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Sedimentology and depositional environment of Injana Formation's sandstone member, Kurdistan Region, Iraq

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Abstract: Fourteen thin sections from the sandstone bed of Injana Formation in Chamchamal area were studied by scanning electron microscopy (SEM) and polarized microscope. The petrographic component, and fauna content were determined. Sandstone is calclithite-sedarinite (litharenite) according to Dott's (1964) and Folk's (1980) classifications. The major petrographic constituents are: quartz, K-feldspar, calcite, chert, plagioclase, and fossil (algae). The Injana Formation in Chamchamal area was interpreted as littoral and later in a fluviolacustrine environment deposit.

Keywords: Miocene, Injana, sandstone sedimentology, Kurdistan Region, Iraq

INTRODUCTION

The Upper Fars Formation was initially designated in the Fars area in Iran (Busk & Mayo, 1918). In 1984, the former formation was named Injana in Iraq by Jassim *et al.* who selected the type section at Injana near the old police station, 120 km northeast Baghdad (the capital of Iraq). This endorsement was issued by Al-Rawi *et al*. (1992).

The Injana Formation exists in Iraq widely; it also extends into northern Syria, Turkey, and over large areas in southern Iran (Bellen *et al*., 1959; Jassim & Buday, 2006).

The Injana Formation conformably overlies the Middle Miocene Fatha Formation and underlies the Mukdadiya Formation. The formation at Injana area (type section) is essentially a clastic sequence, consisting of fining-upwards cyclothems of sandstone, siltstone, marl and claystone (Al-Juboury, 1994). The lowermost part of Injana Formation consists of approximately 20 m of transitional fluvio-deltaic facies with significant channel development (Al-Juboury, 1994).

A lack of detailed studies on age determination can be noticed due to non-abundance and poor preservation of fossils within the clastic succession of the Injana Formation, whereas in Syria, the accepted age is the Upper Miocene–Lower Pliocene (Lababidi & Hamdan, 1985; Al-Juboury, 2009).

Injana Formation was studied stratigraphically and sedimentologically by many authors such as Dunnington (1958); Bellen *et al*. (1959); Kukal & Saadallah (1970); Basi (1973); Salvik & Al-Hashimi (1973); Al-Mubarak & Youkhana (1976); Yakta (1976); Al-Sammarai (1978); Buday (1980); Al-Banna (1982); Jassim *et al*. (1984); Al-Katan (1985); Al-Maroof (1986); Al-Rawi & Mohammad (1987); Jawad *et al*. (1988); Al-Kurukji (1989); Othman (1990); Al-Rawi *et al*. (1992); Al-Juboury (1994); Al-Baidari (1997); Al-Bassam & Al-Baidari (2000); Al-Juboury (2001); Al-Fattah (2001); Al-Haidary (2003); Al-Sayegh & Al-Nuaimy (2004); Aghwan (2004); Al-Rashedi (2005); Jassim & Buday (2006); Mahdi (2006); Basi (2007); Al-Juboury (2009); Awadh *et al*. (2013); Al-Jaefir & Al-Shamari (2015); and Aziz (2017).

The main aims of this research are to define lithology, component, and depositional environment of Injana's sandstone member in the Chamchamal area, northeastern Iraq. This member represents a good aquifer in northern Iraq; therefore, determining the mineralogy and their percentages help indicate the provenance and facies change of this important unit in the region.

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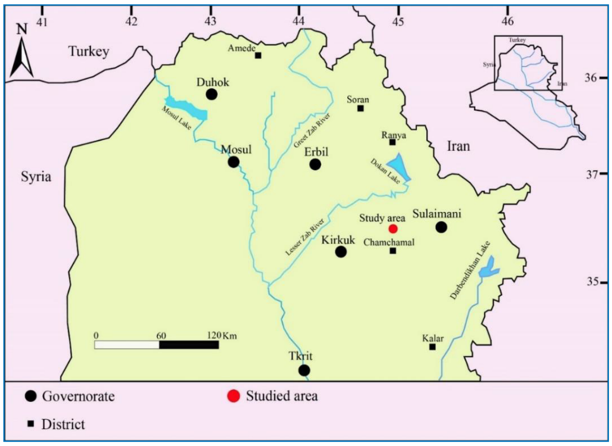

Figure 1: Index map shows the studied outcrop.

GEOLOGIC SETTING

The selected outcrop section is located 2 km northwest of the main Kirkuk-Sulaimani Highway. The latitude of the location is approximately 35°34’48.7” N and the longitude is about 44°54’52.4” E (Figure 1).

