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Occurrence and relationship of the Aqra, Bekhme and Govanda formations in the Soran (Rawanduz) area, Kurdistan Region, northeastern Iraq

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Abstract: The present study focuses on the presentation of field and laboratory evidences for the first record of the Aqra Formation (Maastrichtian) outcrop at the top of the Tanjero Formation in the Soran area, Erbil Governorate. The previous studies indicated its outcrops as Middle Miocene Govanda Formation between Merga Red Bed Series and Tanjero Formation. The present study discusses relations of this outcrop with Govanda and Bekhme formations in the Sulaimani and Duhok governorates in terms of environment and tectonics. In the Soran area, the formation has variable thickness ranging between 2-160 m and underlies either Red Bed Series or Govanda Formation (Middle Miocene). The study documented many stratigraphic and paleontological evidences to prove occurrence of the Aqra Formation in the area. Additionally, we discussed the significance of its occurrence in detail by which many tectonic and stratigraphic issues of the area are unlocked. One of the issues is occurrence of Tanjero Formation between the Aqra and Bekhme formations and it separates the two formations in two different age ranges and tectonic episodes. Another issue is the documentation of the occurrence of the Aqra Formation inside the Thrust Zone by which the distribution of the formation is extendable beyond Main Zagros Thrust Fault. The study includes a detailed stratigraphic column and tectonic model of the formation to show the coastal area, patchy reef, and shelf environment of the Aqra Formation.

Keywords: Aqra Formation, Bekhme Formation, Govanda Formation, Kometan Formation, Maastrichtian carbonate, Zagros Foreland Basin

INTRODUCTION

The present study focuses on the presentation of field and laboratory evidences for first record of Aqra Formation in the Soran area, at the top of the Tanjero Formation (Maastrichtian). The formation crops out directly at the south of Zagros Thrust Fault and is overlain by Red Bed Series and Govanda Formation (Middle Miocene). Sissakian (1997) considered its exposure as Govanda Formation on the geological maps of Iraq; therefore, brief descriptions of the two formations are necessary here.

The Govanda Formation (Middle Miocene)

According to Bellen *et al.* (1959), the formation was first described by Dunnington *et al*. in 1957. They added that its type locality lies on the northwestern slopes of the Govanda Plateau (Mesa) in the Imbricated Zone of northeastern Iraq at latitude 37° 07’ 58” N and longitude 44° 12’ 53” E in Erbil Governorate. They further added that the lithology of the type section, from the top to the bottom comprised of the below parts. The lowermost part is composed of 6 m of a polygenic basal conglomerate and passing upwards into conglomerates with pebbly sandstones and siltstones. These terrigenous clastics rested below 20 m of sandy and silty detrital limestones that contain abundant allochthonous Cretaceous fossils. The overlying 80-90 m (as the upper part and main body of the formation) consisted of limestones of reef-fore reef facies. Jassim *et al.* (2006) considered the Govanda Formation as the deposits of early Middle Miocene and has a thickness up to 150 m.

According to Buday (1980), the Govanda Formation belongs to shallow marine reef-fore-reef environment and is strongly affected by the supply of the nearby rising land, as testified by the presence of clastics not only at the bottom, as in the type locality, but sometimes intercalating with the limestones too. He added that its lower contact is unconformable and the formation transgressed on the Red Bed Series and its upper contact is not visible. In Penjween area, Jassim *et al.* (2006) stated that the thickness of the formation is about 100 m and it comprised of a basal conglomerate (containing chert pebbles derived from the Qulqula Radiolarian Formation), which passed upwards and laterally into fossil rich sandy limestone and capped by thick oyster-bearing limestone. They added that the formation overlies unconformably the Suwais Group, Tanjero Formation, and locally by the Qulqula

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Formation. Karim *et al.* (2018) studied the stratigraphy and facies analysis of the Govanda Formation in the Iraqi part of the Sanandaj-Sirjan Zone (at southern boundary of the Shalair Valley) and found many index fossils of Miocene. Additionally, they recorded an angular unconformity between Qulqula Radiolarian Formation at the base and Govanda Formation at the top. They added subjection of the Sanandaj-Sirjan Zone to an extension and not compression during Miocene as cited in some previous studies. Smail (2015) studied three sections of this formation between Mergasur and Ruste valleys while Abdula *et al.* (2018a) studied the section of the formation in Gali Baza in the Soran area.

Aqra Formation (Maastrichtian)

This formation is famous as a stratigraphic unit of Maastrichtian in the High and Imbricated zones of northern Iraq and according to Bellen *et al.* (1959) and Buday (1980), it consists of reefal limestone and contains many Maastrichtian index fossils such as *Loftusia*, *Omphalocyclus*, *Orbitoides*, rudists and *Actionella*. Karim & Surdashy (2006) and Karim *et al.* (2007) concluded that Aqra Formation, in Sulaimani Governorate, is grown either on conglomerate of Tanjero Formation or on its sandstone and underlies Red Bed Series in Chwarta, Mawat, and Raniya (Qandil) areas.

Geological setting of the studied area

The studied area is part of the Soran District in Erbil Governorate, Kurdistan Region, northeastern Iraq (Figure 1). The present newly mapped outcrops of the Aqra Formation elongate northwestward from the west of Galala village, on the Choman Stream, and passes through Guezan, Ser Kawa, Nawre villages and end at Chomani Smail Agha village at 9 km northwest of Soran town.

The sampled section is located directly to the east of the Guezan village in the Roste Valley at 2 km north of Dar Al-Salam village at the latitude and longitude of 36° 37’ 20.96” N, 44° 45’ 35.32” E. All the outcrops are located at the south of Main Zagros Thrust Fault between Thrust Zone and Imbricated Zone of Buday (1980) and Jassim & Buday (2006a).

METHOD OF THE STUDY

During fieldwork, we inspected several sections by naked eyes and using hand lenses X10 and X30 magnifications.

