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EMPHASIZING LITHOSTRATIGRAPHIC RULES IN DISTINCTION OF FORMAL UNITS: SINJAR VS KHURMALA FORMATIONS, CASE STUDY

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ABSTRACT

Recognition, identification, and correlation of formal lithostratigraphic units should always follow the rules of the definition of lithostratigraphic units established in the Stratigraphic Code of Nomenclature, set by the International Stratigraphic Commission.

This case study is attempting at elaborating on this argument by discussing the identification and differentiation between the Sinjar and Khurmala formations in outcrop and well sections.

Stratigraphic data for this study were compiled basin-wide, with nearly fifty localities of both formations from the Zagros foreland basin of Kurdistan in NE Iraq. Examinations include a review of microfacies documentation, Facies reinterpretation as well as sequence analysis.

The Sinjar and Khurmala formations are carbonate units developed during the final filling stage of the Zagros foreland basin of northeast Iraq. The Sinjar Formation is characterized by shallow marine coralgal-foraminiferal limestone of reefal, lagoonal, shoal, and overall ramp setting. Other lithologies such as dolomitic limestone or marly limestone are minor and secondary. The Khurmala Formation, on the other hand, is dominated by thick beds of dolostone with secondary lithologies including recrystallized limestone and dolomitic limestone and marly limestone. Microfacies analysis of the Khurmala Formation reveals that it represents a lagoonal lithofacies equivalent to the lagoonal facies of the Sinjar Formation but intensively dolomitized at specific areas of the basin. This close relationship between the two formations, leading in some cases to mixing between both lithologies or rather confusion and misidentification. The best way of differentiating between the two units is by adhering to the lithostratigraphic rules and principles of the formal stratigraphic description, which emphasize the formal lithostratigraphic description of each formation.

INTRODUCTION

Naming, describing, and distinguishing lithostratigraphic units is vital for working with geologic units accorded formal status. Such procedures, if widely adopted would assure consistent and uniform usage in classification and terminology, and therefore, promote unambiguous stratigraphic communication (NACSN, 2021).

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Lithostratigraphic units like formations or members are formal rock units identified, recognized, delimited, nominated, and distinguished from other likewise units based on general lithologic characters and stratigraphic position. The North American Commission on Stratigraphic Nomenclature was a pioneer in setting the rules and bases of how to identify and recognize certain lithostratigraphic units (NACSN, 1961). In Article 3 and Article 4 of their code, they explain in detail these rules. They emphasize in Article-4 "*Article 4. A rock-stratigraphic unit is a subdivision of the rocks in the earth's crust distinguished and delimited on the basis of lithologic characteristics*". They add in remark (a) of the stratigraphic code, Rock-stratigraphic units are recognized and defined by observable physical features rather than by inferred geologic history. No changes had being made to this definition, which emphasizes the importance of the lithologic characters in recognizing formal lithostratigraphic units (NACSN, 1983; and 2021).

The International Commission on Stratigraphy (ICS) followed similar descriptions and restrictions on this rule. They define lithostratigraphic units as "*A Lithostratigraphic unit is a body of rocks that is defined and recognized on the basis of its lithologic properties or combination of lithologic properties and stratigraphic relations* (Hedberge, 1976; Salvador 1983; Murphy and Salvador, 1999).

In recent years the diversity and expansion of geological research and survey works led to misidentification and confusion in recognizing some stratigraphically related formal units. Misidentification stems from overlooking the basic lithologies and focusing on lithofacies and/ or depositional environments as an identification tool, thus assigning the wrong unit.

The aim of this work is to apply the stratigraphic confusion between the Khurmala and the Sinjar Formation of the Zagros foreland basin as a case study to demonstrate the importance of relying on the lithology as a decisive factor in the identification of a given lithostratigraphic unit. Both units are carbonate (Sinjar is mainly limestone and Khurmala is dominantly dolostone) and deposited during the shoaling stage of the Zagros Foreland Basin (Al-Qayim *et al*., 1988; Al-Qayim, 2011; 2019; 2021; 2022; and 2023, Lawa and Mardan, 2019; Karim *et al*., 2018; and Tamar-Agha *et al*., 2015). They are known of being closely and stratigraphically related representing lateral facies change of the same shallow marine carbonate unit (Bellen *et al*., 1959; Buday,1980; and Jassim and Goff, 2006).

MATERIAL AND METHODS

Research data are mainly based on the revision and re-evaluation of stratigraphic sequence and facies analysis of 50 previously published studies on almost 50 localities (both surface and subsurface) for Sinjar and Khurmala Formations (Figure 1). The microfacies analysis of these studies is reviewed, and facies documentation is reinterpreted. The stratigraphic status of these localities is revised in light of the foregoing lithostratigraphic principles. Two localities are chosen as a reference section for a detailed presentation of ideal lithologic characters for each formation. These are the Qaradagh (Branan Mountain, Sulaimani area) locality for the Sinjar Formation, and the Gara Anticline (Dohuk area) for the Khurmala Formation.

