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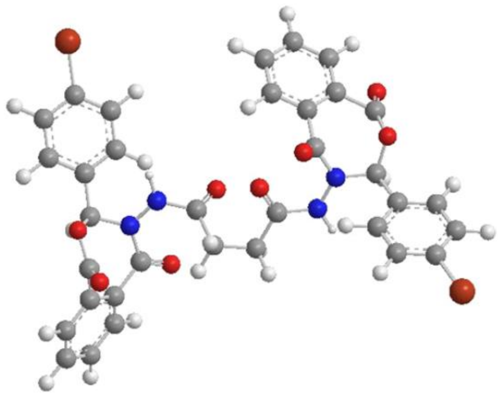

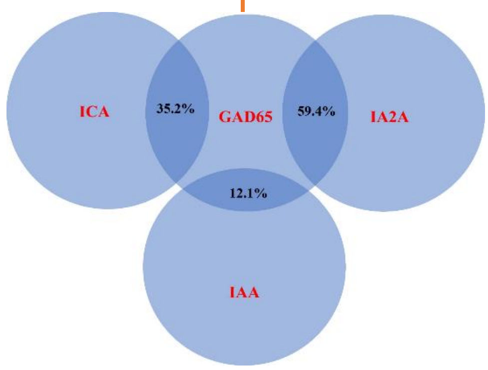

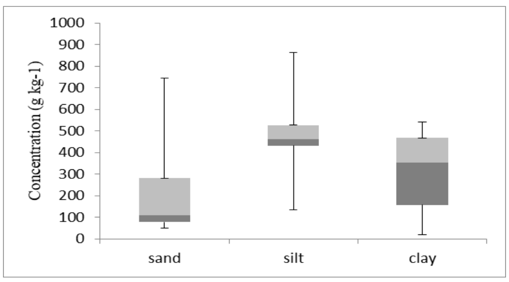

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Microfacies analysis and Depositional Basin Model of the Upper Cretaceous, Kurdistan Region, Northern Iraq

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Abstract

This study focuses on the Upper Cretaceous system in the Zagros fold and thrust belt in the Kurdistan Region / Iraq. The impression of this study is created by the variety of formations, facies change, and age of the Cretaceous formations, as well as the different consequences of the contact situation between the formations, particularly the Qamchuqa-Bekhme and Kometan-Shiranish contacts formations. Through investigation, evaluation, and combination of results from Lithostratigraphy and Microfacies of seven sections in various locations of KRI/ Iraq, new paleogeography of the Late Cretaceous of Northern Iraq is constrained. The microfacies of entire Late Cretaceous formations in different sections outcome 16 sub-microfacies types demonstrating open marine deep shelf environment of Shiranish Formation, the entire reef (back-reef, fore-reef, reef body) environment of Bekhme Formation and pelagic open marine ramp depositional environment of Kometan Formation.

The output results of stratigraphy and microfacies of Late Cretaceous depositional successions in the Kurdistan Region are paleogeography maps reconstruction. During the Turonian to Early Santonian periods, the Kurdistan Region and northern Iraq were pre-subduction basins due to the presence of open marine outer ramp carbonate of the Kometan Formation in the east (Sulaimaniyah province exceeding Hizop area) and inner shelf of Tanuma and Khasib formations in the center and west (Erbil province). Major regression and unconformities covered the West of the study region during the Middle-Late Santonian; the result of this regression degraded the entire inner shelf facies that deposited during Turonian-Early Santonian periods. During the Early-Middle Campanian, a foreland basin emerged in the extreme northeastern and the Kurdistan Region, which was covered by open marine of the Shiranish Formation and reef platform of the Bekhme Formation. The Kurdistan Region was an active foreland basin margin in the Upper Campanian-Maastrichtian, with a greatly expanded Tanjero Formation, an Aqra reef in the north, and an open marine Shiranish Formation in the center and west.

Introduction

The study area is located in the extreme northeastern Part of the Arabian Plate, in the Kurdistan Region of Iraq (KRI) (Figure 1). The Upper Cretaceous outcrops cover most parts of northeastern KRI (Ahmed et al., 2016). The succession of the Upper Cretaceous is different in the east and north of the KRI. 7 sections were selected in the Sulaimaniyah and Erbil governorates for this study (Figure 1). The Qamchuqa, Kometan, Shiranish, and Tanjero formations are exposed in the selected section at Dokan area, while toward the Shakrok area the succession changes to Qamchuqa, Bekhme, and Aqra formations (Bellen *et al*., 1959; Buday, 1980). Numerous researches on the Late Cretaceous successions in KRI have been published, however the lateral facies alterations, formation age, and contact nature are all lacking, and this study will examine all of these data. Moreover, the basin evolution during Late Cretaceous.

The Arabian platform during the Early Cretaceous was involved in the thick succession of dolomite and limestone, this succession covers most of Iraq (Jassim and Goff, 2006, Aqrawi et al., 2010). In the Bekhme area the reefal massive limestones 300-350 m thick of the Bekhme Formation (L. Campanian - E. Maastrichtian) overlies Qamchuqa Formation and the contact is an erosional nonconformity, without major angular discordance, but with polygenetic conglomerate at the base of the Bekhme Formation and extensive dolomitization below (Bellen et al., 1959). At Bekhme Gorge during Late Campanian the depositional environment was relatively shallower than other areas the Shiranish Formation deposited, the Bekhme Formation deposited Early to Late Campanian and conformably overlies by Late Campanian Shiranish Formation and Bekhme Formation is equivalent to Early Campanian Part of Shiranish Formation at in known areas Dokan, Rania and Azmar (Ahmed et al., 2016).

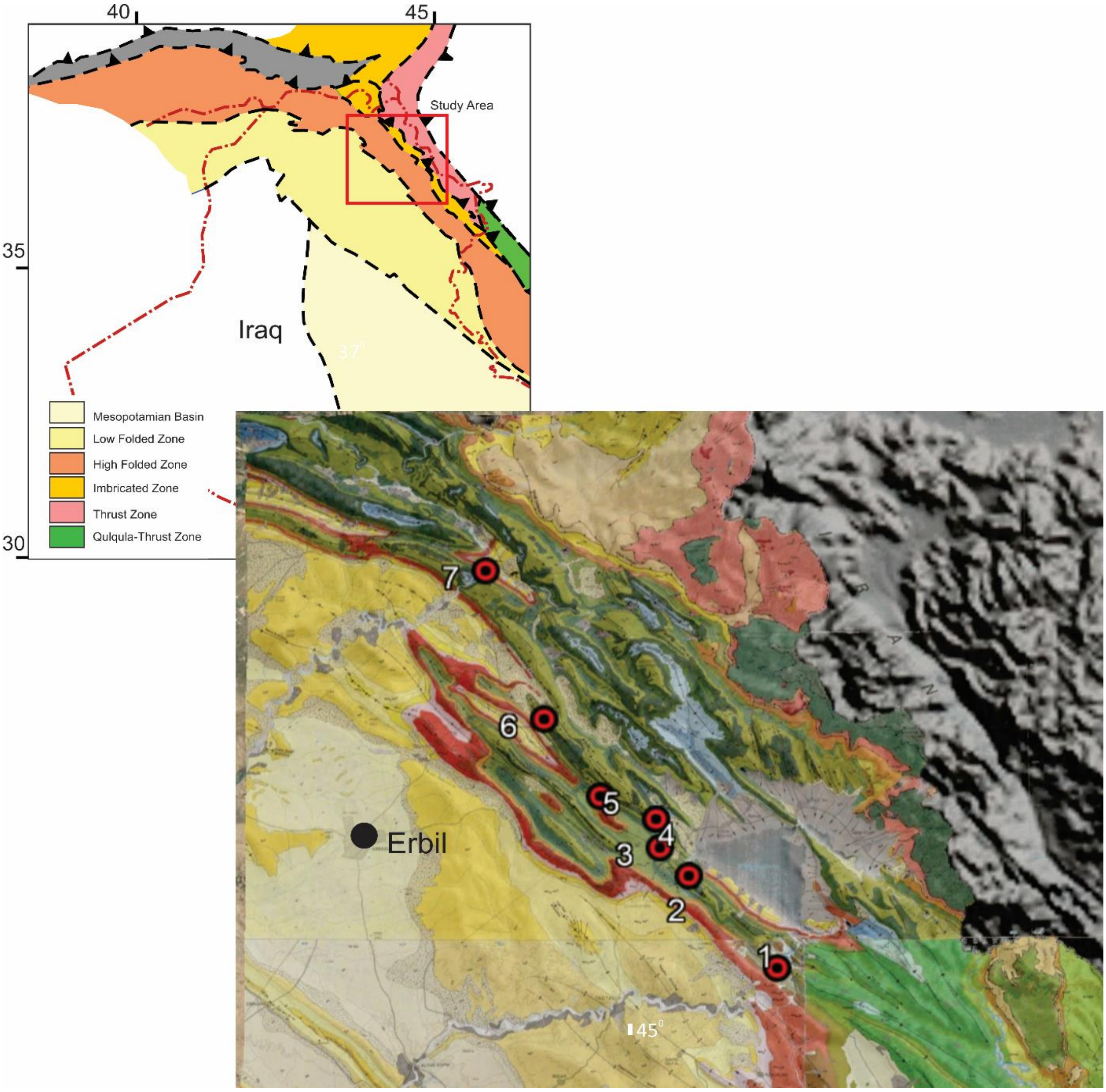

Figure 1: Tectonic sub-division of NW of Zagros Fold and Thrust belt in Kurdistan Region-Iraq (modify from Aqrawi et al., 2010; Jassim and Goff, 2006). The location map shows the area of a review study. The left map is a geological map of KRI from Sissakian 1997. The green color in the Geological map represents the Cretaceous formations. The 1: Dokan, 2: Badawan, 3: Hizop, 4: Kodara, 5: Kuna Flusa, 6: Garawanani Khwaru and 7: Bekhme

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However, in the Dokan area, pelagic limestone of the Kometan Formation was deposited during Turonian and overlies Qamchuqa Formation (Taha, 2022). In the Dokan area, the upper contact of the Kometan Formation is with the overlying deep marine Shiranish Formation is considered an unconformable boundary and indicated by the presence of a glauconitic pebbly sandstone bed of about 0.5 m at the base of the Shiranish Formation (Al Mutwali and AL-Haidary, 2012; Lawa, 2018; AL-Wazan 2007).

Geological Setting and tectonic subdivisions of the Kurdistan

Zagros fold and thrust belt is a longitudinal belt path through Iran, Iraq, and Turkey as a result of the Eurasia-Arabia collision (Aqrawi *et al.*, 2010). The main trend of this belt in Kurdistan is NW-SE (Ahmed, 2013). Tectonic Features and subdivisions of the Kurdistan region are Low Folded Zone, High Folded Zone, Imbricated Zone and Thrust zone. The Cretaceous outcrop successions appear in the High Folded Zone. The upper limit of the High folded zone starts in the Zakho area at the Turkish border in the northwest and the lower limit is in the Darbendikhan-Halabja area near the Iranian border in the southeast (Figure 1). The High folded zone is characterized by large and high anticlines cored by Mesozoic formations. It was uplifted during part of the Paleogene. The main folds trend in High Folded Zone NW-SE in the eastern part of the range, and E-W in the western part.

During the Aptian-Cenomanian period, the Qamchuqa Platform was a shallow carbonate sequence deposited in Kurdistan (Buday, 1980). In the High Folded Zone, the Bekhme Formation was deposited on a carbonate platform developed on the Qamchuqa ridge (Jassim and Goff, 2006). The Late Campanian–Late Maastrichtian stratigraphic column is represented by the succession comprised of the Shiranish Formation, Tanjero, and Aqra formations in Maastrichtian (Lawa, 2018). The Cretaceous sequence in the studied region is around 2,000 m thick and is part of the 8 and 9 Tectonic Megasequences (AP. 8 and 9) (Sharland et al. 2001; Aqrawi *et al.*, 2010). The pelagic limestone of the Kometan Formation and the marly limestones and marlstones of the Shiranish Formation are two marine-deposited formations in the Upper Cretaceous of NE Iraq (Taha, 2008).

The late Cretaceous in Kurdistan can be divided into three phases: (1) pre-drowning (Qamchuqa Formation), (2) syn-drowning or transitional (Gulneri Shale and Dokan limestone formations), and (3) post-drowning phases (Turonian-Maastrichtian) (Taha, 2008). In the Aptian-Albian the area was a part of the Passive margin of the Arabian Plate (Aqrawi et al, 2010, Ahmed et al. 2016). Slightly the effect of the Arabian-Eurasian Subduction appears during Cenomanian-Turonian. In the Campanian-Maastrichtian time in response to the obduction on the northeastern Arabian Plate the passive margin totally ended and the Kurdistan foreland basin developed (Figure-2 A and B).

