



Integrated stratigraphic study of the Cretaceous petroleum-potential succession, Sulaimani area, Kurdistan, Iraq

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Article info

Original: 06.10.2015

Revised: 30.05.2016

Accepted: 16.06.2016

Published online:

01.07.2016

Key Words:

Cretaceous, Kurdistan,

Stratigraphy, Iraq,

Petroleum System

Abstract

The Cretaceous sequence of Kurdistan Region of northeast Iraq form an important petroleum system in housing potential source rocks such as the Balambo, Sarmord and Shiranish Formations. It also includes an important reservoir rocks supplied with good secondary porosity such as the Qamchuqa and Kometan Formations. This study examined surface and subsurface sections of these units from Sulaimani area of Kurdistan region of northeast Iraq using stratigraphic analysis, microfacies investigations, lithostratigraphic correlation in an attempt to characterize these units at this area and to give an insight regarding the stratigraphic architectural impact on the development of their petroleum system. Microfacies analyses show the occurrences of deep to shallow marine facies. It ranges between basinal foraminiferal- Oligostiginal grainstone to wackestone (Balambo, Sarmord, Kometan, Shiranish, and parts of the Tanjero Formations) to bioclastic -foraminiferal packstone to wackestone of the Qamchuqa Formation. The Dolostone part of the Qamchuqa Formation is characterized by medium to coarse crystalline planar-e to planar-s type mosaic.

The Late Cretaceous units of the Kometan, Shiranish, and Tanjero Formations in both outcrop and neighboring subsurface sections, show little stratigraphic differences within the study area from elsewhere in Kurdistan Region. The Early Cretaceous units of the Balambo, Sarmord and Qamchuqa Formations (which are the focus of this study), however, show lateral and vertical stratigraphic variations in lithology and thicknesses in both northward and westward directions. The basic difference is the change of the deep marine Oligostiginal marly limestone of the Balambo Formation into the dolomitized platform carbonates of the Qamchuqa Formation in both directions. This lateral changes passes through a transitional zone of interfingering relation, which is up to 15Km in width. This zone plays an important role in developing the Cretaceous petroleum system of the area.

Introduction

The research has been suggested by a group of geologists in the Directorate of Geological Survey and Mineral Investigation in Sulaimani, and accomplished by the cooperation of the staff of geological Department, University of Sulaimani.

Generally, the Cretaceous deposits of northeast Iraq are considered to be one of the most oil prolific successions along the Arabian Plate Margin including Iran and the Arabian Gulf region (Sadooni and Alsharhan, 2003, Sadooni, 2004, Aqrabi et al 2010, and Sharp et al., 2010). It forms part of the extensive Arabian platform which is developed during progressive transitional history of plate margin from passive to active tectonics. Recent interests in this sequence have been renewed as triggered by recent oil exploration campaign which sweeps Kurdistan Region of north Iraq. Such interests encourage different institutes to study and reexamine these deposits geologically and stratigraphically in an attempt to contribute to the

regional evaluation of Cretaceous petroleum system of Kurdistan region. The examined Cretaceous successions include the Balambo Formation (Valanginian – Turonian), Qamchuqa Limestone Formation (Hautervian – Albian), Sarmord Formation (Valanginian – Aptian), Kometan Formation (Turonian – Santonian), Shiranish Formation (Campanian – Ma'astrichtian), and the Tanjero Formation Campanian – Ma'astrichtian). Some of these units are proven to be potential reservoir rocks such as the Qamchuqa, Komtan, and Shiranish Formations in oil fields including Kirkuk, Taq Taq, Miran East, Bai Hassan, Chemchamal, and Khabbaz. Others are considered source rocks such as the Balambo, Sarmord, and Shiranish Formation. However special attention is given to the Qamchuqa and Balambo Formations and their stratigraphic relationships due to their prime role in hydrocarbon accumulation of the lower Cretaceous petroleum system. Other units which are proven to be potential reservoirs especially by developing secondary porosity, such as the Kometan, and Shiranish Formations are reviewed in brief within the general stratigraphic framework of the area.

The studied area is situated in the Sulaimani Governorate and based on surface and subsurface sections from Sulaimani area (Fig. 1). It extends mainly to the northwest of Sulaimani city between N 35° 30' and N 35° 55', and E 44° 50' and E 45° 22'.

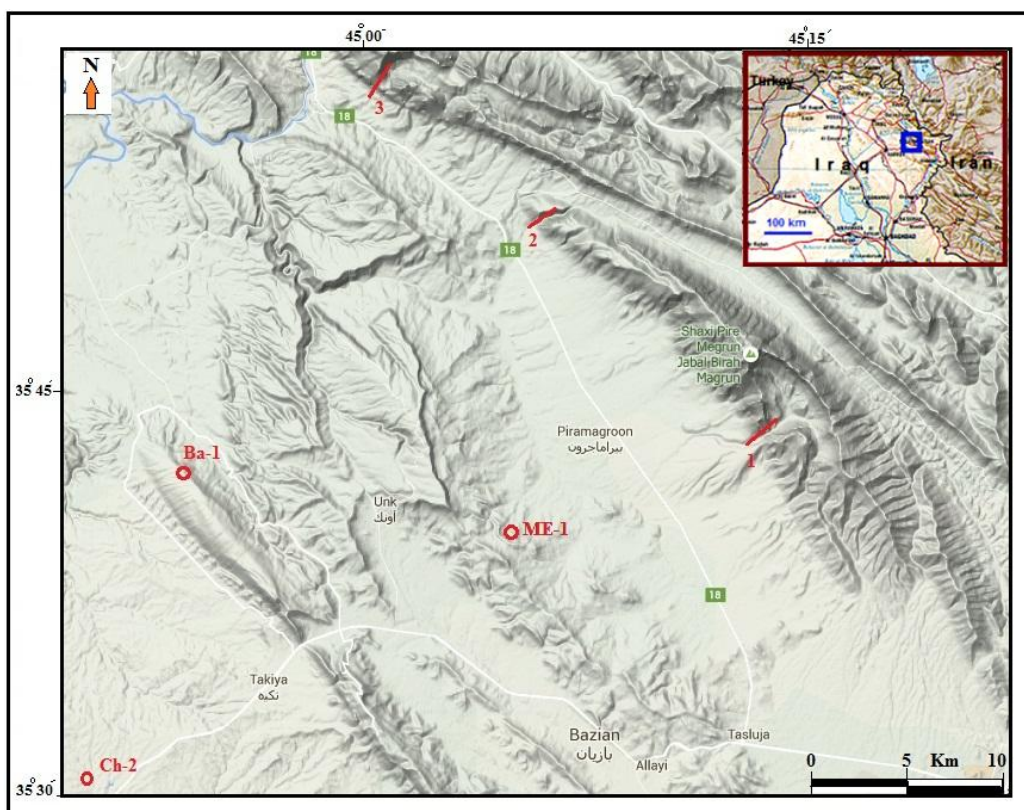


Fig. 1. General location terrain map of the study area showing distribution of the studied localities

The study area to the east is bounded by the Azmar-Surdash anticlines of the imbricate zone of northeast Iraq (Al-Qayim, et al., 2012). This part has structurally complicated Cretaceous outcrops. The area to the west is delineated by the Baranan ridge of the Qaradagh mountain range. It exposes outcrops of the Tertiary sequence. Therefore surface studies were focused on the Pira Magroon- Surdash anticlines. At this part good exposures of the interesting Cretaceous units are surfaced and become accessible by transversal valleys and gorges. Three main traverses were selected for the surface studies. These are the Zewe section which runs at the southern part of the Pira Magroon anticline, the Tabin section at the northwestern plunge of Pira Magroon anticline and the third is taken at the Qamchuqa Gorge at the Surdash anticline (Figs. 1& 2). At each locality a detailed traverse is taken across the structural strike to examine the stratigraphic succession. Along each traverse stratigraphic description and measurement were conducted including lithologic

variation, sedimentological characters, stratigraphic boundaries and associations. Samples were collected systematically for each stratigraphic unit (Table 1). All samples were thin-sectioned for petrographic examination, microfacies analysis, to assist stratigraphic differentiations. Subsurface data were collected from three wells at three neighboring oil fields to the west of Pira Magroon Mountain to show lateral extension, and to demonstrate lithostratigraphic correlation of the studied stratigraphic units. These wells are Bazian-1 (Ba-1), Miran East -1 (ME-1), and Chemchamal-2 (Ch-2).

Table 1. Samples distribution at the studied sections and units.

