Ternary diagram and Pie-Diagram revealed that the sediments of the studied area are immature; affected more by mechanical than by chemical weathering. Variations in heavy mineral distributions also reflect tectonically-controlled fluvial channel switching.

Appearance of pyrite in the heavy mineral assemblages at depth 22 – 22.2 m may record the evolution in reducing environments and confirm its authigenic origin.

تحليل المعادن الثقيلة لترسبات العصر الرباعي في الجزء الجنوبي للسهل الرسوبي العراقي

لمى عزالدين المختار

المستخلص

تناول البحث دراسة المعادن الثقيلة لسبع وثمانين عينة عائدة لواحد وخمسين بئرا محفورا في المنطقة الجنوبية للسهل الرسوبي ضمن تتابعات العصر الرباعي (الهولوسين والپلايستوسين) لايجاد تراكيز المعادن الثقيلة في هذه الرواسب (الجزء الرملي منها +63 مايكرون) وانتشارها في ترسبات ذلك العصر إضافة الى معرفة مصادرها وأصولها ومقارنة النتائج الحالية مع دراسات سابقة.

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بينت النتائج وجود اختلافات في تراكيز معظم المعادن الثقيلة في الآبار المختارة وتشابه في نوعيتها حيث انها مكونة على الاكثر من المعادن المعتمة ومعادن البايروكسين والهورنبلند والابيدوت والكارنت وبدرجة أقل من معادن الزركون والروتايل والتورمالين والستورولايت والكاينايت والكلورايت والبايوتايت وهذه المعادن تعود أصولها الى صخور متحولة (الشست والنايس والامفيبولايت) وصخور نارية قاعدية (الكابرو والبازلت) مع مساهمة قليلة للصخورالرسوبية القديمة المعاد ترسيبها.

من دراسة الاشكال الثلاثية و ZTR index و Pie-Diagram تبين ان ترسبات منطقة الدراسة غير ناضجة معدنيا وان تاثير التجوية الميكانيكية على الصخور المصدرية اكثر من التجوية الكيميائية والاختلاف في توزيع المعادن الثقيلة تؤثر تكتونيا على مسارات القنوات النهرية وان المنطقة لاتزال نشطة تكتونيا كما ان ظهور معدن البايرايت على عمق 22 – 22.2 متر تحديدا ربما يسجل بيئة مختزلة ويؤكد على الأصل الموضعي النشأة للمعدن.

وضحت الدراسة وجود مصادر مختلفة للمعادن الثقيلة في رواسب العصر الرباعي أهمها المعقدات الصخرية النارية والرسوبية في تركيا وسوريا والتي نقلت فتاتياتها بواسطة نهر الفرات والفتاتيات المنقولة من شمال شرق العراق بواسطة نهر دجلة وروافده إضافة الى التكوينات المجاورة والتي رواسبها منقولة من الدرع العربي والتي حدد تاثيرها بالمنطقة الواقعة غرب نهر الفرات.

INTRODUCTION

The Mesopotamia Plain (MP) occupies the central part of the Mesopotamia Foreland Basin (MFB). It has been an area of subsidence since the Late Cretaceous. After various episodes of marine ingression the Late Neogene strata indicate a fluvial depositional environment. The sediments are strongly influenced by the input of the Euphrates and the Tigris rivers and their major tributaries which have their outlet into the Mesopotamia Plain. During the uplift of the Zagros Mountains, the rivers of Mesopotamia migrated west and southwest during the Pleistocene and Holocene. Recent studies (Aswad *et al*., 2011; Aziz *et al*., 2011 and Aswad *et al*., 2013) advocate that the Late Cretaceous convergency of the Neotethys was responsible for supplying the Mesopotamia foreland basin with more basic materials. This study focuses on the well-studied Quaternary (i.e. Pleistocene and Holocene) subsurface sequences of the southern part of the Mesopotamia plain, Nasiriyah area, using heavy mineral analysis to assess the provenance and tectonic evolution of the Quaternary fluvial succession.The study area lies between 45° 00' 00'' – 46° 30' 00'' easting and 31° 00' 00'' – 32° 00' 00'' northing (Fig.1).

During the fifties of the last century, the petroleum exploration in the lower Mesopotamia Plain supplied a lot of geological data that led to a new thought as to the evaluation of the area, one of these interesting interpretations was presented by Lees and Falcon (1952) based primarily on the modern geomorphological and geological evidence of recent tectonic activity. Since then many authors studied the Mesopotamia Plain geologically, hydrogeologically, geological hazards and geomorphology, such as Ali (1977); Minarikova (1979 and 2004); Ali and Khoshaba (1980); Yacoub *et al*. (1985); Yacoub and Roffa (1988); Aqrawi (1993 and 1994); Dekran and Mahdi (1994); Al-Juboury *et al*. (2001a and 2001b); Al-Basrawi (2004); Al-Marsoumi (2004); Sissakian and Mahdi (2008) and Al-Khateeb *et al*. (2013).