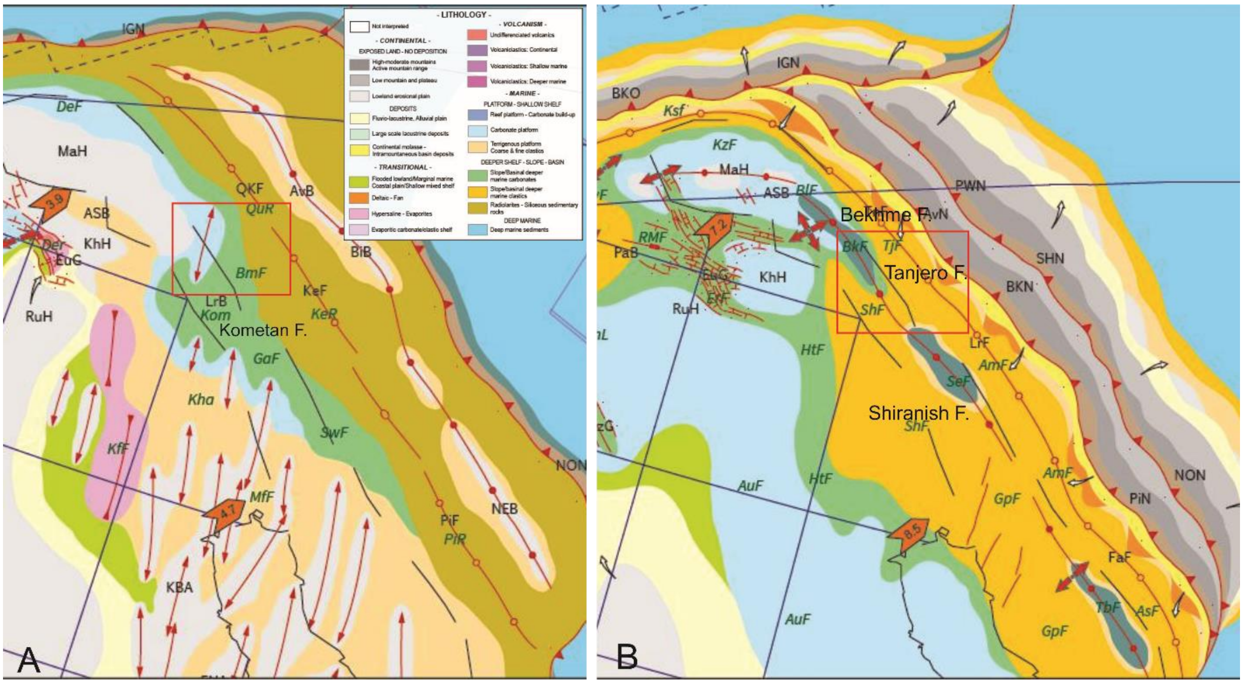

Figure 2: Schematic Paleotectonic map of the northeastern Arabian plate and western Neo-Tethys during A- Turonian, B- Campanian (Barrier et al., 2018). The red rectangular represents the study area.

Materials and Methods

For understanding the depositional basin and lateral facies change, seven sections have been selected (1: Dokan, 2: Badawan, 3: Hizop, 4: Kodara, 5: Kuna Flusa, 6: Garawanani Khwaru and 7:Bekhme,) for lithological description and collecting samples more than 30 field trips have been done for studying the lithostratigraphy and collecting samples. About 100 samples were collected from different formations from studied sections for microfacies study.

Results and Discussion

Stratigraphy of the studied sections

In the studied area, we selected 7 places to better understand the lateral facies change and depositional basin (Figure 1) to study the stratigraphic succession and 6 detailed cross-sections. Each location comprises of detail stratigraphic section to correlate and construct the basin model of the KRI area during the Late Cretaceous. The sections are:

Stratigraphy of Late Cretaceous in the Dokan and Hizop area:

The selected Dokan section is located about 2.5 km to the NW of Dukan city at the western limb of the Kosrat anticline that belongs to the High Folded Thrust Zone (Figure1). In this section the dark brown massive dolomites of Albian-Aptian Qamchuqa Formation is directly overlain by white-weathering Kometan Formation, The Dokan and Gulneri are absent in the selected Dokan section. The Kometan Formation has thicknesses of approximately 120m in this section, which is composed of well-bedded, light grey or white limestone with common chert nodules and stylolitic bedding planes (Figure 3). Glauconitic layers (0.5 m thick) possibly representing Coniacian-Santonian unconformities (Ahmed et al., 2015, Bellen, 1959) or represent only Early Campanian unconformity (Abawi et al., 2006; Jassim and Goff, 2006; Haddad and Amin, 2007; Jaff et al., 2015; Al-Sheikhly et al., 1989; Jassim et al., 1989; Malak et al., 2021) (Figure 3) overlay the Kometan Formation. Campanian deposits of the Shiranish Formation in this section are composed of 70 m of Marly Limestone light brown in color, highly fractured, and interbedded with dark grey shale, which is overlain by the Tanjero Formation (Fig.3). In the Badawan Section (Figure 1), the oldest outcrops belong to the Kometan Formation (Figure 3). In this area, the lithology of the Kometan Formation is well-bedded fine grain open marine limestone of Kometan Formation (Figure 3) and the rhythmic marl and marly limestone sequence of the Shiranish Formation (Figure 3). Through widely field investigation no any Glauconitic layers found between them. In Hizop Section the Kometan changes from bottom to up the lower 6.16 m is thinly bedded of milky to light grey limestone tough, rich in iron oxide with stylolite bedding plane (20-50 cm bed thickness) with increasing iron oxide nodules upward and light color, 5m Thinly bedded of milky to light grey limestone tough, rich in iron oxide with stylolite bedding plane and contain Ammonite with Bitumen, 2.8 m thinly beds of Stylolitic light grey hard Marly Limestone, 6.4 m of Thinly bedded, light grey to brown Limestone interbedded with thinly beds of shale (3 cm) at upper part of Light grey to pale blue Limestone with thinly beds of shale rich in iron oxide that represent the proposed last bed of Kometan Formation and the contact with overlying Shiranish Formation (Figure 3).

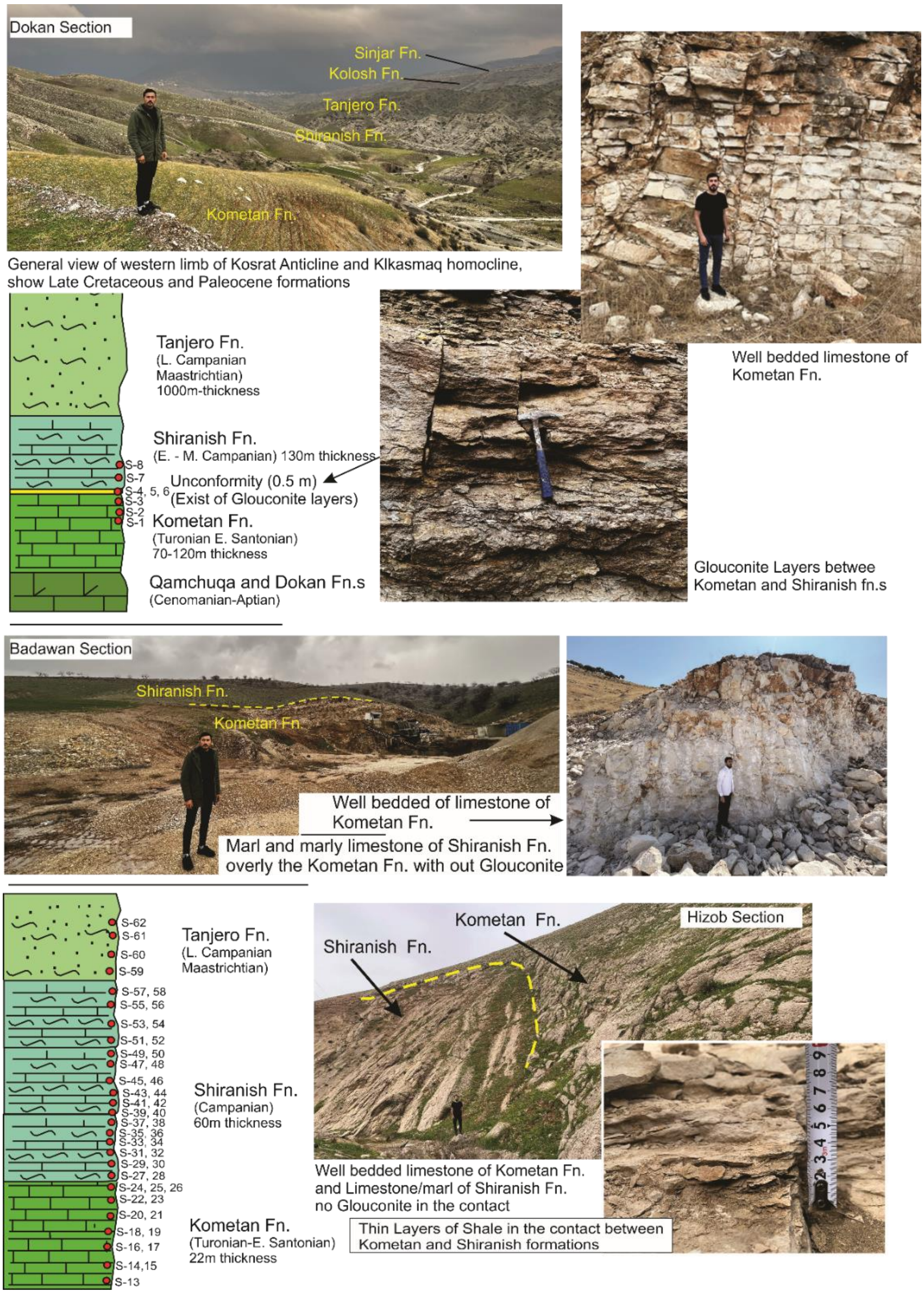

Figure 3: Stratigraphic column of Late Cretaceous in Dokan, Badawan and Hizop areas. Show the major unconformity between Kometan and Shiranish formations. The photos show the outcrops of the formations.

The Shiranish Formation at this section is about 60 m of marl and marl limestones interbedded with dark grey shale and blue shales, no marks, no signs of bioturbation and burrows –exist glauconitic – sandstone or breccia or Conglomerates this indicate a conformable between Shiranish and overlying Tanjero Formation and sharp lithological change from pale blue to dark grey pelagic marl of Shiranish Formation into light green and red shale and sandstone interbedded with then beds of Limestone which indicates Tanjero Formation (Figure 3).

Stratigraphy of Late Cretaceous in the Shakrok anticline:

This area is located in the northwestern of the Dokan area (Figure 1), we separate this area because the Kometan Formation laterally toward the north disappears and terminates. For example, the Kodara section is located about 6 Km to the NNW of Hizop Section where the Campanian Shiranish Formation rests directly on eroded Cenomanian-Aptian Qamchuqa Limestone (Figure 4). Because in the upper part of reefal limestone we found an extinct of larger foraminifera belonging to the ***Orbitolina texana*** (Figure 4). This fossil indicates Aptian-Early Cenomanian (El-sheikh and Hewaidy, 1998). New identification of major unconformities and erosional break from Cenomanian up to Campanian periods. The Qamchuqa Formation in this section consists of Hard Dolomite and Dolomitic Limestones dark grey on the weathered surface and light yellow in the fresh sample, the upper part of the Qamchuqa is interbedded of light blue marls 1-2m thick and contains Larger Benthic Foraminifera (Figure 4) and well bedded dolomitic Limestone which represents upper contact of the Qamchuqa Formation. The lithofacies of the Shiranish Formation is composed of globigerinal marl and limestone.

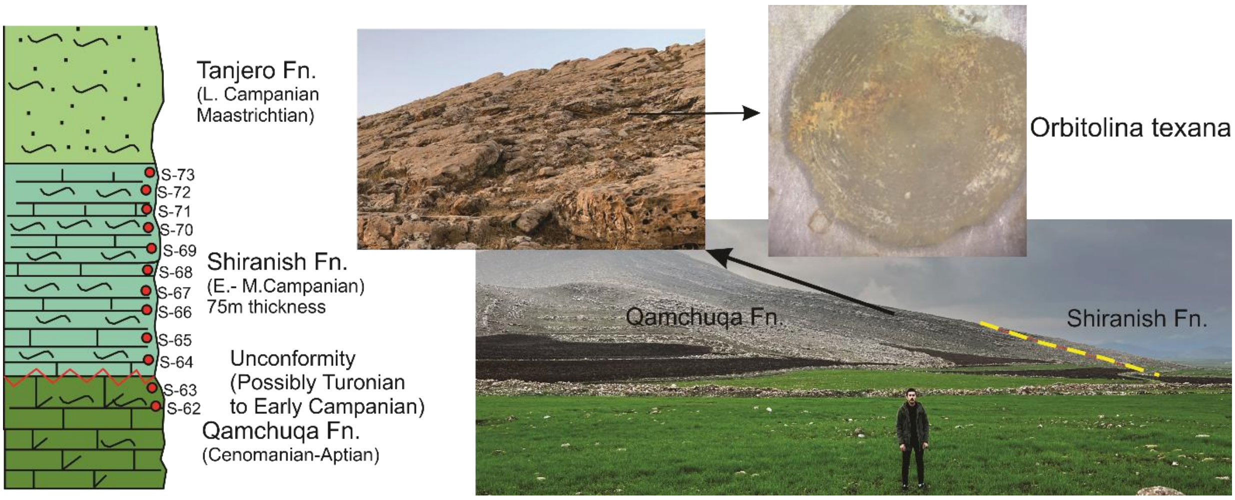

Figure 4: Stratigraphic column of Late Cretaceous in Kodara section. Show the major unconformity between Qamchuqa and Shiranish formations. The upper photos show the upper part of the Qamchuqa Formation containing *Orbitolina texana* species indicating the Aptian-Cenomanian age.