The type section is near Injana area at about 120 km NE of Baghdad toward the southern part of Hemrin Mountain, with a total thickness of 620 m. The formation at Injana area comprises of marls, siltstone, and sandstone (Al-Naqib, 1960). At the selected outcrop section in Chamchamal area near Kirkuk Governorate, the Injana Formation is located in the Low Folded Zone. The main rock components in the area of consideration are clastic of Paleogene, Neogene, and Quaternary that are frequently visible at number of eroded anticlines (Figure 2).

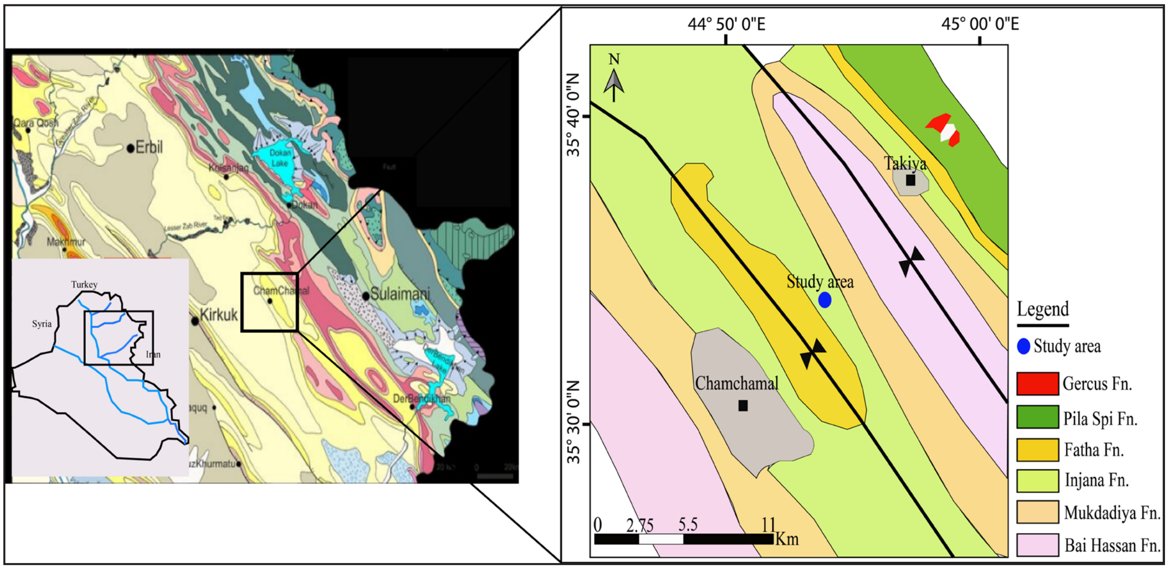

Figure 2: Geologic map of the study locality (adapted from Al-Manmi & Qader, 2021).