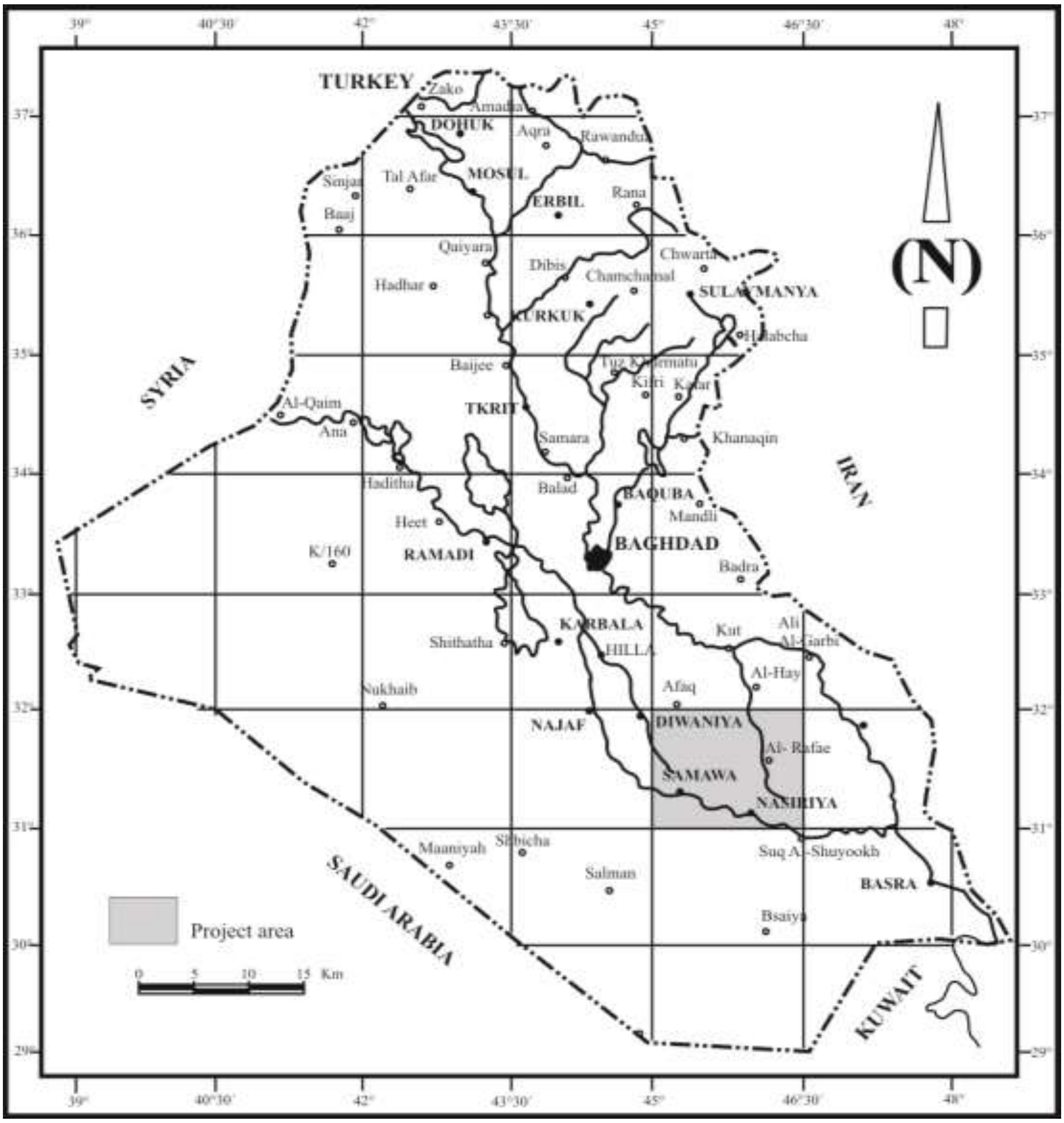

Fig.1: Location map of the project area

GEOLOGICAL SETTING

The study area is covered by Quaternary clastic sediments. The Quaternary includes both Pleistocene and Holocene sediments similar to those of the northern and central sectors of the Mesopotamia plain (Yacoub, 1985). An exceptional sedimentary cycle of Holocene age of marine and estuarine origin is observed by Al-khateeb *et al*., (2013).

The Quaternary sediments wedge out and are limited by the Pre-Quaternary deposits on the western margin of the basin and partly pass into alluvial fan sediments. They pass into the foothill sediments of Jabal Himreen on the other side of the basin.

They consist of rather complicated interbedded sequences of sands, silts and clays which are dominantly of fluvial origin with intercalations of marshy and lacustrine beds appearing at different depth intervals.

SAMPLING AND TECHNIQUES

Eighty seven core samples are collected from 48 shallow boreholes with depth range of 5 – 27 m and 3 deep boreholes with depth range of 18 – 98 m distributed into six sheets; 145, 146, 147, 159, 160 and 161 within the study area, Sample interval varies from 10 – 50 cm.

Laboratory techniques are carried out to separate the heavy from the light minerals using bromoform with specific gravity of 2.89 according to Carver (1971). Binocular and polarizing microscopes are used to identify the heavy minerals.

RESULTS AND DISCUSSION

The heavy minerals fall into the following five groups, arranged in descending order of frequency: opaque, unstable, metastable, ultrastable and alterite. Opaque group includes opaque black minerals represented by dominant magnetite and few ilmenite, leucoxene and chromites. Pyrite is present locally at depth 22 – 22.2 m. Opaque brown minerals are represented by hematite, few goethite and limonite. The average percentage of the opaque group is 30.78%. They commonly occur in igneous, metamorphic and sedimentary rocks (Hamilton, 1976). The average abundance of heavy minerals are shown in Tables (1, 2, 3, 4, 5 and 6).

Unstable group includes amphibole represented by dominant horenblende, few tremolite-actinolite, glaucophane, basaltic-horenblende and pyroxene represented by orth-pyroxene and clino-pyroxene. The average percentage of horenblende, ortho-pyroxene and mono-pyroxene are 15.89%, 4.64% and 18.29% respectively. Hornblende is found usually in metamorphic rocks because it alters from pyroxene both during early magmatic stages of crystallization of igneous rocks and during metamorphism. Orthopyroxenes are common constitutes of igneous rocks such as gabbro and pyroxenite while some clinopyroxene occur in igneous rocks such as basalt, gabbro and pyroxenite and others occur in metamorphic rocks (Hamilton, 1976).