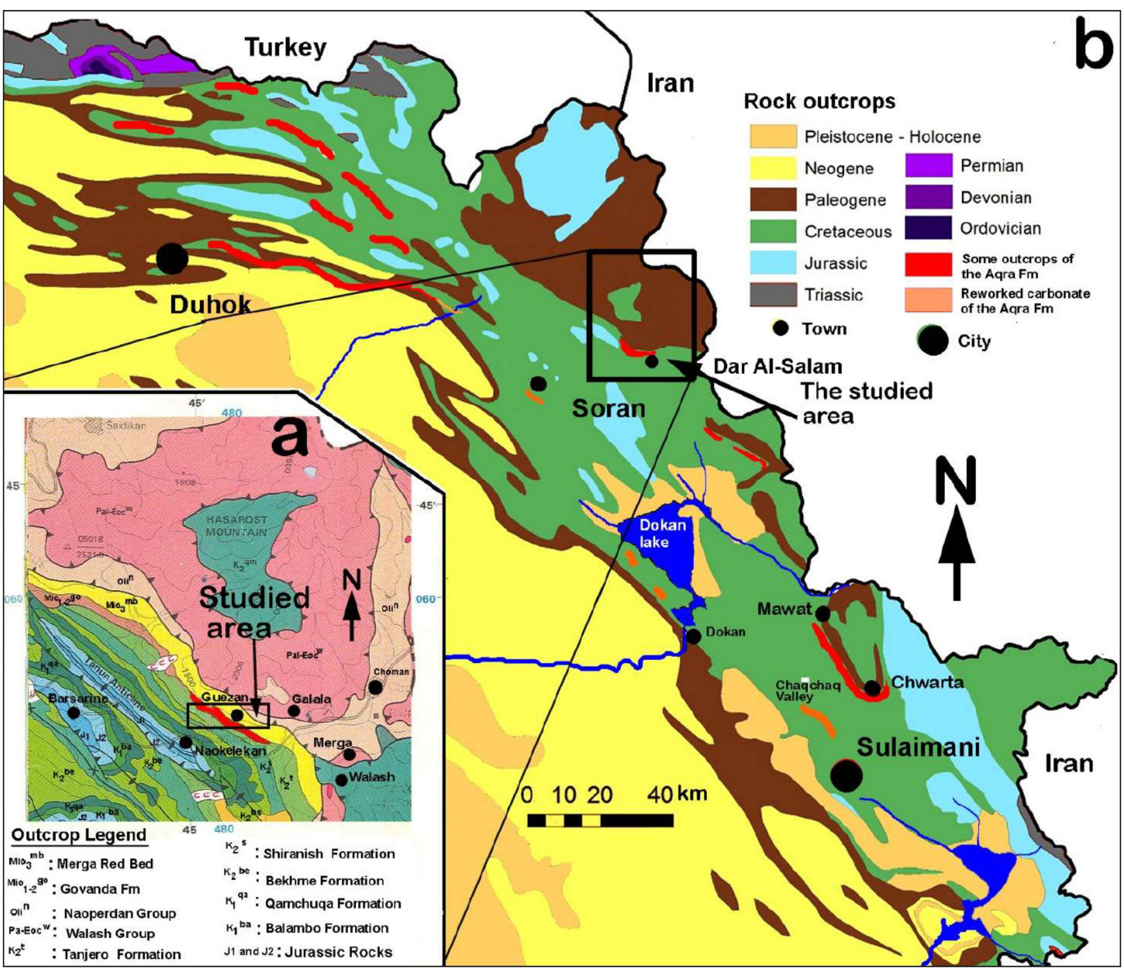

Figure 1: (a) Location; (b) Geological Map of the studied area (modified from Sissakian, 1997).

During this process, a suitable section was selected for sampling, a total of 20 samples were collected, and the same number of petrographic thin sections were prepared from the samples. The lower and upper boundaries and the whole thickness of the Aqra Formation were inspected for determination of the vertical lithological changes while the lateral changes were determined by tracing the aerial distribution of the formation for tens of kilometers by which the exposures were plotted on the geological map of the area (Figure 2).

We studied the thin sections under the stereomicroscope and polarizer microscope for determining if the outcrops belong to Aqra or Govanda formations. All the lithological, stratigraphical and paleontological evidences were photographed, defined and discussed for proving the affinity of the outcrops. The previous studies were critically examined and compared to the results of the present one.

RESULTS

The indicators of Aqra Formation occurrence in Soran area

Fossil indicators in the field

In the studied section in the Soran area (Figure 3), the Aqra Formation contains very well preserved Maastrichtian micro-and macrofossils such as *Omphalocyclus*, *Loftusia*, *Orbitoide*, rudists and *Actionella* (Figures 4 and 5).

These fossils occur in either high or low-density populations in the fine grain detrital limestone which are barren of terrigenous clastic sediments. Field inspection shows that these fossils are in life position since the top of most of them are facing upwards and preserved right-side up (see Mülayim *et al.*, 2020). Oysters and other pelecypods are well preserved, with many shells having both their valves intact. Most of the fossils are barren of abrasion and the delicate appendages of rudists are

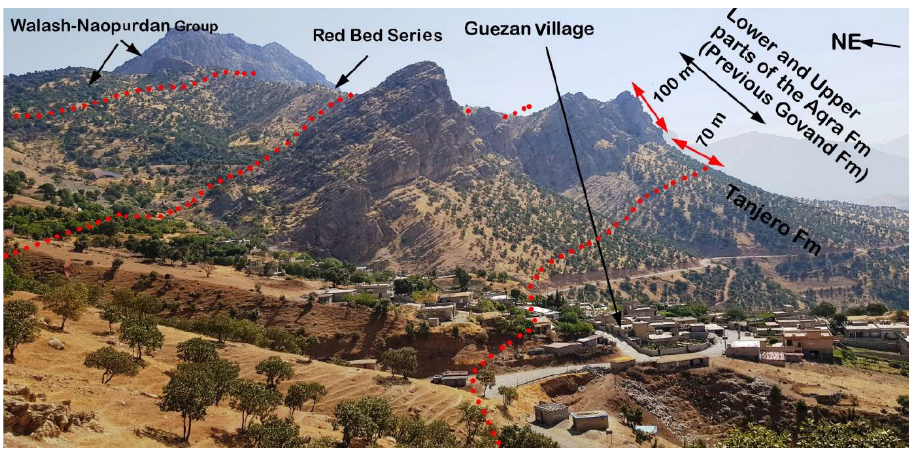

Figure 2: An outcrop of the Aqra Formation near Guezan village about 170 m thick.