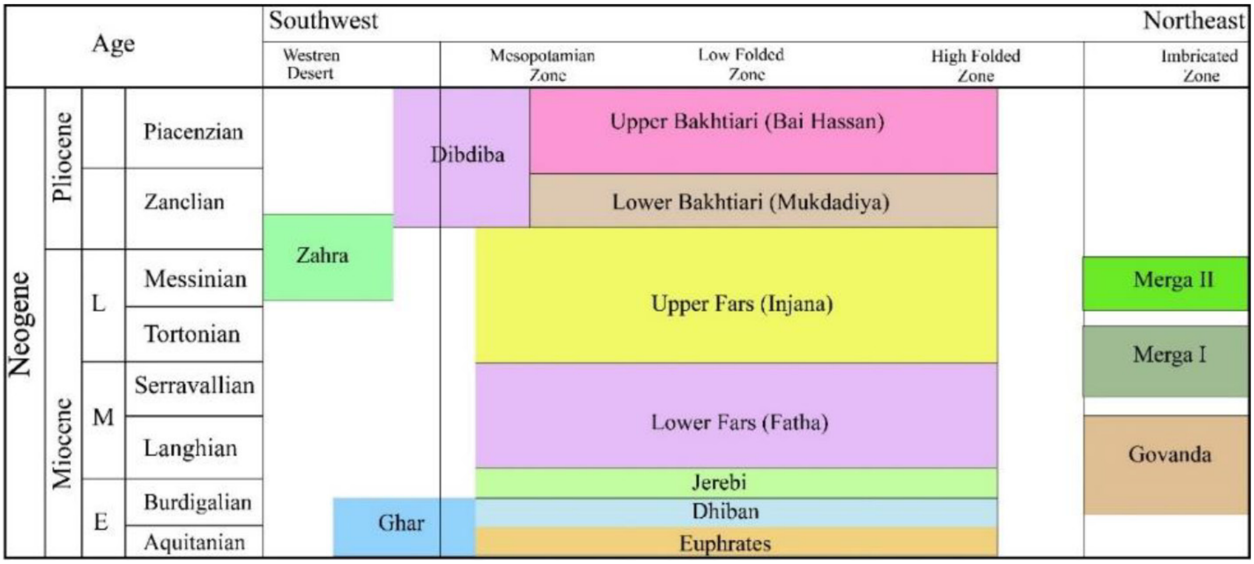

Figure 3: Correlation chart of the Neogene Period in Iraq (modified from Jassim & Buday, 2006; Jassim *et al.*, 2006).

In Chamchamal area, the Injana Formation conformably is overlaid by Mukdadiya Formation (Lower Bakhtiari Formation) and is underlain by Fatha Formation (Lower Fars Formation) (Figure 3). In the studied area, the formation is 500 m thick and the thickness of sandstone member is 44 m. Injana Formation comprises of marls, siltstones, sandstones and gravels. Infrequent layers of carbonates, clays, and bentonites that reflect fresh water deposits are also present. According to its stratigraphic setting, the age of this formation is reported as Late Miocene (Bellen *et al.*, 1959).

METHODS OF STUDY

Field work was performed during the winter of 2009 to choose the appropriate outcrop of Injana Formation. The underlying Fatha (Lower Fars) Formation and overlying Mukdadiya (Lower Bakhtiari) Formation were recognized. The section was measured and 14 samples for making thin sections and for SEM study was collected systematically based on vertical facies change for further petrographic investigation. The sandstone bed was described by hand specimen using 10X lenses. The petrographic study of sandstone is carried out through thin sections prepared at the work shop of Salahadin University in Iraq. The samples were coated by gold and studied at Colorado School of Mines in U.S.A. for indicating minerals by using scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

Lithology

Detrital sediments of Injana Formation are represented by thick layers of silty mudstone and sandstone. Two main facies are recognized in Injana Formation; coarse grained sediments which includes channel deposits and are divided into two subfacies; intraformational conglomerates and sandstones and fine-grained sediments which represent overbank environment and are divided into four subfacies; alternated claystone and/ or mudstone and siltstone sediments, mudstone and claystone sediments (Basi, 2007).

Figure 4: Sandstone bed in Chamchamal area shows cross bedding.

Sandstone member of Injana Formation is selected for this study. Various large-scale fining-upward cycles were present and repeated in sediments of the Injana Formation. The main characteristics of these cycles change from coarse-grained sediments in the lower part to fine-grained sediments in the upper part. The cycle starts with sandstones passing gradually upwards into siltstones, mudstones and/or claystones. In the selected outcrop section in Chamchamal area, most Neogene units significantly have low thickness that may be due to proximity of provenance and topographical setting.

According to lithology and petrographic study, the grain size and sorting of the sandstone member in Injana Formation at selected section comprised of fine-medium grain and moderately-well sorted. Sets of cross-bedding are observed on the surface of the sandstone beds particularly from the lower part of the beds. Each of the sets of cross beds vary in thickness and range approximately between 20-30 cm (Figure 4). In this member of sandstone, the grain size of the sediments decreases upward with increasing thickness of the sets of cross bedding. This sandstone internally, are mostly medium to thick bedded, with cross-bedded structures (Figure 4). The sedimentary structures change in their type upward, too. They change from cross-bedding at the base of the sandstones to horizontal bedding, at the uppermost part of the sandstones (Figure 4).

