**IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)\
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)**

Vol.19, No.2, 2023 ***p 57 – 68***

LITHOFACIES STUDY OF BAI HASSAN FORMATION SEQUENCE (UPPER PLIOCENE) IN BEKHEIR ANTICLINE, ZAKHO AREA NORTHERN IRAQ

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Received: 06/ 09/ 2022, Accepted: 15/ 01/ 2023
Keywords: Bai Hassan Formation; Lithofacies; Upper Pliocene; Bekhair anticline; Zakho area; Iraq

ABSTRACT

The current study included the Bai Hassan Formation (Upper Bakhtiari) in the Zakho area of northern Iraq. Depending on the grain size class, structures, degree of rounding, sorting, and some other detailed field observations. This formation was divided into eleven lithofacies which are matrix-supported conglomerate, clast-supported conglomerate, laminated sandstone, sandy gravel, planar cross-bedded conglomerate, interbedded siltstone-mudstone, gravely sandstone, interbedded sandstone-conglomerate, lime matrix-supported conglomerate, and caliche lithofacies. These lithofacies are distributed into six coarsening-upward cycles consisting of complete and incomplete cycles, and these lithofacies include sedimentary structures such as imbrication pebbles, bedding plain, load cast, and gravely cross-bedding. The environment of the Bai Hassan Formation represents conjunctive alluvial fan with possible internal lake environments. The study includes the determination of source areas such as sedimentary, igneous, and metamorphic rocks.

INTRODUCTION

The Pliocene sequences, comprising the Mukdadiya and Bai Hassan formations, are widely spread in the High Folded and Foothill zones. It plays a key role in the geology of the Middle East because of its thickness and stratigraphic position (Ali and Khoshaba, 1981). According to Jassim and Goff (2006), the Bakhtiari Formation (which includes Upper and Lower Bakhtiari) was initially reported from Iran by (Busk and Mayo, 1918), and the formation was identified by (Bellen *et al*., 1959) in Iraq as well. The name of the Upper Bakhtiari Formation in Iraq has been changed to the Bai Hassan Formation (Al-Rawi *et al*., 1992). The studied area is located in Zakho region, Duhok Governorate in the North of Iraq at the Northern limb of Bekheir anticline at the high folded zone, and the formation is exposed (Figure 1), at Longitude 42°67'67" E, Latitude 37°13'17"N (Figure 2). Bai Hassan Formation is underlain by ya Formation (Lower Pliocene), the lower contact of Bai Hassan Formation can be detected on the first appearance of massive conglomerate units (Bellen *et al*., 1959). This formation is overlain by inclined recent sediments and the Mukdadiya and Bai Hassan formations mark the active molasse deposits. This basin formed during the Alpine Orogeny when the continent-continent plates collision of the Arabian with the Anatolian and Iranian microcontinents took place (Adeeb, 2006).

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A number of studies have been done on the Bai Hassan Formation, such as Al-Adool (1982), who studied the sedimentology of the Bakhtiari group in Northern Iraq and suggested a fluvial environment of deposition. Issa (2012) studied the sedimentary structures and determined the paleocurrent to the Bai Hassan Formation, Northeast Iraq, and proved that it is heading from northwest to southeast.

The main goal of this study is to focus on the lithofacies, their nature and number, and detailed sedimentological data such as the description of sedimentary cycles to interpret depositional conditions associated with these sequences.

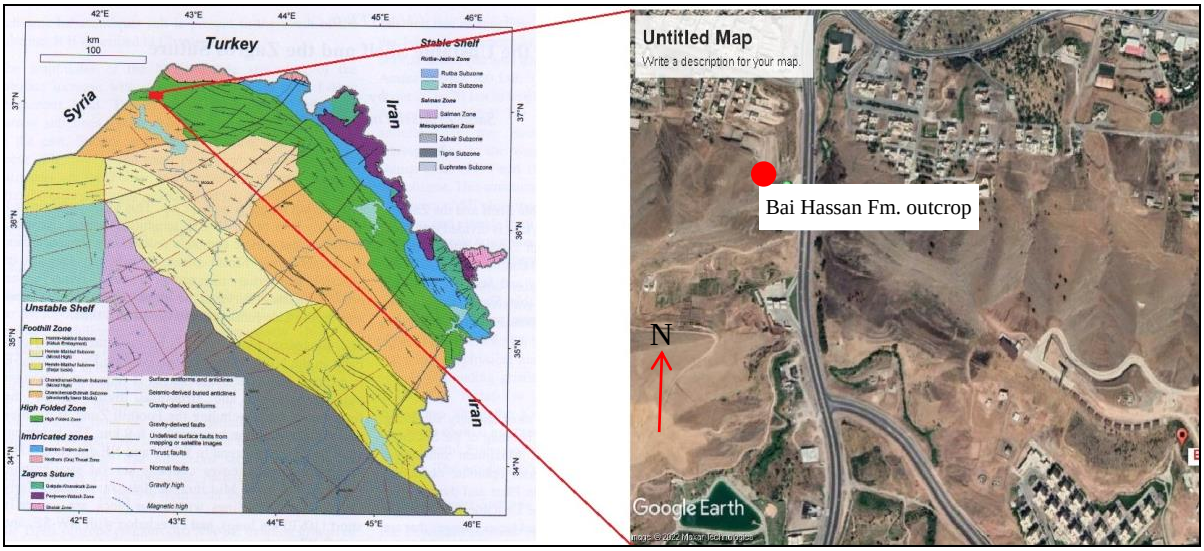

Figure 1: Satellite image with a tectonic map showing the studied section modified from (Jassim and Goff, 2006).