In Shakrok Anticline (Figure 1) specifically in Kuna Flusa, and Garawanan sections the succession of the Late Cretaceous formation changes compared to the previous sections. The sequence of the formations form the old to young are Bekhme, Shiranish and Tanjero formations (Figure 5). In the Garawanan and Kunaflusa sections the well-bedded light yellow dolomites of the Qamchuqa Formation are directly overlain by 45m reefal Limestone and Dolomites Bekhme Formation and with 0.8m of glauconitic calcareous sandstone at the top (Figure 5) which represent the upper contact of Bekhme Formation. This contact possibly represents unconformities during Turonian to Early Campanian or Early Campanian (Ahmed et al., 2015, Bellen, 1959, Abawi et al., 2006; Jassim and Goff, 2006; Haddad and Amin, 2007; Jaff et al., 2015; Al-Sheikhly et al., 1989; Jassim et al., 1989; Kaddouri, 1982, Malak et al., 2021). The Shiranish Formation consists of two parts the lower part is about 13m of highly fractured marly limestone light brown in color, interbedded with dark grey shale, while the upper part is about 35 m thick of light yellow to milky marly limestone overlain by light green and red shale and sandstone interbedded with then beds of Limestone which indicates Tanjero Formation (Figure 5).

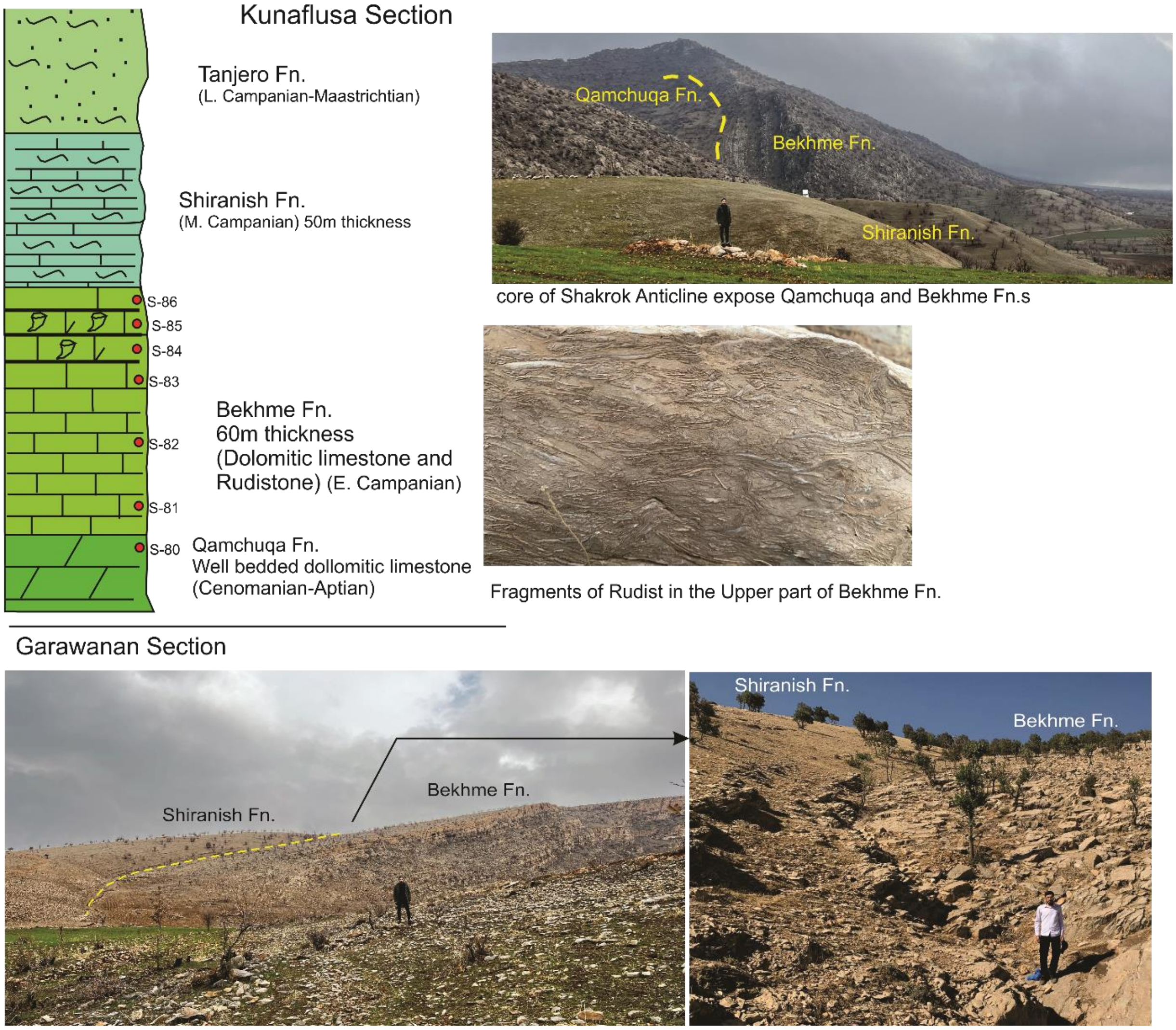

Figure 5: Stratigraphic column of Late Cretaceous in Shakrok Anticline. Show terminate of lateral continuity of the Kometan. The photos show the outcrops of the Late Cretaceous formations.

Stratigraphy of Late Cretaceous in the Bekhme anticlines:

In the area where the Bekhme Formation developed and glowed especially in the Gali-Ali Beg gorge and Bekhme Anticline exceeding 300m thick (Figure 6). Bekhme section is located about 40 km to Northeast of Akre City, which lies at Bekhme Gorge western bank of the Greater Zab Rivers. The Cretaceous formations that exist in the selected Bekhme section are Sarmord, Qamchuqa, Bekhme, Shiranish and Tanjero formations. Bekhme Formation overlies the Qamchuqa Formation and the thickness is about 311m. Compose of secondary dolomites, fore-Reefal limestone, recrystallized limestone and dolomitic limestone pregnant with bitumen. Depend on Bellen et al. (1958) describe unconformable relations between the Bekhme Limestone and the underlying Qamchuqa Formation are confirmed by the basal conglomerate. Depending on field investigation we identify this calcareous conglomerate with a thickness of about 10m (Figure 6). This conglomerate we found in this section only.

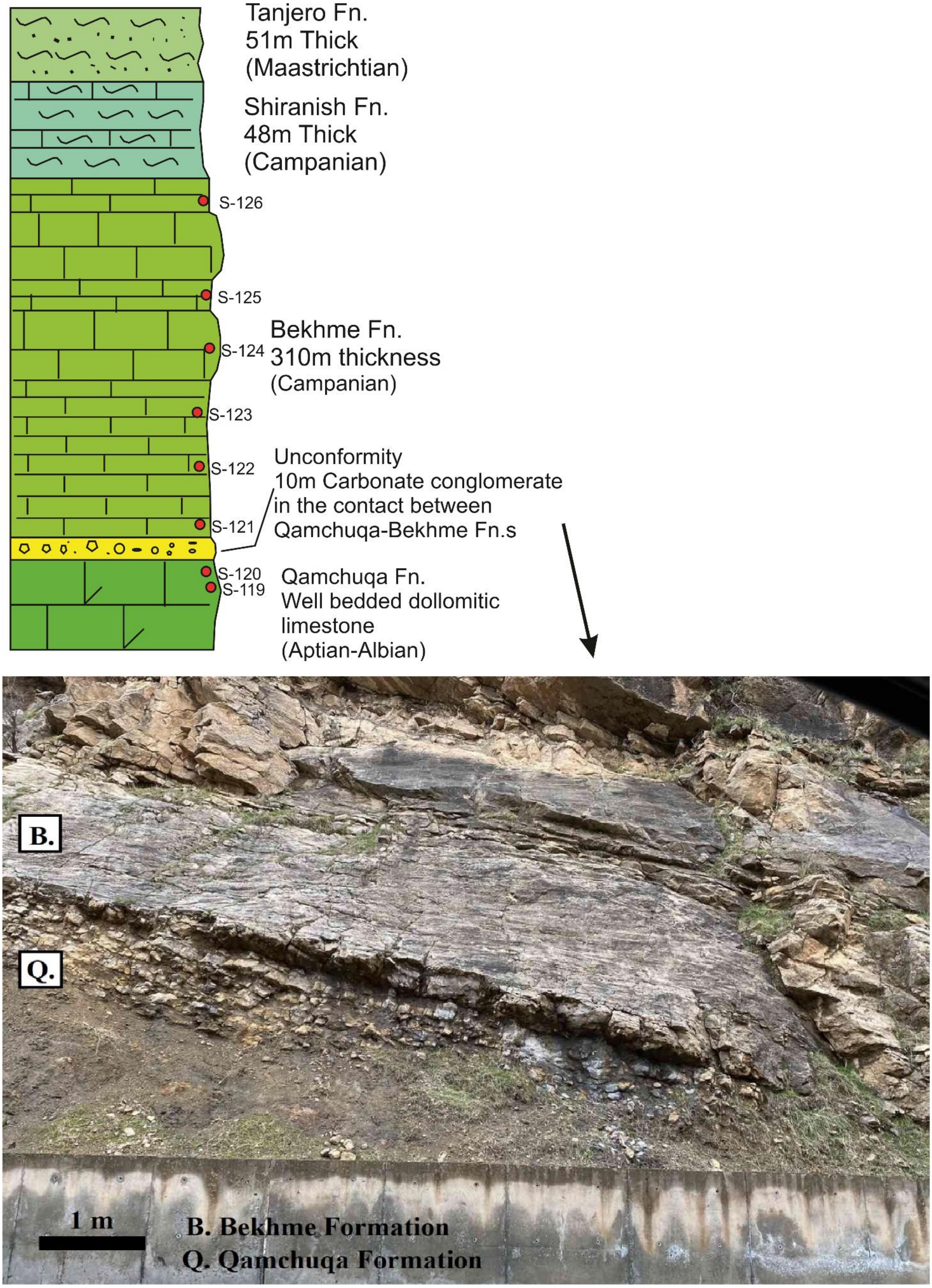

Figure 6: Stratigraphic column of Late Cretaceous in the Bekhme Anticline and Gali-Ali bag gorge. Show development of Bekhme Formation. The photos show the outcrops of the Late Cretaceous formations.

Microfacies Analysis

The study of microfacies is very important to the identification of the depositional environment, correlation and identification of the Formation. Prepared 70 thin sections from Kometan, Bekhme and Shiranish formations to study the microfacies under the polarizing microscope. To identify the types of microfacies and the depositional environment we use the Dunham classification of carbonate rocks was used to identify the exact microfacies, which were subsequently compared to the standard microfacies of (Flügel, 2010)

Microfacies analysis of the Kometan Formation

1- Planktonic Foraminiferal Wackestone submicrofacies (K1)

This submicrofacies is recognized in the Kometan Formationthe at the upper part of the Kometan Formation at the Dokan section below the glauconitic bed at the contact with the overlying Shiranish Formation. The components are Planktonic Foraminiferal with rounded fine sand-sized glauconite within micritic groundmass (Plate 1, a,b,c&d) . The common diagenesis prosses that are perceived within this submicrofacies are Micritization and cementation and fracturing in both sections.

Interpretation: due to the existence of Planktonic Foraminiferal this submicrofacies in both sections, this is common in open-marine environments. Deep shelf, slope and basinal settings Flügel (2010).

2- Foraminiferal Packstone submicrofacies (K2)

This submicrofacies is recognized in the upper part of the Kometan Formation at the Dokan and Badawan sections. The main components are globular foraminifera such as *Globigerinelloides ultramicara, Heterohelix reussi, Hedbergella planispira, Hedbergella holmedelensis, Whiteinenella archaeocretacea* in both sections (Plate 1, e&f). All grains are scattered in the micritic groundmass. The common diagenesis presses observed within this submicrofacies in both sections are Micritization, compaction and fractures are filled by over-close packed blocky cement.

Interpretation: presence of species that contain, as Dicarinella primitive *(Dicarinella imbricata, Dicarinella concavata, Dicarinella hagni, Marginotruncana renzi, Marginotruncana sigali, Marginotruncana marginata, Marginotruncana coronata* (Plate 1,e&f).indicates relatively deep marine environments (200-1500m.) within the upper slope. The presence of species of mentioned Planktonic Foraminiferals, indicates relatively deep marine environments within the upper slope (Flügel, 2010).

3- Calcispher Packstone submicrofacies (K3)

This microfacies is recognized at the upper part of the Kometan Formation at the Badawan section near contact with the Shiranish Formation. The main constituent is calcispher with *Muricohedbergella holmdelensis, Heterohelix planat, Archaeoglobigerina blowi* (Plate 1, g&h), diagenesis prosses observed within this submicrofacies is compaction and grains are over closed.