Sections	Tanjero	Shiranish	Kometan	Qamchuqa/Balambo	Sarmord
Zewe	3	-	4	11	4
Tabin	1	1	3	17	-
Qamchuqa Gorge	3	3	7	15	4
Total	7	4	14	43	8

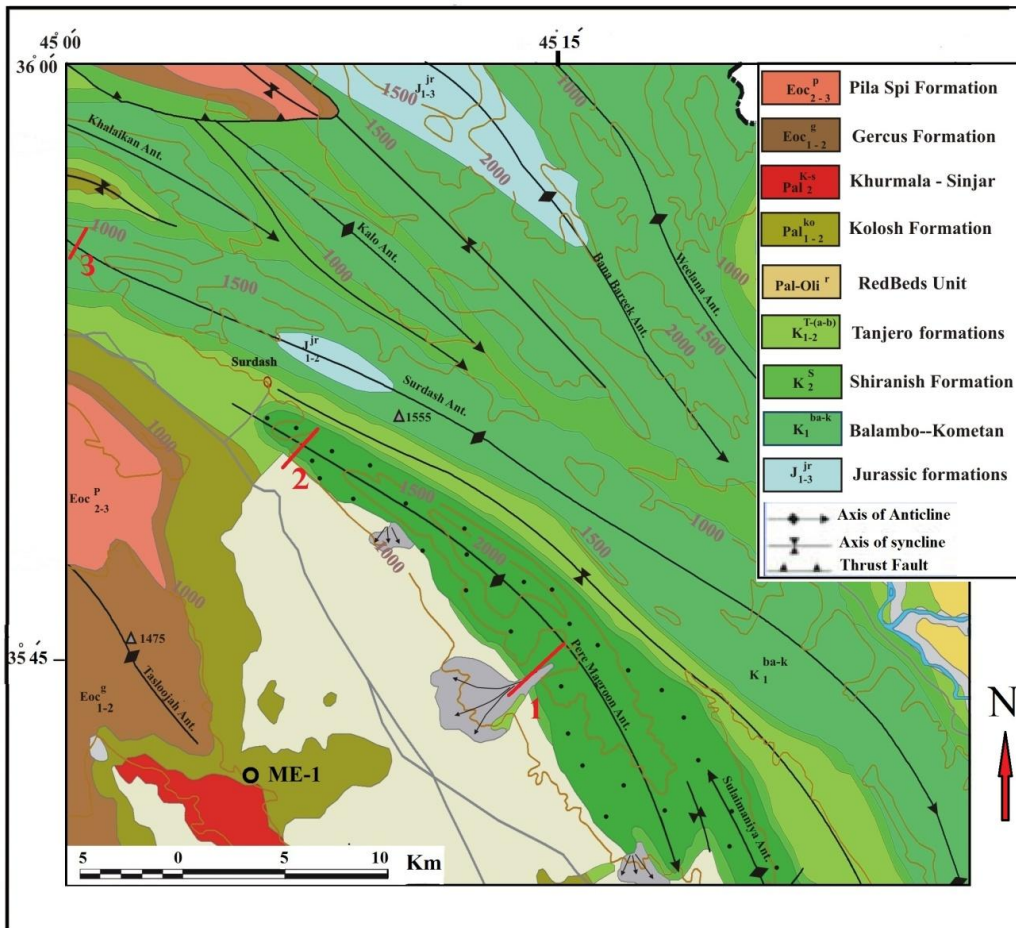


Fig. 2. General geologic map of the study area (from Ma'ala, 2008), showing location of the studied sections. (1- Zewe, 2- Tabin, 3- Qamchuqa Gorge).

Stratigraphy

The stratigraphic succession of the study area plays an important role in the development of the major folds of the area including Pira Magroon Mountain. At this huge anticline massive unit of limestone of the Qamchuqa and Balambo Formations forms the core of the structure while the softer clastic-dominated rocks of the Shiranish and Tanjero Formations exposed at flanks. The following review of the stratigraphy of the study area basically relay on field observations and stratigraphic description from three localities (Zewe,

Tabin, and Qamchuqa Gorge). Stratigraphic columns were constructed for each area (Figs. 4, 5, and 6). Results of microfacies analysis were used to refine stratigraphic sequence and differentiate between stratigraphic units. Lithostratigraphic correlation is applied to interpret stratigraphic association and subdivisions. In addition, reviews of previous studies are considered to compile the regional stratigraphic setting.

To simplify stratigraphic correlation and to avoid confusion of stratigraphic nomenclature followed from different sources, a simple stratigraphic chart is constructed to show relation between the studied stratigraphic units (Fig. 3). This chart used two standard stratigraphic nomenclature systems. The first and the widely used for outcrop area of Kurdistan region is made by Bellen et al (1959). The other system is more locally used and still in an informal stage. The latter is commonly used by petroleum geologist especially at Kirkuk area is followed using IPC stratigraphic nomenclature system published in Al Shdidi *et al.* (1995), and Haddad and Ameen (2007). Some of these informal stratigraphic names are used in this work to simplify the description of the stratigraphic subdivisions of the studied succession. The paragraphs below review the stratigraphic characters and relations of the potential units.

Lower Sarmord Unit

This is the main and lower unit of the original Sarmord Formation of Bellen et al. (1959). The formation had being subdivided into three new formations (Upper, Middle, and Lower Sarmord Formations) by Ditmar (1971) and the petroleum geologists of the Iraqi National Exploration Company especially for the Kirkuk area oil fields. This unpublished subdivision scheme was amended by Sadooni (1995) and Al Shdidi et al, (1995).

Localities AGE	(Al Shdidi et al.) (1995) (Haddad & Ameen (2007)	Localities of this study							(Bellen et al., 1959)	Localities AGE		
	Kirkuk Area	Ch-2	Ba-1	ME-1	Qamchuqa Gorge	Tabin	Zewe	Qamchuqa Gorge	Sulaimani			
Maastrichtian		Tanjero/ Shiranish	Tanjero	Tanjero	Tanjero	Tanjero	Tanjero	Tanjero	Tanjero	Tanjero	Maastrichtian	
Campanian	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Shiranish	Campanian	
Santonian	Kometan	Kometan	Kometan	Kometan	Kometan	Kometan	Kometan	Kometan	Kometan	Kometan	Santonian	
Coniacian											Coniacian	
Turonian											Turonian	
Cenomanian	Dokan/ Gulneri	Dokan			Dokan ?	Dokan ?		Dokan	Dokan		Cenomanian	
Albian	Upper Qamchuqa	Upper Qamchuqa	Balambo/ Qamchuqa	Balambo/ Qamchuqa	Q a m c h u q a	Q a m c h u q a	UD UL MD	Upper Balambo	Q a m c h u q a	UD UL MD ML LD LL	Balambo	Albian
Aptian	U. Sarmord Lower Qamchuqa	U. Sarmord Lower Qamchuqa	Lower Qamchuqa	Lower Qamchuqa				Lower Balambo				Aptian
Barremian	Lower Sarmord	Lower Sarmord	Sarmord	Sarmord				Lower Sarmord	Sarmord	Sarmord		Barremian
Hautervian												Hautervian
Valanginian	Garagu											Valanginian
Berriasian	Chia Gara		Chia Gara	Chia Gara				Chia Gara	Chia Gara	Chia Gara		Berriasian

Fig. 3. Compiled stratigraphic chart of the examined units at the studied localities showing correlation with previous studies at the neighboring areas, and compiling the different stratigraphic nomenclatures used in this work.

Generally, the unit is exposed at the central valley of the Pira Magroon anticline. The unit bottom is well exposed at the central part of the anticline at Zewe section. Thickness range between 100-150 meters. It is generally consists of buff green calcareous marlstone which alternate with cyclic beds of light gray marly limestone. Cycles are thinning upward with thickest limestone beds of up to one meter (Fig. 7). The boundary with the overlying Balambo Formation is gradational and marked by the intercalation zone of

marlstone and limestone. Qaradaghi (2007), Henson (1948), and Bellen et al. 1959. however had recognizes a sharp boundary between Sarmord and the overlaying Qamchuqa Formation at other locality from Pira Magroon anticline which is marked by a 5-10 cm. thick bioturbated horizon reflecting clear environmental changes between the two formations.

