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Petrography and Mineralogy of Injana Formation (LateMiocene) in the Central Part of Iraq

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Abstract: *The petrographic studies of the sands and sandstones of Injana Formation (LateMiocene) in the studied area indicate that they are immature, poorly sorted, mostly clayey and classified as Litharenite. They are composed essentially of sedimentary rock fragments followed by quartz , metamorphic rock frogments and feldspar.The predominant type of sedimentary fragments is carbonate. The study of heavy minerals indicates that epidote group is forming the main heavy minerals, followed by amphibole, pyroxene and garnet.The source area based on petrographical and heavy minerals studies is interpreted to be composed essentially of sedimentary followed by igneous and metamorphic rocks.*
The study of clay minerals indicate the presence of montmorillonite, chlorite, illite and kaolinite. The origin of most of these minerals is detrital, however, the chlorite is considered partly diagenetic.
Keywords: *Injana Formation , Petrography , Mineralogy*

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بتروغرافية ومعدنية تكوين انجانة (المايوسين الاعلى) فيوسط العراق

المستخلص
الدراسة البتروغرافية للرمال و الصخور الرملية لتكوين انجانة (الماويوسين الاعلى) في منطقة الدراسة بينت بأنها غير ناضجة وردينة الفرز وتصنف بالليث ارينايت .تتكون هذه الرمال و الصخور الرملية بصورة رئيسة من حبيبات لاجزاء من صخور رسوبية ثم الكوارتزثم تليها اجزاء من الصخور المتحولة والفلدسبا ر .ان نوع الحبيبات السائدة ذات الاصل الرسوبي هو اجزاء من الصخور الجيرية . دراسة المعادن الثقيلة بينت بأن محموعة الابيدوت هي الرئيسة تتبعها معادن الامفيبول و البايروكسين والجارنيت .ان صخور المصدر اعتمادا على الدراسة البتروغرافية و المعادن الثقيلة .استنتجت بأنها تتكون بصورة رئيسة من صخور رسوبية تم تليها الصخور النارية و المتحولة .دراسة المعادن الطينية بينت وجود معادن المونتموريلينايت والكلورايت والالايت والكاؤلينات .ان اصل اغلب هذه المعادن هو فتاتي بينما الكلورايت هو جزئيا فتاتي وجزئيا تحوري .

I. Introduction

Core samples from Injana Formation (Late Miocene) were collected from six boreholes from Baiji and three boreholes from AL-Mihzam localities, in the northern of SamaraCity, on the western side of Tigris River, central part of Iraq
(Fig.1).

Thestudied samples represent the depth from 15.3 meters to 83.2 meters which comprise clastic sequence as interbeded sandstones, siltstones, mudstonesandclaystones aswell as thin beds of carbonates. Nomuch work was carried out in the studied area. However, thorough stratigraphic and sedimentological works were carried out to the formation outside ofthe studied area (e.g.Bellen *et aL*.,1959; Kuklal and SaadaIa, 1970; Basi , 1973 ; Al –Mubarak and Yokhanna , 1976; AL-Samarrai, 1978; Jassim *et al*., 1984; AL-Rawi *etal* 1993 and Sawsan *et al*.,2017). All of the aforementioned previous works were considered the formation as continental to subcontinental and deltaic to fluviatilc environment. However ,Basi (2007) studied the formation in the studied area sedimentologically and interpreted the environment to be meandering fluviatile environment.

The purpose of this work is to reveal petrographic description and information on the heavy and clay mineralogy of the studied rocks and to interprate their provenance history.

II. Petrography

Petrographic study of sands and sandstones

The identification of the sandsand sandstones constituents was performed by means of binocular microscope .Their percentages were estimated semiquantitavly as shown in table 1. Alizerin Red S following friedman's(1959) procedure was used to differentate the carbonate cementing minerals .

Petrographic study of 39 samples of the Injana Formation was carried out and the results are presented in table 1. The study revealed the presence of quartz,feldspar and rock fragments. The sandstones are cemented mainly by calcite with subordinate iron oxides, silica and gypsum . the sands and sandstones are mainly classified as litharenite according to Folk's classification with subordinate feldspathiclitharenite (Folk,1974). The following is the description of the sands and sandstones constituents:

1- Quartz

The average percentages are 22.04 and 26.0 in Baiji and Al-Mihzam localities. The grains are mainly subrounded to subabgular with subordinate angular to rounded grains .