Interpretation: the abundance of calcispher and existence of Planktonic Foraminiferal common in open-marine environments. Deep shelf, slope and basinal settings (Flügel 2010).

4- Bioclastic packstone submicrofacies (K4)

This submicrofacies are recognized at the upper part of the Kometan Formation near the contact with the Shiranish Formation at Hizob section, the main components are bioclasts and diverse forams (Plate 1, i&j), and all components are attached by micritic groundmass. The common diagenesis prosses observed within this submicrofacies are micritization, silicification, cementation, and the fractures filled by blocky cement.

Interpretation: the abundance of bioclasts and the presence of various Foraminifera found in open-marine environments. Deep shelf, slope, and basinal environments (Flügel, 2010).

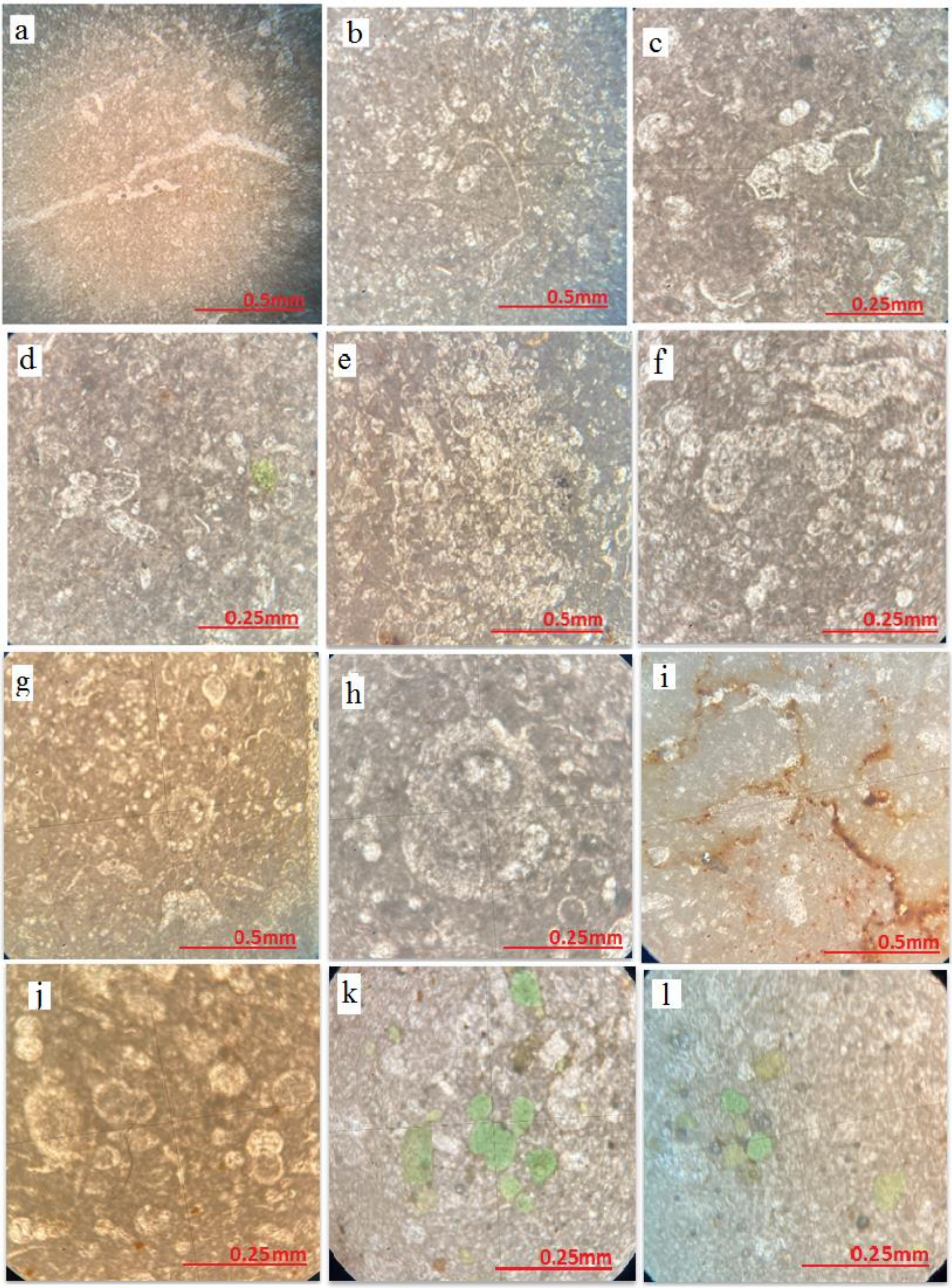

Plate 1: Microfacies analysis of the Kometan Formation. a, b, c& d: Planktonic Foraminiferal Wackestone, Dokan section, S. No. 101, 102 & 3. e & f: Foraminiferal Packstone submicrofacies, Dokan and Badawan sections, S. No. 2 & 9. g&h: Calcispher Packstone submicrofacies, Badawan section, S. No. 10. i&j: Bioclastic packstone submicrofacies, Hizop section, S. No. 25. k&l: Bioclastic Glauconitic Packstone to Grainstone submicrofacies, Hizop Section, S.No. 15&16.

5- Bioclastic Glauconitic lime Packstone to Grainstone submicrofacies (K5)

This submicrofacies is recognized in the middle part of the Kometan Formation at the Hizop section. It is consisting of 30% bioclastic, 25% subrounded to rounded course sand-sized Glauconite and a diversity of benthic foraminifera (Plate 1, k&l). Micrite envelopes are coated around some grains causing the grains undermined. All grains are scattered in sparry calcite cement. Micritization, compaction and recrystallization are common processes observed within this submicrofacies.

Interpretation: the presence of bioclastic grains, subrrounded to rounded coarse sand-sized Glauconite and diversity of benthic foraminifera in this submicrofacies indicates basinal environments (Fluegel, 2010).

Microfacies Analysis of Bekhme Formation

1- Echinoidal Wackstone submicrofacies (B1)

This submicrofacies are recognized in the middle part of the Bekhme Formation at the Garawanani Khwaru section. The major constituents of this submicrofacies are represented by echinoids with Miloilids (plate 2, a&b). All types of particles are embedded in micritic cement. Dissolution, cementation and micritization are affected by groundmass and skeletal grains and fractures filled by granular cement.

Interpretation: the properties of this submicrofacies indicate deposits in calm water in sheltered reef parts (Flugel, 2010). The occurrences of a high number of echinoids in micritic indicate moderate energy in shallow water environments (Wilson, 1975 and Flugel, 2010).

2- Benthic Formaineferal Packstone submicrofacies (B2).

This Submicrofacies type is recognized in the upper part of the Bekhme Formation at the middle part of the Formation at the Bekhme section. Diverse benthic foraminifera in both sections (plates 2, c&d). These grains are dispersed throughout the micritic groundmass in both sections. This submicrofacies exhibit the diagenesis processes of Pyritization, cementation (Drusy cementation) in the Kani Kulk section, and granular cement filling of fractures, while in the Bekhme section, Micritization compaction and cementation are perceived.

Interpretation: According to Vecchio and Hottinger (2007), planktonic foraminifera associations with rich "calcispheres" are good indicators of the outer shelf environment. Characterizing sediments deposited in quiet water below the wave base in an off-reef setting (Flugel, 2010).

3- Pelletoidal Grainstone submicrofacies (B3)

This submicrofacies is recorded in the lower part of the Bekhme Formation at Bekhme sections. The common grains are peloids in both sections (plate 2, e,f,g&h). These grains are encased in sparry calcite cement in this section grains. This microfacies ground mass is rich in reddish to brown iron oxide materials and the diagenesis process of dissolution, compaction, cementation and oxidation are observed in the Bekhme section.

Interpretation: This grainstone submicrofacies with sparry calcite cement indicated a deposit in a high-energy shoal environment (Wilson, 1975 and Flugel, 2010).

4- Echinoid grainstone submicrofacies (B4)

This submicrofacies is recognized in the middle part of the Bekhme Formation at the Garawanani Khwaru section. The major constituents of this submicrofacies are represented by fragments of echinoids (plate 2, i&j). All types of particles are embedded in coarse crystalline sparry calcite cement. Dissolution, cementation and micritization are affected by groundmass and skeletal grains.

Interpretation: The properties of this submicrofacies point to deposits in high-energy backreef environments (Flugel, 2010). The presence of a large number of echinoids in sparry calcite suggests a moderate to high energy shallow water environment (Wilson, 1975 and Flugel, 2010). According to Penney and Racey (2004) the current miliolides and echinoids with marine rim cement indicate high energy settings.

5- Rudistone-Floatstone submicrofacies (B5)

This submicrofacies is recorded in the upper part of the Bekhme Formation at the Kuna Flusa section. The component of this submicrofacies is mostly comprised of rudist fragments of pelecypods and coral only and size more than. The composition consists of rudist fragments of pelecypods and corals and association with

Miliolids (plate 2, k&l). All these particles are scattered in the micritic groundmass. The common diagenesis processes that affected the groundmass and grains are dissolution, cementation, and compaction.

Interpretation: the great diversity of organism's properties within this microfacies with a concentration of encrusting organisms indicate deposits in the slope toward the toe of slope environments. It represents the reef flank beds and the wind-facing side against the open sea. It is distinguished by an abundance of large-sized reef detritus (Schlager, 2002). Floatstone and rudstone designate limestones with transported grains larger than 2 mm (plate 4, l, m & n). Roles of organisms in the construction of reef carbonates (Fluegl, 2010). The formation of rudstones needs erosion and transport. Erosion can be triggered by shallow water settings allowing destruction by storms. Slopes are common depositional settings of rudstones (Fluegl, 2010).

6- Microcrystalline Dolostone submicrofacies (B6).

This submicrofacies is found in the upper part of the Bekhme Formation at Kuna Flusa and Bekhme sections. dolomite mineral with sugar texture and equal crystal sizes represented a high percentage more than 75% in the matrix (plate 3, a,b,c,d &e) that formed by the action of the diagenesis substitution process in carbonate deposits, in which Dolomite mineral crystal formed completely faces (Enhedral), particles sizes were increased upward that indicate the diagenesis process becomes more intense (Fuchtbauer and Goldscmidt, 1956).

Interpretation: the facies have high porosity as a result of the late diagenesis process and reflected the condition of the supratidal environment because of the lack of fossils in these facies.

Microfacies Analysis of the Shiranish Formation

1. Globigerinoides Wackstone-Packstone submicrofacies (S1).

This submicrofacies has widespread distribution within the Shiranish Formation where it is recognized in the upper part of the Formation in the Hizop section. The main components are Globigerinoides, diverse forams and Glauconite in micritic groundmass (Plate 4, a&b). The main diagenesis processes observed are micritization, Oxidation, pyritization, cementation (granular cement-filled fossils, and Compaction.

Interpretation: This is common in deep shelf and basinal limestone settings due to the presence of Globigerinoides in both sections (Flügel, 2010).

2. Foraminefral Packstone submicrofacies (S2).

This submicrofacies is recognized at the lower part of the Shiranish Formation at Badawan and Garwanani Khwaru sections. In the Badawan the main components are diverse foraminifera's, glauconite and organic matter in micritic groundmass (Plate 4, c&d,) and the diagenesis process that is preserved in this submicrofacies at the Badawan section is Oxidation, in Garawanani Khwaru section the constituents are diverse foraminifera's, glauconite and organic matter (Plate 4, e&f). All grains are scattered in micritic groundmass and the diagenesis process that is preserved in this submicrofacies at both sections are Micritization and cementation.

Interpretation: The presence of diverse foraminifera and glauconite in micritic groundmass indicates relatively open marine environments. (Flügel, 2010).

3. Globogirinoids Packstone submicrofacies (S3).

This submicrofacies is recognized in the middle part of the Formation in the Hizop section. The main components are Globogirinoids, diverse forams,Glauconite and bioclasts of Pelecypod shell, grains are devoted to micritic groundmass (Plate 4, g,h,i&j). The main diagenesis process observed are micritization, Oxidation, pyritization, cementation (granular cement-filled fossils, and Compaction.

Interpretation: Because of the presence of Globigerinoides in both sections, this is common in deep shelf and basinal limestone settings (Flügel, 2010).