Metastable group includes epidote, garnet, staurolite, kyanite, biotite and chlorite. The average percentage of these minerals in the studied area are 7.67% for epidote, 7.99% for garnet, 1.20% for staurolite, 0.46% for kyanite, 1.82% for biotite and 2.63% for chlorite.

The following genesis and mode of formation of the different heavy minerals are taken after Mange and Maurer (1992). The epidote occurs in the green-schist regional facies. The contact metamorphic rocks (e.g. hornfelses), and the epidote together with clinozoisite are common product of low to medium grade metamorphism. Garnet is common in a variety of metamorphic rocks and is also present in plutonic igneous rocks, pegmatites, in ultramafic varieties and in some acid volcanics. Staurolite is almost exclusively a product of medium-grade regional metamorphism of argillaceous sediments (i.e. mica schist), less frequently in gneisses. Kyanite occurs in gneiss, granulites and pelitic schist which are generated by the regional metamorphism of mostly pelitic rocks. It is considered as an indicator of the metamorphic zone higher than the one in which staurolite forms but preceding sillimanite grade. Biotite is ubiquitous in all types of igneous rocks and occurs in granite and granitic pegmatites. It also occurs in rhyolite and andesite. Biotite is also widespread in gneisses, green schists and in amphibolites facies rocks. Chlorite occurs in low-grade metamorphic rocks and is most common in the green schist facies. However igneous rocks chlorite is generated by the hydrothermal alteration of ferromagnesian minerals. Weathering processes of igneous and metamorphic can also produce chlorite and in sedimentary rocks it often forms authigenically during diagenesis.

Ultrastable group includes zircon; rutile and tourmaline .The average percent of zircon, rutile and tourmaline in the studied area are 1.49%, 0.34%, 2.14% respectively. Zircon is particularly ubiquitous in silicic and intermediate igneous rocks; it may reach high concentration in some beach sands and placers whereas rutile is widespread accessory mineral in metamorphic rocks, particularly in schist, gneiss and amphibolites; it is less significant in igneous rocks, where it occurs in hornblende-rich plutonic types and in pegmatite. Tourmaline crystallizes in granite, granite pegmatites, in veins and in contact or regionally metamorphosed rocks. In schist, gnieses and phyllites it may form by metasomatism or occurs as recrystallized detrital grains.

Alterite group includes minerals which are difficult to differentiate by Polarizing microscope because it cannot have any character to be recognized, their average percent in all study area is 1.92%.

Other minerals such as titanite, monazite, brookite, anatase, celestite, sillimanite and andalusite are present only as traces.

Table 1: Average abundance of heavy mineral (%) in samples from the studied borehole in Sheet 145 (T = Trace)

Heavy Minerals	B.H. 1	B.H. 2	B.H.3	B.H.4	B.H.5	B.H.6	B.H.7	B.H.8	B.H.9	B.H.10
Opaque	28.06	33.96	32.70	29.68	32.61	32.67	25.29	30.97	24.19	32.79
Alterite	2.04	1.79	2.02	1.04	1.13	1.33	2.59	3.49	1.64	2.19
Zoisite-Epidote	8.67	9.44	7.49	4.34	12.16	7.33	8.45	7.35	6.15	9.84
Horenblende	20.92	12.54	21.73	20.95	9.83	13.33	16.96	13.03	15.93	16.39
Ortho-Pyroxene	3.06	2.24	3.52	4.75	7.04	4.67	4.41	5.25	4.26	6.01
Clino-Pyroxene	18.88	25.49	7.71	14.93	17.48	20.0	20.39	22.32	26.58	15.30
Zircon	2.04	T	0.44	0.62	0.53	–	0.26	T	0.86	2.19
Rutile	–	–	0.78	0.62	–	–	T	T	0.32	–
Tourmaline	1.02	0.92	1.76	0.63	1.66	3.33	1.49	0.29	1.24	2.19
Garnet	6.63	4.68	7.69	7.69	13.59	8.67	11.10	8.25	10.55	6.01
Staurolite	1.02	1.79	0.46	0.83	0.60	–	1.68	2.38	0.86	0.55
Kyanite	0.51	0.33	–	–	–	0.67	0.77	0.29	0.32	–
Glaucophane	–	–	–	–	–	–	–	0.29	T	–
Tremolite-Actinolite	1.02	1.42	1.32	2.29	0.87	0.67	1.82	2.60	1.41	–
Chlorite	4.59	2.81	4.14	5.44	0.60	4.67	0.77	1.45	2.25	1.09
Biotite	1.53	1.15	1.11	3.53	0.60	2.67	3.57	1.48	1.32	4.37
Celestite	–	0.31	–	–	–	–	0.33	–	0.63	–
Titanite	–	–	0.15	–	0.27	–	–	0.29	–	–
Basaltic-Horenblende	–	0.92	T	–	–	–	0.25	0.29	0.63	–
Brown-Pyroxene	–	0.28	–	–	0.27	–	–	T	0.63	–
Sillimanite	–	T	–	–	–	–	–	–	–	–
Anatase	–	–	0.21	–	–	–	–	–	–	–
Monazite	–	–	–	–	–	–	T	–	–	–

Table 2: Average abundance of heavy mineral (%) in samples from the studied borehole in Sheet 146 (T = Trace)