Figure 2: Field photographs, Lower contact of Bai Hassan Formation.

METHODOLOGY

The present study includes the upper Pliocene sequence, which includes the Bai Hassan Formation. This study benefited from the methods of Nichols (2009) for clastics analysis, where a field sketch and graphic sedimentary log are drawn to represent the field information. The collected field data are such as sedimentary cycles, sedimentary structures, grain size, lithofacies, and environmental Interpretations Figure (3 and 4). Also, a square shape was taken in the field to determine the percentage of clasts in Figure (5) the results were represented in Figure (10).

LITHOFACIES OF BAI HASSAN FORMATION

Bai Hassan Formation consists of eleven lithofacies that are distributed within six-coarsening upward cycles (Figures 3 and 4), and the lower contact of this formation is determined by the first appearance of massive conglomerates above Mukdadiya Formation as shown in Figure (2). The thickness of the exposed part of this formation is about 230 m. The mean lithofacies are summarized in Table (1).

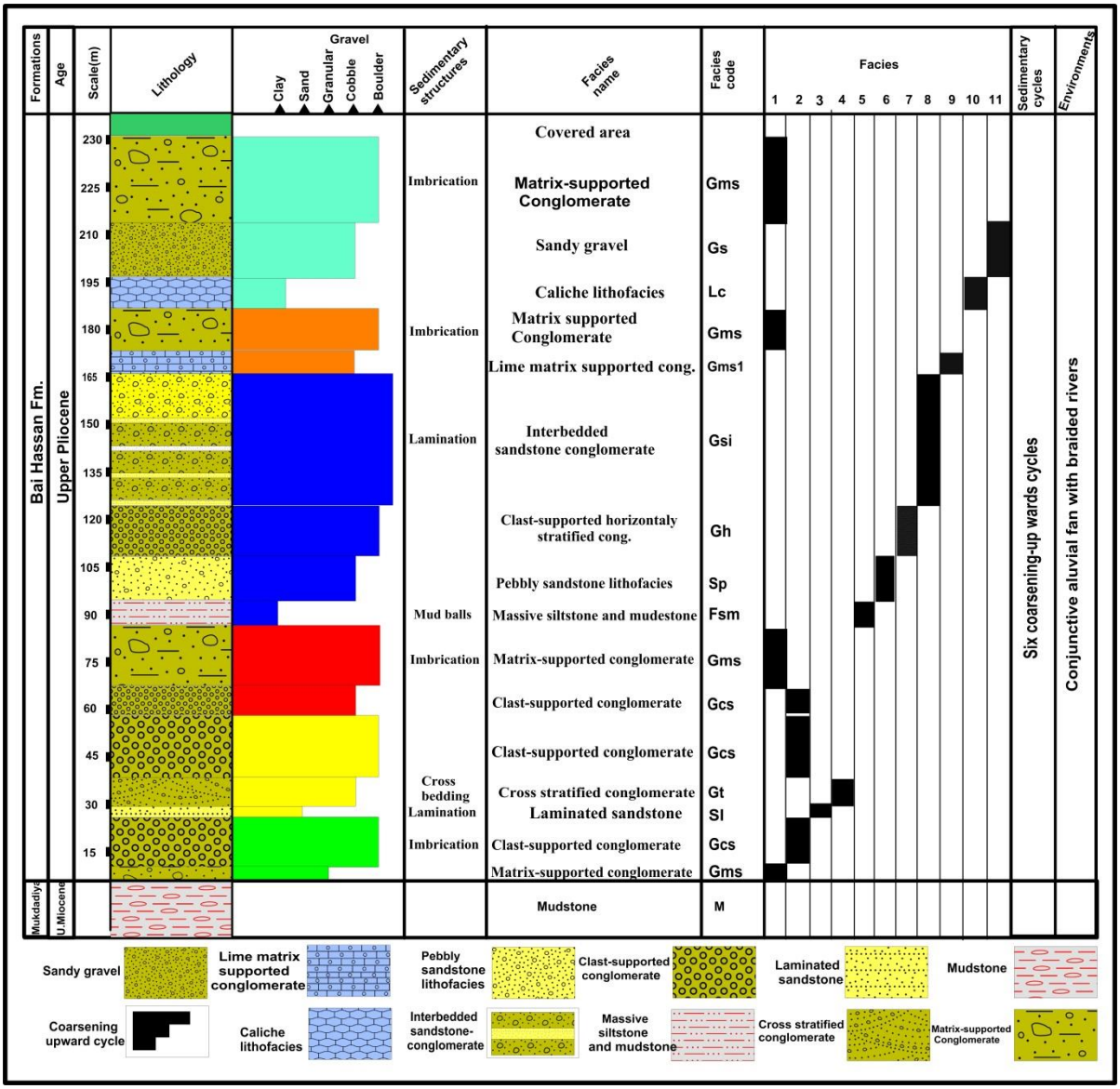

Figure 3: lithological log of the Bai Hassan Formation at the Zakho region, Dohok Governorate.