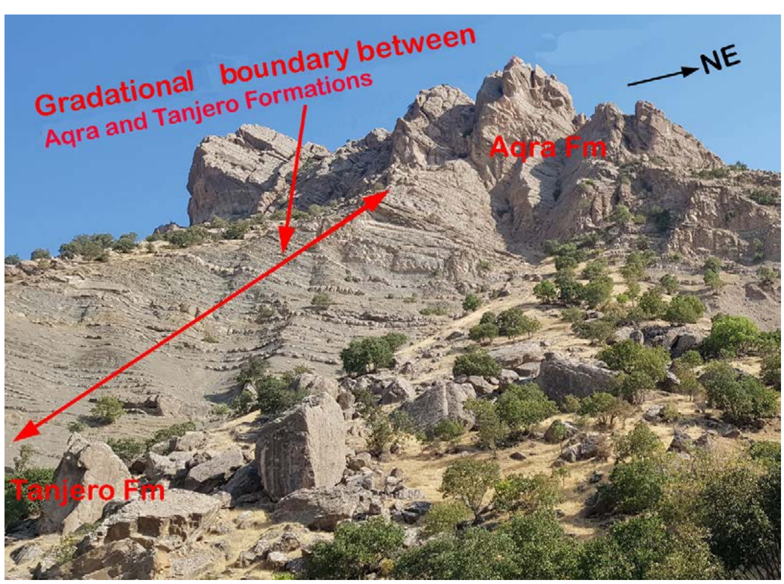

Figure 3: Gradational boundary between Tanjero and Aqra formations at 500 m east of Guezan village.

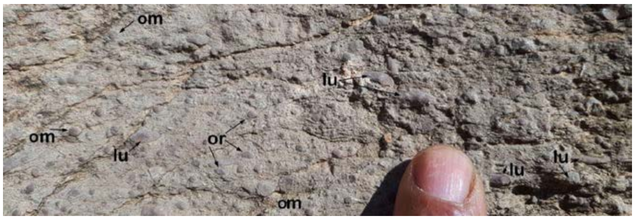

Figure 4: Different Maastrichtian fossils on surface of a hand specimen, *Omphalocyclus* (om), *Orbitoides* (or), *Loftusia* (lu), they are identified by hand lens and microscope.

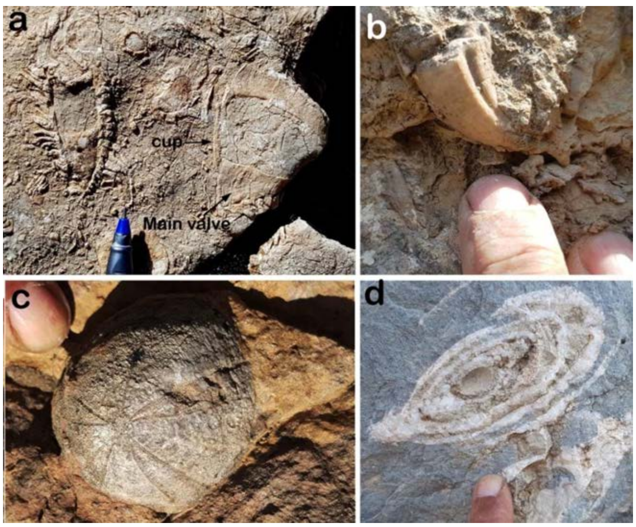

Figure 5: Different fossils in their life position, (a) rudists with their cups; (b) a rudist in right side up position; (c) an echinoderm; (d) cross section of *Actionella* (gastropod).

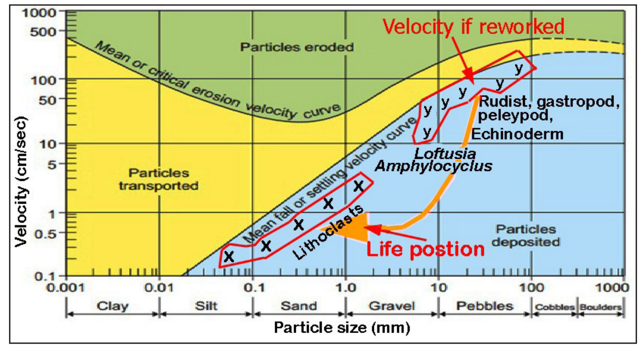

Figure 6: Plotting the large fossils and lithoclasts on the Hjulstrom (1935) curve for relation between sediments grains size deposition and water velocity. It shows reworking unfeasibility of the large fossils, coexisting with fine grain sediments without the association with same sized large lithoclasts.

well-kept (Figure 5a and 5c). The sizes of some rudists' shells reached 10 cm in diameter and are attached in life position to the substrate with both valves still attached together (Figure 5a). Therefore, these fossils do not show any signs of reworking since they are not associated with the same size of lithoclasts or terrigenous pebbles as shown on the curve of Hjulstrom (1935). In contrast, the Govanda index fossils of Miocene age such as *Borelis melo curdica* and *Borelis melo melo*, red algae and corals (Bellen *et al.*, 1959; Karim *et al.*, 2018) are absent in the studied section.

There is a 30-million-year gap between Maastrichtian Aqra Formation and Middle Miocene Govanda Formation; therefore, any reworked fossils of the former formation in the latter one occurred after 30 million years. This long geologic time is sufficient for total lithification of Aqra Formation and enough for converting to rigid and indurate rocks. Therefore, the Govanda fossils record must be associated with coarse lithoclasts in various sizes from sand to cobbles and bearing Maastrichtian fossils (Figure 6). Where these lithoclasts were not observed, the reworking is suspect, but the associations of different aged index fossils are distinct.

Macro and microfossils in thin sections

For supporting the result of the field works, we prepared twenty thin sections and studied them under a binocular microscope. The study determined many microfossils that belong to the *Orbitoides*, *Siderolites*, *Loftusia*, and *Omphalosyclus* (Figures 7 and 8). Other indicated fossils are: *Orbitoides* sp.; *Siderolites Calcitropoides* Lamarck; *Omphalocyclus macroporus* Lamarck; *Orbitoides apiculata* Schlumberger; *Orbitoides media*. Yet these fossils were identified too, Orbitoides *gruenbachensis* Papp; *Loftusia cf. minor*; *Loftusia harisoni* Cox; *Loftusia cf. morgana* and *Sulcoperculina dickersoni*. Besides, *Salpingoporella* sp.; *Sulcoperculina* sp.; *Textularia* sp. and *Cymopolia ellongata* Defrance are also present.