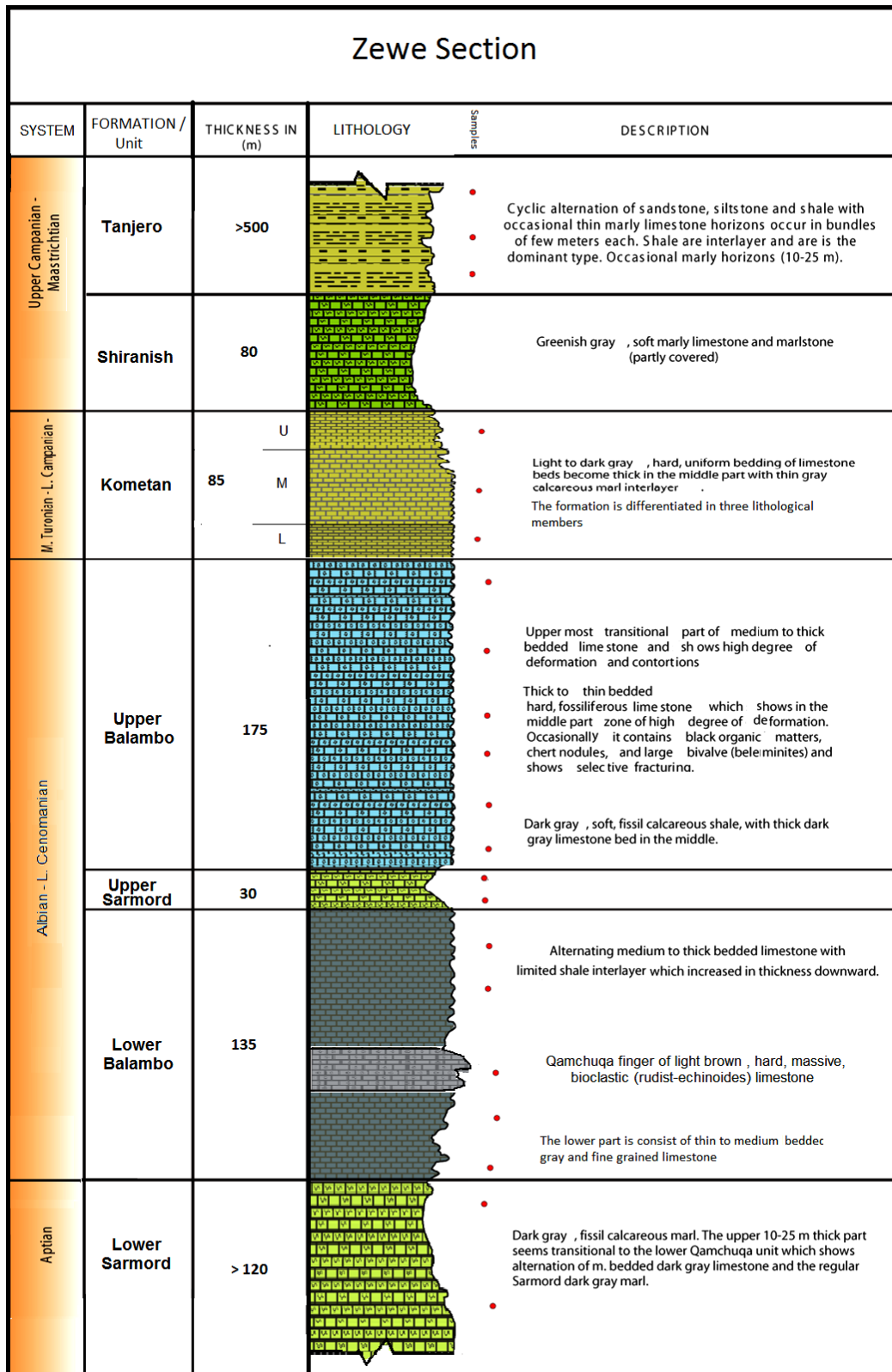


Fig. 4. Stratigraphic column of the studied sequence at Zewe gorge outlet locality. (Vertical scale is approximately 1cm= 20 meters).

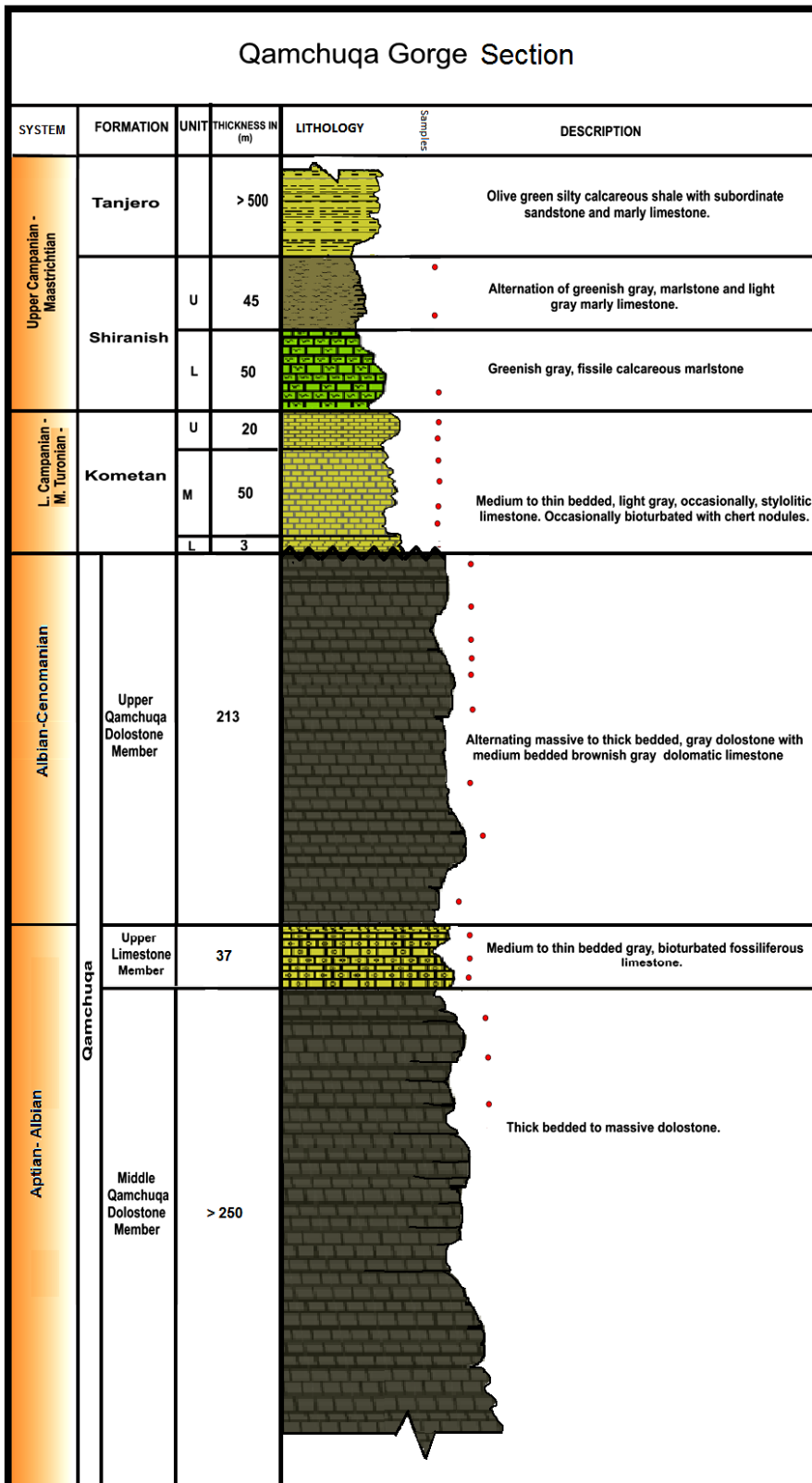


Fig. 6. Stratigraphic column of the studied sequence at Qamchuqa gorge locality. (Vertical scale is approximately 1cm= 20 meters).

The lower contact of this unit with the Chia Gara formation is often covered due to active slumping at the central valley steep sides. At Zewe no direct contact of the Sarmord Formation with the Qamchuqa Formation is noticed on both limbs of the anticline, however, the outcrops of the northeastern limb of Pira Magroon mountain show what look like an inter-fingering relation between what seems like Qamchuqa and

Balambo limestone Formations (Fig. 8). This observation is based on lithologic color differences as well as microfacies of the examined samples from the southwestern limb. The outcrop there is hard to access due to the steep cliff, and this relation is not noticed on the accessible southwestern limb.



Fig. 7. Gradational contact between the Lower Sarmord Unit and the overlying lower part of the Balambo Formation (Lower Balambo Unit) at the Southwestern limb of Pira Magroon anticline, Zewe section.



Fig. 8. Contact of Lower Sarmord Unit and the overlying Balambo Formation at the eastern limb of Pira Magroon anticline, Zewe locality. Notice the overlying massive carbonate horizon (Possibly Qamchuqa Formation) at this intermediate locality.

Lower Balambo Unit

The Balambo Formation originally defined by Bellen et al. (1959) from the type section area at Sirwan valley near Halabja (Southeast of Sulaimani city, 8 km south of Halabja) as 762 meters of marly limestone sequence. The age is designated to be Valanginian to Turonian. Azmar Mountain (to the east of the study area) by Abawi and Hamoodi (2008) shows that its age ranges between Middle–Late Albian. In addition Abawi and Hamoodi (2010) believed that the upper 63 meters of the Balambo Formation succession at Azmar Mountain is of Middle - Late Cenomanian and possibly belongs to the Dokan Formation.

The Balambo Formation at Pira Magroon Mountain is not firmly recognized and always considered as the upper part of the Qamchuqa Formation (Ma'ala, 2008). However using Abawi and Hamoodi (2008 and 2010) studies and the microfacies analysis results assist in recognition of this formation at the Zewe section replacing the Qamchuqa Formation. The thick carbonate sequence of Zewe locality which underlay the Kometan Formation is considered here as the Balambo Formation. It is subdivided by the intervention of the Upper Sarmord Unit (which is recognized here only) into two informal units: the Upper Balambo and the Lower Balambo Units.

The Lower Balambo Unit is recognized by the highest limestone ridge of the southwestern flank of the Pira Magroon Mountain. It is about 135 meters thick. It is characterized by alternating massive and thick bedded, light gray fossiliferous limestone with medium to thick bedded clayey limestones (Fig. 9a and 9b). It, occasionally, contains up to 10 cm chert nodules occurs in horizons (Fig. 9c). Macrofossils are not common but infrequently recognized including belemnite or ammonite fossils (Fig. 9d). The middle part of the unit display high degree of deformation and selective fracturing (Fig. 9b).