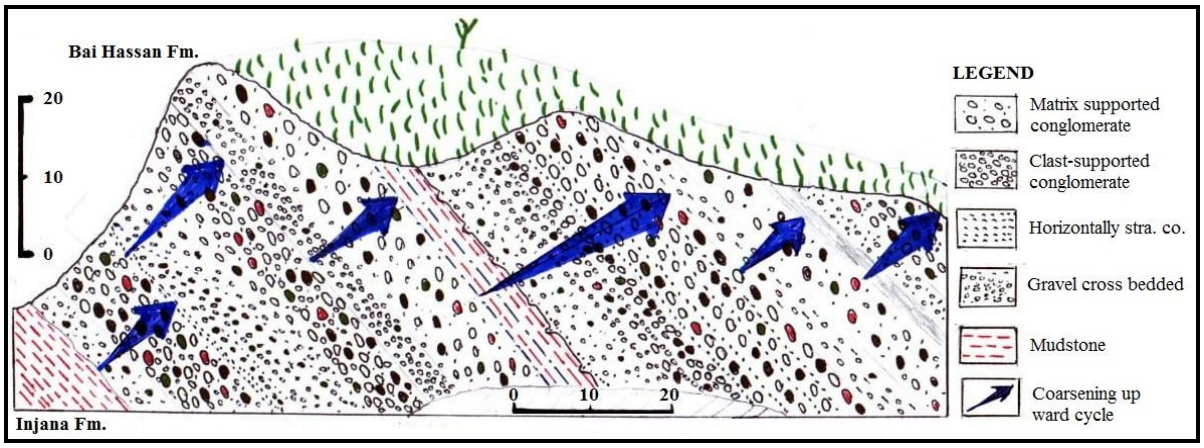

Figure 4: Sketch diagram of Bai Hassan Fm. Section.

Table 1: Lithofacies description and interpretation.

Lithofacies	Characteristics	Interpretation
Matrix-supported conglomerate (Gms)	Massive, poorly sorted. little imbrication	Debris flow deposits
Clast-supported conglomerate (Gcs)	Massive, pebble to boulder, rounded, imbrication	Longitudinal bar with channel lag deposits
Laminated sandstone (Sl)	Medium to very coarse gray sand, moderately sorted	Deposition from the upper plane bed flow at the bar tops
Cross-stratified conglomerates (Gt)	Pebble clasts with sandy matrix, poorly sorted, heterogeneous, and well-rounded	Deposition from bedload transport migration of bar form
Interbedded siltstone-mudstone (Fsm)	Massive, beds in thickness from 1 – 3 m, reddish brown color	Deposition from low suspension falling out in bodies of standing water
Pebbly sandstone (Sp)	Granule to pebble clasts with coarse sand, load casts structures	Channel lag deposits
Interbedded sandstone-conglomerate (Gsi)	Massive sandstone beds with conglomerate beds	Deposition from sediment gravity flows
Lime matrix-supported conglomerate (Gms1)	Clasts range from 1cm to 4 cm, poorly sorted, sub-rounded, with lime mud matrix	Deposition with very rich solutions of calcium carbonate in arid climate
Caliche lithofacies (Lc)	Lime mud, white color, and bed thickness is 1m – 2m	Alkaline conditions in semi-arid climate
Sandy gravel (Gs)	Gray color consists of clasts that are rounded, poorly sorted, and imbricated with sandy matrix.	Deposition from the basal fill of the channel
Horizontally stratified conglomerate (Gh)	Pebble to cobble-sized clasts, subrounded to well-rounded, clast-supported	Deposition from hyper-concentrated grain flows

Figure 5: The field photograph shows a 60 cm x 60 cm grid used in the clast count analysis.

- **Matrix-supported conglomerates lithofacies (Gms)**

This lithofacies is above the contact between the Mukdadiya and Bai Hassan Formations and repeated in the third, fifth, and sixth sedimentary cycles, and contain a high proportion of the matrix, its color is light brown to reddish brown. This facies comprises grains ranging from 3 to 30 cm in diameter, the grains have rounded shapes, and are poorly sorted. The grains have different origins with different colors too, and show some imbrication. These facies present as thick beds (1 to 7 m), and without stratification (Figure 6A and Figure 8D). The Gms gives evidence of debris flow during stream flood deposits in semiarid climates (Miall, 2006).