Petrography of Injana sandstone member

Petrographic investigation was performed using thin sections and scanning electron microscopy (SEM) for sandstone of the Injana Formation in Chamchamal area, NE Iraq. The upper Miocene sandstone of the Injana Formation in Chamchamal is mainly composed of detrital quartz, feldspar, and rock fragments (mostly sedimentary rock fragments), besides matrix and cement. Among framework

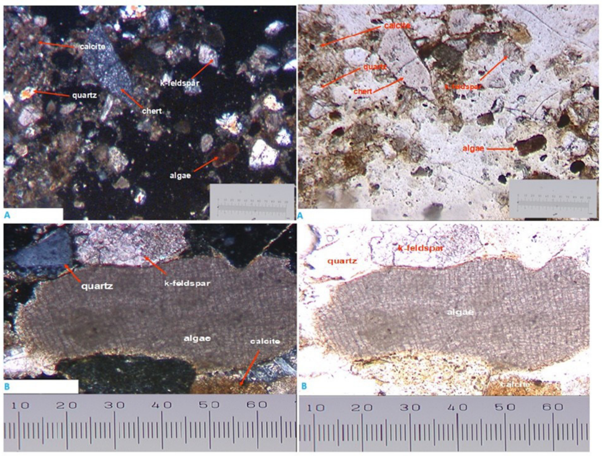

Figure 5: Optical photomicrograph displaying: A. Quartz, feldspar, chert, calcite and algae, B. Quartz, K-feldspar, algae and calcite (the ruler is in mm unit).

component, rock fragment is the most dominant constituent. This sandstone is comprised of fine to medium-grained sandstone with subangular grains (Figure 5).

The quartz particles are generally very fine -to-medium grained, subangular with slightly undulous extinction. Quartz (mostly monocrystalline) presents in the selected sandstone member with range of 20-25%. The subangular quartz grains indicate short transport distance (Figure 5A and Figures 6B, 6E). Monocrystalline quartz is mostly composed of reworked sediment and plutonic igneous rock. Quartz growth in acidic volcanic rocks commonly results in well-developed crystal morphologies with pyramidal and even bi-pyramidal terminations (pointy at both ends). Crystal terminations will be rounded during vigorous sediment transport, but if the transportation distance is short then the sharp edges will remain (Al-Salmani *et al*., 2024). Feldspar is the least abundant framework component of Injana Formation. Feldspar in general is not the main component (10%). The detrital feldspars mainly include potassium feldspar and less abundant plagioclase. The fresh feldspar grains are representing arid to semi-arid climate (Figures 5A and 6A).

Lithic is the main constituent of sandstones member. The lithic fragments mainly comprise sedimentary rock fragments (Figures 5A, 5B and 6D). It is including 10% argillaceous rock fragments (shale and siltstone fragments), 5% chert rock fragment fine-medium, subangular-subrounded, and 25% carbonate (Figure 5). Algae present in the sandstones of the Injana Formation form up to 1% of the constituents (Figure 5). The above percentages are determined by using point counting. According to Folk classification (1980) for sandstone and based on previously mentioned composition of main detrital constituents; quartz, rock fragments, K-feldspar, the Injana sandstone member is categorized mostly as lithic arenite. The rock fragments of Injana Formation are mostly sedimentary rock fragment and therefore the sandstones are classified as sedarenite and due to the high proportion of calcite rock fragments named calcarenite (Figure 7A).

The cement value of the sandstone member is about 15%. Calcite is the dominant carbonate cement in Injana