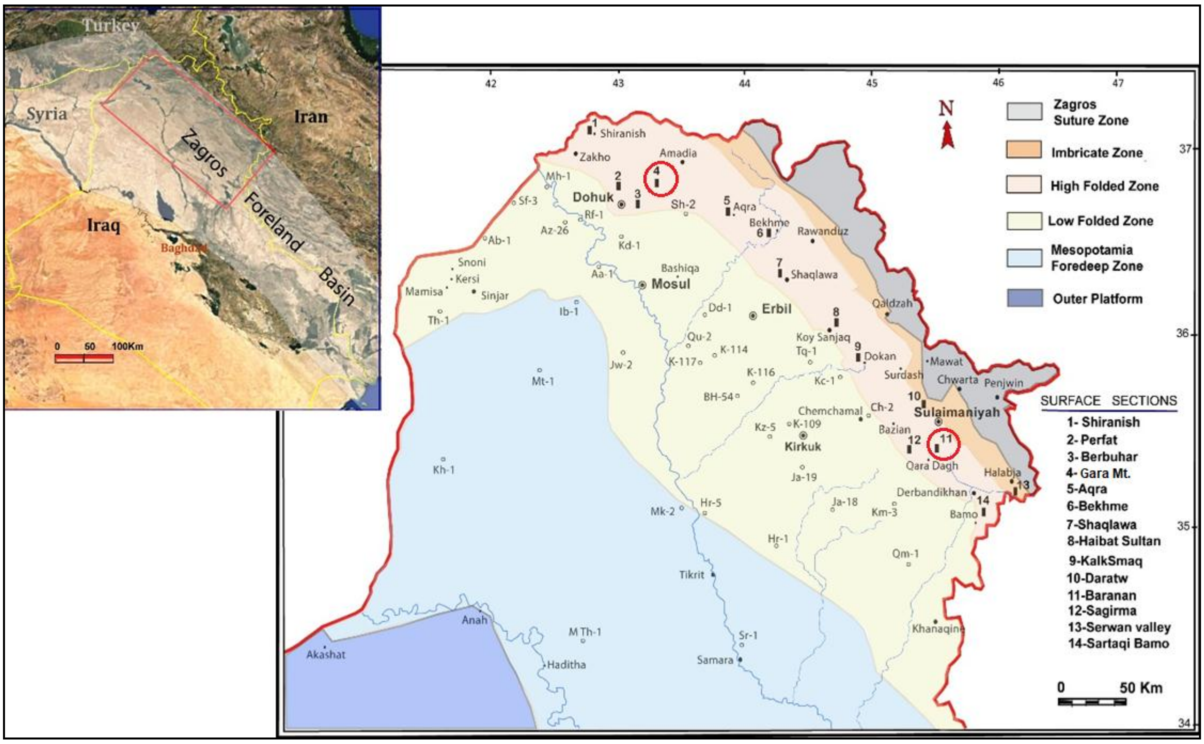

Figure 1: Location Map of Northern Iraq showing major tectonic zones and examined localities. Detailed investigated reference sections are circled in red (Tectonic divisions from Fouad, 2015).

STRATIGRAPHY

The Zagros foreland basin during the Late Paleocene – Early Eocene passes through a shoaling stage during which shallow marine carbonates cover extensive parts of the basin. These carbonates are represented by coralgal reef, nummulitic shoals, and tidal limestone of the Sinjar Formation forming patchy-distributed banks developed over the forebulge depozone of the basin (Al-Qayim, 2019; 2022; and 2023). These carbonates gradually extend over the foredeep area of the basin forming an extensive lagoonal limestone and over the back-bulge area in the form of ramp deposits. The first case is represented by the intermixing with the upper part of the Kolosh Formation siliciclastic sediments, and the second show intercalation within the back-bulge Aaliji Formation marlstone sediments (Al-Qayim, 2022). Part of these limestones, especially the lagoonal limestone, were subjected to intensive dolomitization at certain parts of the basin, which develops a cyclic sequence of thick-bedded dolostone of the Khurmala Formation. At the final filling stage of the basin, reddish subcontinental siliciclastic sediments of the Gercus Formation were deposited covering both formations in many examined localities. Below is a brief review of the stratigraphic association of each formation.

- ***Sinjar Formation***

A limestone unit of bank and associated facies with extensive distribution. In type-section, Bellen *et al.* (1959) described it as follows

“ Type locality and section.

– **Location:** Near the village of Mamissa, on the Jebel Sinjar, at lat. 36° 22' 33" N, long. 410 41' 23" E.

Brief description of the type section

– **Thickness:** 577 feet (176 meters).

– **Lithology:** Limestone, showing elements of algal reef facies, lagoonal miliolid facies, and shoal nummulitic facies usually recrystallized and yellowish.

– **Fossils:** *Alveolina globosa* Leymerie, *Alveolina primaeva* Reichel, *Dictyoconus arabicus* Henson, *Dictyokathina*, *simplex* Smout, *Idalina sinjarica* Grimsdale, *Miscellanea miscella* (d'Archiac and Haime), *Nummulites atacicus* Leymerie, *Opertorbito*lites sp., *Saudia labyrinthica* (Grimsdale), *Taberina daviesi* Henson, discocyclinids, miliolids, operculinids, valvulinids, *Parachae*tetes *asvapatii* Pia.

– **Age:** Paleocene, " lower" Eocene".

The formation has a patchy distribution over most parts of the basin from Sinjar to Dohuk passing southeastwards into Shaqlawa, Kirkuk, Dokan, Sulaimaniyah, and down to Sirwan Valley (Figure 1) (Bellen *et al*., 1959; and Al-Qayim 2022). It shows massive-thick-bedded limestone which often represents the bank associations such as the area of Sinjar, Sulaimani, or Sirwan Valley (Bellen *et al*., 1959; Al-Syyab and Al-Siddiki, 1970; Mallick and Al-Qayim, 1985; Tamar-Agha *et al*., 2015; Al-Dulaimi and Al-Dulaimi, 2017; and Lawa and Mardan 2019). However, in other areas such as Dohuk, Bekhme, Shaqlawa, Kolosh, and Dokan, it is developed as intercalations of thin to medium-bedded limestone intermixed with the upper part of the Kolosh Formation (Bellen *et al*., 1959; Al-Qayim and Salman, 1986; Al-Qayim *et al*., 1988; Al-Qayim and Al-Shaibani, 1995; Karim, 1997; Tamar-Agha *et al*., 2015; Al-Dulaimi and Al-Dulaimi, 2017; Lawa and Mardan, 2019; Barzani and Al-Qayim, 2019; and Al-Qayim, 2022). The formation shows varieties of carbonate facies including coalgal reef, nummulitic shoal, mollusck-miliolid lagoonal limestone, alveolinid shoals, and stromatolitic tidal limestone of the bank facies association in addition to ramp carbonate intercalations of bioclastic grainstone.