- **Clast-supported conglomerates Lithofacies (Gcs)**

The Gcs occurs in the first, second, third, and fourth cycles of the section, it occurs as beds of ortho-conglomerate a 1 to 6 m thick, clast supported, massive. Grains in this facies range from 2 mm to 30 cm in diameter. The grains are composed of different types of rocks, and characterized by are subangular to well-rounded shapes and poorly sorted, imbrication pebbles the clasts have different colors, mostly black, and their matrix is sand (Figure 6B). Facies is interpreted as high energy traction with bed load transported by turbulent flow (Bridge, 2003).

- **Laminated sandstone Lithofacies (Sl).**

This lithofacies occurs in the second cycle of the section, the lower part of this facies is medium sand and its upper part is very coarse. The thickness of the Sl is (30 cm) and appears a gray or brown color in the lower part while the upper part is gray, and the lower and upper contact is sharp as well as contains cross lamination and facility (Figure 6C). It is interpreted as a deposition of the upper flow regime at the bar tops during low water stages or predominantly suspension under plane bed flow conditions (Tha *et al*., 2015).

Figure 6: Field photographs. **A)** matrix-supported conglomerate lithofacies (Gms), **B)** Clast supported conglomerate lithofacies (Gcs), **C)** Laminated sandstone lithofacies (Sl), **D)**Veins filled with white secondary carbonates material in horizontally stratified lithofacies in Bai Hassan Fm. In Zakho section.

- **Cross-stratified conglomerates Lithofacies (Gt)**

This lithofacies is located in the middle of the second cycle of the succession and consists of clasts ranging from 1 mm to 4 cm in diameter, with sand matrix, poorly sorted, heterogeneous, and their clasts are well rounded. The thickness of this facies is 1 m, grey-colored, and contains sedimentary structures such as gravel planar cross-bedded (Figure 7). The Gt is deposited from bedload transport migration of bar bedform (Miall, 1996).

- **Interbedded Siltstone-Mudstone Lithofacies (Fsm)**

This lithofacies occurs in the fourth cycle of the succession, and it is interbedded between Siltstone and Mudstone which has 1 m thickness and laterally changes to 3 m. This facies is massive, without sedimentary structures. The siltstone beds are grey while mudstone beds are

red (Figure 8A). The Fsm has interpreted a deposition from low suspension falling out in bodies of standing water or floodplain and overbank deposits (Suzuki *et al.*, 1997).

- **Pebbly Sandstone Lithofacies (Sp)**

This lithofacies occurs in the fourth cycle of the succession, the thickness of this facies is 2 m, grey color. The facies consist of clasts ranging from 2 mm to 4 cm in diameter and coarse- to very coarse-grained sandstone matrix. The clasts are subrounded, poorly sorted, and rarely imbricated. The sedimentary structures such as Load casts structures are located at the bottom of this facies, these structures occur at sand-mud interfaces in deltaic and fluvial sediments generated by the differential loading of waterlogged sand on an unconsolidated mud (Selly, 1976) (Figure 8B).

- **Horizontally stratified conglomerate Lithofacies (Gh)**

This lithofacies occurs in the upper part of the formation in the study section, it occurs as a bundle of pebble conglomerate alternating to a bundle of cobble conglomerate with a total thickness of more than 6 m (Figure 8C). The clasts are subangular to subrounded, imbricated, and poorly sorted in a matrix of very coarse-grain sandstone. This facies contain joints and veins filled with white secondary carbonate material (Figure 6D). The veins are secondary sedimentary structures. The Gh results from deposition from hyper-concentrated grain flows or migration of longitudinal bedform (Smith, 1990).

- **Interbedded sandstone-conglomerate Lithofacies (Gsi)**

This lithofacies occurs in the upper part of the formation and consists of massive sandstone beds alternating with conglomerate beds separated by sharp contacts. The sandstone beds are hard, grey in color, contain small pebbles, and it no more than 0.5 m in thickness (Figure 8D). The conglomerates are overwhelmingly clast-supported, with a matrix of coarse sandstone, sorting of both the matrix and the clasts is generally poor. Conglomerate beds range in thickness from 1 to 6 m. The occurrence of the conglomerates as repetitive sharp-based units, and the complete absence of cross-stratification, point to deposition from sediment gravity flows (Higgs, 1990).