At the lower half of the unit a horizon up to 20 meters thick is characterized by massive grayish fossiliferous limestone. Fossils are fragmented with large fragments of pelecypods (Fig. 9e). Microfacies analysis of samples from this horizon (See the following section) indicate the occurrence of bi-clastic rudist- echinoides grainstone to packstone. Contact with the underlying Lower Sarmord Unit is seemingly conformable and characterized by zone of intercalation of light gray limestone of the Lower Balambo Unit and grayish marlstone of the Lower Sarmord Unit. The upper contact with the Upper Sarmord Unit is partly covered by talus and seemingly conformable.

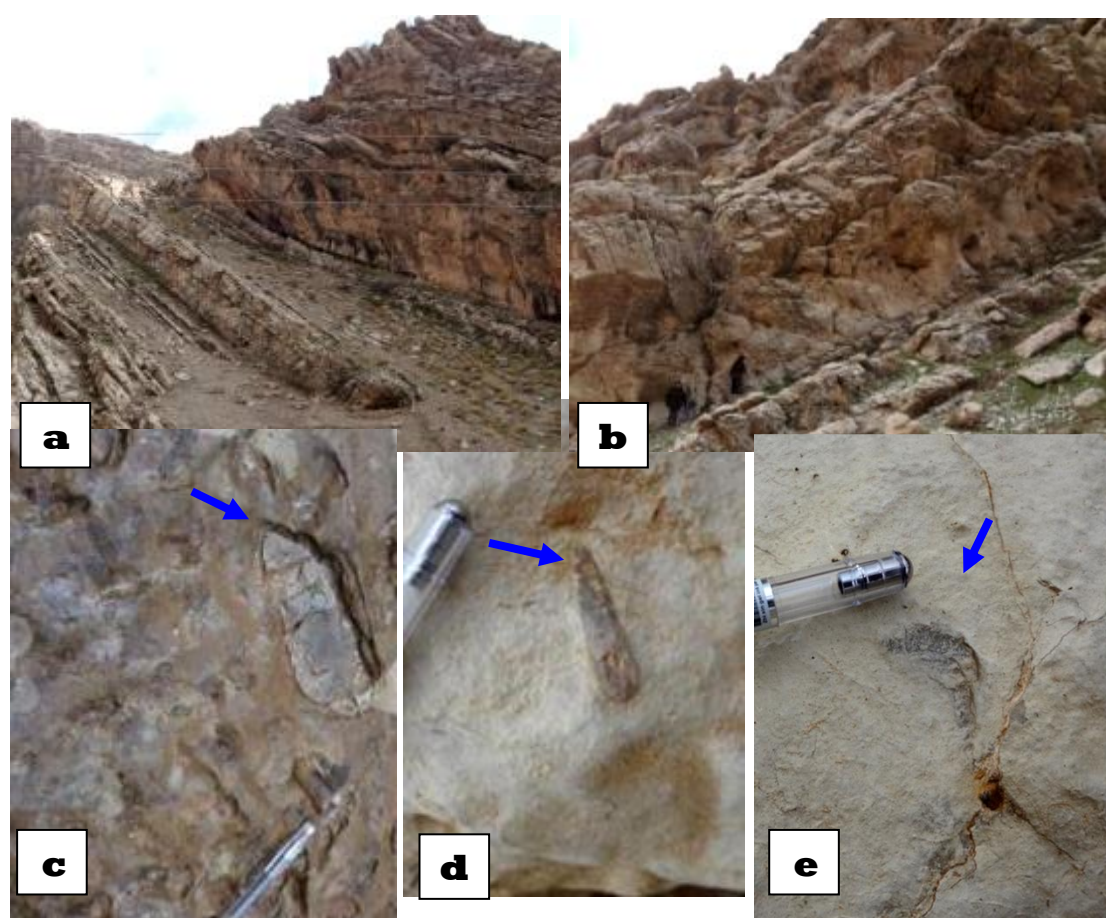


Fig. 9. Field photos of the Lower Balambo Unit at Zewe locality. a) Alternation thick to massive and medium to thin bedded limestone. b) Highly deformed and intensively fractured massive limestone. c) Chert nodule horizon at massive limestone beds. d) Belemnite (arrow) of the fossiliferous gray massive limestone unit. e) Pelecypods fragments at the lower half of the Lower Balambo Unit.

Upper Sarmord Unit

It is typically exposed at Zewe locality. It reaches up to 30 meters in thickness. The soft sediments of this unit form a characteristic deep valley between the hard and protruding limestone ridges of the Upper Balambo Unit on one hand and the and Lower Balambo Unit on the other hand (Fig. 10). It is lithologically characterized by soft, fissile, black to dark gray (weathered to buff color) calcareous shale (Fig. 11). The shale is infrequently alternate with thick horizons of yellowish gray marly limestone. The upper boundary with the Upper Balambo Unit is sharp and characterized by clear lithologic changes. The lower boundary is partly hidden underneath soil cover.

Upper Balambo Unit

The formation is again recognized only from the Zewe locality with thickness of 175 meters (Fig. 4). It is characterized by thick to thin bedded, hard, gray, fossiliferous limestone (Fig. 12a). It shows in the middle part, a zone of high degree of deformation (Fig. 12b). Occasionally, it contains black organic matters, chert nodules and large belemnites and ammonites (Fig. 12c, 12d and 12e).



Fig. 10. Sharp boundary between limestone of the Upper Balambo Formation and the black shale of the Upper Sarmord Formation.

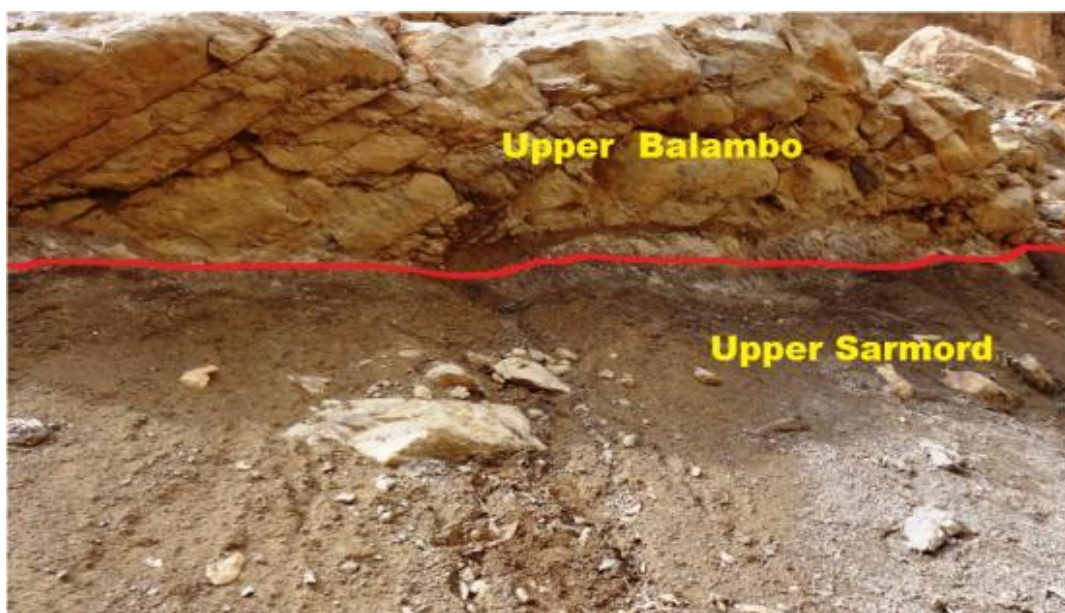


Fig. 11. Buff-colored (weathered) black shale of the Upper Sarmord Unit below limestone ledge of the Upper Balambo Unit .

The formation especially at thin bedded units shows selective fracturing. The lower contact with the black shale of the Upper Sarmord Formation is sharp and possibly unconformable, and the upper contact with the Kometan Formation is seemingly gradational.

Qamchuqa Formation

The Formation is well exposed in Qamchuqa gorge (the type locality), at Tabin section and as a finger in the Zewe section. In all cases the formation show no much differences in term of lithologic characters (Figs. 5 and 6). The formation at the type-section area and according to Bellen, et al.(1959) is subdivided into six alternating dolomite and limestone members (UD, UL, MD, ML, LD and LL). This subdivision is very clear in both Qamchuqa gorge, and Tabin localities. However, focus is given to the upper three members (UD, UL, MD) of dolostone, limestone, and dolostone to avoid repetition of the description and due to the inaccessibility of the lower part of the formation at Tabin locality. The general lithology of the formation is the same at both localities and characterized by thick hard sequence of alternating gray, fossiliferous limestone and dark gray crystalline dolostone units.

Below is a brief review of the stratigraphic characters of these three members.

