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Heavy Mineral Distribution of Al-Rahaliyah Quarries Al-Anbar Governorate, Central Iraq

Aliaa H. Al-Dulaimi*[1] , Abdulhameed Alhadaithy[1], Hasan Kattoof Jasim [2]

[1] Department of Applied geology, College of Science, University of Anbar ,Ramadi,Iraq;
[2] Department of geology, College of Science, University of Baghdad;
*E-mail: aly21s4005@uoanbar.edu.iq

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Heavy Minerals; Quarries; Sandstone; Quaternary deposits; Ternary stability.

ABSTRACT

In the present study, 10 sand samples were collected from 10 different stations located in the building material quarries of the Al-Rahaliayh area. Heavy minerals were separated from the light ones using heavy liquid separation techniques. The analysis revealed that the heavy mineral content comprises approximately 38.39% opaques, 2.86% chlorite, 3.82% Pyroxenes, 3.93% hornblende, 5.94% biotite, 6.51% muscovite, 2.85% epipodite, 10.97% zircon, 10.59% tourmaline, 9.64% rutile, 2.35% garnet, and 1.63% kainite. Based on these results, the sands of the Al-Rahaliyah quarries are compositionally mature and stable, as indicated by the high concentration of ZTR (stabilized minerals) and the slow concentration of unstable minerals (biotite, pyroxene, and hornblende). Tectonically, the Al-Rahaliyah sands are situated within a stable and tectonically inactive environment. Therefore, the dominance of stable minerals (ZTR) indicates a lengthy transport distance and repeated sedimentary recycling. Furthermore, the high proportion of quartz and the presence of minerals of acidic plutonic igneous origin, such as muscovite and ZTR, indicate that the main source rocks are acidic plutonic igneous rocks, most likely originating from the Arabian shield. Additionally, though less significant, sources include metamorphic and sedimentary rocks, likely transported from highland regions in the north and northeast of Iraq.

Introduction

Silicate minerals occupy an important place among all mineral groups, comprising approximately 25% of all known minerals and approximately 40% of the most commonly occurring minerals. Moreover, they constitute the entirety of the minerals found in igneous rocks, which themselves make up more than 90% of the Earth's crust [1]. In Iraq, the Injana Formation (Upper Miocene) is extensively exposed. This formation comprises an upward-fining sequence of sandstone, siltstone, mudstone, and limestone [2]. Initially deposited in a marine environment, the Injana Formation gradually transitioned into river and lake habitats, making it a representative example of lower fine-grained molasse sediments [3].

Mineral composition analysis is commonly used to determine the types of sedimentary processes occurring within a depositional basin, the nature of sedimentary provenance, and the source rocks. The presence of heavy minerals in river sediments is closely related to the characteristics of the source location, and the processes that occur throughout the sedimentary cycle influence their composition. [4]. Several previous studies have focused on the Injana Formation ([5], [6], [7], [8], [9], [10]), examining its hydromorphometric features and their associated geomorphological risks in the Al-Rahaliyah area [26]. Additionally, studies have investigated the hydrochemical properties of groundwater in the Rahaliyah-Ekhedhur region, located west of Razzaza Lake. These studies concluded that the groundwater in this studied region is classified as slightly-brackish and very hard, indicating that the water is excessively mineralized [27]. By contrast, the present study focuses on the distribution of heavy minerals in the

*Corresponding author at : Department of Applied geology, College of Science, University of Anbar ,Ramadi,Iraq
ORCID:https:// https://orcid.org/0000-0000-0000-0000 ,
Tel: +964 7812101107
Email: aly21s4005@uoanbar.edu.iq

Al-Rahaliayh Quarries, located in Al-Anbar Governorate, Central Iraq.

Location of Studied Area

The study area comprises building material quarries located between Al-Habaniya and Al-Razzaza Lakes, to the west of Al-Rahaliyah City in Al-Anbar Governorate. The area is situated within longitudes (43°:22':00") E and (43°:30':00") E and latitudes (33°:57':00") N and (09°:32':00") N, covering an area of more than 60 Km² (Fig. 1).