A field section at Branan Mountain of the Sulaimani area is measured and described in detail as a reference section for the Sinjar Formation (Figure 2). The total thickness of the Formation reaches 130 m. including the intercalated part with the Kolosh Formation sediments. The section consists of 50 meters of thick limestone units of the bank facies association (Figure 3a). The bank here consists of two massive units each reaching 20 – 25 m., and separated by 5 – 10 m green marly shale. Recognized facies include algal grainstone (Figure 3b), nummulitic shoal (Figure 3c), and tidal limestone at the upper part (Figure 3d). The lower part is represented by 80 meters of intercalations of fossiliferous limestone with olive green silty shale and sandstone of the Kolosh Formation. The limestone units of this interval are dominated by *Nummulite*, *Assilina*, *Lepidocyclina*, and other larger benthic foraminiferal bioclasts representing lag or storm deposits of the ramp facies (Figure 3e).

- ***Khurmala Formation***

The Khurmal Formation is dominated by dolostone lithology and minor shale interlayers. It is described by Bellen *et al.* (1959) as follows

“ Type locality and section.

– **Location:** LP.C. Well K-114 at lat. 45° 56'15.50" N, long. 430 45' 21.78" E; between drilled depths 3225 and 3860 feet. The elevation of the well is 1185 feet and drilling was completed 31.6.54.

Brief description of the section.

– **Thickness:** Approximately 607 feet true thic1mess (185 meters)
– **Lithology:** Dolomite, sub-oolitic in parts, and finely recrystallized limestone. Probably chemical limestones, interfingering strongly with material from the Kolosh formation.

– **Fossils:** Largely obliterated by recrystallization and dolomitization. Miliolids, Small valvulinids, clavulinids, and very rare "ghosts" of indeterminable alveolinids Small gastropods and fragments of *Algae* also occur, but these are not determinable either specifically or generically.

– **Age:** Paleocene and “lower Eocene”

The dolomite is extensive and developed in varieties of textures (Barzani and Al-Qayim, 2019). The sequence often consists of cyclic, thick to massive, up to 2 meters dolostone units, which alternate with thin shale horizons often barren of any fossils. Dolomitization is so severe that most of the original components were destroyed and nothing is left but ghosts or relics of some marine fossils, which points towards the lagoonal origin. Ghosts of stromatolitic dolostone are often recognized at the top of each dolostone unit.

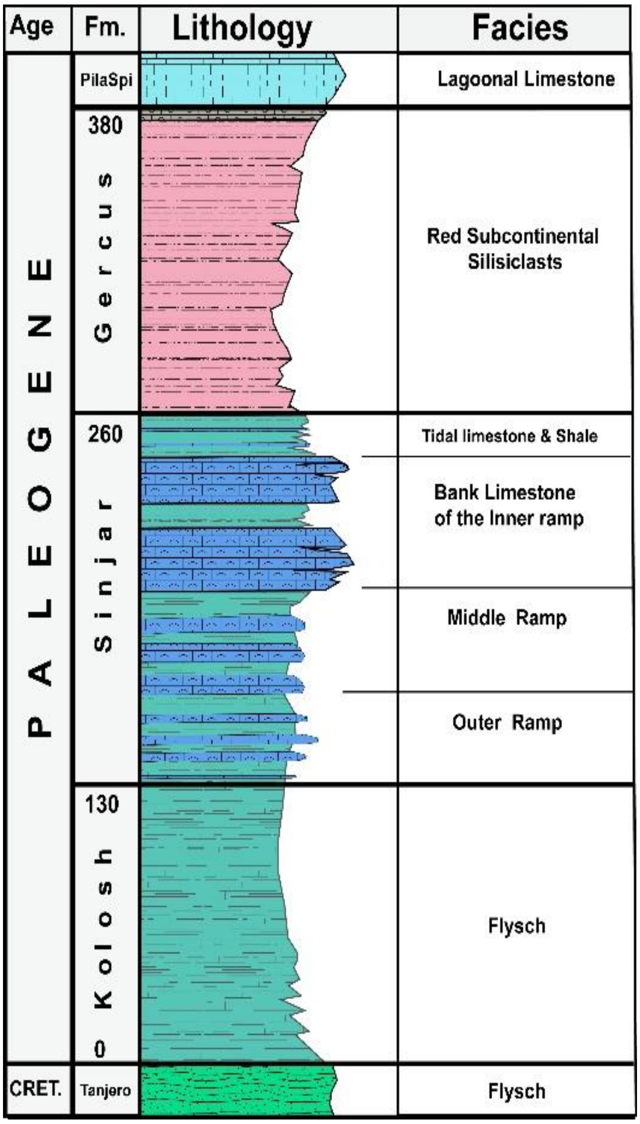

Figure 2: Stratigraphic column of Sinjar/ Kolosh Formation at Branan mt., West of Sulaimaniyah, showing lithologic characters and facies types.