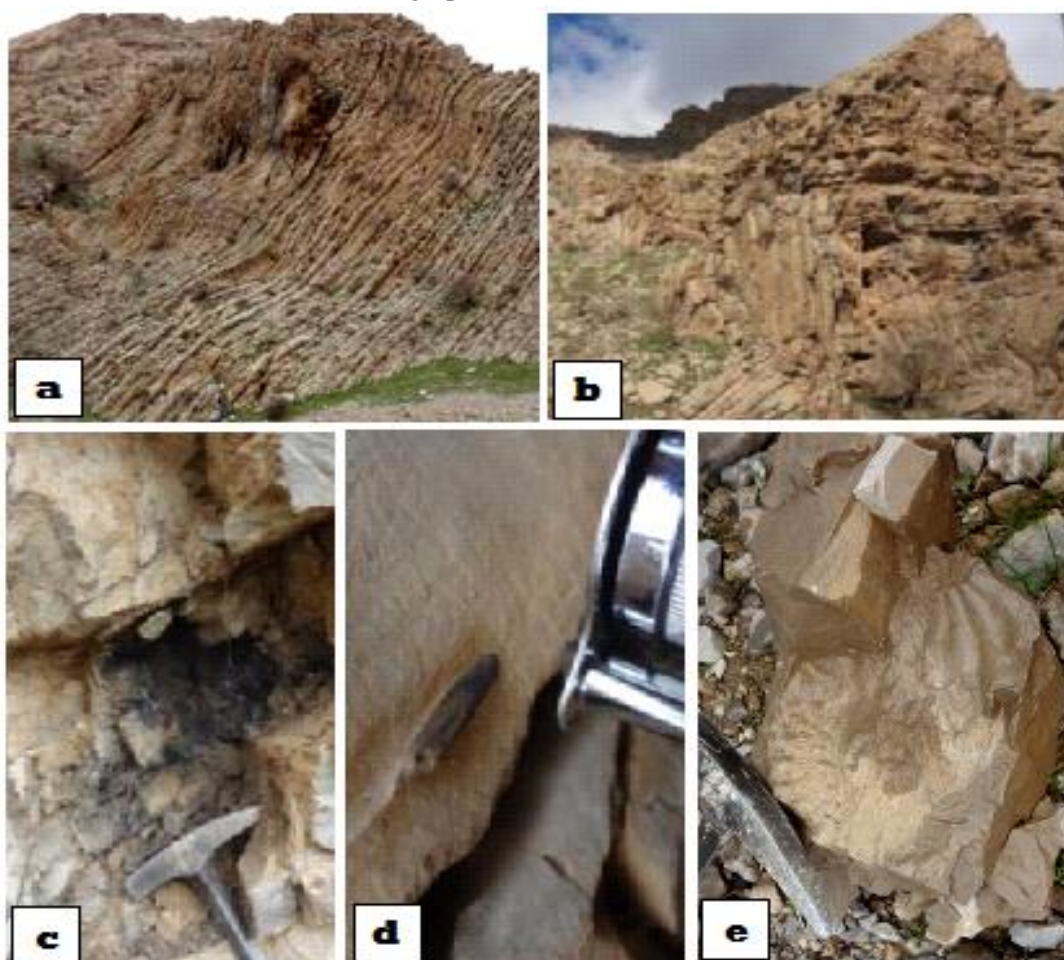


Fig. 12. Field photos of the Upper Balambo Unit. a) Medium to thick bedded limestone at upper part. b) Highly deformed medium bedded strata in the middle part. c) Pocket of black organic matter at fracture zone. d) Belemnite cast replaced by chert. e) Ammonites of the Upper Balambo Unit.

Lower Dolomite Member

The measured thickness of this unit is >100 and >250 meters in Taben and Qamchuqa Gorge sections respectively. It forms a major scarp developed at the central part of the formation. It is characterized by dark brown, hard, dense, and massive to thick bedded dolostone unit (Figs. 13a). The massive dolostone units are the main resistant and protruding bodies. It shows common vuggy fabric associated with secondary white

dolomite cement (Fig. 13c). Other parts are intensively fractured with open multi directional fracture systems (Fig. 13b). The lower and upper contact of this unit is seemingly sharp.

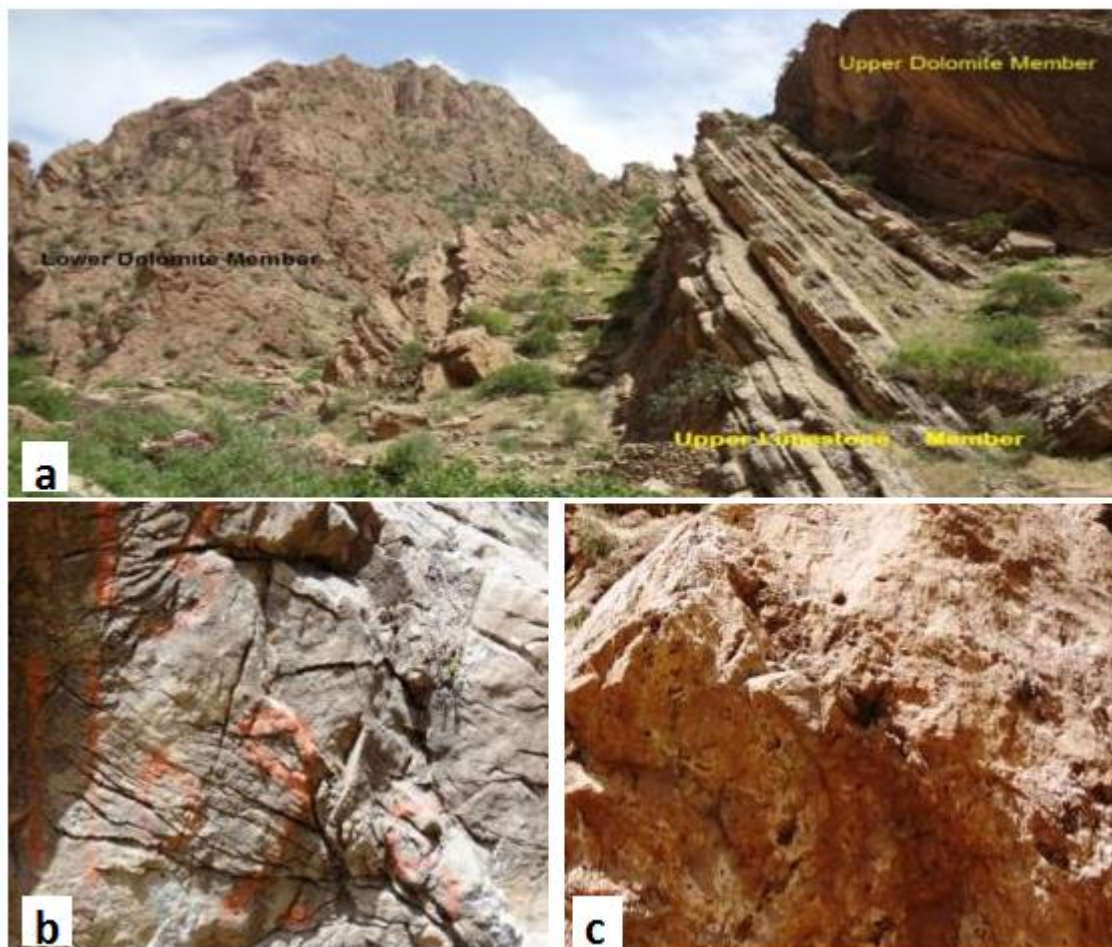


Fig. 13. a) Alternating medium bedded dolomitic limestone with massive to thick bedded gray dolostone of the Lower Dolostone member at Qamchuqa gorge locality. (b)- Open fracture system of the dolostone, Lower Qamchuqa Formation, Qamchuqa Gorge locality, (c) Vuggy dolostones with white dolomite cement of the massive dolostone units of Lower Qamchuqa Formation, Qamchuqa Gorge.

Upper Limestone Member

This member is clearly recognized as a generally light gray and softer unit sandwiched between the two hard massive dark dolostone units (Figs. 14a and 14b). It has a thickness of 30 and 37 meters in Tabin and Qamchuqa Gorge sections respectively. It is generally characterized by a light gray to greenish, slightly argillaceous, fossiliferous and intensively bioturbated limestone. Bioturbations shows light brown fillings which highlight a *Thalassinoid* type of bioturbation (Fig. 15a). Intensive bioturbation and fracturing generate the rubbly looking features of these rocks (Fig. 15 b). At upper part beds shows shallowing marked by cross laminated (Fig. 15c) or parallel laminated calcarenite (Fig. 15d). Microfacies study of this unit shows that it is dominated by miliolid bioclastic wackestone.

Upper Dolomite Member

This Formation is recognized at Tabin locality (150 m) and at the Qamchuqa Gorge locality (213m). It is characterized by cyclic alternation of dark gray, thick bedded to massive dolostone with medium bedded, gray, dolomitic limestone (Fig. 16a).



Fig. 14. a) The upper dolomite unit overlaying the light gray bioturbated limestone member, Tabin section. b) Subvertical beds of the bioturbated upper limestone member, Qamchuqa gorge section.



Fig. 15. Photos of sedimentological features of the upper limestone member, Qamchuqa gorge section. a) Thalasiniodes bioturbation. b) Rubbly limestone due to fracturing and bioturbation. c) Cross laminated calcarenite. D) Parallel laminated calcarenite

Four major cycles were recognized (Fig. 16b). The dolomitic limestone units are thinner in occurrences and occasionally associated with marl strings or inter-layers. The massive dolostone units on the other hand represent the thicker and harder parts. It is commonly vuggy with vugs are up to 10cm wide, and partly filled by white dolomite cement (Fig. 16c). These vugs are aligned in a sub parallel pattern following fracture system pattern. Fractures are either filled by late dolomite white cement or remained open by successive leaching (Fig. 16d). The upper boundary of this unit with the Kometan Formation show gradational contact. However based on microfossil contents there seems to show a faunal break between the two formations (Buday and Jassim, 1987).