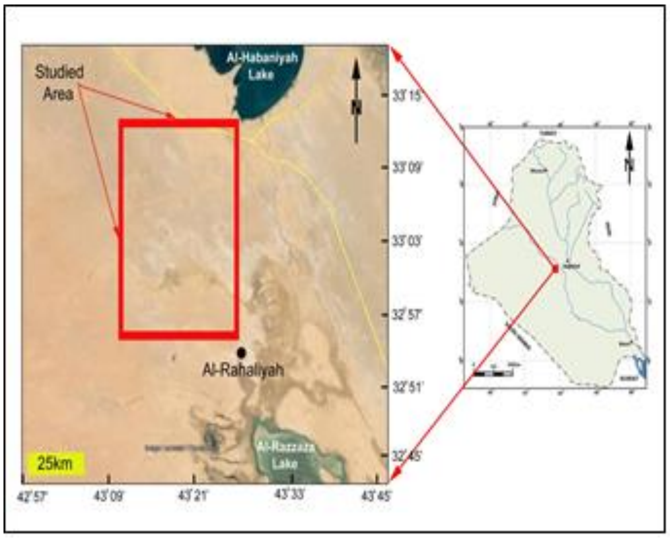

Fig. 1. Map showing the location of the study area [11].

Geology of Study Area

The study area is part of the Quaternary deposits, which were accumulated by flooding in the main valleys of the region. The local names of these valleys are Wadi Al-Mejara, Wadi Thealba, and Wadi Al-Rodha (Fig. 2).

Fig. 2. Aerial photograph of the region under investigation containing the main valleys [11].

The production of Quaternary sediments, including gravel, sand, and mud, distributed throughout the study area, was substantially influenced by these valleys. These valleys experience two waves of flooding during the flood seasons, leading to the formation of floodplains and the accumulation of sediments. The presence of gravel indicates high-energy flood events (Fig. 3).

Fig. 3. Main valleys in the studied area: (A image): Wadi Thealba; (B image): Wadi Al-Rodha.

The study area includes outcrops of the late Miocene–Pliocene Injana Formation. This formation represents lower fine-grained molasse sediments that were initially deposited in a marine environment and later transitioned to a fluvio-lacustrine environment [3].

The lithology of the Injana Formation is primarily composed of alternating layers of red, brown, and gray marls, siltstone, and sandstone, with occasional occurrences of freshwater limestone. Thin gypsum layers are also present ([8], [25]).

In the study area, the Injana Formation (late Miocene) is exposed as scattered outcrops and as horizontal sequences. The formation is primarily red in color and comprises multiple progressive cycles of sandstone and siltstone, showing a fining-upward pattern. The thickness of the exposed rock in the research area ranges from 5 m to 12 m (Fig. 4).

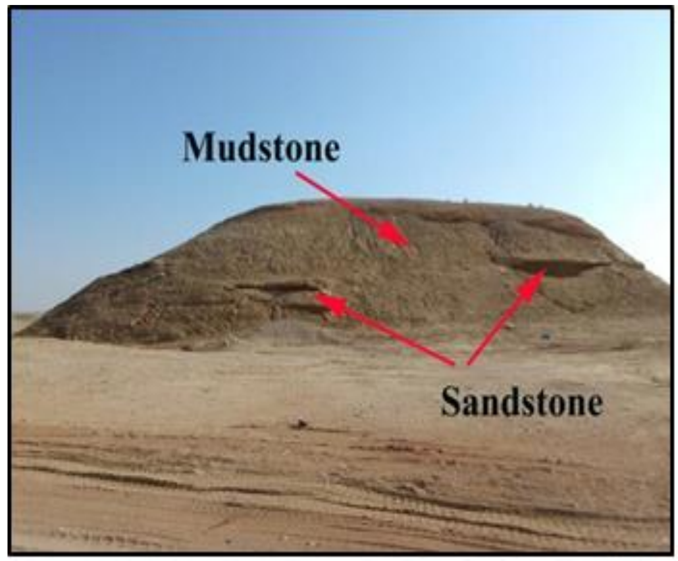

Fig. 4. Outcrops of Injana Formation (late Miocene–Pliocene) in the studied area.

No evidence of bedding or stratification is found in the Quaternary layers. The alluvial deposits, which are one type of Post-Pliocene deposits, comprise a mixture of gravel, sand, silt, clay, and conglomerates [12].