Heavy Minerals	B.H. 1	B.H. 2	B.H.3	B.H.4	B.H.5	B.H.6	B.H.7	B.H.8	B.H.9	B.H.10
Opaque	27.99	36.81	31.95	27.57	26.93	23.41	30.36	29.43	36.25	30.34
Alterite	2.47	3.07	2.29	1.23	1.65	1.59	2.58	1.76	2.29	1.95
Zoisite-Epidote	7.78	11.66	5.21	7.41	4.69	4.76	6.25	5.06	5.59	6.55
Horenblende	17.96	16.56	16.73	21.39	23.05	24.21	17.48	22.05	10.84	12.63
Ortho-Pyroxene	3.95	3.07	5.59	6.99	4.48	4.37	5.09	4.18	5.30	5.34
Clino-Pyroxene	24.01	14.11	26.36	16.05	27.20	22.22	22.88	22.83	12.06	28.40
Zircon	0.24	T	T	1.23	0.74	0.39	1.06	0.87	4.99	1.46
Rutile	–	–	–	1.23	T	0.39	–	0.22	T	0.25
Tourmaline	0.94	–	0.31	0.41	0.23	1.59	1.02	0.88	1.77	1.70
Garnet	4.42	7.36	4.76	9.05	3.50	4.37	7.17	5.93	15.63	6.31
Staurolite	0.24	1.23	0.99	1.23	1.66	0.79	0.75	0.66	3.33	0.73
Kyanite	0.47	0.61	0.31	0.41	0.25	0.79	–	0.89	0.76	–
Glaucophane	–	T	–	–	0.25	–	–	–	–	–
Tremolite-Actinolite	0.96	T	0.31	2.06	1.17	4.37	1.91	1.77	0.78	0.98
Chlorite	5.95	4.91	1.30	0.41	0.70	3.75	0.17	0.44	0.98	0.49
Biotite	1.19	0.61	2.29	2.88	2.61	1.98	2.59	2.19	1.59	1.70
Celestite	–	–	–	–	–	–	–	0.22	0.27	–
Titanite	0.72	–	0.61	–	–	0.79	–	0.22	T	0.25
Basaltic-Horenblende	–	–	0.31	–	0.93	–	0.68	0.43	0.27	0.49
Brown-Pyroxene	0.75	–	–	–	–	0.39	–	T	–	0.49
Anatase	–	–	–	–	–	–	–	–	–	–
Sillimanite	–	–	–	–	–	–	T	–	–	–
Monazite	–	–	–	–	–	–	–	T	–	–
Brookite	T	–	–	–	–	–	–	T	–	–
Andalusite	–	T	–	–	–	–	–	–	–	–

Table 3: Average abundance of heavy mineral (%) in samples from the studied borehole in Sheet 147 (T = Trace)

Heavy Minerals	B.H. 1	B.H.2	B.H.3	B.H.4	B.H.5	B.H.6	B.H.7	B.H.8	B.H.9	B.H.10
Opaque	31.06	31.87	29.44	28.69	31.53	27.91	33.36	27.16	20.0	28.17
Alterite	3.03	2.75	1.64	2.98	0.92	2.91	0.88	0.43	1.88	2.71
Zoisite-Epidote	6.06	5.49	7.25	8.0	7.28	12.79	4.99	10.34	10.0	7.16
Horenblende	18.18	18.68	19.11	18.16	19.69	16.28	17.59	17.24	13.13	14.61
Ortho-Pyroxene	6.06	3.85	2.47	5.37	2.41	4.65	4.98	3.88	5.0	5.89
Clino-Pyroxene	16.67	19.23	19.65	19.45	9.46	11.63	18.31	24.14	31.25	21.51
Zircon	1.52	T	0.42	0.76	1.52	1.74	0.27	T	1.25	1.01
Rutile	–	–	0.75	–	0.60	–	0.27	0.43	–	0.38
Tourmaline	1.52	–	0.96	1.64	1.69	3.49	0.54	0.43	3.75	1.70
Garnet	3.79	2.19	7.65	5.69	7.03	15.12	6.33	8.62	6.25	9.51
Staurolite	1.52	T	0.69	1.05	0.20	1.74	0.88	0.43	1.88	0.91
Kyanite	2.27	T	0.42	1.14	0.46	T	T	T	0.63	0.27
Glaucophane	0.76	–	–	0.38	–	–	–	–	–	–
Tremolite-Actinolite	2.27	2.15	0.48	2.01	2.04	T	2.09	–	0.63	1.96
Chlorite	3.03	9.89	6.82	3.27	12.84	–	7.29	3.45	1.88	0.64
Biotite	1.52	2.75	0.96	0.76	1.89	1.74	1.96	2.59	0.63	1.96
Celestite	–	T	0.54	–	0.80	–	–	–	–	–
Titanite	–	–	T	–	0.20	0.58	T	–	0.63	0.38
Basaltic-Horenblende	–	1.09	0.27	–	–	T	T	0.86	1.25	1.28
Brown-Pyroxene	–	–	0.27	–	–	–	0.27	T	–	–
Sillimanite	–	–	–	–	–	–	–	–	–	–
Anatase	–	–	–	–	–	–	–	–	–	–

Table 4: Average abundance of heavy mineral (%) in samples from the studied borehole in Sheet 159 (T = Trace)