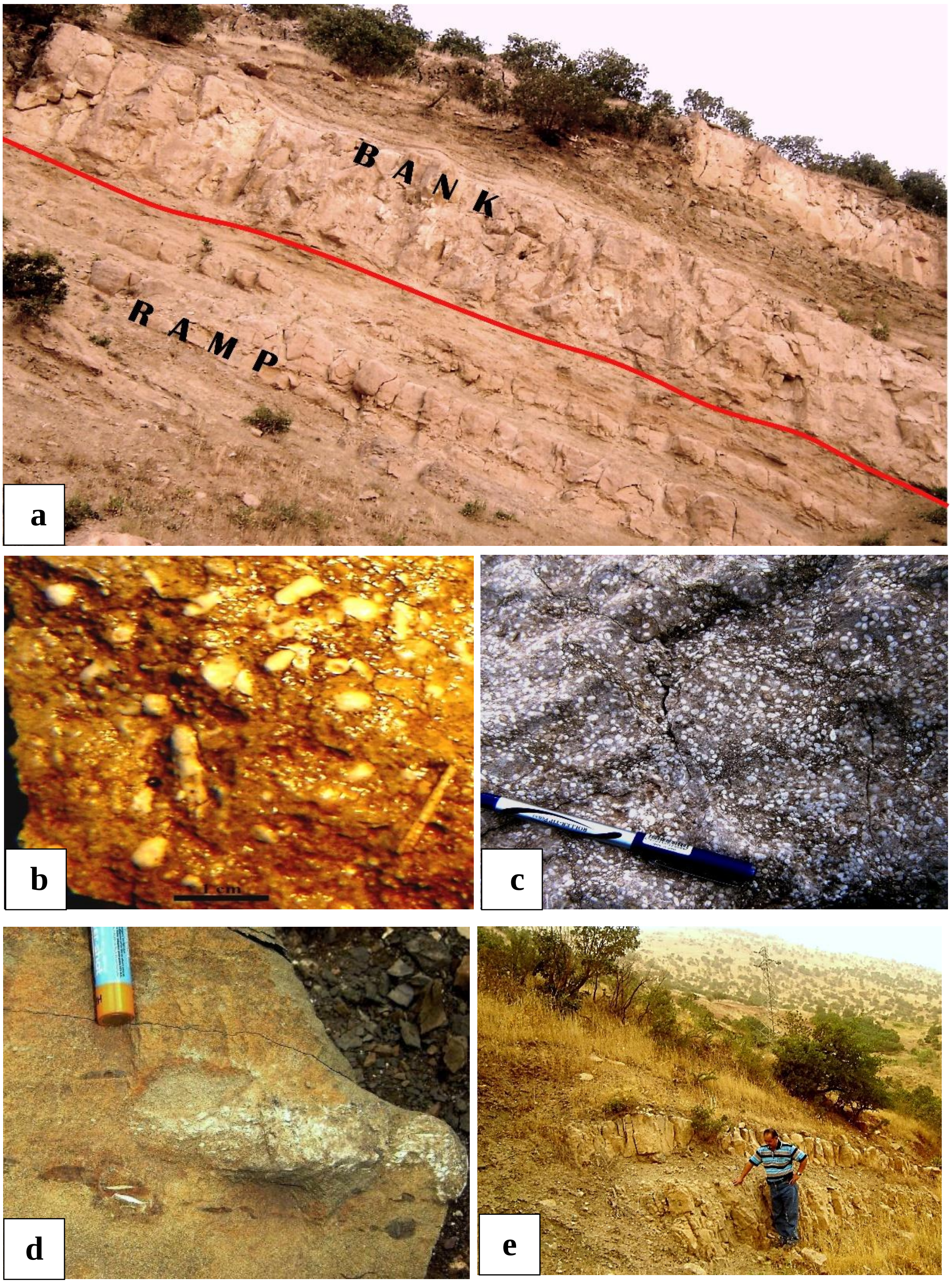

Figure 3: **a)** General view of the Sinjar Formation at Branan Mt. near Sulaimaniyah showing the development of bank limestone over the ramp facies. **b)** Algal packstone limestone of Sinjar bank limestone, Branan Mt. **c)** nummulitic grainstone of the shoal facies, Sinjar bank, Branan Mt. **d)** Pocket of storm bioclastic deposits within the green sandstone of the Kolosh Formation, outer ramp, Branan section. **e)** The upper part of the Sinjar bank of Branan section shows tidal limestone facies.

A reference section, which typifies the Khurmala Formation is selected from Gara Mt. of the Dohuk area. Its description and detailed lithology is burrowed from Barzani and Al-Qayim (2019) and Al-Qayim and Barzani (2021).

The thickness of the Formation is 91 m and generally consists of buff to gray, medium to thick-bedded stromatolitic dolostone alternating with thin beds of buff to dark gray shale or marlstone. Shale interlayers increased in thickness upwards. The studied section is divided into three units based on the dolostone/shale ratio (Figure 4). Microscopic study of these dolomite shows that they consist mainly of fine to medium crystalline dolomite mosaic (Barzani and Al-Qayim, 2019). Ghosts of the original components are rarely recognized and represented by lagoonal fauna (Figure 5b). This sequence has general lithologic characters quite similar to the sequence of the type section at the Kirkuk structure. Similar succession is also examined from Geli Zanta (Figure 5c), Atrush (Figure 5d), and Aqra (Figure 5e).