Most of the quartz grains are monocrystalline with small amount of polycrystalline. The monocrystalline grains are forming more than 90% of the identified grains. They are moderately sorted and range from 0.11 to 0.28 mm in size. Some of the grains show andulus extinction. Inclusions are common and the identified minerals are tourmaline ,zircon and volatile bubbles (?). The polycrystalline grains are less in percentages and they are coarser in grains size than the monocrystalline quartz grains.

2-feldspar

The average feldspar content is 6.76 and 4.19 in Baiji and Al-Mihzam localities. The grains range in size from 0.16 to 0.3 mm and they are mainly angular to subangular ,however subrounded grains are observed. Some of the grains are completely altered into clay and sericite and only their outline are preserved. Two types of feldspar are observed ;alkali feldspar and plagioclase. The alkali feldspar are represented by orthoclase and microcline. The orthoclase is recognized by cloud relief whereas the microcline by cross-hatching twining.

The plagioclase feldspars are of albite twining; however , some of them have carlsbad twining as a combination of carlsbad and albite twining. Some of the grains altered. The identified plagioclase minerals range from andesine to bytonite ,based on degree of maximum extinction angle of albite and carlsbad twining .

3-Rock fragments

The rock fragments are the highest constitunts recorded in the studied sands and sandstones. Their average ranges from 41.77 to 54.63 in Baiji and al-Mihzam localities. They are relatively coarser than any other components and range in size from 0.18 to 0.46 mm. The recognized rock fragments aresedimentary, igneous and metamorphic types. The identified sedimentary fragments are carbonates, chert,sandstones and argillaceous. The metamorphic rock fragments are represented mainly by schist, slate and phyllite whereas the identified igneous rock fragments are acidic igneous fragments (granite and pegmatite) , andesite, rhyolite and basalt.

4- Cement

Four types of cement were recognized; calcite, gypsum , iron oxide and silica.Most calcite cement is sparry calcite and some of them are micritic with clay minerals. The iron oxide cement is trace in amount and present as thin films coating the boundary of the grains and even sometimes the whole grains. The silica and gypsum cement also are trace in amount and present in few samples.

5- Matrix

The matrix is polymineralogic. It is composed of clay and silt size grains .The grains of matrix are randomly distributed between the minerals constituntes of the rocks and form as binder to the detrital grains. It is thought in this study that most of the matrix is detrital in origin. However, some of them might be formed by disintegration and alteration of the rock fragmeats and unstable grains such as feldspar and mica.

Petrographic study of mudstones and claystones

The studied fine grained sediments of Injana Formation are represented mainly by mudstone with few claystone units. The petrographic study of mudstones and claystones revealed that they are composed of clay minerals,quartz and sometimes with subordinate micriticcalcite .The identified clay minerals are montmorillonite, Kaolinite, illite and chlorite as described in detail later. Petrographic names are mudstones, sandy mudstones and claystones.

III. Mineralogy

1- Heavy minerals

The heavy minerals study was carried out in the laboratory by separation of heavy sand fraction from the light fraction by bromoform liquid of specific gravity 2.84-2.818. The 60-200 fraction was studied by polarizing microscope and about 300 grains were counted for each glass slide. The heavy minerals assemblages of the sandstones of the Injana Formation revealed the presence of three groups: opaque, altertite and transparent minerals. The average percentage of the heavy minerals in each locality is presented in table 2.

a-Opaque minerals :

Opaque minerals were identified in all of the samples but in different proportion. They are represented mainly by hematite and limonite. The shapes of the identified minerals are domainantly subrounded to subangular.

b-Alteriteminerals:
The alterite minerals are very difficult to determine and they can be recognized by XRD or electronic microscope. Their average ranged in the studied sediments from 10.86 to 11.60 in Baiji and and Al-Mihzam localities.

c-Transparent minerals
The identified species of the transparent minerals are epidote, amphibole, pyroxene , garnet, zircon , rutile , tourmaline, titanite, biotite and chlorite. For the the purpose of description the identified transparent minerals are classified in this study into four groups: epidote,amphibole,pyroxene and others.

Epidote group
It is the most abaundant group in the studied transparent heavy minerals. It consists mainly of epidote and clinozosite .The epidote crystals varies in colour from colourless to pale green. They are mostly non-pleochroic and with minerals parallel extinction.The clinozoisites are recognized as worn prism and moderate birefrengness.

Amphibole Group
The amphibole group is represented mainly by hornblende with subordinate tremolite-actinolite and glaucophe in trace amount. The hornoblend is green to brownish green in colour, slightly corroded and mostly elongated.Tremolite-actinolite, both are optically the same, therefore can not be divided . They are colourless , elongated and with small extinction angle.