Heavy Minerals	B.H. 1	B.H. 2	B.H.4	B.H.5
Opaque	29.52	46.26	26.90	33.92
Alterite	1.98	1.73	1.02	2.03
Zoisite-Epidote	7.53	9.56	4.57	6.80
Horenblende	19.22	8.39	29.44	8.95
Ortho-Pyroxene	3.96	5.29	4.06	5.46
Clino-Pyroxene	12.71	8.75	13.71	15.58
Zircon	0.73	1.41	–	6.17
Rutile	0.53	–	–	1.54
Tourmaline	1.95	1.09	0.51	3.53
Garnet	11.89	12.02	2.54	10.42
Staurolite	1.43	1.41	–	1.69
Kyanite	0.76	0.32	1.02	0.22
Glaucophane	–	–	–	0.22
Tremolite-Actinolite	1.78	–	2.54	–
Chlorite	2.39	0.68	10.15	1.32
Biotite	1.72	2.09	3.05	0.44
Celestite	–	0.64	0.51	–
Titanite	0.96	–	–	–
Basaltic-Horenblende	0.99	0.36	–	–
Brown-Pyroxene	–	–	T	–
Sillimanite	–	–	–	–
Anatase	–	–	–	–
Monazite	T	–	–	–
Brookite	–	–	–	–
Muscovite	–	–	T	–

Table 5: Average abundance of heavy minerals (%) in sample from the studied borehole in sheet 160 (T = Trace)

Heavy Minerals	B.H. 1	B.H.2	B.H.3	B.H.4	B.H.5	B.H.6	B.H.7	B.H.8
Opaque	37.5	26.04	29.03	32.0	20.71	34.84	36.25	24.14
Alterite	1.70	2.28	1.94	3.20	1.84	3.29	0.83	2.07
Zoisite-Epidote	11.93	6.38	4.52	6.40	7.48	13.73	3.33	8.97
Horenblende	9.09	19.39	11.61	11.20	17.50	8.39	3.75	8.97
Ortho-Pyroxene	1.70	5.31	1.94	4.0	8.57	3.69	1.67	4.83
Clino-Pyroxene	7.95	21.52	33.55	27.20	28.32	21.63	4.58	33.79
Zircon	2.27	1.14	0.65	–	1.05	0.24	11.67	1.38
Rutile	0.57	0.19	–	–	–	0.47	3.75	–
Tourmaline	-	0.67	1.94	5.60	1.68	0.94	18.75	3.45
Garnet	22.16	9.21	4.52	5.60	4.93	5.25	2.92	8.97
Staurolite	2.27	1.26	4.52	0.80	0.98	2.04	2.92	–
Kyanite	0.57	0.93	–	–	–	0.63	–	–
Glaucophane	–	–	–	–	T	–	–	–
Tremolite-Actinolite	–	1.53	–	1.60	2.36	0.79	–	2.07
Chlorite	–	1.73	0.65	–	1.44	0.24	0.42	-
Biotite	2.27	1.45	2.58	0.80	1.07	2.83	–	1.38
Celestite	–	0.28	0.65	–	–	–	–	T
Titanite	T	0.67	–	1.60	0.29	1.02	–	–
Basaltic-Horenblende	–	0.55	0.65	–	1.56	–	–	–
Brown-Pyroxene	–	–	–	–	–	T	–	–
Sillimanite	–	–	1.29	–	T	–	–	T
Anatase	–	–	–	–	–	–	–	–

Table 6: Average abundance of heavy mineral (%) in samples from the studied borehole in Sheet 161 (T = Trace)

Heavy Minerals	B.H. 1	B.H.2	B.H.3	B.H.4	B.H.5	B.H.6	B.H.7	B.H.8	B.H.9
Opaque	28.15	28.12	33.45	27.65	21.09	25.41	26.02	19.98	31.96
Alterite	0.75	1.26	1.52	0.42	1.64	3.08	1.28	1.56	3.49
Zoisite-Epidote	3.06	8.0	6.39	2.63	11.74	11.38	9.68	13.76	9.60
Horenblende	13.49	13.78	15.67	5.22	24.63	15.91	16.09	21.53	16.49
Ortho-Pyroxene	7.48	5.98	4.40	7.19	5.91	2.95	5.02	4.41	4.73
Clino-Pyroxene	20.04	21.82	14.15	24.60	10.42	18.77	13.86	16.84	12.76
Zircon	2.06	2.34	1.47	1.99	2.79	1.79	2.24	1.10	1.75
Rutile	–	0.23	0.22	0.63	0.65	–	–	0.23	0.60
Tourmaline	4.15	2.84	2.62	4.8	2.29	2.59	4.89	1.99	0.97
Garnet	7.06	3.11	0.74	4.88	12.24	11.01	11.68	12.42	11.20
Staurolite	T	1.39	0.75	1.81	1.64	0.36	0.29	0.67	1.06
Kyanite	1.27	0.63	0.97	0.24	0.50	0.36	0.89	0.23	0.37
Glaucophane	–	–	T	–	T	0.25	–	–	T
Tremolite-Actinolite	8.18	5.44	4.22	6.07	1.82	1.05	4.22	1.32	0.60
Chlorite	1.99	2.56	5.65	2.18	1.37	0.56	2.16	0.45	0.60
Biotite	1.54	1.76	0.97	2.15	1.93	2.09	0.89	2.22	2.57
Celestite	0.79	0.45	1.21	1.34	–	0.25	0.78	–	–
Titanite	–	–	–	–	T	0.05	–	0.45	T
Basaltic-Horenblende	–	0.32	–	T	1.44	0.86	–	0.88	1.19
Brown-Pyroxene	–	T	–	–	T	T	–	–	T
Sillimanite	–	–	–	–	–	–	–	–	–
Anatase	–	–	0.22	–	–	–	–	–	–

▪ Distribution of Heavy Minerals

The heavy mineral assemblage is characterized by abundant hornblende, clinopyroxene, orthopyroxene, garnet and epidote. Mica (includes chlorite and biotite) and ultrastable minerals ZTR (zircon, tourmaline and rutile) are present in almost all samples but in highly variable quantities (Tables 1, 2, 3, 4, 5 and 6). Other minerals, such as tremolite-actinolite, clinozoisite, zoisite, staurolite, kyanite, glaucophane, titanite and celestite, occur irregularly in small or trace amounts. Sillimanite, brookite, anatase, monazite and andalusite present as trace in some boreholes. Chromite appears at depths ranging between 8.8 to 30 m in boreholes 2, 3, 4, 5, 7, 9 in sheet 146, boreholes 5 and 8 in sheet 147 and boreholes 5, 6 in sheet 161. Pyrite appears only in boreholes 2/159 and 9/145 at depth 22 – 22.5 m, its appearance refers to authigenic origin and records brackish and fresh water environments (Mange and Wright, 2007).