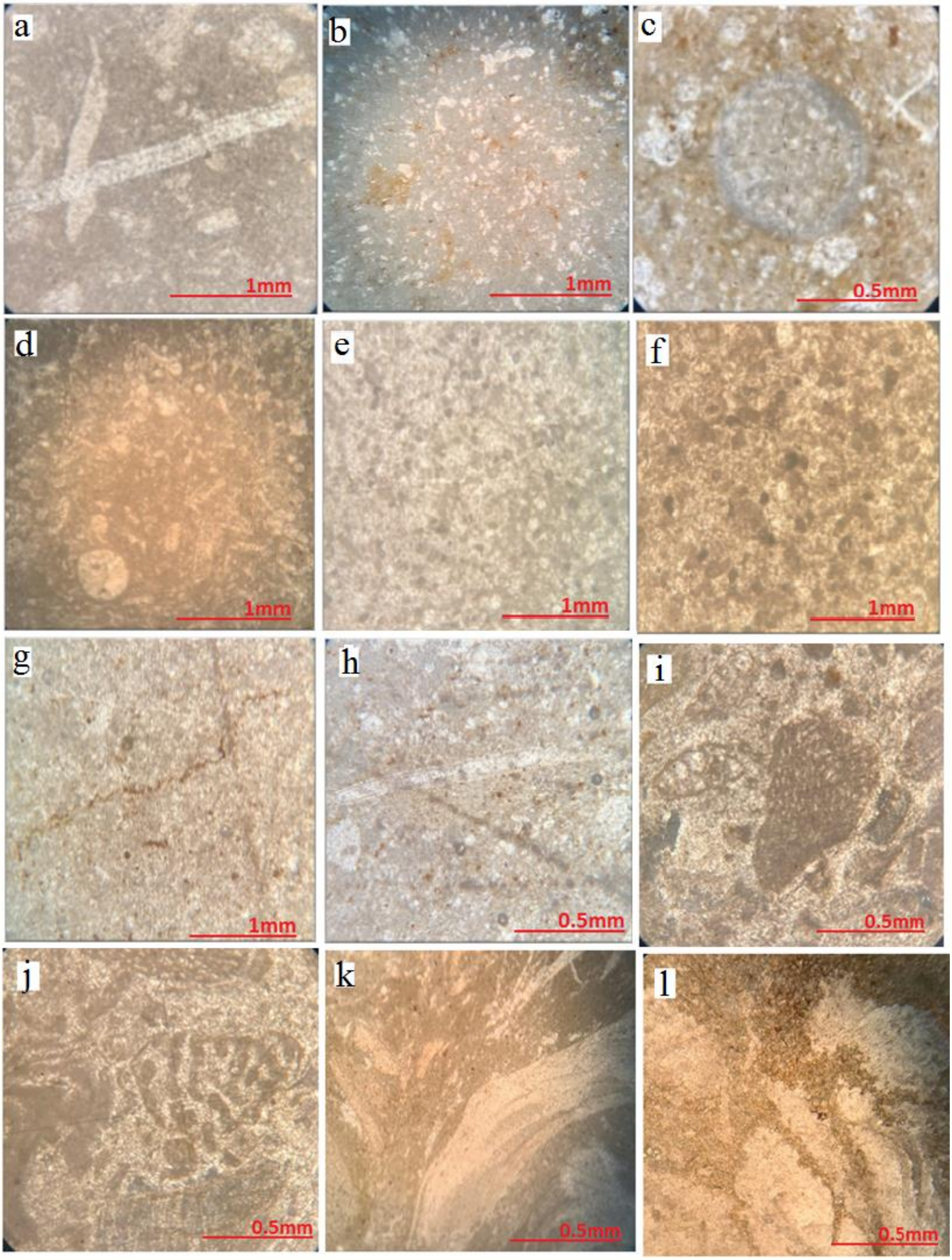

Plate 2: Microfacies Analysis of Bekhme Formation. a&b: Echinoidal Wackstone submicrofacies (B1), Garawanani Khwaru section, S.N. 88 c&d: Formaineferal Packstone submicrofacies (B2), Bekhme section. S.N. 126 & 113. e,f,g&g: Pelletoidal Grainstone submicrofacies (B3), Bekhme section, S.N. 122 & 114. i&j: Echinoid grainstone submicrofacies (B4), Garawanani Khwaru section, S.N.89. k&l: Rudistone-Floatstone submicrofacies (B5), Kuna Flusa section. S.N. 84,85 & 86.

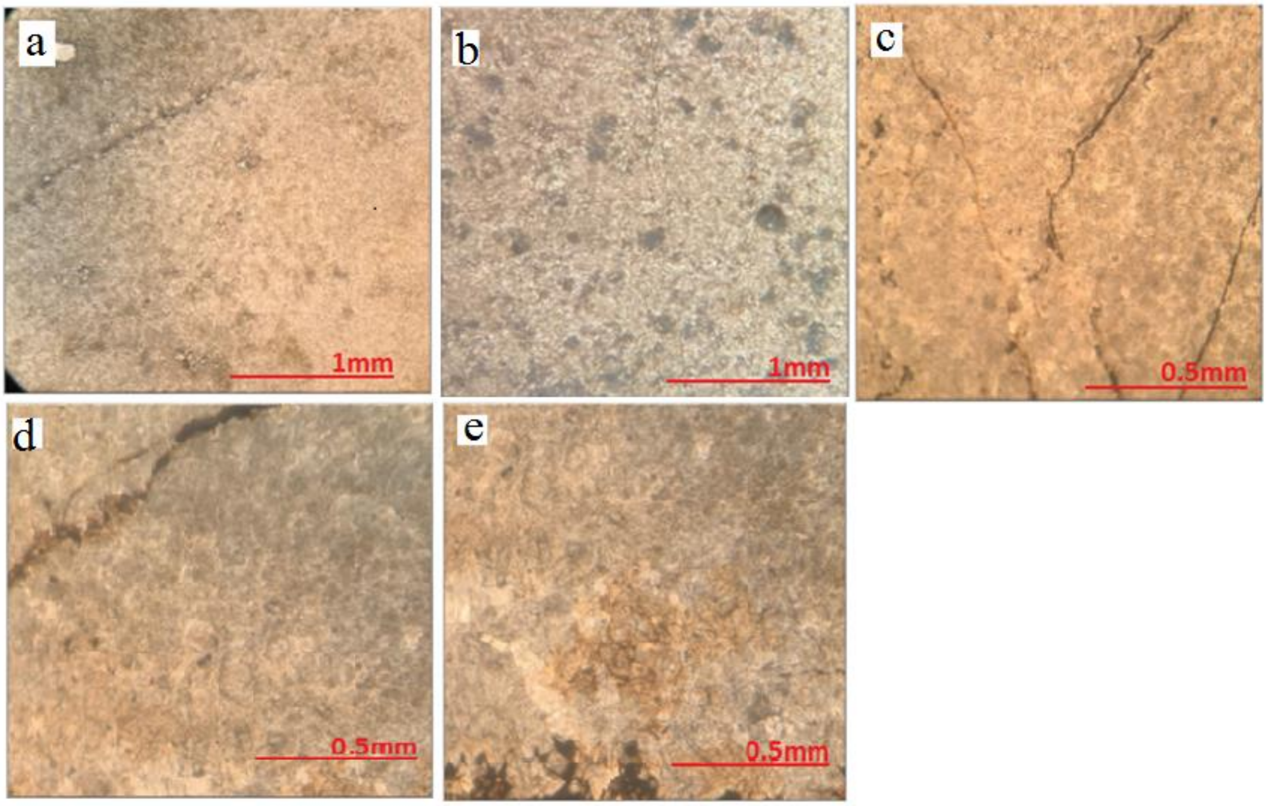

Plate 3: Microfacies Analysis of Bekhme Formation. a,b,c,d&e: Microcrystalline Dolostone submicrofacies (B6), Kuna Flusa & Bekhme sections, S.N. 87, 75, 76& 127.

4. Bioclastic Glauconitic Packstone submicrofacies (S4).

This submicrofacies is recognized at the lower part of the Shiranish Formation at the Dokan section above the glauconitic bed with the underlying Kometan Formation. It is consisting of bioclastic, subrrounded to rounded coarse sand-sized Glauconite, diversity of benthic foraminifera and organic matter (Plate 4, k&l). All grains are scattered in micritic cement. dissolution and moldic porosity are common processes observed within this submicrofacies.

Interpretation: This submicrofacies implies deep marine sediments because it contains bioclastic grains, rounded to subrounded coarse sand-sized Glauconite, and a variety of foraminifera. (Fluegel, 2010).

5. Foraminiferal Packstone-Grainstone submicrofacies (S5).

This submicrofacies is recognized at the lower part of the Shiranish Formation near the contact with the underlying Kometan Formation at the Hizop section. The main components are a diversity of benthic foraminifera, rounded medium sand-sized Glauconite, and organic matter (Plate 5, a&b). All grains are scattered in micritic groundmass. The common diagenesis presses observed within this submicrofacies is compaction and fractures are filled by over close packed blocky cement.

Interpretation: presence of species that contain keeled, as *Dicarinella primitive, Dicarinella imbricata, Dicarinella concavata, Dicarinella hagni, Marginotruncana renzi, Marginotruncana sigali, Marginotruncana marginata, Marginotruncana* coronate withing micritic groundmass (Plate 5, n). indicates a relatively pelagic platform (Flügel, 2010).

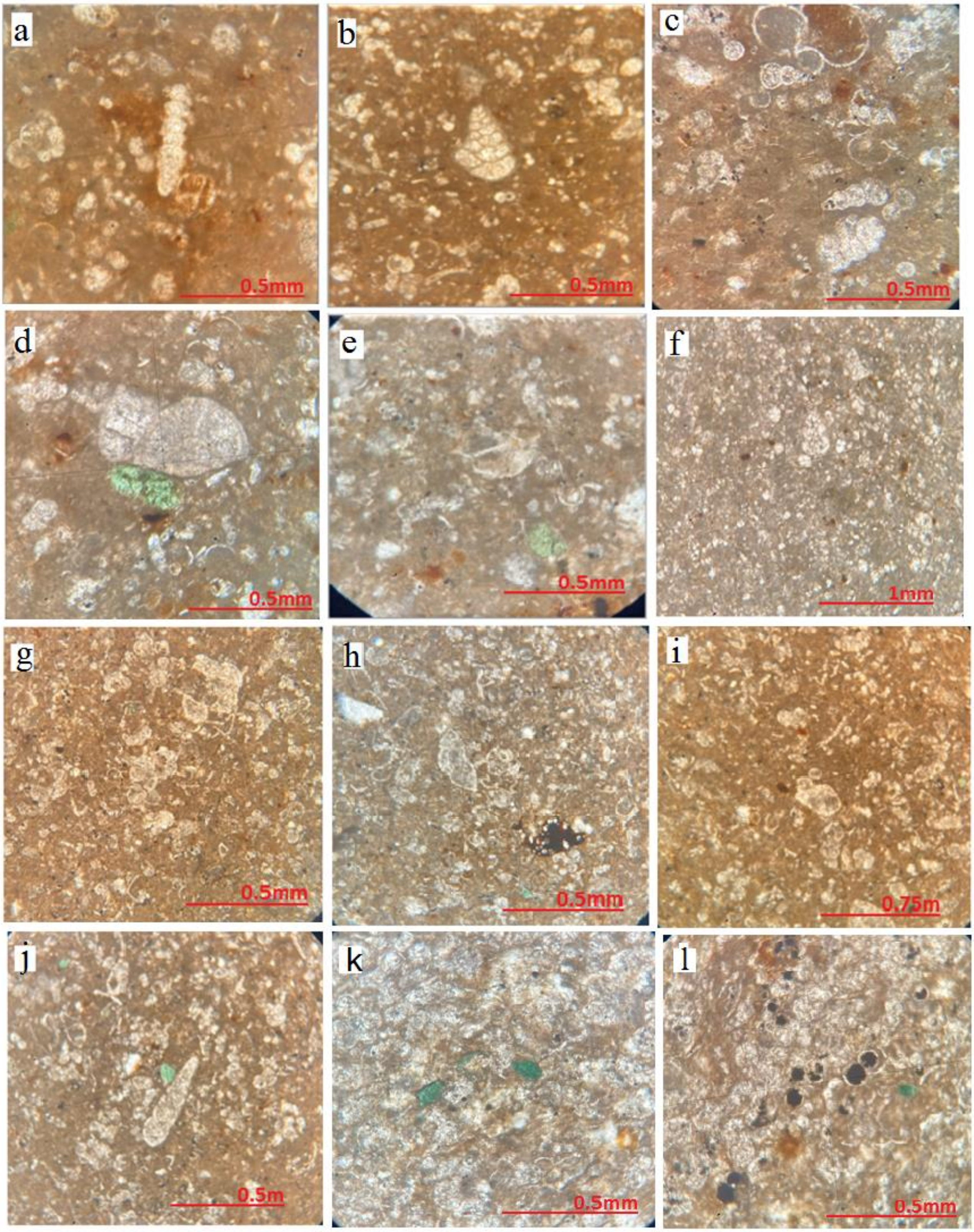

Plate 4: Microfacies Analysis of the Shiranish Formation. a&b: Globigerinoides Wackstone-Packstone submicrofacies (S1), Hizop section,S.No. 62. (c,d,e&f): Foraminiferal Packstone submicrofacies (S2), Badawa, Garawanani Khwaru sections, S.No. 12,91, 92 & 119. g,h,i&j: Globogirinoids Packstone submicrofacies (S3), Hizop section, S.No. 44. k&l: Bioclastic Glauconitic Packstone submicrofacies (S6), Dokan- section,S.No. 7&8.