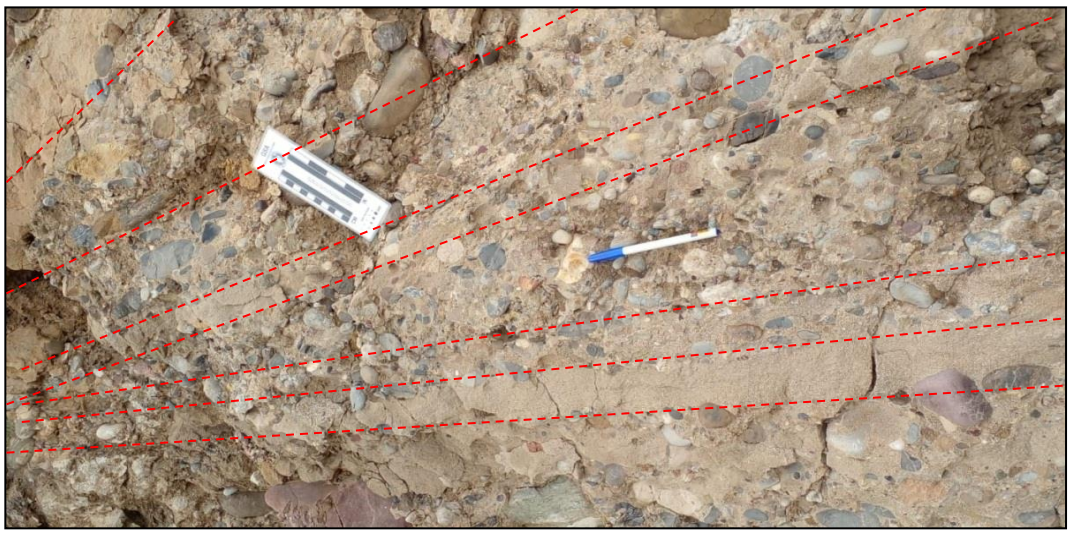

Figure 7: Field photographs. Cross-stratified conglomerate lithofacies (Gt).

Figure 8: Field photographs. **A)** Interbedded Siltstone-Mudstone lithofacies (Fms), **B)** Pebbly Sandstone lithofacies (Sp), with erosional structures (flute cast, load casts small channels) at the bases **C)** Planar stratified conglomerate lithofacies (Gh) **D)** Sandstone-conglomerate inter-bedded lithofacies (Gsi).

- **Lime Matrix supported conglomerate Lithofacies (Gms1)**

This lithofacies occurs in the fifth cycle of the succession, and it is composed of clast ranging from 1 to 4 cm in diameter, poorly sorted, subrounded, and poorly imbricated, and most of the clasts are surrounded by lime mud matrix with carbonate cement which gave it high hardness. This facies is light brown in color, moderately hardness, and 2 m thickness (Figure 9A). High uplift led to the deposition of these facies with very rich solutions of calcium carbonate and with an arid climate (Adeeb, 2006).

- **Caliche Lithofacies(Lc)**

This lithofacies occurs in the sixth cycle of the succession, and it consists of lime mud without skeletal grain, it is 2 m in thickness and white (Figure 9C). It was observed in the upper part of the Bai Hassan Formation. In sediments of a semi-arid climate, the contents of organic matter are low, causing increasing Ph-value (alkaline condition), and the rate of evaporation is high. This causes precipitation of $CaCO_3$ which concretion is known as calcrete (caliche or kankar) (Reineck and Singh, 1980). Its origin is related to three parameters: soil

formation, surface processes, and associated processes with groundwater infiltration and evaporation (Al-Adool, 1982).

- **Sandy Gravel Lithofacies (Gs)**

This lithofacies occurs in the sixth cycle of the succession, and it is characterized by low hardness, grey color, and 1 m thickness, the upper and lower contacts are sharp and inclined at a 30° north and consist of clasts ranging from 2 mm to 4 cm in diameter surrounded by sandy matrix, these clasts is rounded, poorly sorted and imbricated show in the upper part of the Figure (9B). This facies is deposited by gravelly braided river (Kumar *et al.*, 2007).