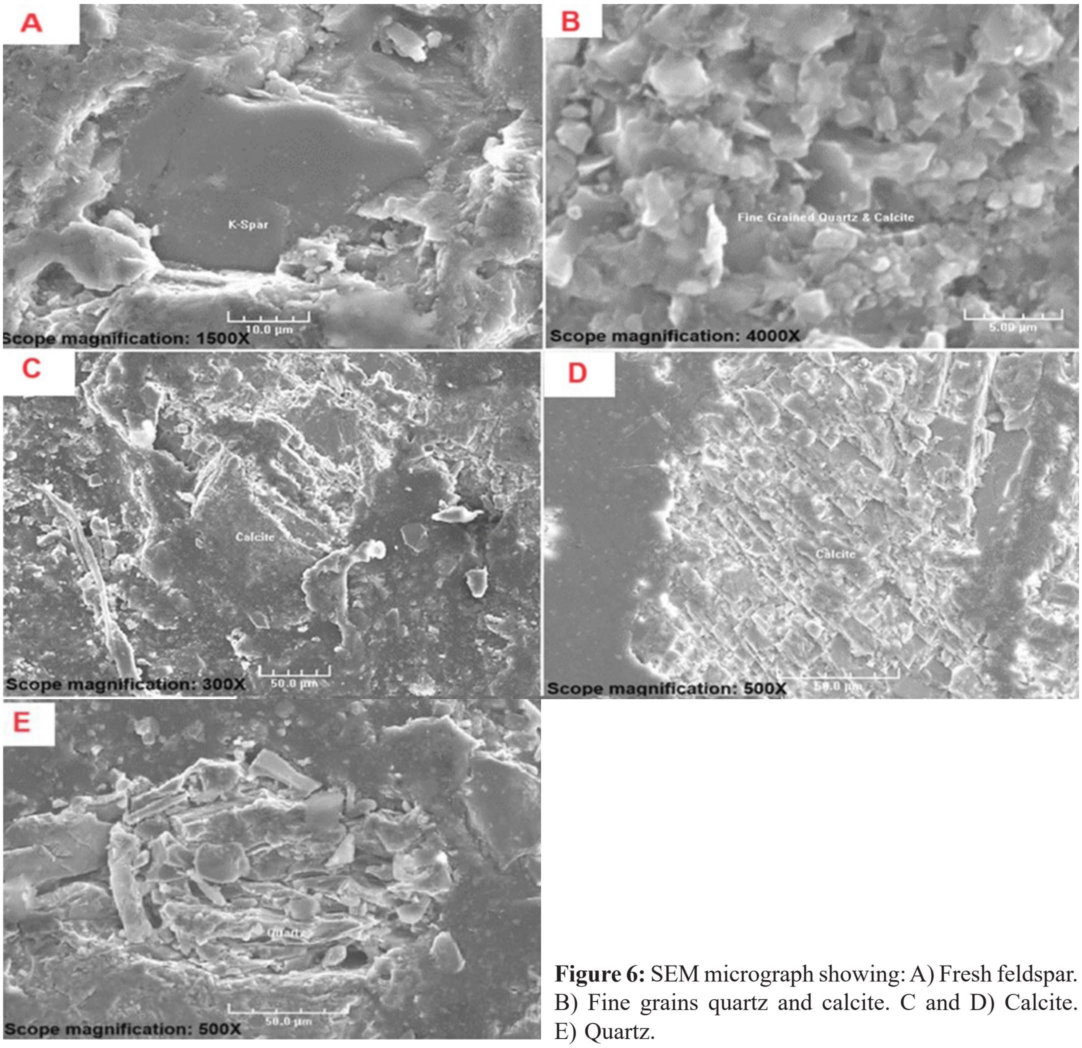

Figure 6: SEM micrograph showing: A) Fresh feldspar. B) Fine grains quartz and calcite. C and D) Calcite. E) Quartz.

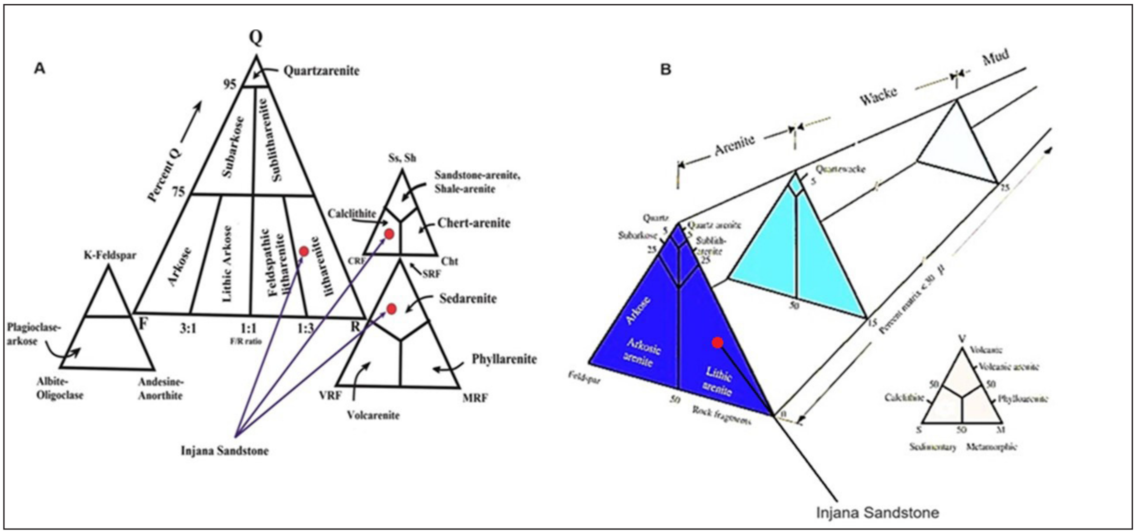

Figure 7: A) Sandstone type according to Folk's (1980) classification of sandstone, B) Sandstone type according to Dott's (1964) classification of sandstone.

sandstone that mainly fill in intergranular pores (Figures 5A, 5B, 6C, and 6D). The matrix consists of silt and clay. The value of matrix in Injana sandstones is about 10% of the overall composition. Based on Dott's (1964) classification, when the matrix ratio is less than 15% it is considered arenite not wacke and when the main component's ratio includes high percent of lithic related to quartz and feldspar then the sandstone is named lithic arenite (Figure 7B). According to the main component's ratio, angular to subangular grains and poorly sorted grains, the sandstone of the Injana Formation is texturally and mineralogically not mature.