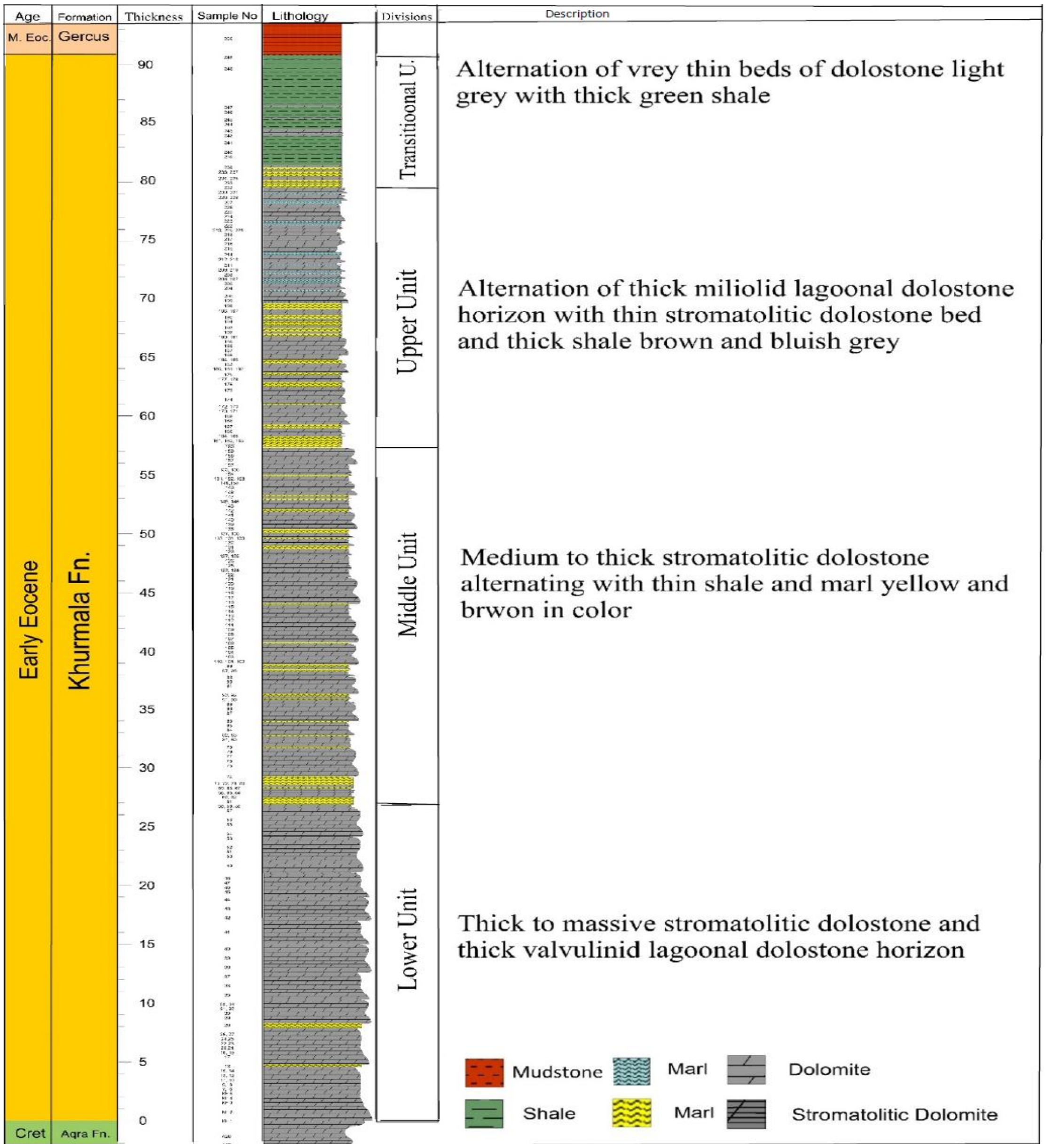

Figure 4: The stratigraphic column of the Khurmala Formation at Gara Mt., Dohuk area, showing detailed lithologic characters and units (After Barzani and Al-Qayim, 2019).