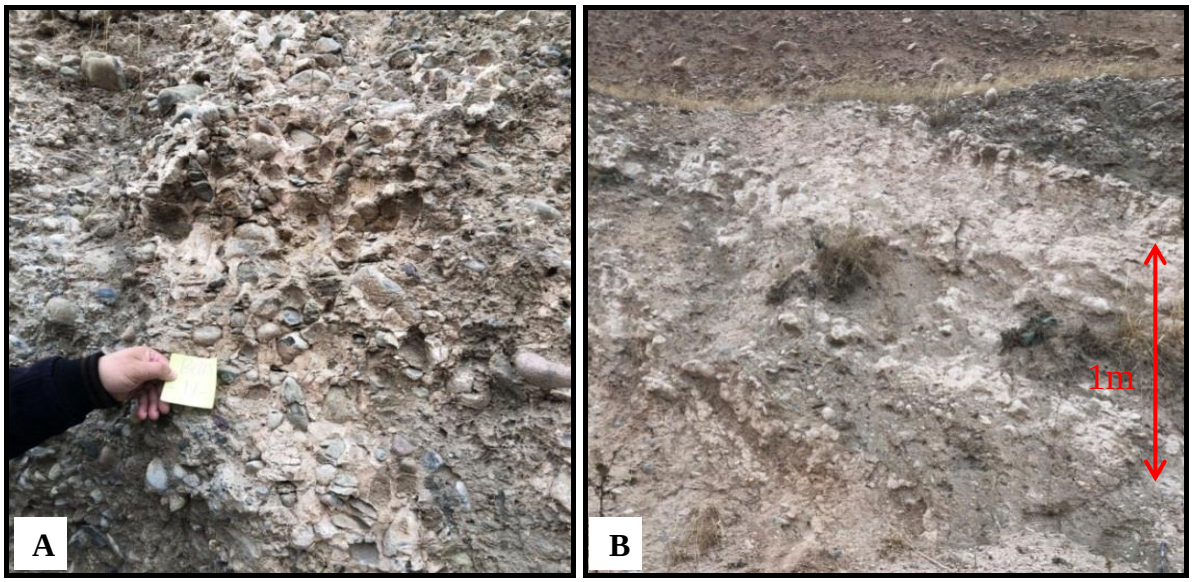

Figure 9: Field photographs. **A)** Lime matrix-supported conglomerate lithofacies (Glm), **B)** Caliche lithofacies (Lc) and sandy gravel lithofacies (Gs).

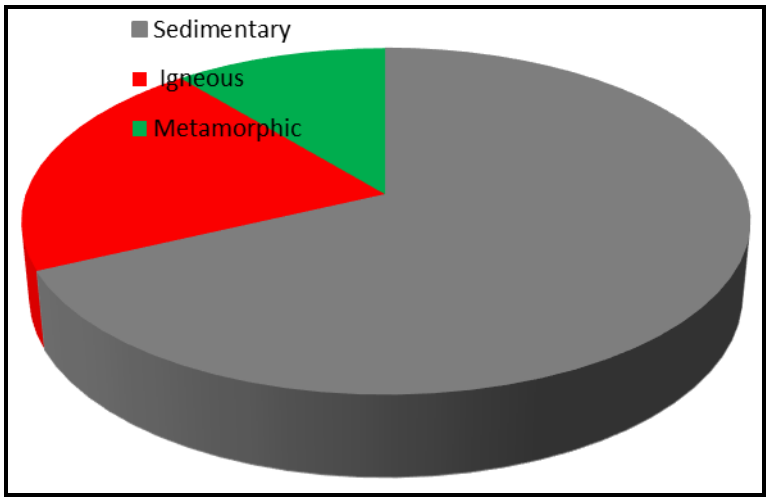

Figure 10: Showing the rock structure of gravel of Bai Hassan Fm.

DEPOSITIONAL MODEL OF BAI HASSAN FORMATION

Bai Hassan Formation represents the peak time for the Alpine Orogeny in this region, as the thickness of the continental crust increased rapidly and unprecedentedly, and the

sedimentary, igneous, and metamorphic rocks were uplifted in the north and northeast of Iraq, which resulted in the increased supply of these types of rocks detritus (Adeeb, 2006). The source area uplift, basinal subsidence, basinal topography, and size of the catchment area may have played a big role in changing the sedimentary facies (Kumar *et al*., 2007). The schematic depositional model of this formation (Figure 11) shows the change from fine-grained facies of rivers to coarse-grained alluvial fans facies and gravel-braided rivers. The increase in rainfall at that time also played a role in mobilizing coarse gravel for long distances to the sedimentation basin. The presence of calcareous material suggests semi-arid climate (Sigdel, 2013).