Most of these microfossils belong to the Campanian-Maastrichtian time, especially the Maastrichtian. *Loftusia harisoni* Cox, *Siderolites calcitropoides* Lamarck, and *Orbitoides apiculata* Schlumberger were identified by Abyat *et al.* (2014) in the Tarbur Formation (Maastrichtian interval) in southwest Iran. Abdelghany (2003) determined the species *Orbitoides apiculata*, *Omphalocyclus macroporus*, *Sulcoperculina dickersoni*, *Siderolites calcitropoides*, and *Orbitoides media* in the Simsima Formation (Late Campanian-Maastrichtian) from the northern Oman Mountains. Robles-Salcedo *et al.* (2013) discovered *Siderolites calcitropoides* and *Orbitoides gruenbachensis* in Upper Cretaceous siliciclastic carbonate (Northeastern Spain). Solak *et al.* (2017) found the species *Orbitoides apiculata*, *Siderolites calcitropoides*, and *Omphalocyclus macroporus* in the Central Taurides-Turkey and were assigned by Solak *et al.* (2017) to the Maastrichtian age. Based on the aforementioned, it is clear that the studied section belongs to the Aqra Formation based on the microfossils assemblage and the determined age.

Tectonic and geographic evidences

The geographic and tectonic locations of the Aqra Formation in the Chawrta-Mawat and Qandil areas aid the

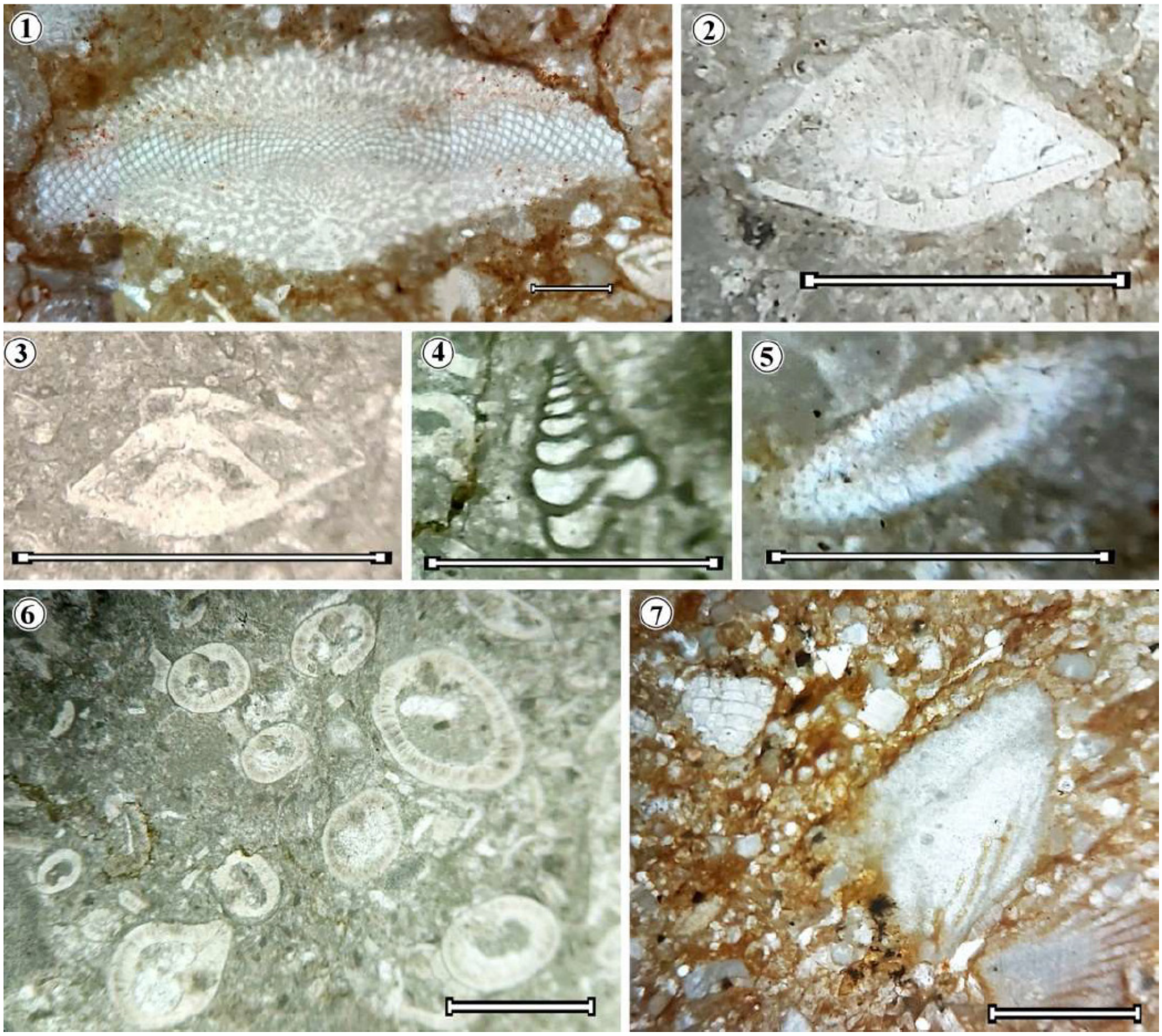

Figure 7: 1. *Orbitoides* sp.; 2. *Sulcoperculina dickersoni*, axial section (S. 11); 3. *Sulcoperculina* sp. (S. 22); 4. *Textularia* sp. (S. 7); 5. *Cymopolia ellongata* Defrance, oblique section (S. 20); 6. Packstone with shell and fragments of rudists (S. 7); 7. Detrital limestone (S. 15), the scale is 1 mm for all.

occurrence of Aqra Formation in Soran area since it occurs in similar tectonic, stratigraphic, and geographic locations of the two former areas. Karim (2004) studied the Aqra Formation in the Chawrta-Mawat and Qandil areas where it is located between the Tanjero Formation and the Red Bed Series. In all the above three areas, the Aqra Formation occurs as ridge dipping nearly 25-35 degrees northeast. All these areas are directly located to the south of both the Zagros Main Thrust Fault and Walash-Naopurdan Series (or Ophiolite in some places) (Figure 1). In the three areas, the Aqra Formation is overlain by the Red Bed Series (in Soran area it is called the Merga Red Bed). In all these areas, the geologists can trace the ridge in the field on Google Earth image from Chwarta to Soran areas passing by Mawat and Qandil areas (Figure 9). Along this ridge, the Aqra Formation has similar characteristics such as discontinuous occurrence since it disappears intermittently in some places and appears in others above Tanjero Formation. Where it disappears, either the Red Bed Series or Govanda Formation overlies the Tanjero Formation. An example of such an occurrence is very clear around Mawat town where it has a thickness of more than 50 m in its southeast while the formation disappears towards the southwest and west of the town and Red Bed Series occupies its stratigraphic position. The same occurrence is observable near Guezan village, 20 km northeast of Soran town where the formation is about 160 m thick in the east of the village while it reduces to 60 m at its eastern part and changes to 2 m near Chomani Smail Agha village (Figure 10).