Figure (2) shows the distribution of heavy minerals in the studied area using Pie-Diagram. It shows that ultrastable minerals represented by ZTR are increasing in the west bank of the Euphrates river whereas the non-stable minerals (pyroxene, hornblende and epidote) increase at the east bank of the river. This reflects the different sources of the sediments. Mica minerals (represented by chlorite and biotite) and epidote minerals (represented by epidote, zoisite and clinozoisite) increase towards the north and northeast of the studied area. This indicates that the sediments of boreholes situated in this area are supplied by the Tigris River which contains more epidote and mica than does the Euphrates River (Philip, 1968; Abdul Wahab, 1983; and Yacoub, 1988). Amphibole and pyroxene concentrations increase towards the west and south of the studied area. This indicates that the sediments of boreholes situated in this area are supplied by the Euphrates river which contains high amount of these minerals (Al-Bassam and Al-Mukhtar, 2008).

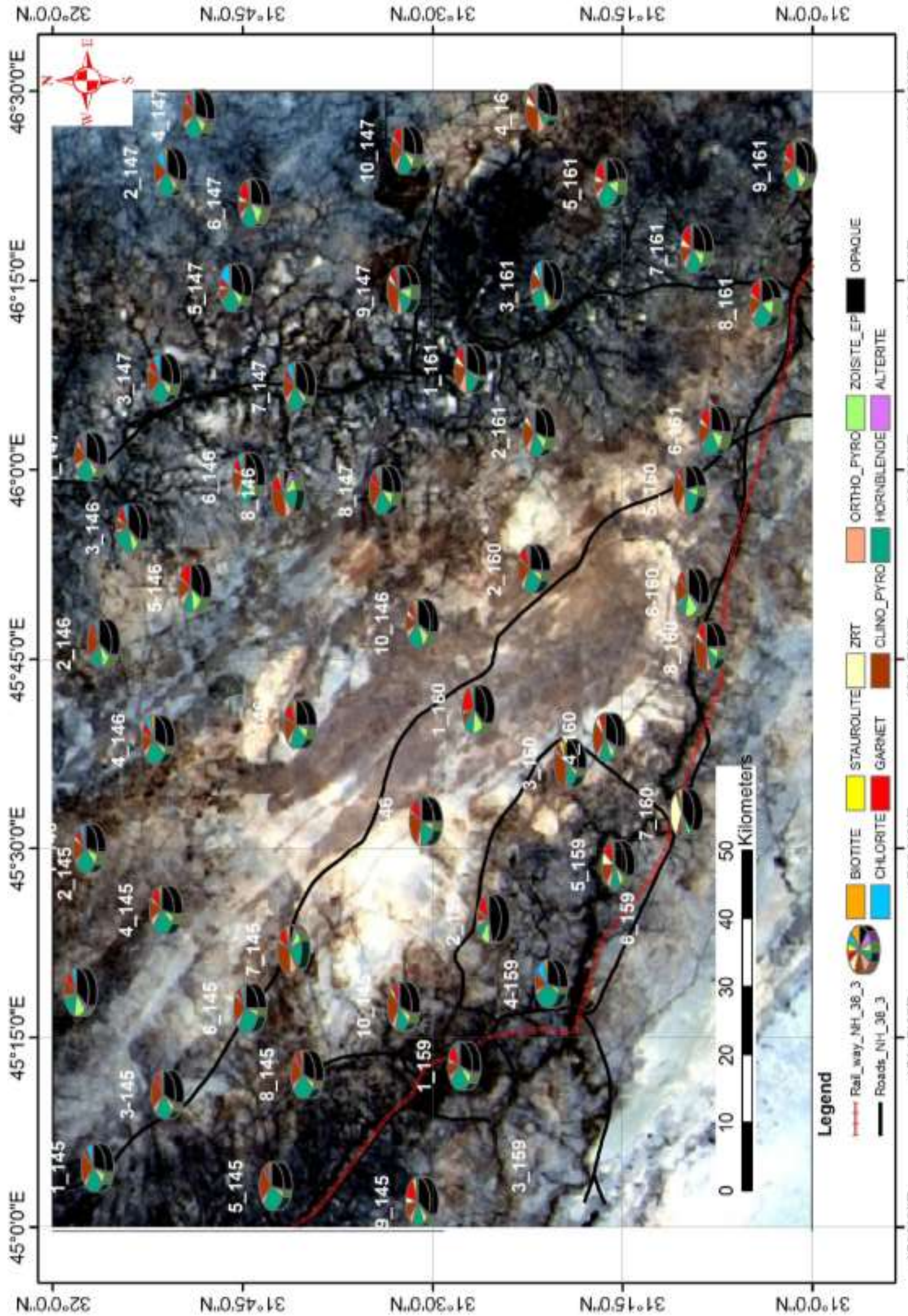

Fig.2: Pie-Diagram showing distribution of the heavy minerals in all boreholes studied