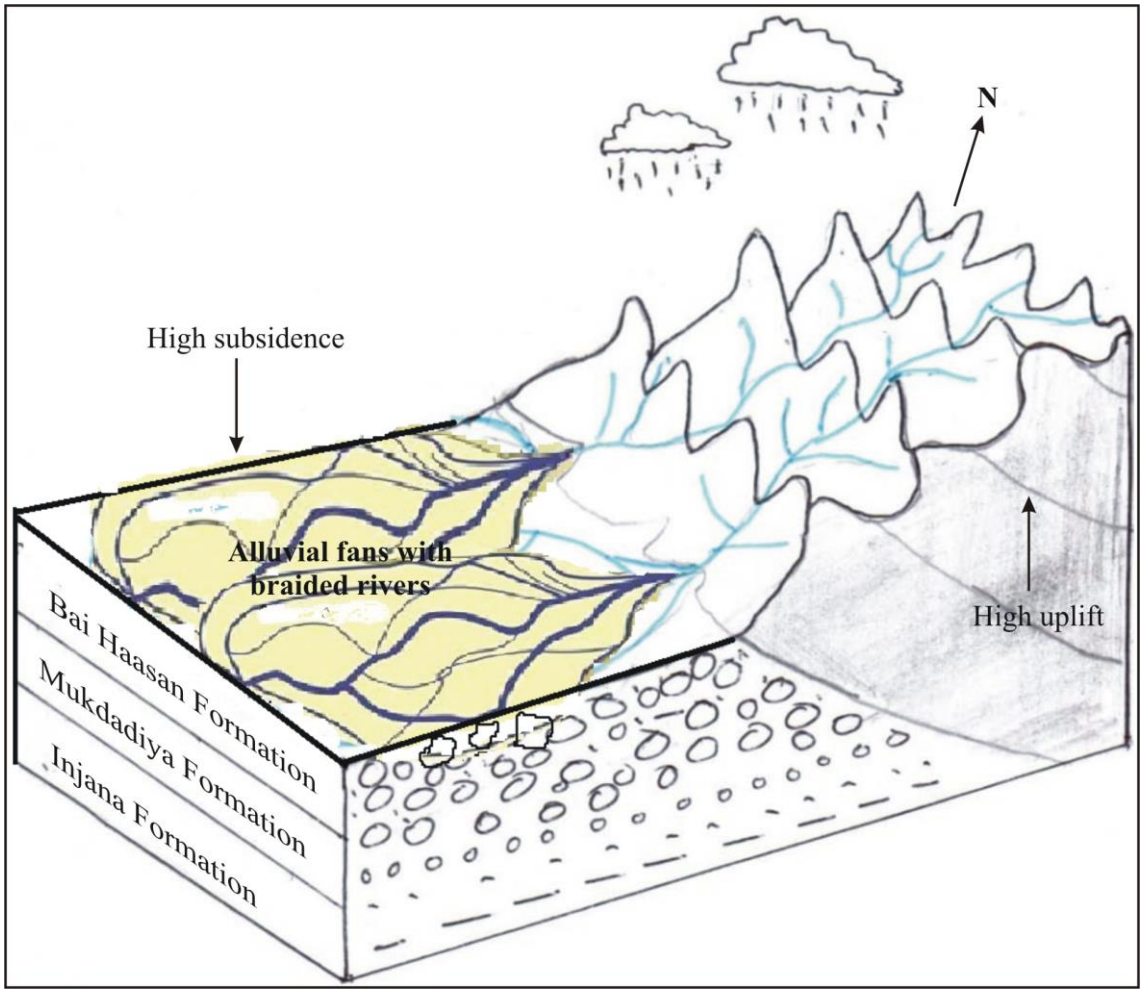

Fig.11: Depositional model of Bai Hassan Formation in Zakho section.

DISCUSSION

Bai Hassan Formation is composed principally of six coarsening upward cycles, the first cycle starts with matrix-supported conglomerate lithofacies and ends with clast-supported conglomerate lithofacies, these facies exhibit the mechanism of avalanching or debris flow of sedimentary materials. The relatively short sediment transport distance, rapid loss of flow capacity with coarsening up grain size, poor sorting, and variable matrix contents. Such patterns were associated with an alluvial fan reaching a body of water. The second cycle starts with laminated sandstone lithofacies and ends with clast-supported conglomerate lithofacies, with cross-stratified conglomerate lithofacies in between, the characteristic feature of this cycle indicates that the sediments were deposited rapidly in the current high-energy

environment of proximal gravely braided rivers (Pandita *et al*., 2014). The third cycle starts with clast-supported conglomerate lithofacies and ends with matrix-supported conglomerate lithofacies, such patterns associated with an alluvial fan setting (Blair and Mcpherson, 1994). The fourth sedimentary cycle consists of four lithofacies, starting with Interbedded siltstone-mudstone lithofacies, which represent deposition in the internal lake environment, followed by pebbly sandstone lithofacies, which is channel deposits, and then clast-supported conglomerate lithofacies deposited from debris flows or pseudoplastic debris flows (Tha *et al.,* 2015) and Interbedded sandstone-conglomerate lithofacies formed by rapid stream on fusing alluvial fans (Al-Adool, 1982). The fifth cycle starts with Lime matrix-supported conglomerate lithofacies formed by high uplift led to deposition with very rich solutions of calcium carbonate, and with an arid climate (Adeeb, 2006), and ends with matrix-supported conglomerate lithofacies formed by debris flow. Finally, the sixth cycle starts with caliche lithofacies and ends with matrix-supported conglomerate lithofacies, with sandy gravel lithofacies in between. caliche lithofacies indicated deposition in freshwater lakes is formed by river cutoff (Al-Adool, 1982) above and below alluvial fan deposits.

CONCLUSIONS

- The origin of coarsening upward cycles is related to the spreading of fluvial sediments by waves of stagnant water.
- Bai Hassan Formation consists of six coarsening up-ward cycles which are composed of eleven Lithofacies such as matrix-supported conglomerate, clast-supported conglomerate, horizontally stratified conglomerate, cross stratified conglomerate, and interbedded sandstone conglomerate lithofacies as well as interbedded siltstone-mudstone, pebbly sandstone, laminated sandstone, lime matrix-supported conglomerate, caliche, and sandy gravel lithofacies.
- Bai Hassan Formation is deposited in alluvial fans and braided river environments with internal lakes that have a dry climate and high uplift in source rocks and subsidence in the basin.