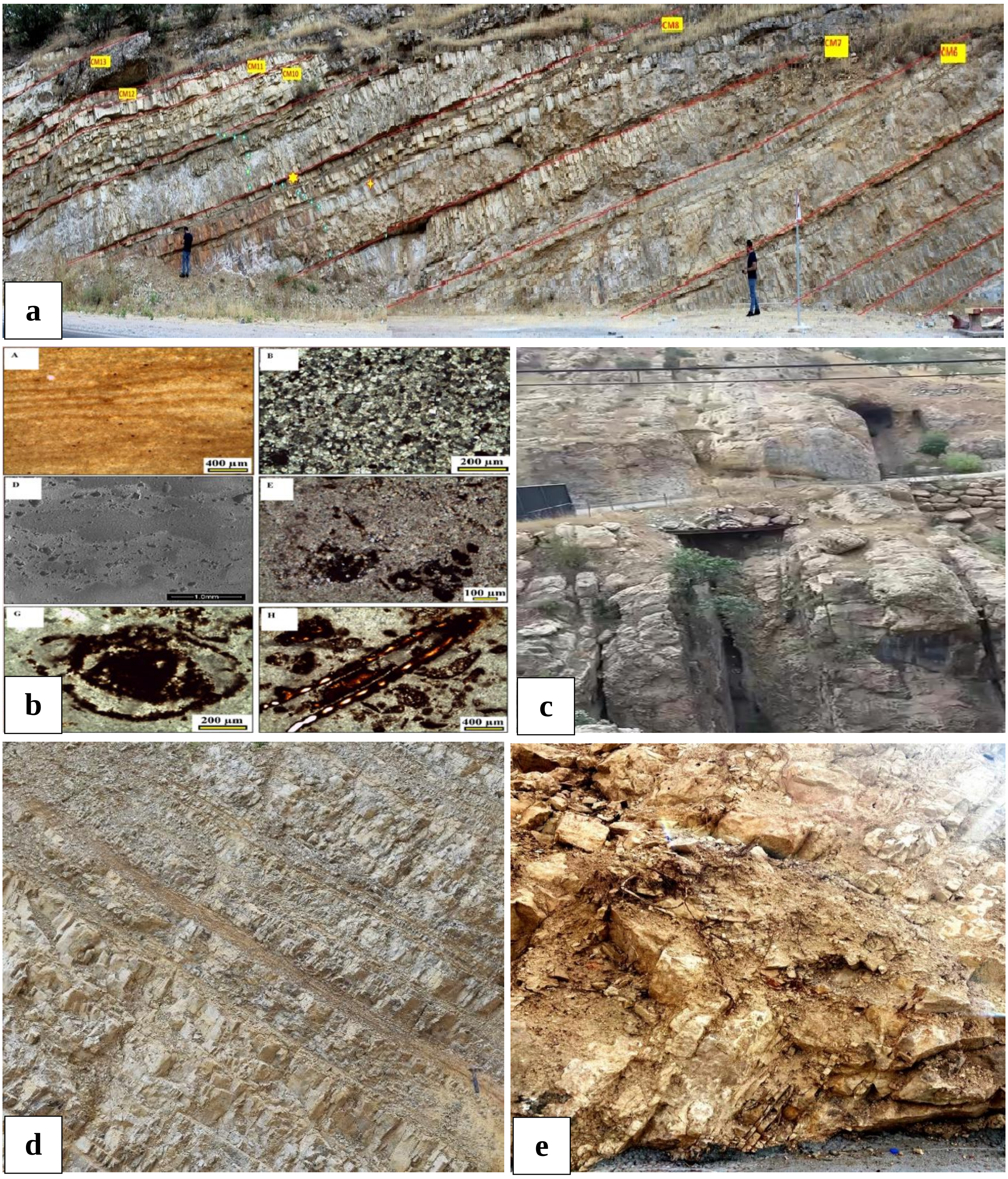

Figure 5: **a)** General view of the Khurmala Formation at Gara Mt. Succession consists of thick-bedded dolostone with thin shale interlayer. **b)** Varieties of the dolomite fabric of the Khurmala section at Gara Mt. including ghost stromatolitic dolomite (A and D), Medium crystalline (E), ghost of lagoonal bioclasts: valvulinids (E), miliolids (G), and green algae (H). **c)** Thick dolostone units of Geli Zanta. **d)** Thick bedded dolostone of Khurmala Formation at Atrush. **e)** Slightly marly dolostone of Khurmala Formation at Aqra.

STRATIGRAPHIC REVISION

Based on the foregoing stratigraphic principles, the formal definitions of both formations, and the stratigraphic status of each formation at the examined localities, the stratigraphic identity of the 50 previously published studies was reviewed and re-evaluated. Revision includes original facies sequence, lithologic association, and stratigraphic status. The stratigraphy of some localities of these studies had been reinterpreted and changed in accordance with principles of the international stratigraphic rules of nomenclature (Table 1).

Table 1: Listing of revisited localities from 50 previous studies showing their facies type, main lithologic characters, original stratigraphic status, and the newly suggested stratigraphic assignment by the current study. (Red labeling indicates changing a status).

SERIES	YEAR	AUTHOR	LOCALITY	FACIES	MAIN LITHOLOGY	FORMATION	THIS STUDY FORMATION
1	1970	Al-Syyab and Al-Siddiki	Sinjar	Algal Reef	Limestone	Sinjar	Sinjar
2	1973	Al-Omari and Sadik	J. Maqlub	Lagoon	Marly Limestone	Khurmala	Sinjar
3	1975	Al-Shaikh *et al.*	Harrir	Lagoon	Limestone	Khurmal	Sinjar
4	1978	Kassab	K-117	Shoal/ Lagoon	Marly Lst. and D Limestone	Khurmal Sinjar	Khurmala Sinjar
5	1985	Mallick and Al-Qayim	Taslujah	Reef / Shoal	Limestone	Sinjar	Sinjar
6	1986	Al-Qayim and Salman	Shaqlawa	Lagoon	Marly Limestone	Khurmala	Sinjar
7	1988	Al-Qayim *et al.*	Haibat Sultan	Lagoon	Marly Limestone	Khurmala	Sinjar
8	1990	Al-Qayim and Nissan	Koysanjaq	Lagoon	Limestone	Khurmala	Sinjar
9	1993	Al-Sordashy and Lawa	Al-Sulaimaniyah	Shoal / Reef	Limestone	Sinjar	Sinjar
10	1995	Al-Qayim and Al-Shaibani	Bekhme Gorge	Lagoonal	Limestone	Khurmala	Sinjar
11	1995	Al-Qayim	Aqra	Lagoonal	Dolostone	Khurmala	Khurmala
12	1995	Al-Qayim	KoiSanjaq	Lagoonal	Limestone	Khurmala	Sinjar
13	1997	Karim	Sartak - Bamo	Shoal / Lagoon	Limestone	Sinjar	Sinjar
14	2001	Al-Sordashi	Sulaimaniyah	Reef / Lagoon	Limestone	Sinjar	Sinjar
15	2005	Amen *et al.*	Sinjar	Reef / Shoal	Limestone	Sinjar	Sinjar
16	2006	Lawa	Sulaimaniyah	Reef / Shoal	Limestone	Sinjar	Sinjar