Possible occurrence of the Aqra Formation inside the Iraqi Trust Zone (southwestern part of the Sanandaj-Sirjan Zone)

In the Soran area, the confirmed outcrops of Aqra Formation (as *in situ* and non-reworked depositions) has a length of 9 km from Dar Al-Salam to Chomani Smail

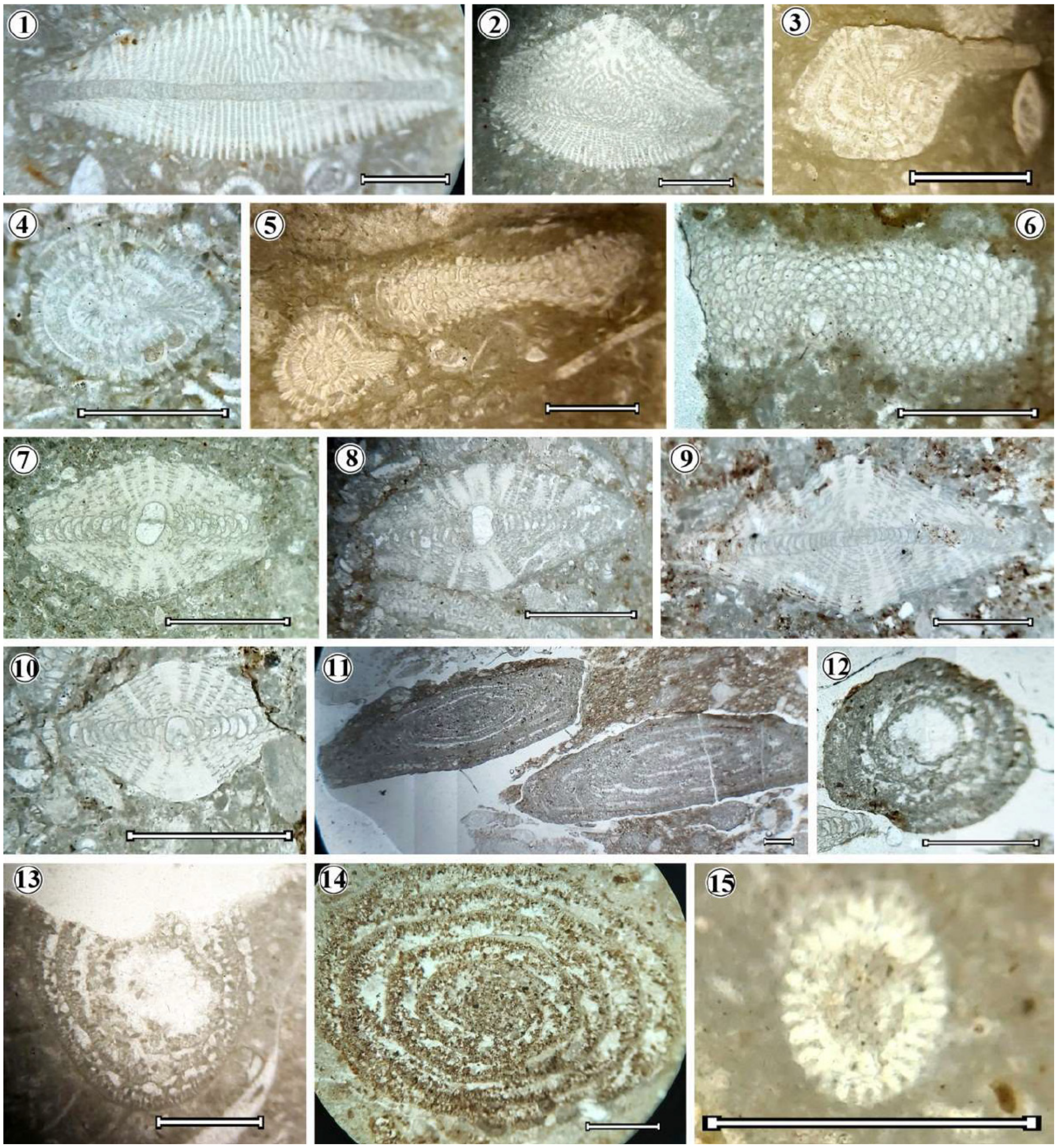

Figure 8: 1. *Orbitoides* sp. (S. 19, 20); 2. *Orbitoides gruenbachensis* Papp; sub axial section (S. 19); 3, 4. *Siderolites calcitropoides* Lamarck; axial sections (S. 20); 5. *Omphalocyclus macroporus* Lamarck; axial section (S. 17); 6. *Omphalocyclus macroporus* Lamarck; subequatorial section (S. 3); 7. *Orbitoides apiculata* (S. 6); 8. *Orbitoides media*; longitudinal section (S. 13); 9. *Orbitoides media*; sub axial section (S. 1); 10. *Orbitoides gruenbachensis* Papp; axial section (S. 11); 11. *Loftusia cf. minor*; axial section (S. 14); 12. *Loftusia harisoni* Cox; equatorial section (S. 13); 13. *Loftusia cf. minor*; sub axial section (16); 14. *Loftusia cf. morgani*; equatorial section (S. 2); 15. *Salpingoporella* sp. (S. 20). The scale is 1 mm for all.

Agha villages, but at 70 km to the northwest, Bellen *et al.* (1959) and Buday (1980) mentioned the occurrence of the reworking Maastrichtian fossils inside Middle Miocene Govanda Formation. These authors found reworked fossils at the lower part of the later formation on Govanda Mesa (Plateau) on the Iraq-Turkey border in front of Main Zagros Thrust Fault (Figure 11). Although, the present author thinks that the lower part of the Govanda Formation belongs to Aqra Formation similar to the section of Chomani Smail Agha (Figure 10) nevertheless, the occurrence of reworked fossils indicated that Aqra Formation was deposited beyond the Main Zagros Thrust Fault inside the Thrust Zone (inside Sanandaj-Sirjan Zone). Therefore, the spatial distribution along both paleo-dip and strike was more extensive than that previously considered. The reworked fossils of the Aqra Formation are common in the upper part of Tanjero Formation in Dokan area, Chaqchaq Valley (northwest of Sulaimani City). In these areas, the reworked fossils and carbonate lithoclasts of Aqra Formation were deposited in a deep basin by turbidity currents forming limestone turbidites inside pelagic marls. The transportation of the limestone was more than 20 km by submarine mass wasting from the

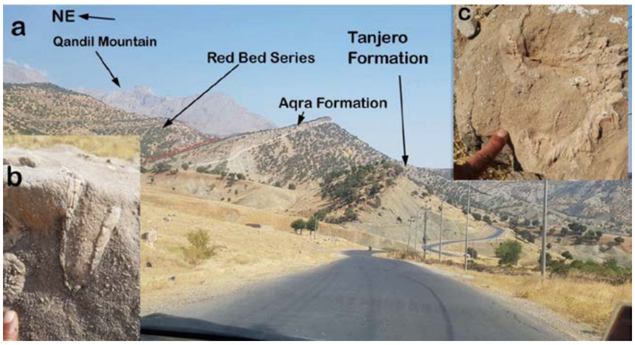

Figure 9: (a) Stratigraphy of the Aqra Formation in the Qandil Mountain toe; (b) and (c) Rudist shells in their life position.