REFERENCES

Adeeb, H.G., 2006. Tectogenesis of the Alpine Molasse Basin in Northern Iraq. Unpublished Ph.D. Thesis. University of Mosul, 204pp.

Al-Adool, D.M., 1982. Sedimentological study of the Bakhtiari Group in selected area, northern Iraq. Unpub. M.Sc. Thesis, University of Mosul, 241pp.

Ali, A.J. and Khoshaba, B.N., 1981. Petrography and heavy mineral studies of Lower Bakhtiari Formation. Jour. Geol. Soc. Iraq, Vol.14, No.1, p. 15 – 24.

Al-Rawi, Y.T., Sayyab, A.S., Jassim, J.A., Tamar-Agha, M.Y., Al-Sammarai, A.I., Karim, S.I., Basi, M.A., Dhiab, S.H., Faris, F.M. and Anwar, F. 1992. New name for some of the middle Miocene – Pliocene formations, Iraqi Geological Journal, Vol.1, p. 1 – 18.

Bellen, R.C., Dunnington, H.V., Wetzel, R. and Morton, D., 1959. Lexique Stratigraphique, Interntional**.** Asie, Iraq, Fasc, 10a, Paris, 333pp.

Blair, T.C., McPherson, J.G., 1994. Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. Journal of Sedimentary Research A 64, p. 450 – 489.

Bridge, J.S., 2003. River and Flood Plain, Backwell Scientific, Oxford, 504pp.

Finzel, E.S. and McCarthy, P.J., 2005. Architectural analysis of fluvial conglomerate in the Nanushuk Formation. Brooks Range Foothills. Alaska. Division of Geological and Geophysical Surveys. Preliminary interpretive rep. no.2.

Higgs, R., 1990. Sedimentology and tectonic implication of Cretaceous fan-delta conglomerates Queen Charlotte Islands, Canada. Sedimentology, Vol.37, p. 83 – 103.

Issa, M.J., 2012. Sedimentary Structures and Determine the Direction of Old Current to the Bai Hassan Formation Northeast Iraq. Ibn Al-Haitham Journal for Pure and Applied Science. Vol.25, No.2, p. 252 – 260.

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Bron, (pub), 341pp.

Kumar, R., Suresh, N., Sangode, S.J. and Kumaravel, V., 2003. Evolution of the Quaternary alluvial fan system in the Himalayan Forland basin: Implications for tectonic and climatic decoupling. Elsevier Ltd INQUA. Vol.159, p. 6 – 20.

Miall, A.D., 1996. The Geology of Fluvial Deposits: Sedimentary Facies, Basin Analysis, and Petroleum Geology: New York, Springer, 582pp.

Miall, A.D., 2006.The Geology of Fluvial Deposits. Springer-Verlag, Berlin.

Nichols, G., 2009. Sedimentology and stratigraphy. A John Welly and Sons, Ltd. UK, 419pp.

Pandita, S.K., Thakur, K.K., Kotwal, S.S. and Bhat, G.M., 2014. Lithofacies association and depositional of Boulder Conglomerate Formation, Upper Siwalik Subgroup, Jammu Himalaya. Himalayan Geology, Vol.35, No.2, p. 135 – 145.

Poole, A. and Robertson, A., 1998. Pleistocene Fanglomerate deposition related to uplift of the Troodos Ophiolite, Cyprus. Proceedings of the Ocean Drilling Program, Scientific Results, Vol.160.

Reineck, H.E. and Singh, I.B., 1982. Depositional Sedimentary environments, 2nd ed., Springer-Verlag, New York, 439pp.

Rust, B.R., 1972. Structure and process in a braided river: Sedimentology, Vol.18, p. 221 – 245.

Selly, R.C., 1976. An introduction to sedimentary. Academic Press, London, 259pp.

Sigdel, A., 2013. Evolution of the fluvial systems and petrography of sedimentary rocks of the Miocene Siwalik Group, Karnali River section, Nepal Himalaya: implications for provenance, paleoclimate and Himalaya tectonics. PhD Thesis, Shimane University, Japan, 127pp.

Smith, S.A., 1990. The sedimentology and accretionary styles of an ancient gravel-bed stream, the Budleigh Salterton pebble beds (lower Triassic), Southwest England: Sedimentary Geology, Vol.67, No. 3 – 4, p. 199 – 219.

Suzuki, S., Asiedu, D.K. and Shibata, T., 1997. Compositions of sandstone of the Kenseki Formation and Paleogeographic reconstruction in the lower Cretaceous, inner side of southwest Japan. Journal of the Geological Society of the Philippines, Vol.LII, No. 3 – 4, p. 143 – 159.

Tha, H.V., Wysocka, A., Pha, P.D., Cuong, N.Q. and Ziolkowski, P., 2015. Lithofacies and depositional environments of the Paleogene/ Neogene sediments in the Hoanh Bo Basin (Quang Ninh province, NE Vietnam). Geology, Geophysics, and Environment, Vol.41, No.4. p. 353 – 369.

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