Table 1: Continued

SERIES	YEAR	AUTHOR	LOCALITY	FACIES	MAIN LITHOLOGY	FORMATION	THIS STUDY FORMATION
17	2006	Al-Banna *et al.*	Bakhair Mt.	Tidal / lagoon	Limestone	Khurmala	Sinjar
18	2009	Salih and Yaseen	W. Sulaimaniyah	Reef	Limestone	Sinjar	Sinjar
19	2012	Al-Ehmeedy *et al.*	Dokan	Lagoon / Reef Mound	Limestone and Dolostone	Khurmala	Sinjar
20	2012	Al-Banna *et al.*	Bekhme Aqra	Lagoon Lagoon	Limestone Dolostone	Khurmala Khurmala	Sinjar Khurmal
21	2016	Al-Sultan	KoiSanjaq	Lagoon	Limestone	Sinjar	Sinjar
22	2014	Omer *et al.*	Shaqlawa	Lagoon	Limestone	Khurmala	Sinjar
23	2015	Tamar-Agha *et al.*	Derbandikhan	Reef	Limestone	Sinjar	Sinjar
24	2015	Tamar-Agha *et al.*	Gerda-Selemani	Reef	Limestone	Sinjar	Sinjar
25	2015	Tamar Agha *et al.*	Kalk Smaq	Reef / Lagoon	Limestone and D. Limestone	Khurmala /Sinjar	Khurmala / Sinjar
26	2015	Tama-Agha *et al.*	Bekhme	Lagoon	Limestone	Sinjar	Sinjar
27	2015	Tamar-Agha *et al.*	Wara Milli	Lagoon	Limestone	Sinjar	Sinjar
28	2015	Tamar-Agha *et al.*	Daigala	Lagoon	D. Limestone	Khurmala	Sinjar
29	2015	Tamar-Agha *et al.*	Harrir	Lagoon	Limestone	Khurmala	Sinjar
30	2015	Tamar-Agha *et al.*	Aqra	Lagoon	Dolostone	Khurmala	Khurmala
31	2015	Tamar-Agha *et al.*	Bashiqa	Lagoon	Dolostone	Khurmala	Khurmala
32	2015	Tamar-Agha *et al.*	Babylo	Lagoon	D. Limestone	Khurmal	Khurmala
33	2015	Al- Banna *et al.*	K-187	Reef	Limestone	Sinjar	Sinjar
34	2016	Karim	Zhalla Dararash	Shoal Shoal	Limestone Limestone	Sinjar Sinjar	Sinjar Sinjar
35	2016	Karim	KalkSmaq Kalozh	Lagoon Lagoon	Limestone Limestone	Sinjar Sinjar	Sinjar Sinjar
36	2016	Karim	Bekhme Saru Kani	Lagoon Lagoon	Limestone Limestone	Khurmala Khurmala	Sinjar Khurmala
37	2017	Al-Dulaimi and Al- Dulaimi	DerbaniKhan	Reef / Shoal	Limestone	Sinjar	Sinjar

Table 1: Continued

SERIES	YEAR	AUTHOR	LOCALITY	FACIES	MAIN LITHOLOGY	FORMATION	THIS STUDY FORMATION
38	2017	Al-Dulaimi and Al-Dulaimi	Qaradagh	Reef / Shoal	Limestone	Sinjar	Sinjar
39	2017	Al-Dulaimi and Al-Dulaimi	Wara Milli	Reef / Shoal	Limestone	Sinjar	Sinjar
40	2018	Asaad and Balaky	Geli Zanta	Lagoon	Dolostone	Khurmala	Khurmala
41	2018	Karim *et al.*	Dara Rash	Lagoon	D. Limestone	Khurmala	Sinjar
42	2018	Karim *et al.*	Dari H Khidir Zawali	Lagoon Lagoon	D. Limestone D. Limestone	Khurmala Khurmala	Sinjar Sinjar
43	2019	Lawa and Mardan	Sulaimani area	Shoal / Ramp	Limestone	Sinjar	Sinjar
44	2019	Barzani and Al-Qayim	Gara Mt.	Lagoon	Dolostone	Khurmala	Khurmala
45	2020	Fattah *et al.*	Dohuk	Lagoon	Dolostone and D. Limestone	Khurmala	Khurmala
46	2020	Rashid *et al.*	Tq-5, Tq-7	Lagoon	Dolostone and D. Limestone	Khurmala / Sinjar	Khurmala / Sinjar
47	2020	Al-Hadeedy and Khalaf	Hijran	Lagoon	Limestone	Khurmala	Sinjar
48	2021	Hussein D.	Tq-4, Tq-5, Tq-6	Lagoon	Marly Limestone	Sinjar	Sinjar
49	2021	Al-Qayim and Barzani	Spindar Berkyat	Lagoon Lagoon	Dolostone Dolostone	Khurmala Khurmala	Khurmala Khurmala
50	2021	Al-Qayim and Barzani	BarBuhar	Reef Mound	Limestone	Sinjar	Sinjar
51	2022	Asaad *et al.*	Berat Mt.	Lagoon / Reef	D. Limestone	Khurmala	Sinjar

DISCUSSION

As seen from Table (1), there are more than a dozen localities, which had been miss-assigned to Khurmala Formation, and in fact, they should be considered as Sinjar Formation using the International Stratigraphic Rules. This misidentification in many cases driven by the influence of the lithofacies of a lagoonal depositional environment rather than the dominating lithologic type. The other possible reason is that some localities of the Sinjar Formation has being affected by a slight to moderate degree of dolomitization to produce dolomitic limestone rather than dolostone of the Khurmala Formation. This had mislead some authors to think that once these localities have some dolomite, they should be considered the Khurmala Formation. In both cases, the dominating lithology is still limestone, and according to the lithostratigraphic principles, they are considered as Sinjar Formation rather than Khurmala Formation. Most of the reassigned localities (misidentified) of the Khurmal Formation into Sinjar Formation belong to the lagoonal facies of the Sinjar Formation. These localities are distributed in different areas but mainly around the Sulamaniyah area. The other case does not exist where a section of the Khurmala Formation is misrecognized as Sinjar Formation. The reason is that the dolomite and dolostone are too striking character for the Khurmala Formation to be missed. In addition, the limited distribution of the typical Khurmala sections.