Pyroxene group
The pyroxene group is dominated by clinopyxene with subordinate orthopyroxene. The clinopyroxenes are mostly colourless and some of themare yellowish green in colour with no or weak pleochrism. The grains are mostly elongated some of them showing inclusions and deeply to partially corroded. The orthopyroxene minerals are colourless with parallel extinction angle and slightly corroded.

Otherminerals
The identified other minerals are dominated by biotite,garnet, rutile and zircon with subordinate tourmaline and titanite. The following is abrief description for some of these minerals:

Garnet
It is isotropic, mostly colourless, rarely brownish, pinkish and yellowish in colour. Most of the crystals are angular, with subordinate subrounded and subangular and have opaque and unidentified mineral inclusions.

Rutile
Rutile is red and orange in colour, high relief and subrounded to rounded.

Zircon
It is rare and not observed in most of the samples. Zircon is mostly colourless with subordinate pinkish grains. It is mostly angular to subrounded ; however,very few rounded and euhedral to subhedral grains are observed.

Chlorite:
Chlorite is mostly green in colour and varies from rounded to subangular and some of the grains showing fractures. Inclusion of opaque minerals are present in some of the grains.

2- **ClayMinerals**
Semiquantitative analysis for caly performed by wighing of 10 grams from the sample, crushing it and then 25% of the acitic acid was added to dissolve the carbonate minerals. The sample is washed carefully from the acid, dried and then weighted to determine the weight of the caly and quartz minerals. Oriented samples were made by using Gipson method (Gipson, 1966) and anlysed by XRD using Cu and K radiator. The clay minerals were identified and calculated by Schultz (1964) and AL-Saadi (1984) methods. The areas under peaks for each individual clay mineral were calculated then the percntages of the clay after the subtraction of the quartz percentages were determined.
The classification of clay minerals given by Millot (1970) is adopted because it verifies the approach of this study. In the studied localities the following types of caly minerals were identified:

1- Montmorillonite

Montmorillonite is identified as the main minerals in all of the studied area. It is varied from 6% to 21% and its not identified in some samples(tables 3 and 4) . However; combined phase of montmorillonite and chlorite is recognized in three samples from Baiji boreholes and treated as one mineral phase because of the difficulty of measuring each of them separately. These samples are not presented in table 3 .

2- Chlorite

Chlorite mineral is identified in most of the studied samples and it is varied form 6% to 36%.

3- Illite

Because it is dfficult to estimate semiquantitvelly the percentages of palygorskite, therefor, illite mineral is combined with palygorskite in most of the studied sediments. Howerever, in few samples it is possible to estimate the percentages of illite mineral.The illite is totally missing in some of gypcrete samples in the Quaternary sediments of thestudied area (Basi and Karim,1992) and the palygorskite is identified and estimated alone and is considered to be formed diagentically as it is connected with secondary evaporate minerals (condition of high Mg^{++} necessary for the formation of palygorskite). Because of the non-identification of palygorskite in the studied sediments alone, as in the sediments associated with gypcrete of the Quaternary sediments and the missing of evaporate minerals in the sediments, suggested the presence of illite alone in the studied samples in which the illite is combined with palygorskite as one phase.

4- Kaolinite

Kaolinite mineral is present in most of the studied sediments in various proportions. It ranges form <1% to 11%.The Kaolinite is present in the claystones and sandstones.

IV. Discussion

The Injana Formation is typical fluviatile sediments (Basi,2007) which were developed by the rapid erosion and uplifted mountains in the north and northeastern part of Iraq and the deposition in troughs suffering continuous subsidence in their basins.

Petrographic study of Injana sands and sandstones reveals that they are immature poorly sorted and mostly clayey . They are composed essentially of sedimentary rock fragments (mainly carbonate)followed by quartz and then by metamorphic and igneons rock fragments. The sandstones components are cemented essentially by carbonate, then followed by iron oxides. The sands and sandstones are classified as litharenite according to Folk classification (Folk, 1974). The immaturity and composition of the sands and sandstones requires rapid erosion promoted by high relief and/ or aridity, as feldspar and rockfragments are relatively stable in these conditions.The source area based on the petrography indicates the sedimentary rocks(mainlythe oldercarbonate formations exposed at the north and northeast part of Iraq)as the main source of the studied sediments with subordinate metamorphic and igneous rocks.

The identified heavy minerals in the studied InjanaFormation are opaque minerals, epidotie pyroxene amphibole, biotite,granet,zircon,rutile and titanite. The heavy minerals assemblages indicate a combination sources of metamorphic rocks and intermediate to basic igneous rocks with minor contribution from acidic igneous rocks. However; large contribution from older sedimentary rocks (mainly carbonate) based on petrography and heavy minerals studies is suggested.