The Quaternary deposits in the study area are composed of a combination of mud, sand, and gravel (Fig. 5).

Fig. 5. Quaternary deposits in the studied area mixture (gravels, sand, and mud sediment).

Materials and Methods

Ten distinct sandstone samples were collected from the Al-Rahaliyah region. The lithology of the source rocks and the mineralogical composition of the detrital deposits in sand or sandstone provide important insights into the origin of the material. One of the most substantial and widely applied methods for determining the provenance of sand and sandstone is heavy mineral analysis. The mineralogical composition of the source area, along with various processes that occur during the sedimentation cycle, influences the accumulation of heavy minerals [13].

Three stages were followed in this method, which are presented below

1. Separation of heavy and light minerals from sand fraction using heavy liquid (Bromoform) [17].
2. Preparation of mounting slide using Canada balsam.
3. Determination of the type and percentage of heavy and light minerals using a polarizing microscope.

Heavy Minerals

Heavy minerals are crucial due to two reasons: they may have commercial value, and they can provide information regarding the origin of the sandstone or sands.

Based on color, two distinct categories of heavy minerals are identified in the Al-Rahaliyah quarries: opaque and transparent minerals. Opaque minerals represent the primary components and are typically equidimensional in shape, ranging from angular to sub-rounded forms.

Results and Discussion

Opaque minerals comprise an average of 38.3% of all heavy minerals, with a range of 35.2 to 43.8% (Table 1). Stable, metastable, and unstable heavy minerals are included in the transparent heavy mineral group. The average content and general properties of these minerals are as follows: Epidote has an average content of 2.85%. It is olive green in color and typically spherical in form. Garnet ranges in color from colorless to pink and exhibits a uniform appearance. With an average content of 2.35%, its grains are primarily sub-angular to sub-rounded in shape. Chlorite has a content ranging from 2.2 to 3.8, with an average of 2.86%. Chlorite grains may be green, greenish-gray, or colorless. It is a metamorphic mineral typically found in metamorphic rocks. Pyroxene occurs in two forms: clinopyroxene and orthopyroxenes. This mineral is characterized by a green color and sub-rounded prismatic grains, with a combined average content of 3.82%. Hornblende ranges from 3.1 to 5.7, with an average 3.93%. Zircon is generally colorless but may exhibit hues ranging from deep blue to black. Well-rounded zircon grains indicate reworking through multiple sedimentary cycles. Muscovite is colorless with a tabular grain form and has an average of 6.51%. Biotite is distinguished by its brown tint and high pleochroism, with an average content of 10.59%. Tourmaline has a honey tone and exhibits strong pleochroism. Rutile is characterized by an elongated shape and a dark red color, often with a black halo. The percentage of kyanite ranges from 1.2 to 2.2, with an average content of 1.63%. Other minerals, including undifferentiated minerals and those with contents below 0.2%, collectively account for approximately 2%. The objective of this heavy mineral analysis is to determine the source rock of the sediments.

1. Opaques indicate that the source rocks include all major kinds of rocks, namely, sedimentary (clastic and carbonates), igneous, and metamorphic rocks [15], [16].
2. Zircon, tourmaline, muscovite, and biotite represent acidic igneous rocks as the source rock [17],[18].
3. Pyroxene and hornblende are indicative of basic igneous rocks as the source rock [19], [20].
4. Garnet, chlorite, kyanite, and actinolite represent metamorphic rocks as the source rock [21]. The percentage ranges and averages of the heavy minerals are presented in (Table 1).

Table 1. Modal analysis, range, and average of heavy minerals in the Al-Rahaliyah quarries