The newly assigned stratigraphy of the reviewed localities for both formations (Table 1) is mapped to show the regional stratigraphic distribution of both formations within the Zagros foreland basin (Figure 6). As seen from the map of Figure (6) the Khurmala Formation typical lithology occupies only a limited part of the original lagoonal limestone facies of the basin. At this area of the typical sequence of the Khurmal Formation where dolostone is the dominating lithology, the formation has a limited distribution within the basin of North-Northwest Iraq. This triangular-shaped area has corners passing near Amadia, Bekhme, and Khurmala Dome of the Kirkuk structure (Figure 6). Any carbonate units within the Kolosh Formation, beyond this area should be considered as Sinjar Formation even if it represents a lagoonal lithofacies.

As far as the restriction of intensive dolomitization in this limited area of the basin, its mechanism and origin are to be studied and discussed in another future research project.

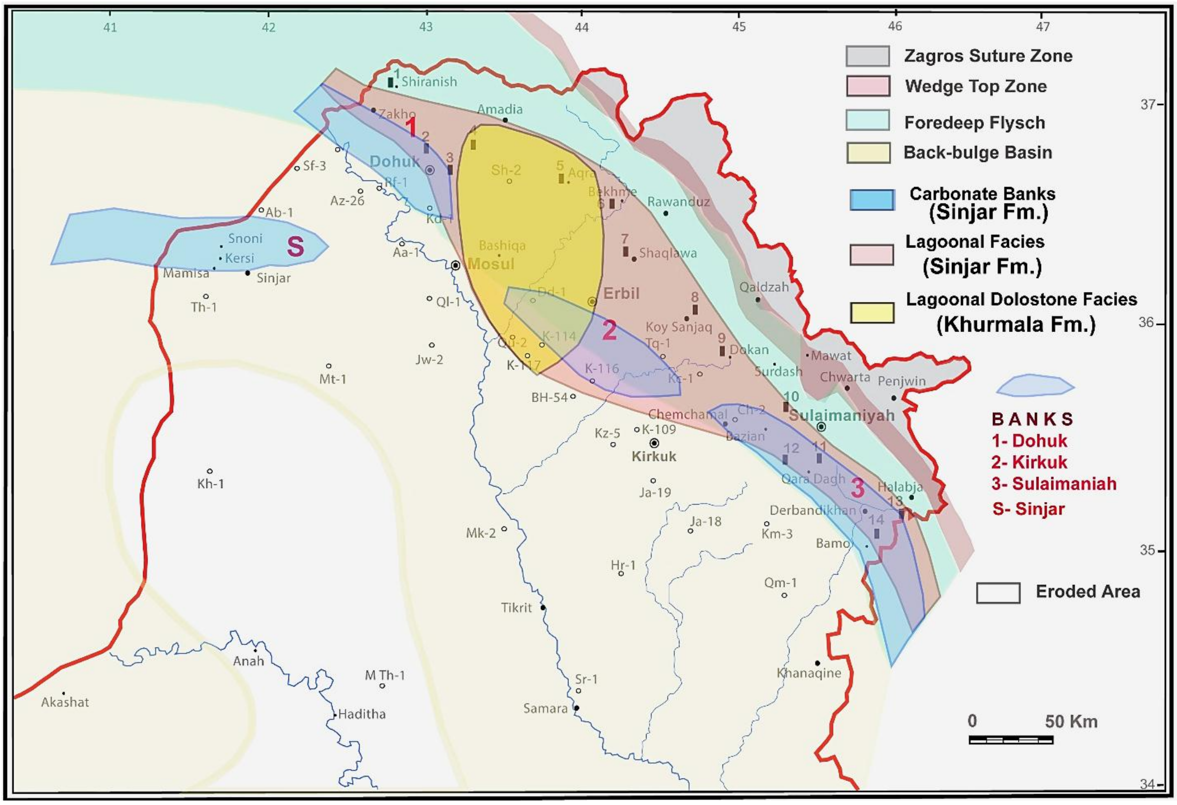

Figure 6: Stratigraphic distribution of Sinjar – Khurmala Formations of the Zagros foreland basin (From Al-Qayim, 2023).

CONCLUSIONS

- In recognition, identification, and differentiation between the formal lithostratigraphic units, we must adhere to the principles of the International Stratigraphic Guide, which emphasize the *"Main Lithology"* as a distinction tool. This is important especially in survey and geologic mapping, in addition to other research work.

- The application of these rules in the distinction between the Sinjar and Khurmala Formation, as a case study, reveals interesting results. The revision of the previous stratigraphic status of both formations in fifty localities shows that many localities with Khurmala Formation designation should be changed to Sinjar Formation. This modification made the distribution of the Khurmala Formation to be limited to an area of triangular shape with corners connecting the Amadya, Bekhme, and Kirkuk structure of N – NW Iraq.

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