Depositional environment

The Chamchamal area during Upper Miocene was shore zone of Mesopotamian foreland basin (Karim *et al.*, 2003). The Injana Formation comprises the lower part of fine marine molasses deposits at the early stages and finally in fluvial and lake depositional setting (Buday, 1980). This steady alteration from marine to inland alluviation displays itself as a characteristic phenomenon of the foreland basins' deposition (Homewood *et al*., 1986). The most distinctive phenomenon of this environment includes the presence of algae, calcite as detrital grain and cement, in sandstone with fine upward grains and planar cross bedding structures.

An estuary is a partly enclosed coastal body of water with one or more rivers or streams flowing into it and with a free connection to the open sea (Dalrymple *et al*., 1992; Wells, 1995). Estuaries are mainly a gradational, building up within a drowned river channel (Nichols, 2009).

The estuarine could be considered as proper depositional environment for upper Miocene Injana sandstone member at Chamchamal area and short sediments transport distance from nearby high relief as a source to coastal area. This can be deduced from sedimentary structure both cross-bedding at the base of the sandstones to horizontal bedding, at the uppermost part of the Injana sandstones and from the interpretation of detrital components as compositionally immature sandstone. Cross-bedding usually occurs in regions of active sediment transport in an estuary, such channels or tidal flats and in places with comparatively low energy deposition, horizontal bedding may form. Estuaries usually show greater energy conditions with cross-bedding nearer to the entrance, where wave activity and tidal currents are more noticeable, while lower energy conditions with horizontal bedding are found farther inland. Immature sediments can be produced even in wet climates from uplifting and rapid erosion and transportation for short distances (Suttner & Dutta, 1986; Le Pera *et al.*, 2001).

The Injana sandstones are classified as litharenite, this type of sandstone based on Boggs (1995) is considered as immature sandstones that initiate within circumstances preferring the production and deposition of a huge size of comparatively nonconstant constituents. Finally, the compositionally immature Injana sandstone signified that the provenance had high relief, quick erosion and transport, and short distance with dry climatic condition (Tucker, 2001).

Some features of feldspar are beneficial for indicating source area, since feldspar is chemically and mechanically not stable as quartz (Boggs, 2009). Presence of fresh feldspar with no sever alteration (Figure 6A) can be used to interpret climate as arid to semi-arid, high relief and short transportation.

Chert rock fragments (Figure 5A) probably were derived from Thrust Zone area, specifically Qulqula

Group (Al-Juboury, 1994). Carbonate rock fragment were also present in Injana sandstone (Figures 5A and 5B). Its presence shows quick mechanical weathering, travelled short distance, as proved by other constituents.

CONCLUSIONS

Using different methods and techniques to add new interpretations on petrography and depositional environment of one of the important units in northern Iraq which represents the final stage of molasse in the region can be concluded by the followings:

- The formation is 500 m thick and the thickness of sandstone member is 44 m.
- The formation comprises of repeated reddish-brownish and gray marls, siltstone, and sandstones. In current study, the sandstone member comprised of fine-medium sand grain and moderately-well sorted sandstone.
- Petrographically, the sandstone member of Injana Formation composites of subangular fine-medium quartz grains, potassium feldspar, and lithic. This sandstone is classified as lithic arenite based on Folk (1980) and Dott (1964) classifications.
- Estuarine considered as a proper depositional environment for Sandstone Member of Injana Formation at Chamchamal area.
- Lithology and sedimentary evidences are suggesting deposition of Sandstone Member of Injana Formation at Chamchamal area in an estuarine environment characterized by a fining-upward sequence, lithic arenite sandstones.
- Compositionally immature sandstone is a consequence of high relief, rapid erosion, and short transport distance in a dry climate.

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AUTHORS CONTRIBUTION

RAA performed analysis and conducted result interpretation. MSN and BAD wrote the whole manuscript. INA contributed to critically reviewing the manuscript and contributing ideas to improve the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

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