The distribution of heavy minerals revealed that there are no uniformity in the distribution of any species of the minerals vertically in the studied area. The non-uniformity in the distribution of these minerals might be related to the random fluctuation in the streams carrying the sediments,grain size, local variation in the source area, the degree of erosion and to lesser extent diagenesis. However, variation in the source area and grain size seems to be most likely.

The identified clay minerals are:montmorillonit, chlorite,illite and kaolinite.For montmorillonite the common occurrence of montmorillonote in the two localities might be suggested a detrital origin. The mineral is transported with other detrital minerals and laid down in fluviatile environment. The missing of montmorillonite in some samples might reflect variation in the source area.Withrespest to chlorite the presence of chlorite mineral in the sandstones and claystones of the studied localitis and its occurrence in most samples, suggested a detrital origin of this mineral. Moreover , the study of heavy minerals in the sandstones revealed the presence of pyroxene, amphibole and biotite minerals(table 2) .Therefore, part of the recognized chlorite mineral could be produced diagenetically from these minerals.For illite it can be formed in alkalin marine environment (potter *et al*.,1980) and could be formed by erosion of igneous and metamorphic rocks rich in mica also . The presence of illite in sandstones and claystones and the fluviatile nature of these sediments (Basi,1997) suggested a detrital origin for illite.For kaolinite the common occurrence of kaolinite in the claystones and sandstones in the studied localities suggested a detrital origin. Kaolinite is formed from weathering of acidic igneous rocks in moist climate (Millot 1970).The non- presence of kaolinite in some samples and the general low amount is most probably related to the low amount of acidic igneous rocks in the source area and to the arid type of climate.The low amount of acidic igneous rocks and the arid type of climate are confirmed fromthepetrographical and heavy mineral studies of the sediments of the formation.

In conclusion,the genesis of montmorillonitc, illite and kaolinite is detrital whereas the chlorite is also mainly detrital and partly diagenetic formed by alteration of pyroxene, amphibole and biotite minerals. The low amount of kaolinite indicated the minority of acidic igneous rocks and the domaineted arid type of climate in the source area also.No specific vertical variations of the clay minerals were observed in the studied area. However, the variation in the percentages of montmorillonite, chlorite, kaolinite and illite might be related to thevariation in the source area.

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Table 1: The average percentages of the constituents in the sands and sandstones of Baiji and Al-Mihzam localities (Average of 39 samples)

Constituents / Locality	Quartz	Feldspar	Sedimentary rock fragments	Igneous rock fragments	Metamor-phic rock fragments	Heavy Mineral	Cement& Matrix
Baiji	22.04	6.76	34.39	1.93	5.45	2.69	26.63
Al-Mihzam	26.0	4.19	47.11	1.28	6.54	1.97	12.79

Table 2: The average percentages of the heavy minerals in the studied localities (Average of 36 samples)

Mineral / Locality	Opaque	Alterite	Epidote	Amphibde	Pyroxene	Garnet	Zircon	Rutile	Chlorite	Biotite
Baiji	39.61	10.86	29.65	8.49	2.40	2.19	0.72	0.52	3.5	2.01
Al-Mihzam	39.20	11.6	27.7	7.98	1.92	7.34	0.53	0.42	1.28	2.01

Table 3: The percentages of clay minerals in Baiji locality

Sample No.	Mont.%	Chlo.%	I11.%	Kaol.%	total	Name of sediments
1	20	15	3	2	40	Caly
2	18	6	3	4	31	Mudstone
3	20	17	8	11	56	Mudstone
4	20	10	11	8	49	Caly
5	-	35	6	9	50	Caly
6	20	20	10	5	55	Caly
7	20	10	11	8	49	Clay
8	10	20	31	3	64	Mudstone
9	8	7	6	1	22	Sandstone
10	-	36	14	2	52	Clastone
11	12	10	5	<1	27	Mudstone
12	20	7	7	<1	34	V.fine sandstone
13	20	17	7	3	47	Claystone
14	18	20	10	2	50	Claystone

Table 4: The percentages of clay minerals in Al-Mihzam locality

Sample No	Mont.%	Chlo.%	I11.%	Kaol.%	Total.	Name of sediments
1	-	30	10	10	50	Claystone
2	21	10	8	2	41	Mudstone
3	6	10	8	-	24	Sandstone
4	15	30	12	2	59	Claystone

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