- **Heavy Mineral Assemblages and Continental Margin Activity**

The relationship between tectonic activity and sedimentation can influence heavy mineral assemblage configurations within the basin and depend on the rate and magnitude of the activity. Nechaev and Isphording (1993) suggested a plate tectonic interpretation of heavy mineral data by comparing the configuration with the possible sources of clastic sediments resulting from different stages of the plate tectonic cycle. They constructed the right angle triangular diagram (MF, MT and GM) linking plate tectonic setting and the heavy mineral assemblages as follows:

1. MF (common constitutes of mafic magmatic rocks) = total content of pyroxene and hornblende
2. MT (common constitutes of basic metamorphic rocks) = total content of pale-colored and blue green amphiboles, epidote and garnet.
3. GM (accessory minerals of granites and sialic metamorphic rocks) = total content of zircon, tourmaline, staurolite, kyanite, andalusite, monazite and sillimanite

Analytical data of heavy minerals of the studied samples are listed as frequencies in Table (7) and plotted as MF-MT-GM diagram in Fig. (3). Clustering of points close to the MF apex, indicates their correspondence with assemblages of active continental margins affinity which are characterized by a relatively high percentage of minerals derived from mafic magmatic rocks with exception the sample from borehole 7/160 which fell within the field of mature passive continental margins which are characterized by a relatively high percentage of minerals derived from old crustal materials of mature passive continental margins with no active tectonic events (e.g. Arabian Shield ?) or as a result of sediment reworking. Fig. (3) shows that all data points of the southern part of the Mesopotamia Plain are close to the MF apex, corresponding to the sediments whose main detrital sources were from an active region.

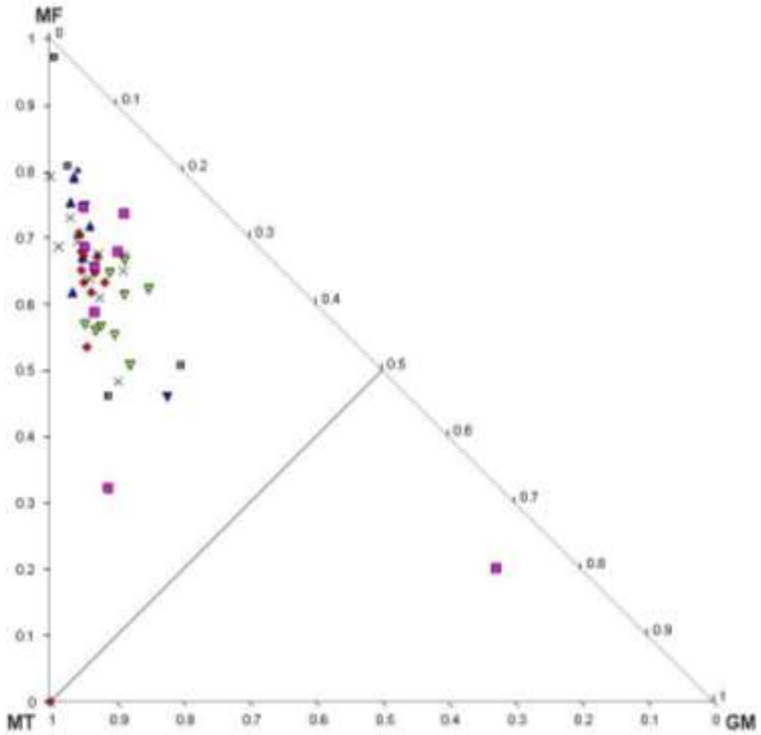

Fig.3: Interrelationship of the MF – MT – GM suites of the studied boreholes (after Nechoev and Isphording, 1993)

Table 7: Heavy mineral frequencies, interrelation and indices of samples studied

Sheet No.	Borehole No.	MT	GM	MF
145	1	13.16	1.89	45.92
	2	19.02	1.84	33.74
	3	10.59	2.23	48.68
	4	18.52	3.28	44.43
	5	10.54	2.88	54.73
	6	13.5	3.56	50.80
	7	16.01	2.83	45.45
	8	13.19	3.30	49.06
	9	22.27	10.85	28.20
	10	14.33	3.89	46.37
146	1	16.32	4.59	42.86
	2	16.46	3.04	40.27
	3	16.5	2.66	32.96
	4	14.3	2.50	40.63
	5	26.26	3.58	34.35
	6	16.67	4.0	38.0
	7	21.62	4.20	41.76
	8	18.78	2.96	40.60
	9	18.74	3.28	46.77
	10	16.94	4.93	37.70
147	1	12.88	6.83	40.91
	2	10.92	T	41.76
	3	15.65	2.49	41.23
	4	16.08	4.59	42.98
	5	16.35	3.87	31.56
	6	27.91	6.97	32.56
	7	13.41	1.69	40.88
	8	19.82	0.86	45.26
	9	18.13	8.37	49.38
	10	19.91	3.89	42.01
159	1	22.19	4.87	35.89
	2	21.94	4.23	22.43
	4	9.65	1.53	47.21
	5	17.44	11.61	29.99
160	1	34.09	5.11	18.74
	2	17.67	3.46	46.22
	3	9.69	7.11	47.10
	4	13.6	6.4	42.40
	5	14.77	3.71	54.39
	6	19.77	3.85	33.71
	7	6.25	33.34	10.0
	8	20.01	4.83	47.59
161	1	18.3	7.48	41.01
	2	16.87	5.81	41.58
	3	11.35	5.81	34.22
	4	13.58	8.84	37.01
	5	25.8	7.22	40.96
	6	23.69	5.10	37.63
	7	25.58	8.31	34.97
	8	28.38	3.99	42.78
	9	22.59	4.15	33.98

MT = Total content of pale-colored and blue green amphibole, epidote and garnet

GM = Total content of zircon, tourmaline, staurolite, kyanite, andalusite, monazite and sillimanite

MF = Total content of pyroxene and hornblende

- **ZTR Maturity Index**

It is a combined percentage of zircon, tourmaline and rutile among the transparent heavy minerals excluding micas and authigenic species. Table (8) indicates that the average value of ZTR index is 0.2 which means that the sediments of the studied area are immature and also indicates a possible redeposition from older sediments; the higher index is the more matured sedimentary material (Aubrect, 2001).