In addition, Bellen et al. (1959), and Ameen and Gharib (2013) had recognized from Dokan area (25 km to the north of the Qamchuqa Gorge locality) the thin Dokan and the Gulneri Formations between the Qamchuqa and the Kometan Formation. Abawi and Hammoudi (2010) and (Karim, *et al.*, 2013) suggest the possibility of the occurrence of the Dokan Formation above the balambo Formation at Azmar mountain. The missing of Dokan and Gulneri formation from the Pira Magroon area, and its occurrences in neighboring areas such as Dokan and Azmar mountain indicate that there is a possible stratigraphic gap between the two formations at the study area.

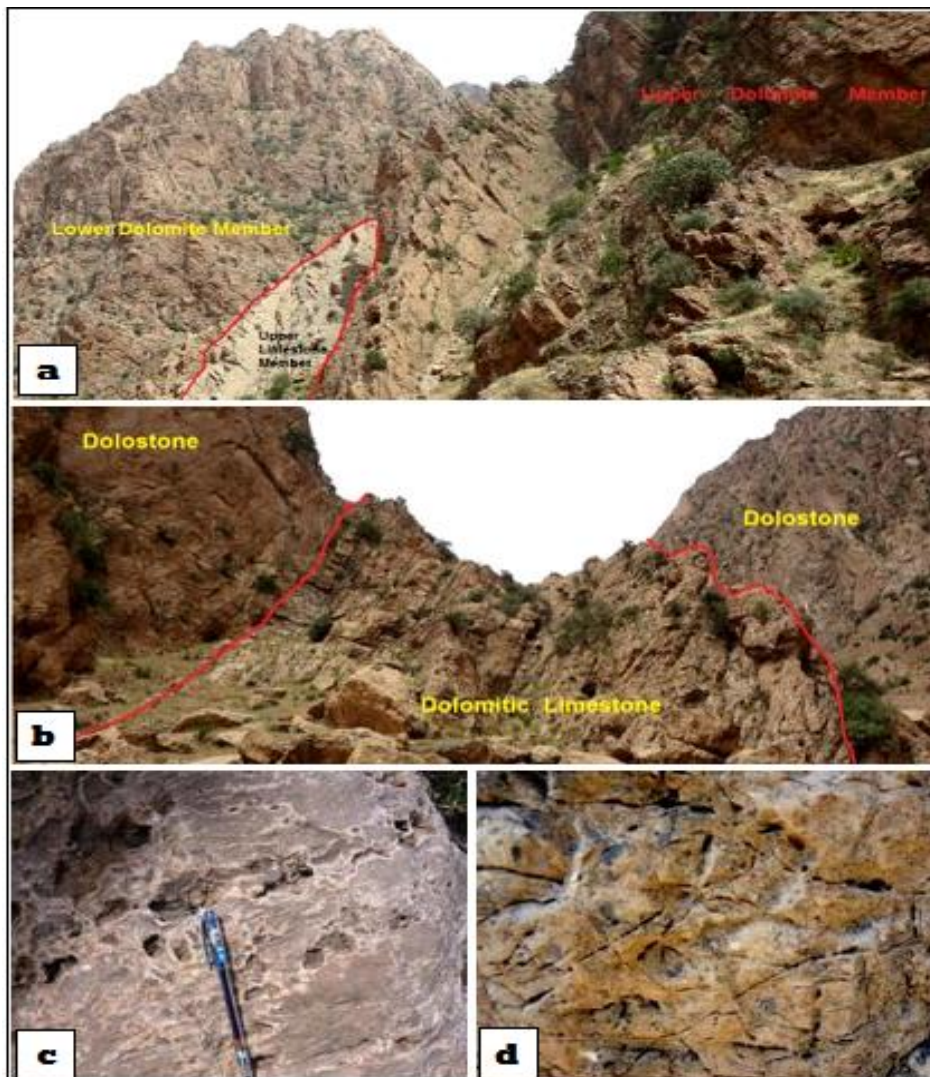


Fig. 16. (a) General view of Lower Dolomite Member, Upper Limestone Member, and Upper Dolomite Member succession at Qamchuqa gorge locality. (b) Cyclic alternation of medium bedded dolomitic limestone and massive dolostone of Upper Dolomite, member, Qamchuqa gorge locality (c) Massive gray, vuggy dolostone with white dolomite cement filling fractures and partly the vugs of the Upper Dolostone Member, Qamchuqa gorge locality. (d) Open fractures in a massive dolostone unit Upper Dolostone Member, Qamchuqa gorge locality.

Microfacies Analysis

Microfacies analysis and description depend basically on the petrographic examination combined with sedimentological and paleontological characteristics observed from field sections and examination of the collected samples (hand specimens and thin-sections). Special attention was given to microfossils and benthic foraminiferal assemblages especially index species due to their importance as stratigraphic and environmental indicators.

Most of the examined samples are deep marine carbonate facies with occasionally intermittent shwallowing. Brief description of diagenetic processes is attempted to assist in recognition of original depositional fabric. Fossil groups identification were assisted comparing examined slides with previously studies section of the same stratigraphic interval such as Ghafor *et al.* (2004), Abawi and Hammoudi (2008 and 2010), Daoud (2011). The distributions of overall petrographic characters in the studied samples were considered to help in vertical facies differentiation. Nomenclature of microfacies emphasizes petrographic major components in addition to the dominating fabric or crystal size (for dolomite microfacies). For dolomite crystal size classification the work of Lucia (1995) is used Classification of microfacies followed scheme of Dunham (1962) with its modification by Embry and Klovan (1971). For dolomite microfacies however for dolomite work of Sibley and Gregg (1987) is followed, which combined observed and microscopic features to describe different dolomite fabrics. Environmental interpretations of the identified microfacies were attempted following Flugel (2009). Below is brief description of the identified microfacies.

a) Foraminiferal Wackestone- Pckstone

The most important grain type of this microfacies planktonic foraminifera of different species. Foram test are usually floating (in case of wackestone) with little fragmentation (Fig. 17a). Bioclastis are skeletal debris of similar forams. Matrix is often clayey lime mud as in the cases of Shiranish Formation. The other type is characterized by dense laminated arrangement of planktonic foraminifera of different assemblages (Fig. 17b). The foraminifera of the latter are embedded in a lime mud as the case of the upper part the Kometan Formation.

b) Bioclastic Foramineferal Wackestone

This microfacies is characterized by the minor occurrence of planktonic foraminifera in addition to silt-size undifferentiated bioclastic debris of most probably foraminifera (Fig. 17c). Matrix is fine crystalline lime mud occasionally clayey. This microfacies is noticed in the Shiranish, Kometan and Balambo Formations of Zewe and Qamchuqa Gorge section. Deep marine pelagic environment is expected using planktonic forainifera assemblages (Fulgel, 2010).

c) Foramineferal Oligosteginal Packstone

Oligostegina in addition to abundant planktonic foraminifera (*Rotalipora Sp.*) are the characteristic grain type of this facies (Fig. 17d). Their densely packed fabrics in lime mud matrix indicate their pelagic environments. Bioclasts of both types were also recognized and partially recrystallized. This microfacies is recognized from the lowermost part of the Kometan Formation of Qamchuqa Gorge section (Fig. 6).