Heavy Minerals	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	Range	Average
Opaques	37.3	35.2	36.1	38.5	43.8	38.5	39.4	40.3	38.5	36.3	35.2–43.8	38.39
Chlorite	3.2	3.1	2.3	3.4	2.3	3.8	2.2	2.5	2.4	3.4	2.2–3.8	2.86
Pyroxene	3.3	4.5	3.6	4.6	3.5	3.9	3.6	4.5	3.2	3.5	3.2–4.6	3.82
Hornblende	4.1	3.3	4.4	4.2	5.7	3.8	3.1	3.4	4.2	3.1	3.1–5.7	3.93
Biotite	5.6	6.7	5.3	6.5	5.6	5.4	4.7	6.6	5.7	7.3	5.3–7.3	5.94
Muscovite	6.4	8.3	7.9	5.2	4.2	5.6	7.6	5.2	9.1	5.6	4.2–9.1	6.51
Epidote	3.6	2.4	2.2	2.7	3.8	2.7	2.7	2.6	2.6	3.2	2.2–3.8	2.85
Zircon	11.5	12.2	12.1	11.3	8.3	9.6	12.2	8.9	11.5	12.1	8.3–12.2	10.97
Tourmaline	9.7	9.6	10.5	10.1	9.8	11.5	11.9	11.5	10.8	10.5	9.6–11.9	10.59
Rutile	10.6	9.7	10.2	9.5	9.4	10.4	8.5	9.8	8.4	9.9	8.4–10.6	9.64
Garnet	2.9	2.7	2.7	1.8	1.2	1.5	1.8	2.5	1.3	2.4	1.2–2.9	2.35
Kyanite	1.5	1.4	2.2	1.2	1.5	1.4	1.7	1.9	1.7	1.8	1.2–2.2	1.63
Others	0.3	0.9	0.6	0.9	0.6	0.9	0.6	0.3	0.6	0.9	0.3–0.9	0.66

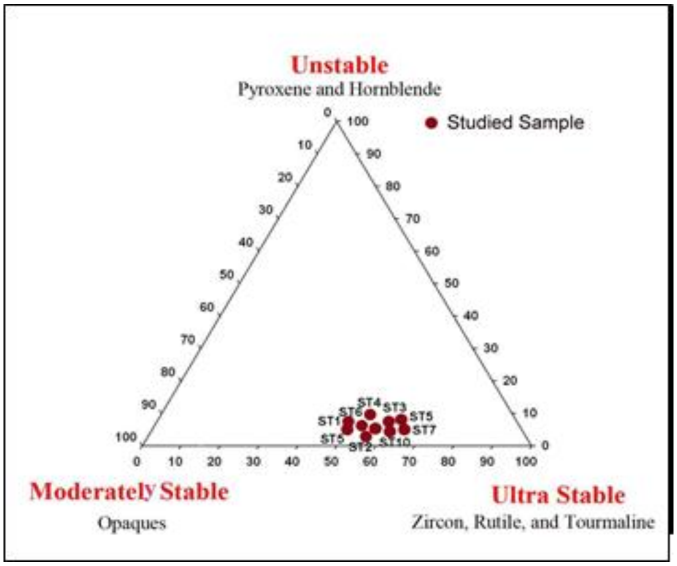

Fig. 6. Photomicrograph of heavy minerals: A: Opaque minerals; B: Biotite mica; C: Muscovite mica; D: Pyroxene; E: Hornblende amphibole; F: Chlorite; G: Zircon; H: Garnet; I: Kyanite; J: Epidote; K: Ritile; L: Tourmaline.

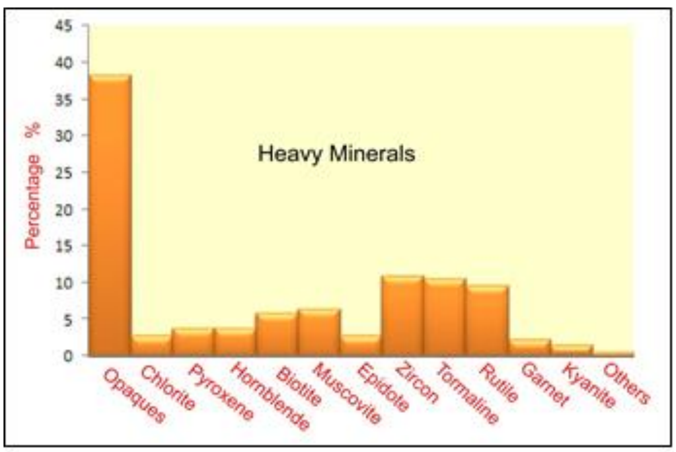

Fig. 7. Percentage of the total heavy minerals.