Table 8: The value of ZTR index in the studied area

Sheet Number	ZTR index
145	0.10
146	0.21
147	0.21
159	0.29
160	0.22
161	0.18
Average	0.20

- **Assessment of Present Study in Comparison with Previous Studies**

The percentage of heavy minerals in the present study (Table 9) coincides with the percentage of heavy minerals of Euphrates and Tigris rivers, confirming that the principle source regions which provide the heavy mineral association of the studied area are essentially Euphrates and Tigris rivers, whose main sources of detritus were an active continental margin of the north and northeast MFB (i.e. Taurus and Zagros Mountains).

Table 9: The average concentration of heavy minerals in the sediments of the Euphrates, the Tigris, Injana, Dibdibba Formations and Mesopotamia plain

Heavy Minerals (%)	1	2	3	4	5	6
Opaques	31.77	24.6	42.0	49.45	32.87	30.78
Pyroxenes	31.81	11.1	1.10	0.52	2.16	22.93
Amphiboles	18.38	24.0	0.83	0.83	1.77	15.89
Chlorite	2.60	5.3	2.60	0.42	1.30	2.63
Garnet	3.73	3.6	5.40	1.12	2.73	7.99
Epidote	2.84	24.4	24.0	1.0	2.09	7.67
Biotite	1.18	2.5	2.6	0.01	0.04	1.82
Staurolite	0.94	0.1	0.83	0.64	1.26	1.20
Zircon	0.75	0.1	5.6	11.81	12.49	1.49
Kyanite	0.51	0.2	0.1	0.04	–	0.46
Tourmaline	0.37	0.2	3.18	3.96	6.69	2.14
Rutile	0.1	0.7	1.31	2.03	1.6	0.34

1: Sediments of Euphrates River (Al-Bassam and Al-Mukhtar, 2008)
2: Sediments of Tigris River (Philip, 1968)
3: Sediments of Injana Formation Najaf and Razzaza area (Al-Bedari, 1997)
4: Sediments of Dibdibba Formation in Tar-Al-Najaf (Al-Mukhtar and Manchi, 2009)
5: Sediments of Dibdibba Formation in west of Karbala (Al-Mukhtar and Manchi, 2010)
6: Sediments of southern part of Mesopotamia plain (present study)

A review of a previous study by Abdul Wahab (1983) for the recent sediments of Tigris, Diyala and Adhaim rivers, indicates that the sediments of the Tigris river and their major tributaries contain heavy minerals represented by predominant amphibole group (including common hornblende with a mean value of 25.49%, brown hornblende with 2.87%, tremolite-actinolite with 0.55% and glaucophane with 0.33%), then epidote group (including epidote with 8.96%, zoisite with 0.95% and clinozoisite with 1.96%)and pyroxene group(including clinopyroxene with 8.05%, brown pyroxene with 2.63% and orthopyroxene with 0.8%). The presence of garnet with percentage of 12.2 and zircon with percentage ranges between 0.27% to 2.32% and other species of heavy minerals are found at very low level or as trace. Abdul Wahab also found high amount of igneous and metamorphic rock fragments which are lacking in the present study. This suggests either a long distance of transportation of sediments or transportation of sediments by river with high capacity during the Quaternary.

CONCLUSIONS

- The present study reveals that fourty percent of the heavy minerals are of metamorphic origin (clino-pyroxene, epidote, chlorite, rutile, staurolite, tremolite-actinolite and kyanite), and those of igneous origin reach up to 7% (zircon, ortho-pyroxene, brown-pyroxene and tourmaline) while heavy minerals of different source rock origin form 48% (opaques, horenblende, biotite and celestite).
- According to the diversity of the above mentioned heavy mineral, the sediments are derived from basic igneous rocks (gabbro and basalt), metamorphic rocks (schist, gneiss and amphibolites) and little participation of older sedimentary rocks.
- The sediments of the studied area are immature as their ZTR index ranges between 0.1 – 0.29.
- The correlation of present study with previous studies shows that the concentration of heavy minerals in the sediments of the studied area coincides with that of the Euphrates and Tigris River to the north and northeast.
- The abnormal increase of the concentration of ultra stable minerals (ZTR) in boreholes 7/160 and 5/159 (west of Euphrates River) refer to different sources of the sediments of this locality, probably the surrounding formations whose sediments had been transported from the Arabian Stable Shelf in the west.
- The main sources supplying the sediments to the studied area are the Euphrates and Tigris rivers whose sediments are transported from the Taurus-Zagros Belt. The other source, which affected the area locally west of Euphrates river, is the surrounding formations whose sediments are transported from the Western Desert.
- Ternary diagram shows that the samples studied fall within the field of active continental margins which is characterized by a relatively high percentage of minerals derived from mafic magmatic rocks. This fact suggests that the southern part of the Mesopotamia plain is still tectonically unstable.
- The mechanical weathering is more effective on the sediments of the source area than chemical weathering.

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