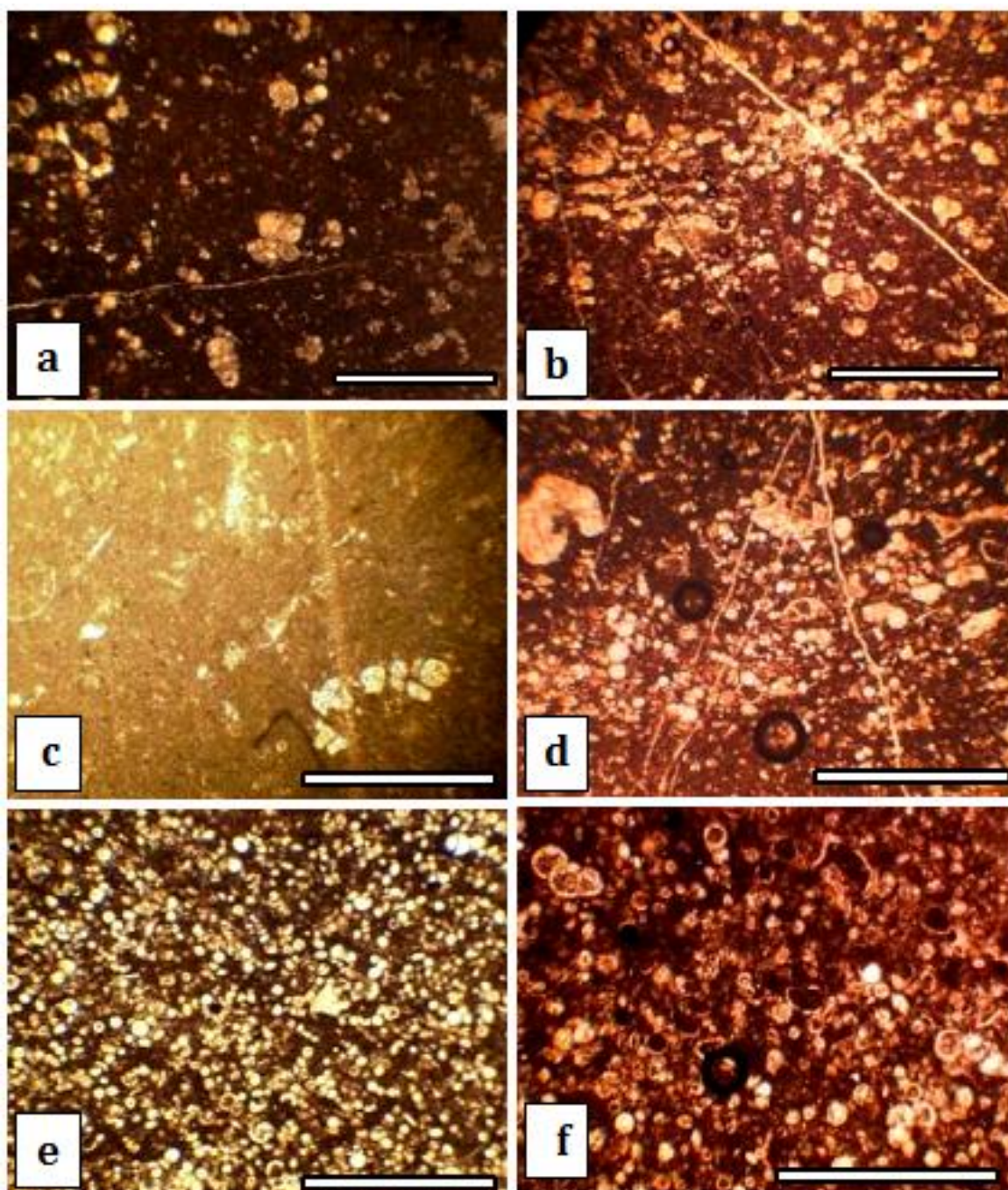


Fig. 17. a) Planktonic foraminiferal wackestone of the Shiranish Formation, Qamchuqa Gorge section. b) Planktonic foraminiferal packstone of the Upper Kometan Formation, Qamchuqa Gorge section. c) Bioclastic foraminiferal wackestone of Qamchuqa Limestone Formation, Zewe Section. d) Foraminiferal Oligosteginal packstone of Lower Kometan Formation, Qamchuqa gorge section. e) Oligosteginal grainstone of the Upper Balambo Unit, Zewe section. f) Oligosteginal grainstone with floating planktonic foraminifera, Lower Kometan Formation, Qamchuqa gorge section. Bar is one millimeter.

d) Oligosteginal Grainstone

A densely packed Oligosteginal limestone is the characteristic features of this microfacies (Fig. 17e). Other minor components include planktonic foraminifera and their skinny bioclasts (Fig. 17f). In addition bioclasts of ostracoda can be seen too. Based on the domination of the Oligostegina this microfacies represents a pelagic environment. This microfacies were recognized in limestone samples located below the Kometan formation of the Zewe and Qamchuqa Gorge section. This facies is recognized at the upper most part of the Balambo Formation in both localities (See discussion below).

e) Bioclastic Grainstone

Bioclasts of this microfacies is dominated by sand-sized, angular fragments and debris of echinoderms, rudists, and mollusk (Fig. 18a and 18b). Echinoderm grains are characteristically overgrown by syntaxial calcite cement (Fig. 18b). Other grains include intraclasts and lumps of calcareous origin (Fig. 18c), matrix is dense micritic type. It is believed to represent a shallowing interval within the deep marine setting of the rest of the formation. This microfacies is recognized from one sample at the middle part of Lower Qamchuqa Formation at Zewe section.

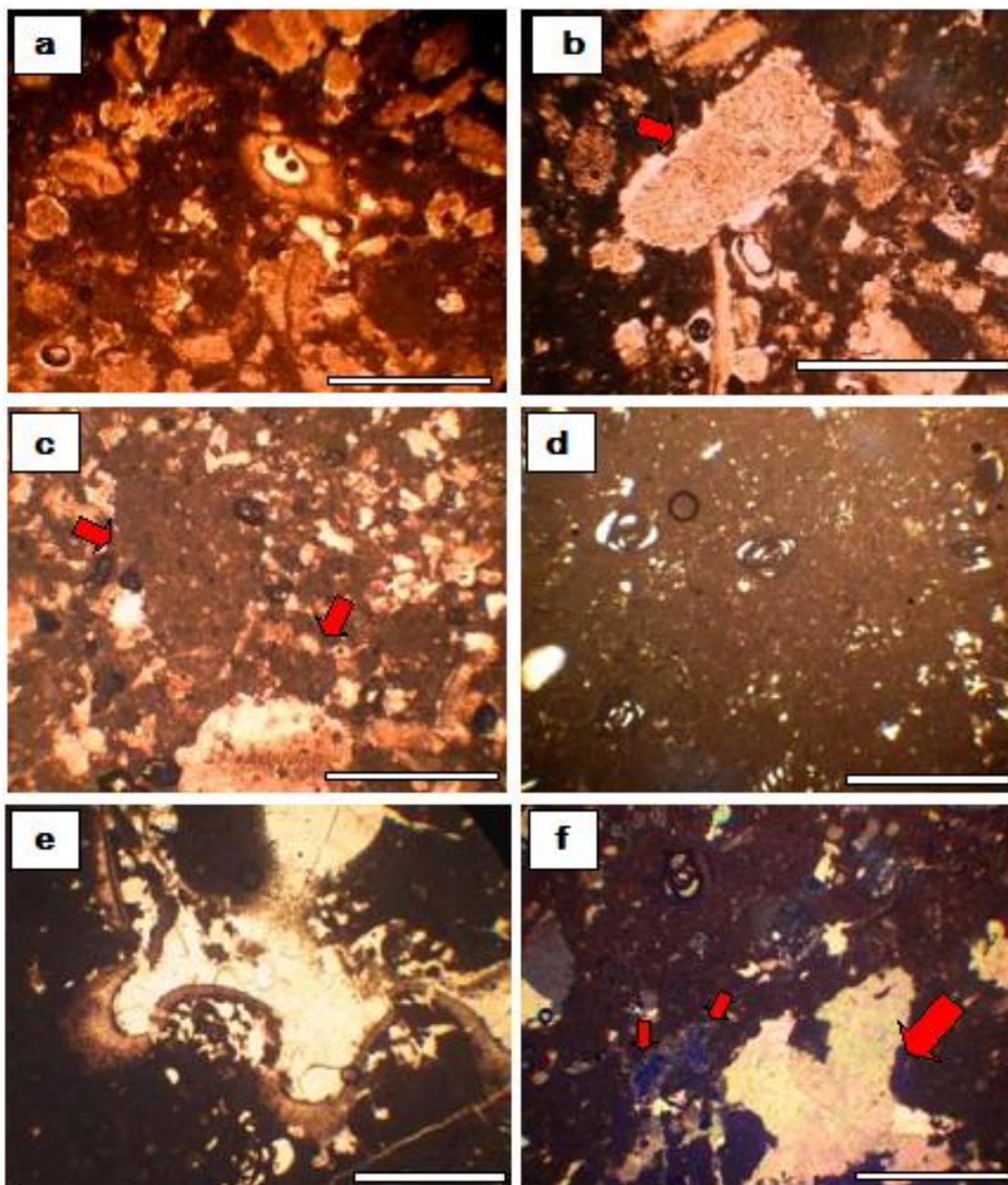


Fig. 18. a) Bioclastic Grainstone of the Qamchuqa Formation finger, Zewe section. Bioclasts are dominated by rudist and echinoderm fragments. b) Bioclastic grainstone showing sand-size echinoderm plate with syntaxial calcite rim, Zewe section. c) Carbonate intraclastic grains of the bioclastic grainstone microfacies of Qamchuqa Formation finger at Zewe section. d) Miliolid wackestone of an intensively bioturbated horizon at the middle part of Qamchuqa Formation, Qamchuqa Gorge section. e) Large shell fragment (probably of rudist) in the bioturbated lagoonal facies of the Qamchuqa Formation, Qamchuqa Gorge section. f) Miliolid Wackestone with leached moldic porosities (small arrows) which are, in some cases, filled by sparry calcite cement (large arrow). Bar is one millimeter.

f) Miliolid-Bioclastic Wackestone

This microfacies is related to 37 meters thick horizon of soft, bioturbated, sometimes laminated limestone located at the middle part of Qamchuqa Formation of the Qamchuqa Gorge section (Fig. 6). It is believed that this horizon represents the upper limestone member of the Zewe area. The characteristic component of this microfacies is floating miliolids (Fig. 18d) and other benthic forams in addition to bioclasts or shell fragments (Fig. 18e) and Ostracods in a lime mud. Unstable bioclasts are frequently leached into moldic porosity or replaced by spray calcite cement (Fig. 18f).