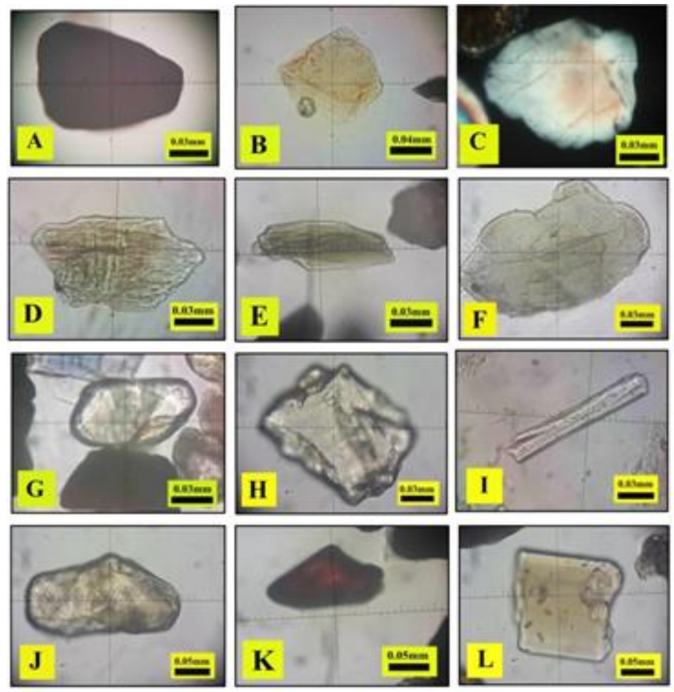

Fig. 8: Ternary diagram of heavy mineral stability of Al-Rahaliyah Quarries samples [22].

Table 2. Approximate relative chemical stability of the heavy minerals of Al-Rahaliyah Quarries.

Heavy Minerals Groups			
Ultra-stable	**Stable**	**Semi-stable**	**Unstable**
Rutile	**Chlorite**	**Epidote**	**Opaque**
Zircon	**Muscovite**	**Kyanite**	**Garnet**
Tourmaline			**Hornblende**
			Pyroxene
			Biotite

The linkage between tectonic setting and sediment composition has long been recognized [23], [24]. By comparing heavy mineral assemblages with potential source areas derived from various stages of the plate tectonic cycle, a plate tectonic interpretation of heavy mineral data was proposed. [24] constructed a right-angle triangular diagram (MF, GM, and MT) linking plate tectonic settings and heavy mineral assemblages, where:

MF: Common constituents of mafic magmatic rocks = total contents of pyroxene, hornblende, and olivine.

MT: Common constituents of basic metamorphic rocks = total contents of pale-colored and blue green amphibole, epidote, and garnet.

MG: Accessory minerals of granites and sialic metamorphic rocks = total content of zircon, tourmaline, staurolite, kyanite, andalusite, monazite, and sillimanite.

When the studied dune samples are plotted on the ternary diagram (Figure 9), the Al-Rahaliyah sediment samples evidently fall within the mature passive continental margin field. These margins are characterized by a high percentage of minerals derived from sialic metamorphic rocks and granites, resulting from intense weathering and repeated sediment reworking in tectonically stable regions. The Arabian shield and its derivative formations, such as the Dibdiba Formation, exemplify such source rocks.

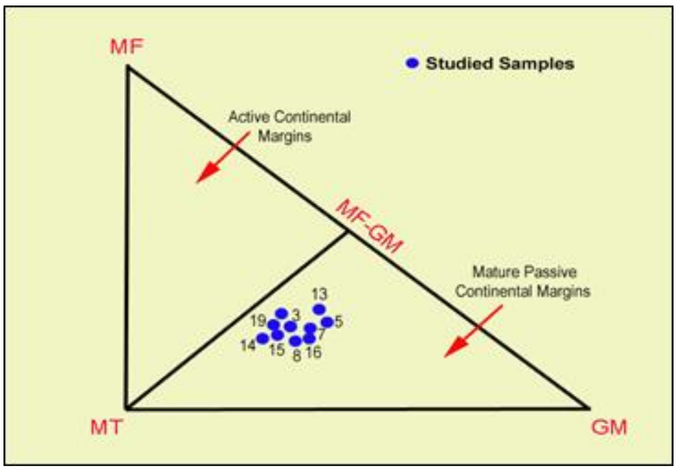

Fig. 9: Interrelationship of the MF-MT-GM suits of Al-Rahaliyah Quarries samples [24]: MF: Pyroxene Amphibole, Olivine; GM: Zircon, Tourmaline, Staurolite, Kyanite, Andalusite, Monazite, Sillimanite; MT: Epidote, Garnet.