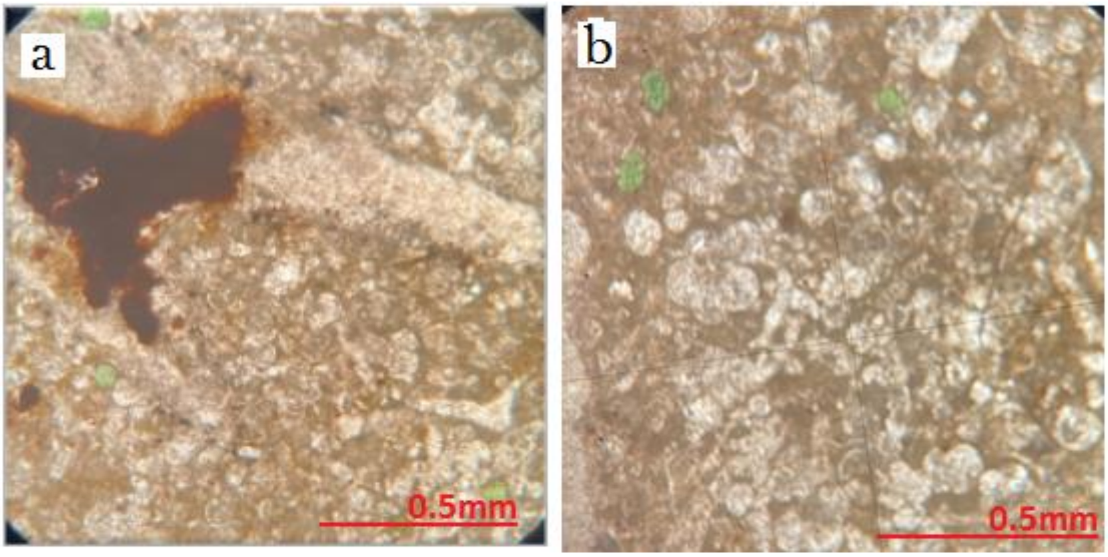

Plate 5: Microfacies Analysis of the Shiranish Formation. a&b:Foraminiferal Packstone-Grainstone submicrofacies (S8). Hizop section, S.No. 30.

Discussion

In this part, depending on lithostratigraphy and Microfacies analysis the basin evolution during Late Cretaceous have been constructed. From the detailed stratigraphic results, seven geological cross-sections have been constructed (Figure 7) to cover all the study areas. From the result of these cross-sections, we easily can correlate the Late Cretaceous formations and conclude the limit of the unconformities. The cross-section starts from the southeast of the study area toward the north and northwest. The modernization of these cross-sections shows the well development of open marine facies (Kometan and Shiranish formations) in the southeast, however the shallow facies (Bekhme Formation) in the north and northwest. The Dokan area (Figure 9 cross-section-1), clearly show the Kometan Formation is well developed with existing of glauconitic layers between Shiranish and Kometan formation representing abrupt deposition during the Middle and Late Santonian periods. The same situation exists toward NW in cross-sections 2 and 3 (Badawan and Hizop sections) (Figure 9 parts 1 and 2) but the thickness of the Kometan Formation reduces. In the cross-section 4 (Kodara section) (Figure 9 part 2) the facies of the Kometan Formation entirely disappear and the Shiranish Formation unconformably overly the Qamchuqa Formation. However, in the cross-section 5 (Kunaflusa section) the reefal facies of the Campanian Bekhme Formation rested on the Qamchuqa Formation and the Shiranish Formation overlay Bekhme Formation (Figure 9 part 2). The same situation exists in the cross-section 6 and 7 (Figure 9 part 2 and 3), in the cross-section 6 (Bekhal) and 8 (Bekhme) the Bekhme Formation clearly appear as an outcrop and widely developed (about 300m thick) (Figure 9 parts 2 and 3).

Share and linked results of the thirteen stratigraphic sections, seven geological cross-sections and biostratigraphic conclude importance results and a clue about many questions to date not solved. Such as depositional basin during Turonian, Coniacian, Santonian and Campanian. Moreover, the results of the microfacies to identify the depositional environment (Table-1) is another clue to visualize the depositional basin and paleotectonic map of KRI during the Late Cretaceous.

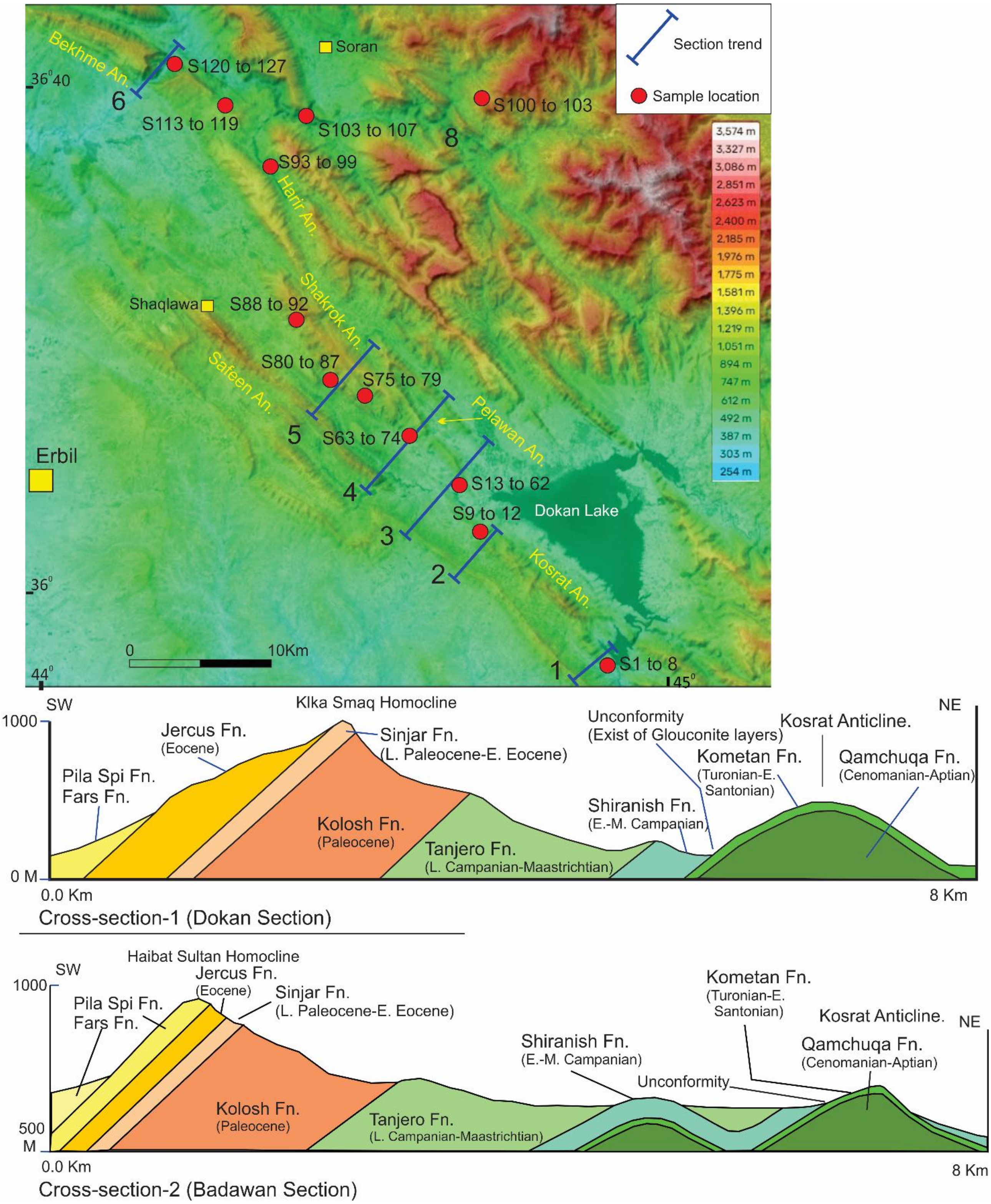

Figure 7: (part-1) Series (6) cross-sections show disappear Kometan Formation and appear Bekhme Formation toward the north and NW. The map shows the location of the cross-section and sample locations. Continue to Part-2 and Part-3

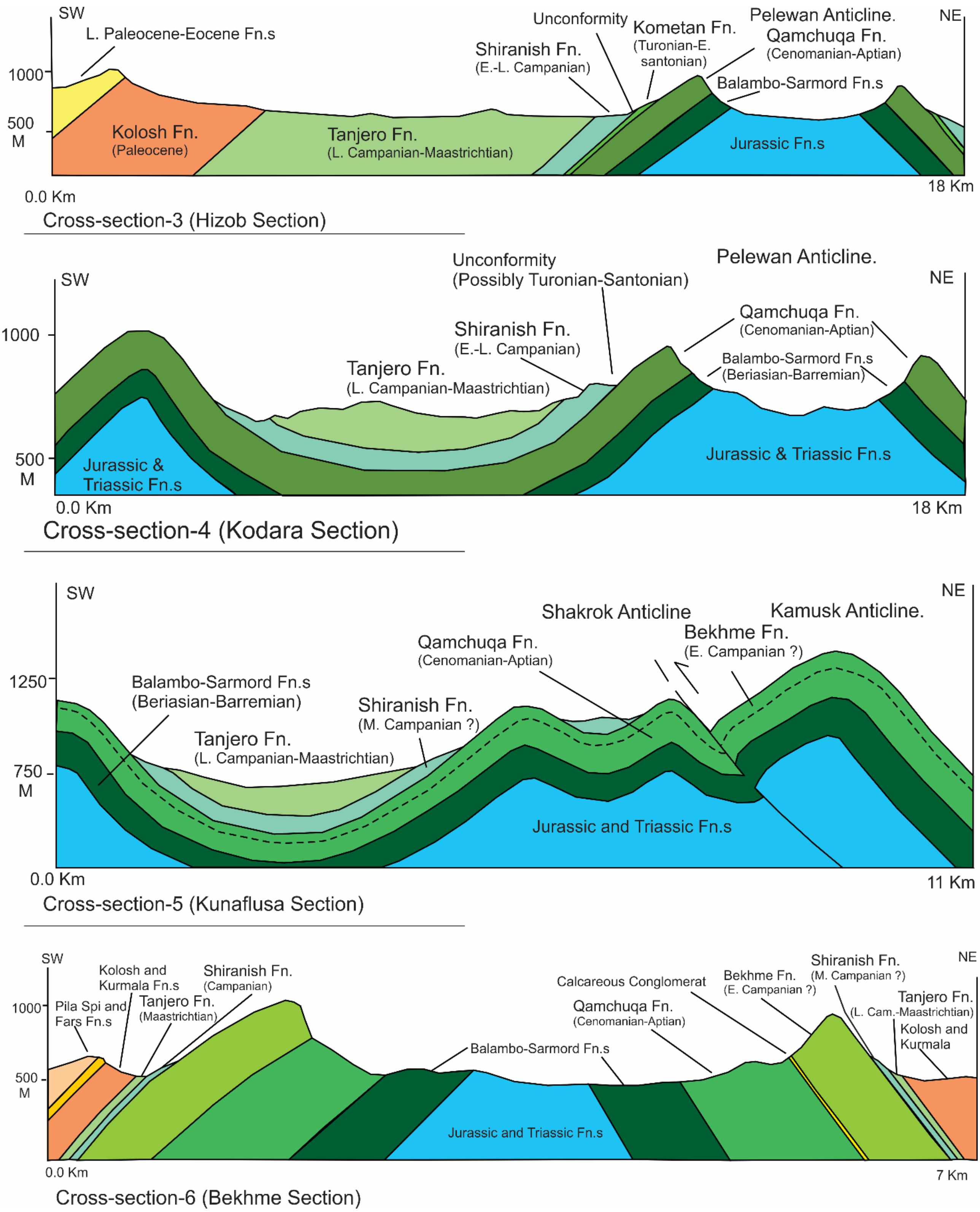

Figure 7: Part2

The result of the 7 stratigraphic sections is to construct a fence diagram (Figure 8) to illustrate the facies development and facies change of the Late Cretaceous formations in the Kurdistan Region. This fence diagram clearly shows that the reefal facies of the Aptian-Cenomanian Qamchuqa Formation exist in all the area indicating the area during this period was a part of a large passive margin platform. The open marine limestone of the Kometan Formation is well established in the East and SE of the study area (Figure 8) as well as the thickness in the Dokan area are maximum (exceeding 120m thick), however in the Hizop and Dar-Alsalam the thickness reduces to 30-10m thick. From Shakrook Anticline toward Korek, and Handren Anticlines are the major line that the Facies of Kometan disappear through the Late Cretaceous sequences. Toward NW and West no any formations, sequences or facies are equivalent to the Kometan Formation. In the West and NW of the area, the Bekhme Formation rested on the Qamchuqa Formation (Figure 8). Existing of 1 m conglomerate in the Bekhme Gorge show the unconformable contact with the Qamchuqa and Bekhme formations. The age of the Shiranish Formation above the Kometan Formation is Early-Middle Campanian. Moreover, the thickness of the formation is reduced to half if rested the Bekhme Formation. Is clearly concluded that the lower part of the Shiranish Formation laterally and the equivalent of the Bekhme Formation indicates the acceptable age of the Bekhme Formation is Middle Campanian.