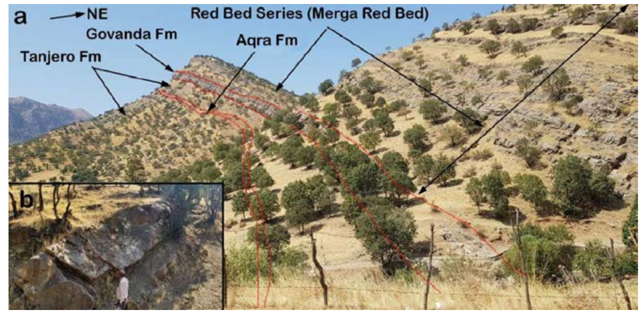

Figure 10: (a) Stratigraphy of the Govanda and Aqra formations in the Chomani Smail Agha Gorge; (b) Aqra Formation is about 2 m thick and located inside Tanjero Formation in the above gorge.

neritic environment in the Chwarta-Mawat area to a deep environment at the present position.

Environments of the Aqra Formation

The Aqra Formation is a shallow water deposit in two different environmental settings. The first is an attached platform as a barrier reef on which the formation was deposited in the Duhok area. The second setting is a patch reef (as bioherms and biostroms) in the coastal areas where the low clastic influx did not prevent biogenic carbonate deposition. This latter setting was prevalent in the Chwarta, Mawat, Qandil and Soran areas where the outcrops of the formation occur now and studied in the present work. The second setting was in a high-energy environment with active tectonism since the formation was deposited in a recently developed foreland basin after obduction of radiolarites and metamorphosed greywackes (volcanic detritus). Therefore, erosion and reworking prevailed in the patch reef settings, but most of these processes were intraformational since no gravels-boulders sized detrital clasts of Aqra Formation, cross bedding, and erosional surfaces were recorded in the present and previous studies.

Many previous studies mentioned reworked fossils of Aqra Formation in other formations such as inside the Govanda Formation (Bellen *et al.*, 1959; Buday, 1980; Jassim *et al.*, 2006; and Smail, 2015). In the studied area, only one locality with reworked fossiliferous sediments was observed below the Red Bed Series (or Merga Red Bed) 500 m northeast of Guezan village. At this locality, the reworked sediment consists of a layer of limestone conglomerate about 1 m thick exposed at the top of the Aqra Formation and comprised of pebbles and boulders of Aqra Formation containing Maastrichtian fossils e.g., *Omphalocyclus* and *Orbitoids*. At this locality, the upper part of the latter formation was completely eroded and replaced by the above-mentioned conglomerate bed. This reworking is not the only one since in Dokan area, Chaqchaq Valley (northeast of Sulaimani City), and Bestana village (west of Kani Watman Restaurant) reworked sediments of the Aqra Formation is common in the upper part of the Tanjero Formation which contain shells of *Omphalocyclus*, *Loftusia* and *Orbitoids* with their bioclasts (see Karim, 2004 and Karim *et al.*, 2015).

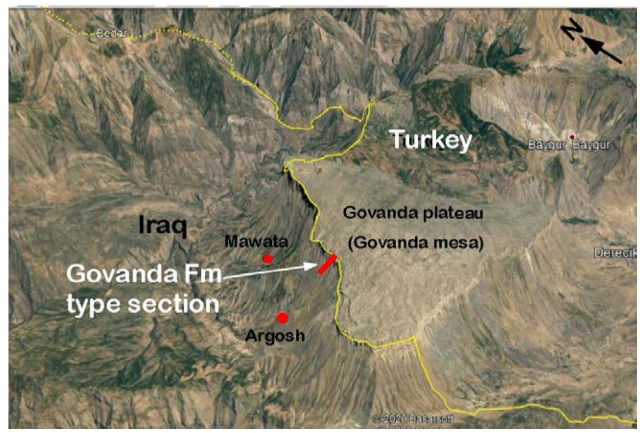

Figure 11: Type locality of the Govanda Formation across edge of the Govanda Mesa (Platuea) on the Iraq-Turkey border.

DISCUSSION

The presence of outcrops or reworked fossils of Aqra Formation in the Soran area above or in the upper part of Tanjero Formation and inside the Govanda Formation are significant stratigraphically. This may put an end to contradicting ideas (disagreements) about the age and tectonics of the Bekhme Formation which was either considered as an equivalent of the Aqra Formation (Late Campanian-Maastrichtian) or Kometan Formation (Turonian-Middle Campanian). In this context, the former age confirmed by Bellen *et al.* (1959), Buday (1980), Al-Qayim (1989), Jassim & Buday (2006b), Al-Mutwali *et al.* (2008), Al-Mutwali & Al-Haidary (2012), Abdallah & Al-Dulaimi (2019) who combined or considered same age of the two formations. These studies further considered the Bekhme Formation as a deposition of the Zagros Foreland Basin after the collision of the Arabian and Iranian plates. In contrast to this, Karim & Ameen (2008), Karim *et al.* (2012), Karim (2013) and Karim *et al.* (2018) concluded another age, which is Turonian-Middle Campanian for the Bekhme Formation and they put the latter formation in the

Neo-Tethys Ocean before foreland basin generation. They mentioned that the formation was not deposited in the basinal setting of the Neo-Tethys, but they indicated it as on its periphery (Northeastern Arabian Platform Margin). These latter studies proved that the Bekhme Formation is spatially and chronologically equivalent to the Kometan Formation since the two formations occupied the shallow and deep physiographic parts of the same basin (Figure 12). Their proof depended on the lateral tracing of the Kometan Formation, from its outcrops in the Sulaimani Governorate, to those of the Bekhme Formation in the Erbil area where the type locality of the Bekhme Formation occurs. With this tracing, they listed many other evidences for their age assignment and lateral combing of the two formations.