Conclusions

Monocrystalline quartz is more prevalent than polycrystalline quartz in the studied samples and exhibits characteristics indicative of derivation primarily from plutonic igneous rocks and reworked sediments. In comparison to k-feldspar (orthoclase and microcline), plagioclase is less abundant and typically sourced from plutonic igneous and metamorphic rocks. The sands of the Al-Rahaliyah quarries are classified as stable sand, as evidenced by their high content of stable heavy minerals (ZTR) and a small percentage of unstable minerals (biotite, pyroxene, and hornblende). Tectonically, the Al-Rahaliyah sands are located within a stable and inactive tectonic environment, supported by the dominance of stable minerals (ZTR), which indicates long transport distances and multiple sedimentary recycling processes. The main source rocks for the Al-Rahaliyah quarry sands are acidic plutonic igneous rocks originating from the Arabian Shield, as indicated by the high percentage of quartz and minerals associated with acidic plutonic igneous origin, such as ZTR and muscovite. Less influential sources include metamorphic and sedimentary rocks, possible transported from the north and northeast of the study area. The tectonic environment of the Al-Rahaliyah Sediments is classified as a mature passive continental margin, characterized by sediment reworking and deep weathering in areas devoid of active tectonic events. This environment is reflected in the comparatively high percentage of minerals derived from granites and sialic metamorphic rocks, such as rutile, zircon, and tourmaline. These source rocks are represented by the Arabian shield and their derived formations, such as the Dibdiba Formation.

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توزيع المعادن الثقيلة في مقالع الرحالية، محافظة الانبار، وسط العراق

علياء حميد الدليمي [1]، عبد الحميد الحديثي [1]، حسن كطوف جاسم [2]

الجيولوجيا التطبيقية،العلوم،الانبار،الرمادي،العراق

الجيولوجيا،العلوم،بغداد

Email: aly21s4005@uoanbar.edu.iq

الخلاصة:

جمعت الدراسة الحالية عشرة عينات من الرمال من عشرة محطات للنمذجه في مقالع مواد البناء في منطقة الرحالية. تم فصل المعادن الثقيلة عن الخفيفة باستعمال السوائل الثقيلة وتبين ان محتوى المعادن الثقيلة فهو يتألف من المعتمة (٣٨،٣٩%)، الكلور (٢،٨٦%)البيروكسين (٣،٨٢%) ،هورنبليند (٣،٩٣%) ،بايوتايت (٥،٩٤%)،مسكوفايت (٦،٥١%)،ايبودايت (٢،٨٥%) ،زركون (١٠،٩٧%) ،تورمالين (١٠،٥٩%)،روتايل (٩،٦٤%)،كرانيت (٢،٣٥%)،كاينايت (١،٦٣%)والاخرى (٠،٦٦%) من خلال النتائج التي تم التوصل لها تبين ان رمال مقالع الرحالية هي رمال ناتجة بسبب المحتوى العالي من المعادن المستقرة ونسبة قليلة من المعادن غير مستقرة (Bi,Px,Hb) تكتونياً تقع رمال الرحالية ضمن بيئة تكتونية مستقرة وغير نشطة وهذا بسبب المحتوى العالي من المعادن المستقرة (ZTR) والتي تشير الى مسافات نقل طويلة ودورات معادة الترسيب.ان الصخور المصدرية الرئيسية لرمال مقالع الرحالية هي صخور نارية جوفية حامضية مصدرها الدرع العربي وذلك بسبب نسبة الكوارتز العالية ونسبة المعادن ذات الاصل الناري الجوفي الحامضي وهي (ZTR) والمسكوفايت هناك مصادر اخرى اقل تأثيراً هي صخور متحولة ورسوبية بسبب النقل من شمال وشمال شرق منطقة الدراسة.

الكلمات المفتاحية: المعادن الثقيلة؛ المقالع؛ الحجر الرملي؛ رواسب العصر الرباعي؛ مخطط الاستقرار ثالثي.