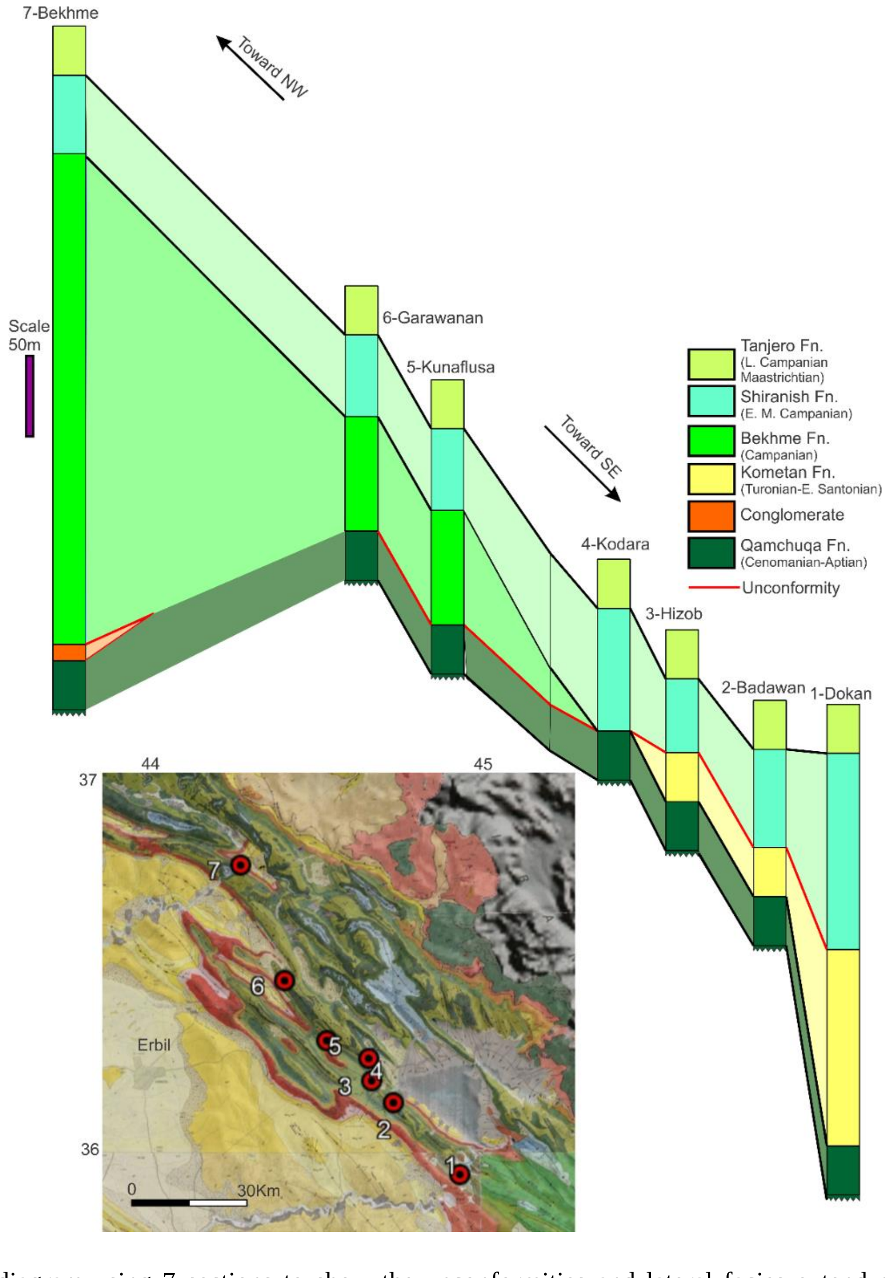

Figure 8: Fence diagram using 7 sections to show the unconformities and lateral facies extend of Late Cretaceous formations in Kurdistan Region.

Table 1: Identification of the depositional environment of Late Cretaceous formations depends on the standard microfacies of the Flügel (2010).

Formation	section	Depositional Environment
Shiranish	Garwanani Khwaru	Open Marine, Pelagic platform
	Hizop	Deep shelf, Pelagic platform
	Badawan	Open Marine
	Dokan	Deep marine
Bekhme	Bekhme	Patch reef platform, Forereef
	Kuna Flusa	Marginal reef
	Garwanani Khwaru	Back reef
Kometan	Hizop	Open Marine, Upper Slope
	Badawan	Pelagic Platform, Rump
	Dokan	Open Marine, Pelagic Platform

Depositional environment of the Late Cretaceous in KRI

During the Aptian-Cenomanian the Kurdistan Region covered by two main facies are: (1) the reefal carbonate platform represents Qamchuqa Formation, and (2) deep open Marine carbonate/marl facies represent Balambo Formation (Ahmed et al., 2016; Aqrawi et al., 2010; Jasim and Guff, 2006). The Late Cretaceous sequences show the reflection of the starting Subduction of Arabian-Eurasian plates, through ending the passive margin and starting the active margin during Late Cretaceous with the ending stage of Kermanshah radiolarite basin and uplifting of Bisitoun Bulge and Neyriz Exotics Bulge (Barrier et al., 2018). In the Late Cretaceous the North of Iraq (KRI) suffer from the rapidly depositional basin change and depending on the result of our data we classify four event cycles of deposition are:

1- Turonian to Early Santonian:

During this period northern Iraq was covered by a shelf ramp depositional environment with the existing non-deposition land area (Figure 9). The Mardin High is in the north (Barrier et al., 2018) and Khlesia High in the west (Jassim and Guff, 2006). The inner shelf and lagoonal depositional environment cover the middle and western of north Iraq characterize by the shallow shoal carbonate of Khasib, Tanuma and Saadi formations (Buday, 1980; Jassim and Guff, 2006; Aqrawi et al., 2010; Haddad and Amin, 2007, Barrier et al., 2018). In the Eastern part of KRI (Sulaymanyah, Dokan, Hizop, Ranian, and Balakaiaty areas) the Kometan Formation is well developed that represents the outer shelf and open marine environment (Figure 9).

2- Middle and Late Santonian:

The visualization of the depositional environment during this period until the date has not constricted well for northern Iraq and KRI. Most researchers such as Abawi et al. (2006); Jassim and Goff (2006); Haddad and Amin (2007); Jaff et al. (2015); Al-Sheikhly et al. (1989); Jassim et al. (1989); Kaddouri (1982); Sissakian et al.(2016) assume the Kometan Formation continue in deposition until Early Campanian. However, Bellen et al. (1959); Dunnington (1958); Ahmed et al.; (2016) identify that Santonian North Iraq suffered from major unconformities.

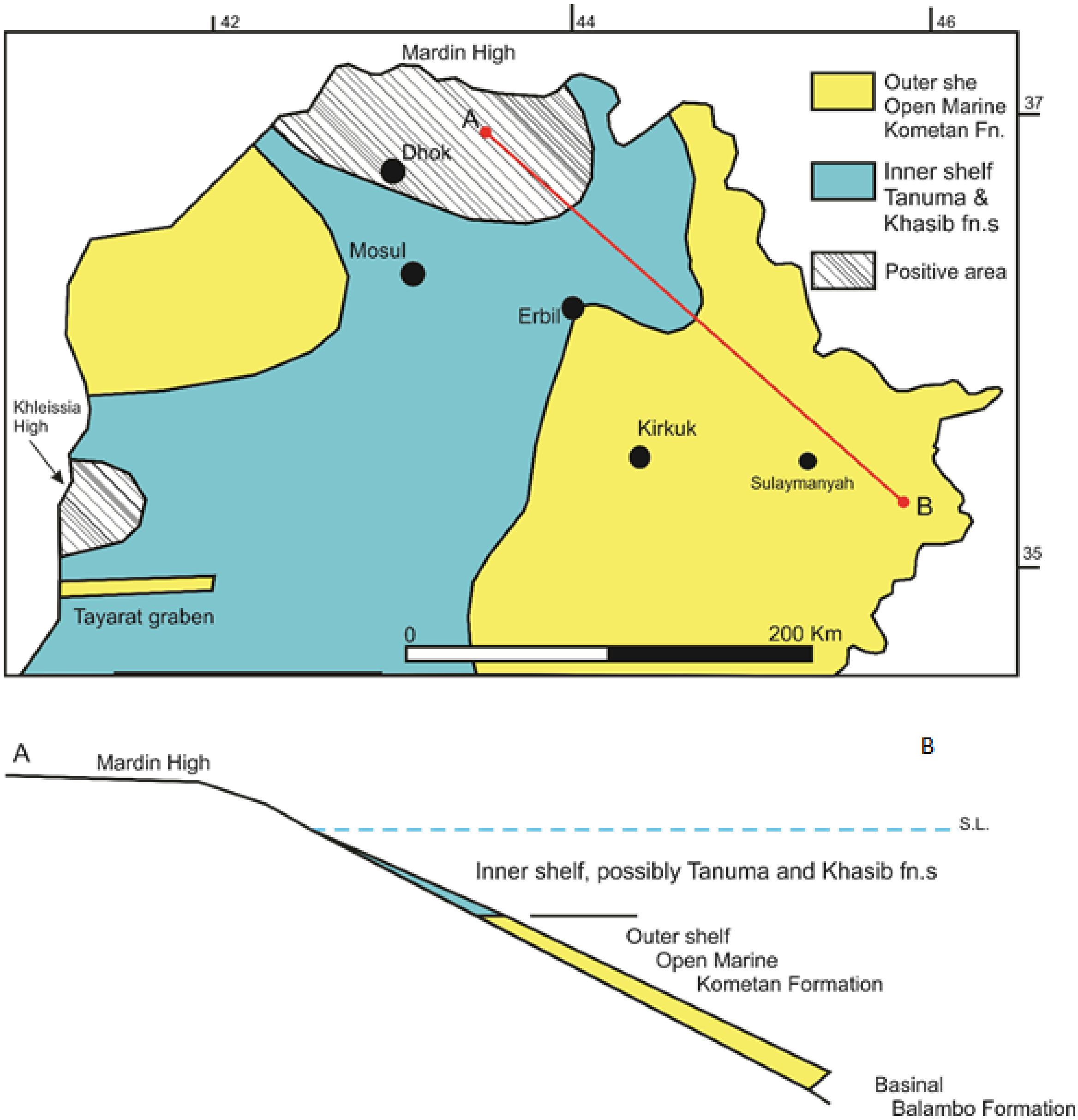

Figure 9: Paleogeographic map of Northern Iraq and KRI during the Turonian to Early Santonian periods. Modified from Jassim and Goff, (2006), Ahmed et al. (2016), and Barriar et al. (2018).

Depending on the result of this study the Middle and Late Santonian are major hiatus exist between Kometan and Shiranish Formation. Most possibly the uplifting and positive area starting in Mosul, Erbil and Dohuk areas (Figure 10) subsequently progressing the regression in both directions to the east and west. Because if we see the fence diagram (Figure 8) explains all the Erbil area does not exist any Turonian sequences which means the Bekhme Formation overly the Qamchuqa Formation and in the Kodara section the Shiranish Formation overly Qamchuqa Formation, also the thickness of the Kometan Formation increase toward east and Southeast (Figure 8).

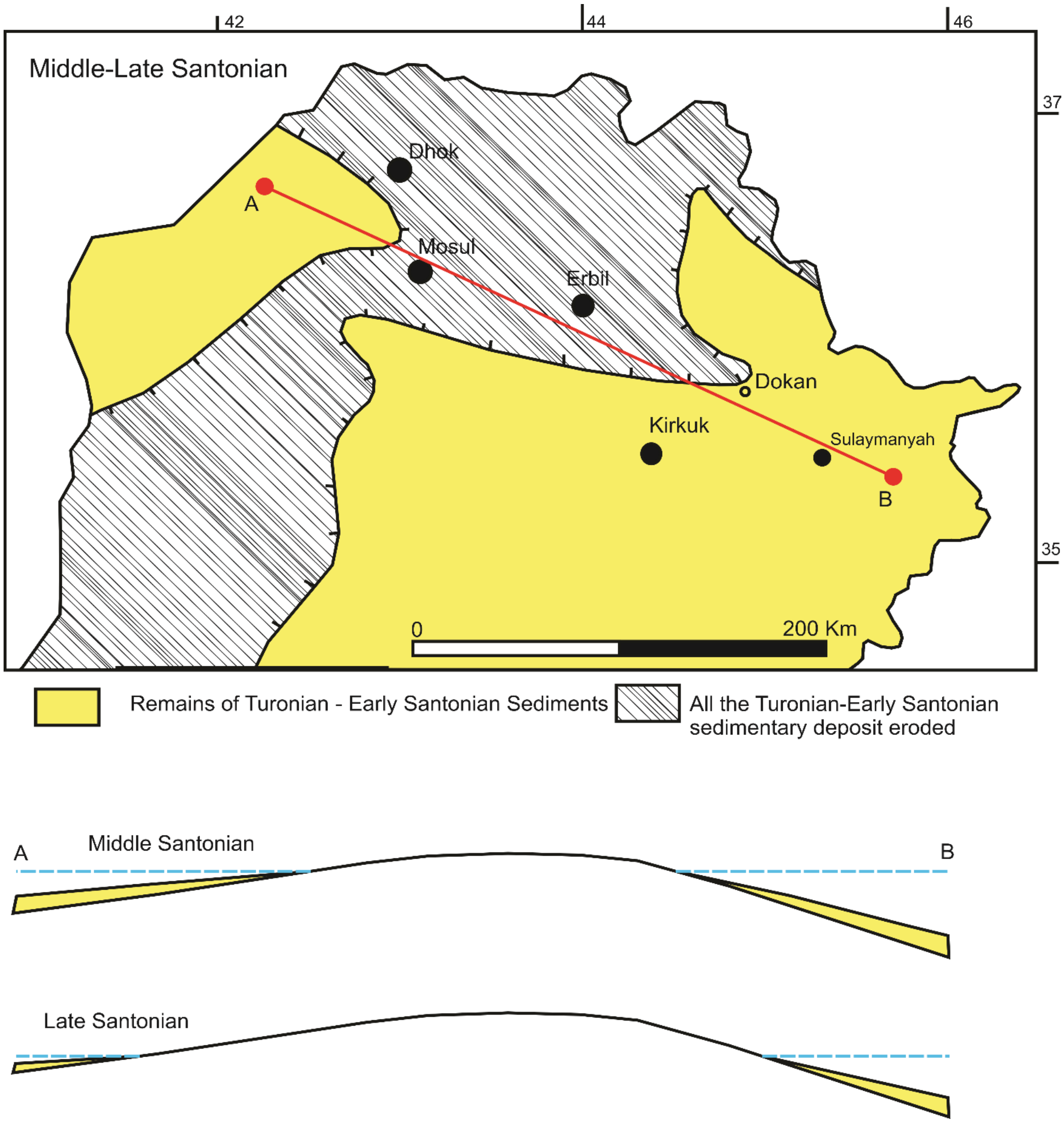

Figure 10: Paleogeographic map of Northern Iraq and KRI during the Middle-Late Santonian period. Modified from Dunnington (1958).