Reasons for assigning Turonian-Middle Campanian age for Bekhme Formation

The end of the controversy is in favor of a Turonian-Middle Campanian age for the Bekhme Formation and its equivalent Kometan Formation. According to the latter age, the Bekhme Formation is separable from Aqra, Tanjero and Shiranish formations both spatially and temporally. The four formations cropped out in the Soran area (see Sissakian, 1997; Abdula *et al.*, 2018b) and their separation is due to exposure in different stratigraphic positions. Thick succession of Tanjero and Shiranish formations (more than 500 m thick) separated the Aqra from Bekhme Formation in the Soran area where they have the age of Maastrichtian and Turonian-Middle Campanian as seen from Figure 13. In this figure the Aqra and Bekhme formations are located at the top and base of the succession and the Shiranish and Tanjero formations (in Sulaimani area) are correlated (combined laterally) to Aqra Formation in the Erbil and Duhok areas. This combination is observable in the paleogeographic and tectonic model (Figure 14).

Another reason for equivalency of the Bekhme Formation to the Kometan Formation is the similarity of its stratigraphic position to that of the Kometan Formation between the Shiranish and Qamchuqa formations. Another reason is the conclusion of Karim (2013) who found the absence of Upper Campanian index fossils in the Bekhme Formation. He believed that the sections studied in previous studies that contained index fossils of the latter age do not belong to Bekhme Formation but are related to either the Shiranish or Aqra Formation. After field checking, the present study confirms the belief of the author since the index fossils of Late Campanian are not observable in the proper Bekhme Formation, especially in its type section.

The only uncertainty of the relation between the Aqra and Bekhme formations occur in the Duhok area where the two formations are in contact with each other in vertical profiles in which the former formation is overlying the latter one. However, Karim (2013) and Karim (2016) explained in detail this stratigraphic relationship by joining the deep and shallow basin Cretaceous and Tertiary formations in one model (Figure 12). In that model, the Tanjero and Shiranish formations change laterally into the upper and lower parts of the Aqra Formation while the Kometan Formation into the Bekhme Formation on the shelf during Turonian-Middle Campanian (Figures 12 and 14).

Model of deposition of the Aqra Formation

The collision of the Arabian and Iranian plates during the Campanian resulted in the uplift of the radiolarites, limestone and metamorphosed volcanic detritus and development of a terrestrial land (foreland) which was a locus of the present Zagros belt. In front of the recently uplifted land, a foreland basin was generated and subsided, in which the Aqra Formation was deposited in two different environmental settings. The first one is a high-energy coastal area (zone)

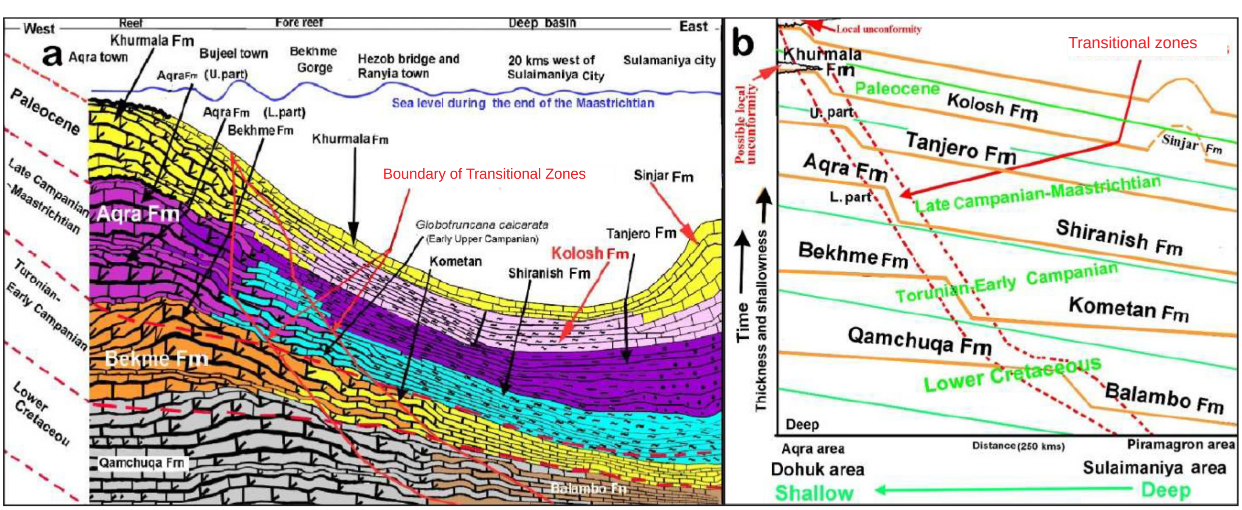

Figure 12: Lateral facies change of the Late Cretaceous-Early Tertiary carbonate of the Iraqi Zagros from deep marine sediments in the southeast to reefal limestone in northwest Iraq (Duhok area) (Karim, 2016).

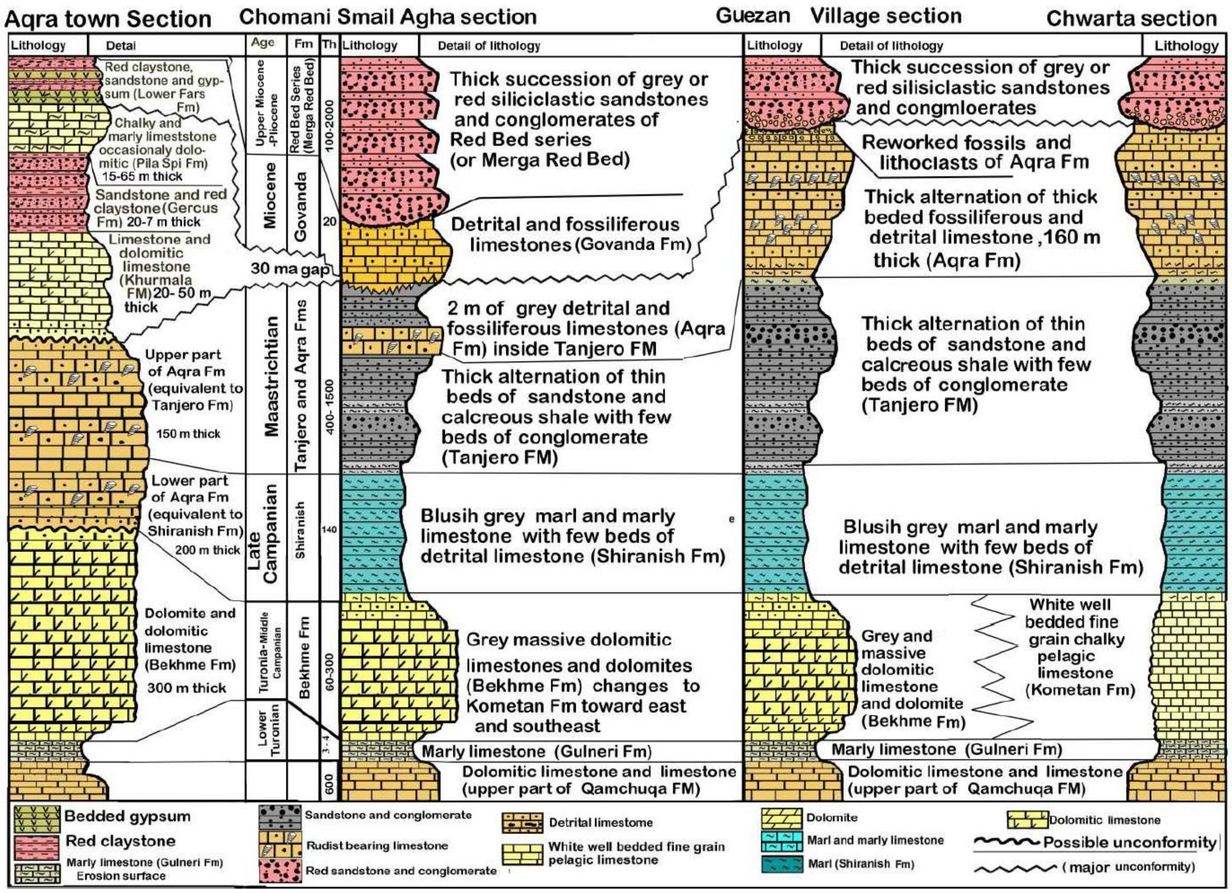

Figure 13: Correlation of four stratigraphic columns of the northern Iraq directly to south of main Thrust Zone shows stratigraphic positions of the Red Bed Series, Aqra, Govanda, Bekhme, and Kometan formations.

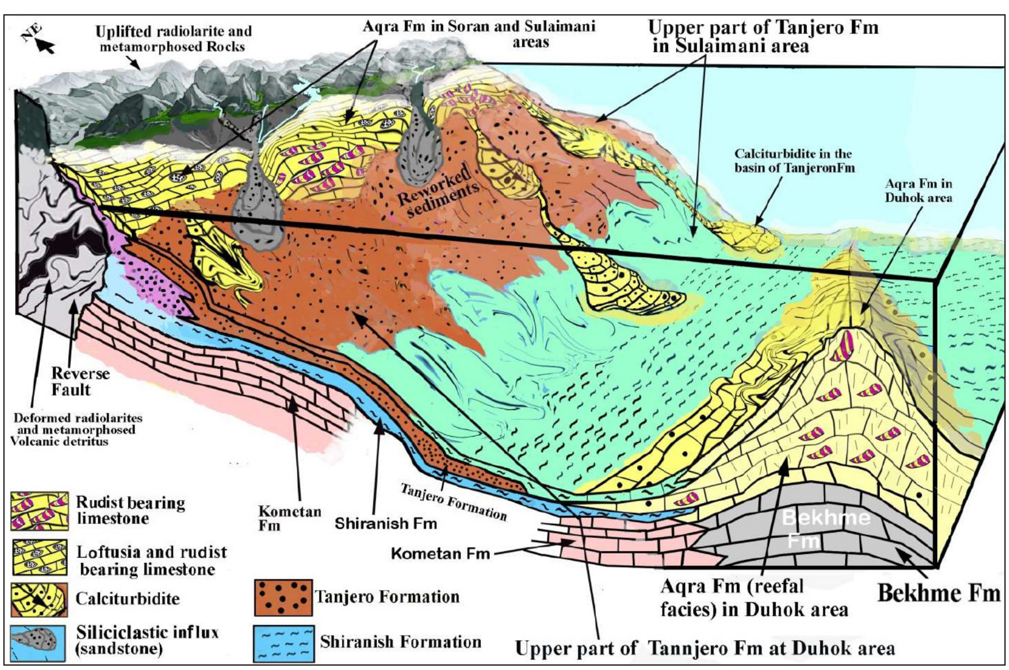

Figure 14: Tectonic and physiographic model of the Late Campanian-Maastrichtian showing location of the Aqra, Bekhme, and Tanjero formations. The lateral gradation of Tanjero and Shiranish to the Aqra Formation is clear while Kometan changes laterally to Bekhme Formation toward southwest.

of the foreland basin where the Aqra Formation survived as a patch reef in association with siliciclastic sediments as shoal carbonates in the form of biostromes and fringing reefs (Figure 14).

This type of occurrence is common in the Soran (present studied area) and Sulaimani areas, which was highly energic (as a part of Maastrichtian basin) and close to the source area. The source area supplied nutrients and detrital carbonates for blooming of large agglutinated foraminiferas and thick-shelled rudists. The second setting was a reefal limestone developed on the submarine high topographies inside the foreland basin far from the coastal areas and source area (Figure 14). This type of setting is very clear in the Duhok area where Bellen *et al.* (1959) first indicated the type section of the Aqra and Bekhme formations and defined them. In this area, the reefal setting gradually changed to a basinal setting toward the southeast (Sulaimani area) where they changed laterally to deep-water turbidite sediments of the Tanjero and Shiranish formations (Figures 12, 13, and 14).

CONCLUSION

1. Outcrops of the Aqra Formation are documented for the first time at the top of Tanjero Formation in the Soran area in this study.

2. The relationship of this outcrop with other outcrops in the Sulaimani and Duhok governorates are discussed in terms of environment and tectonics.

3. The study documented many stratigraphic and paleontological evidences to prove the occurrence of the Aqra Formation in the area.

4. The study discussed in detail significance of these new outcrops by which many tectonic and stratigraphic issues of the area are unlocked.

5. The problem of the spatial and temporal relationship between the Aqra and Bekhme formations is discussed and the two formations are separated and put into two different age and tectonic episodes.

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AUTHOR CONTRIBUTIONS

KHK and HD considered together the idea of the article and prepared thin section samples, photos, and maps, in addition to the identification of fossils and lithoclasts. They participated partly in the discussion chapter. RAA and AOS took the lead in writing the manuscript and participated in the interpretation and discussion of the result of the article with several phases.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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