This situation solves the problem of the asynchronous of Kometan Formation, because the regression and uplifting of the area progress possibly from E. Santonian and continue possibly to Late Santonian (Figure 10). Moreover, the Kometan Formation in some places are Turonian and in others deposited until Campanian, possibly in the extreme east part the Shiranish conformably overlay the Kometan Formation.

3- Early-Middle Campanian**:**

The reflection of the Arabia-Eurasian Subduction clearly appears in the Early-Middle Campanian sediments and depositional environment of KRI. Different environments exist during this period, the inner and outer shelf in the west flysch and open marine in the east with an existing reefal platform between them (Figure 11). The supratidal and shallow carbonate of Hartha Formation well developed in the west (Aqrawi et al., 2010; Jassim and Goff, 2006). During Early-Middle Campanian, the outer-shelf open marine Shiranish Formation cover most parts of Kurdistan except the extreme eastern (Figure 11). In the north during the Middle Campanian large reefal platform well developed represents the Bekhme Formation. In Late Campanian, the northern reefal platform terminated and the Bekhme Formation was replaced by the Shiranish Formation. In the Iran and extreme northeast, the active high area product the source of the flysch facies of the Tenjero Formation that accumulate in the trench (Figure 11).

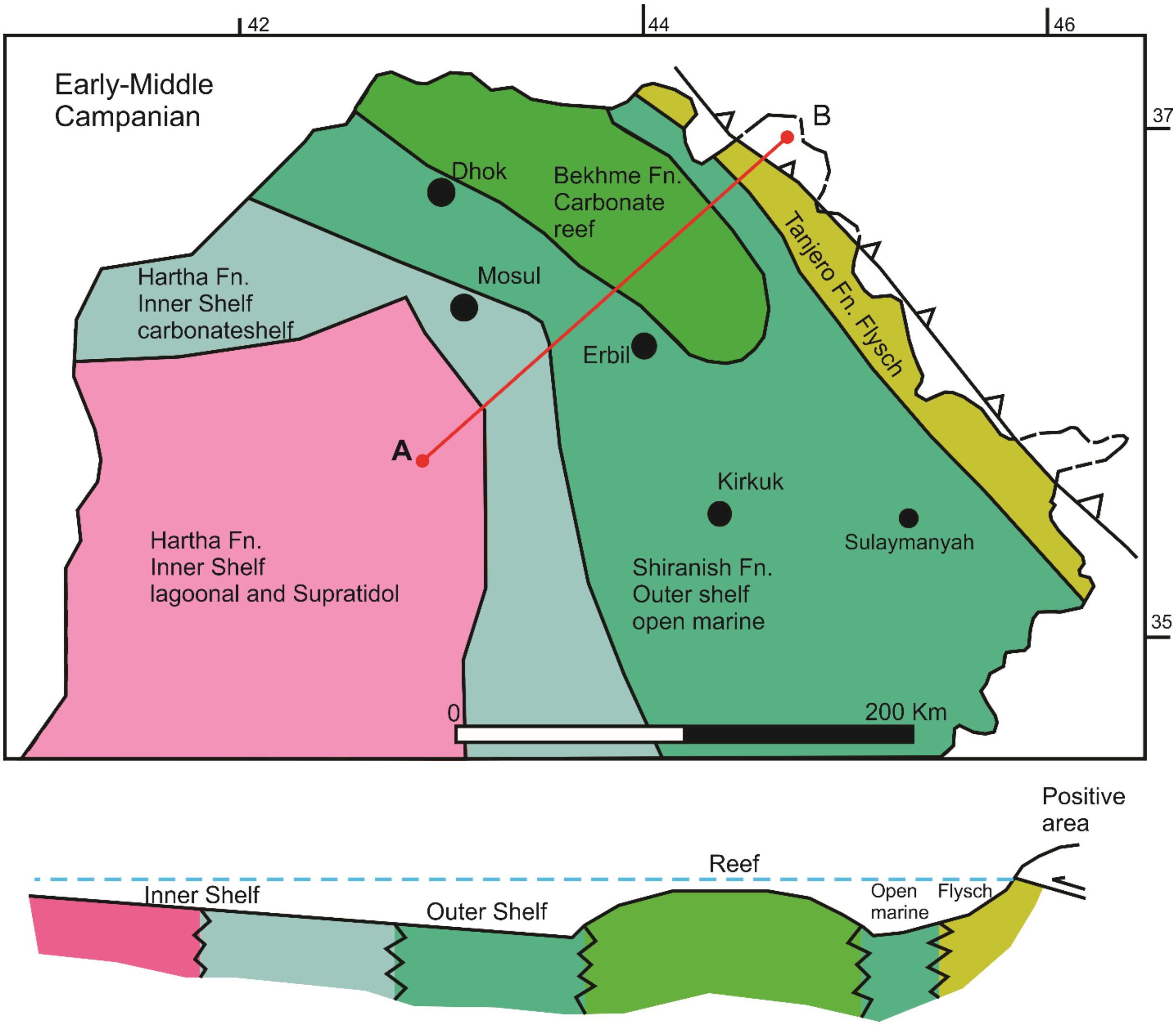

Figure 11: Paleogeographic map of Northern Iraq and KRI during the Turonian to Early-Middle Campanian periods. Modified from Jassim and Guff, (2006), Ahmed et al. (2016) and Barriar et al. (2018).

4- Early-Middle Campanian:

In this period the foreland basin in the KRI developed by existing the flysch turbidities clastic facies of the Tanjero Formation cover most east and northeastern part of the area. The Shiranish Formation slightly regressed toward the west and the clastic deposition of the Tanjero Formation took place (Figure 12). Reefal platform of the Aqra Formation in situ the Bekhme platform, Moreover, in the Late Maastrichtian the Aqra Formation also developed as lenses inside Tanjero Formation in the east (Figure 12).

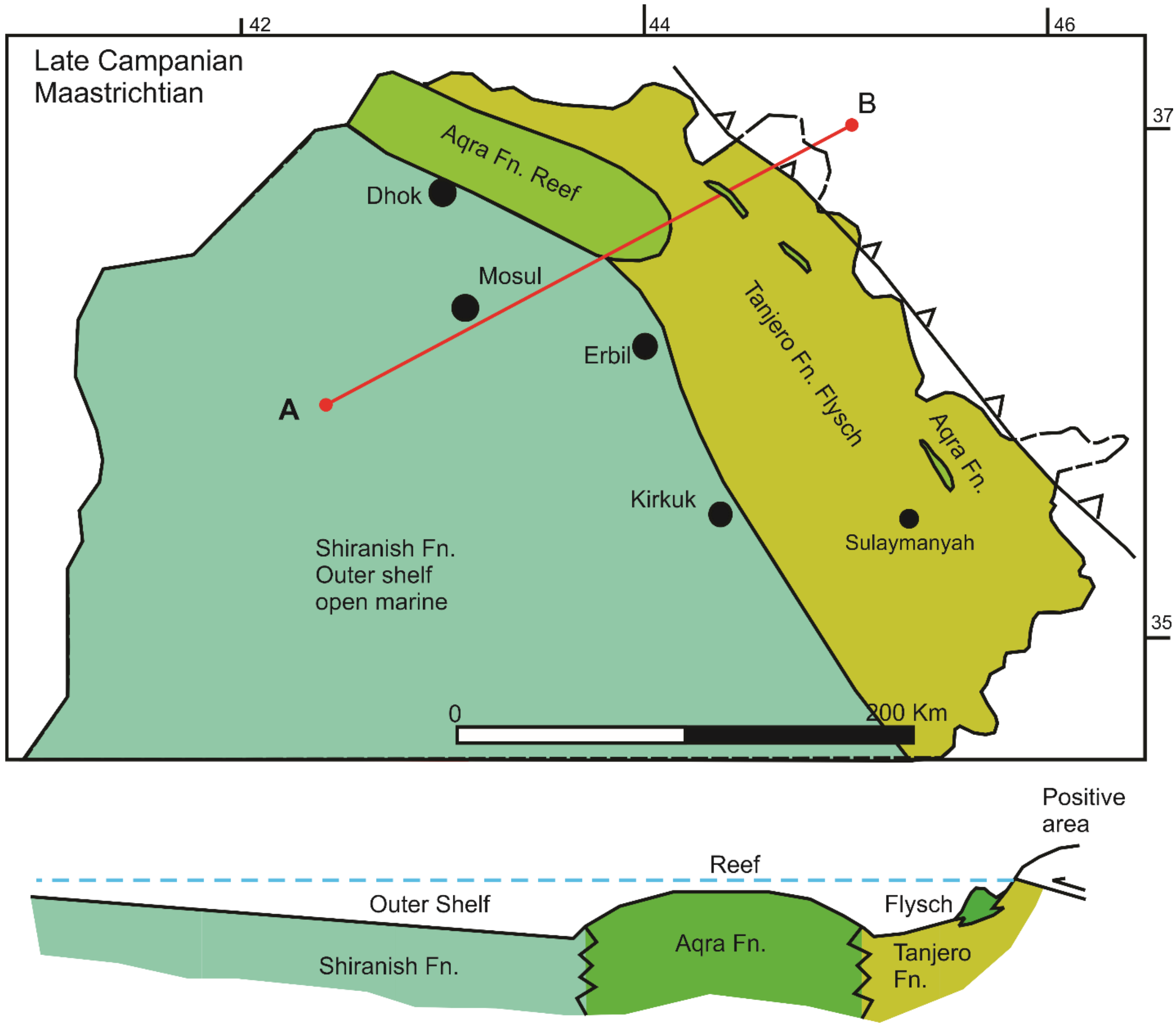

Figure 12: Paleogeographic map of Northern Iraq and KRG during Turonian to Late Campanian- Maastrichtian periods. Modified from Jassim and Guff, (2006), Ahmed et al. (2016), and Barriar et al. (2018).

Conclusions

the Late Cretaceous Period in the Northestern Kurdistan Region, Iraq is one of most complicated periods and shows different contact situations specially between Qamchuqa-Bekhme and Qamchuqa-Kometan, for this purpose thirteen section been selected, those sections has SE-NW trend from Dokan toward Bekhme gorge.

However through microfacies study of the Kometan, Bekhme and Shiranish formations 16 sub-microfacies have been recognized, which indicates pelagic open marine ramp depositional environment of Kometan Formation, open marine deep shelf environment of the Shiranish Formation and entire reef (back-reef, fore-reef, reef body) environment of Bekhme Formation.

The Kurdistan Region and North of Iraq were a pre-subduction basin during the Turonian to Early Santonian period due to the presence of the open marine outer ramp carbonate of the Kometan Formation in the east (Sulaimaniyah province exceed Hizop area) and the inner shelf of the Tanuma and Khasib formations in the center and west (Erbil province). Major regression and unconformities appeared in the West of the study region during the Middle-Late Santonian, which resulted in the erosion of the whole inner shelf facies that had formed during the Turonian-Early Santonian period. The foreland basin emerged during the Early to Middle Campanian and is characterized by flysch facies in the far northeast and the Kurdistan Region. These regions are covered by open marine of the Shiranish Formation and reef platforms of the Bekhme Formation. The Kurdistan Region was an active foreland basin margin during the Upper Campanian-Maastrichtian period, with the Tanjero Formation expanding broadly, the Aqra Reef existing in the north, and the open marine Shiranish Formation extending from the center toward the west.

Conflict of interest

The authors confirm that they are not affiliated with or involved in any organization or entity with financial interests.

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