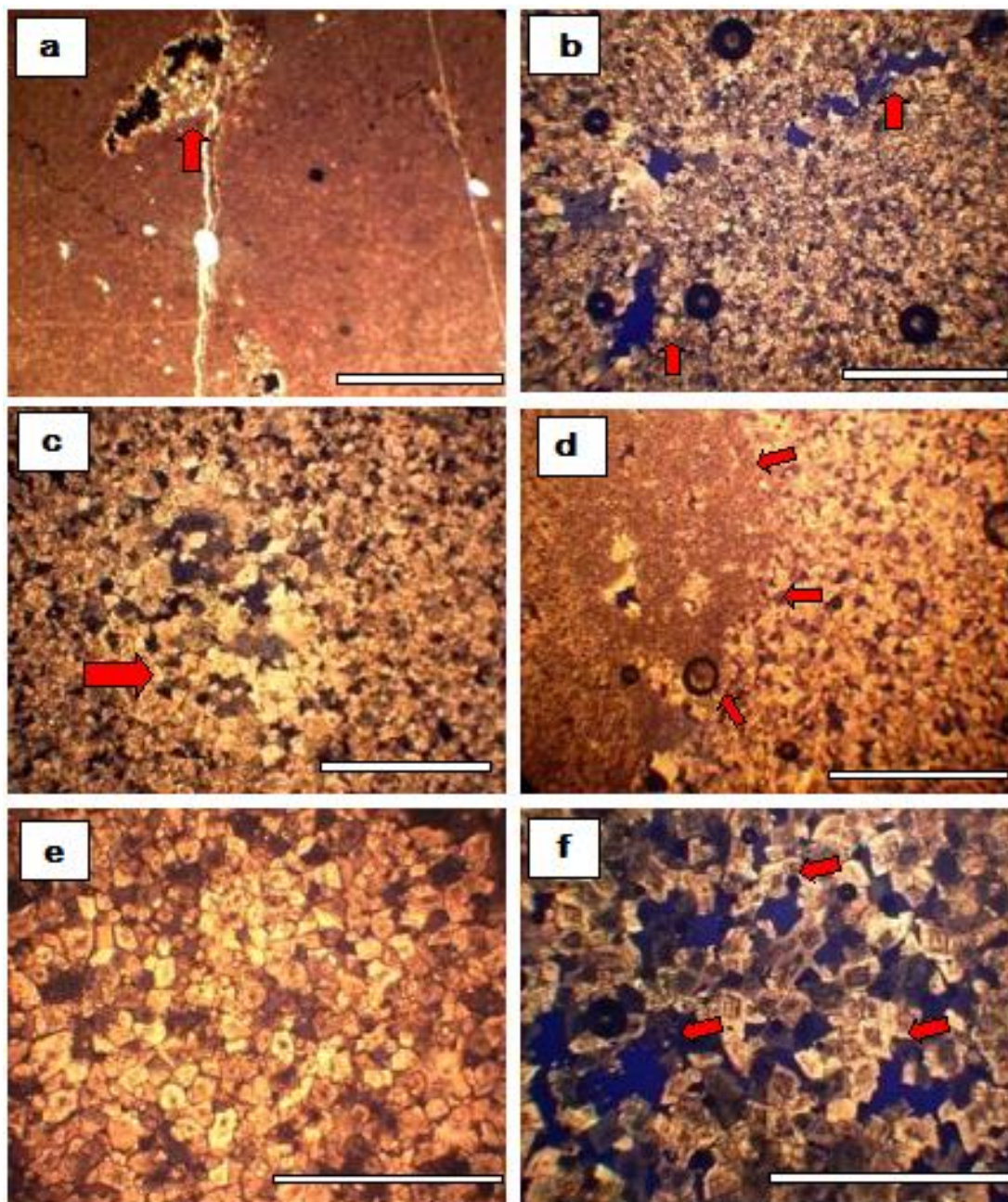


Fig. 19. a) Clayey mudstone microfacies of the Upper Sarmord Unit. Rare ghosts of foraminifera partly replaced by pyrite. b) Medium crystalline dolomite mosaic of planar-s to nonplanar-a type at the upper parts of the Upper Qamchuqa Formation,. Fracture porosity (arrows) is partly filled by dolomite cement. XN. c) Medium crystalline dolomite mosaic with vugs (arrow) filled by coarse crystalline dolomite. Qamchuqa Formation,. d) Ghost of Orbitolina? (arrows) in a medium crystalline dolomite mosaic, Qamchuqa Formation. XN. e) Coarse crystalline dolomite mosaic of plana-e type showing rhombs with cloudy centers. Lower part of Upper Qamchuqa Formation. f) Coarse crystalline dolomite mosaic of planar-e type showing rhombs with clear zonations. Lower part of Upper Qamchuqa Formation. XN. (a) from Zewe section, (b-f) from Qamchuqa gorge section. Bar is one millimeter.

g) Clayey Mudstone

This microfacies represent the dark gray to black shale or clayey marlstone of the Upper Sarmord and Lower Sarmord Units (Zewe section). It shows rare skeletal debris or floating bioclasts which shows replacement by pyrite reflecting a reducing early diagenetic setting (Fig. 19a).

h) Medium Crystalline Planar-s Dolomit

It is characterized by intensive dolomitization. This microfacies comprise medium crystalline dolomite mosaic of planar-s to planar-a types (Fig. 19b, c and 19d). Crystal sizes are of medium size class of Lucia (1995) which range between (20 – 100 μ). Common fracture and micro-vugs porosity are noticed and often filled by successive coarse crystalline dolomite cementation (Fig. 19b). Ghosts of bioclasts (most probably of *Orbitolina*) were rarely recognized (Fig. 19c). It is recognized in the upper part of the Qamchuqa dolomite sequence in Qamchuqa gorge section.

Owing to the abundant mouldic and micro-vugs porosities, these microfacies might be developed by intensive dolomitization of a limestone with original bioclastic packstone type (Randazzo & Zachos, 1984)

i) Coarse Crystalline Planar-e Dolomite

This type of dolomite common to the lower part of the dolomite section of the Qamchuqa Formation at the Qamchuqa Gorge section (Fig. 6).

It is characterized by coarse crystalline dolomite mosaic with common planar-e to less common planar-s forms (Fig. 19e and f). The intensive sucrosic dolomitic mosaic shows coarse crystal fabric of (> 100 μ) with general euhedral shape. Cloudy centered dolomite crystals (Fig. 19e) and zoned dolomite mosaic (Fig. 19f) are commonly recognized which indicate advance stage of dolomitization (Randazzo & Zachos 1984, and Machel, 2005). This type of dolomite, In some cases occurs also as a very coarse crystalline, pore filling dolomite cement within the medium crystalline dolomite mosaic (Fig. 19c). Common porosity types are intercrystalline, microvugs and fractures (Figs. 19b and 19f).

Stratigraphic Subdivisions

The examined sections were aligned almost along the tectonic strike of the Zagros Mountain which trend NW – SE. The lateral stratigraphic variation, if any, will be reflecting lateral changes other than deposition changes related to an on shore-off shore systematic changes. The stratigraphic sequence in both Qamchuqa gorge and Tabin localities show close similarities in thickness, type of stratigraphic units and even their subdivisions (Fig. 20). The differentiation of the Shiranish Formation at both locality into upper and lower units based on lithologic variation (Figs. 5 and 6) simulate basic differentiation at the type locality area (See Al-Qayim *et al.*, 1986). Similarly the Kometan Formation is subdivided into three members based on lithologic characterization (Fig. 4, 5 and 6). For the Qamchuqa Formation, only three lithologic members of the six members recognized by Bellen *et al.* (1959) could be identified in this study due to inaccessibility. However these three units are well correlated in both localities. The stratigraphic sequence at Zewe locality shows some interesting variation in lithology and facies types. This difference is represented by the replacement of the Balambo Formation by the Qamchuqa Formation. The foraminiferal-Oligostigonal argillaceous, light gray, limestone of the Balambo Formation at the Zewe section is replaced by the alternating units of dark brown crystalline dolostone and light gray, argillaceous limestone of the Qamchuqa Formation at Tabin and Qamchuqa Gorge localities (Figs. 4, 5, and 6). This interesting stratigraphic relation has being previously noticed by Henson (1950) and Bellen *et al.* (1959), and discussed by Ameen and Karim (2008), Abdul Hassan *et al.*, (2011) Al-Hakari (2011). These studies postulated the rapid change from the subtidal carbonate platform of the Qamchuqa Formation from the northwest into the deep marine basinal marlstone and limestone of the Balambo Formation towards the south east due to the Middle Cretaceous paleogeographic and tectonic setting of the area (Fig. 3). This stratigraphic change is important as we consider the basic components of the Cretaceous petroleum system of northeast Iraq (see below discussion).

The subdivision of the Balambo Formation at Zewe locality is informal and applied here due to the intervention of its sequence by a 30 meters of black to dark gray shale and marlstone of the Upper Sarmord Unit. The Upper Sarmord name is borrowed from the stratigraphic nomenclature system of the Kirkuk area using lithostratigraphic correlation. To stratigraphically amend this subdivision in a systematic presentation, a regional geological survey of the formation around the study area would be necessary to approve the persistency of these units, and to establish a regional and formal subdivision scheme.

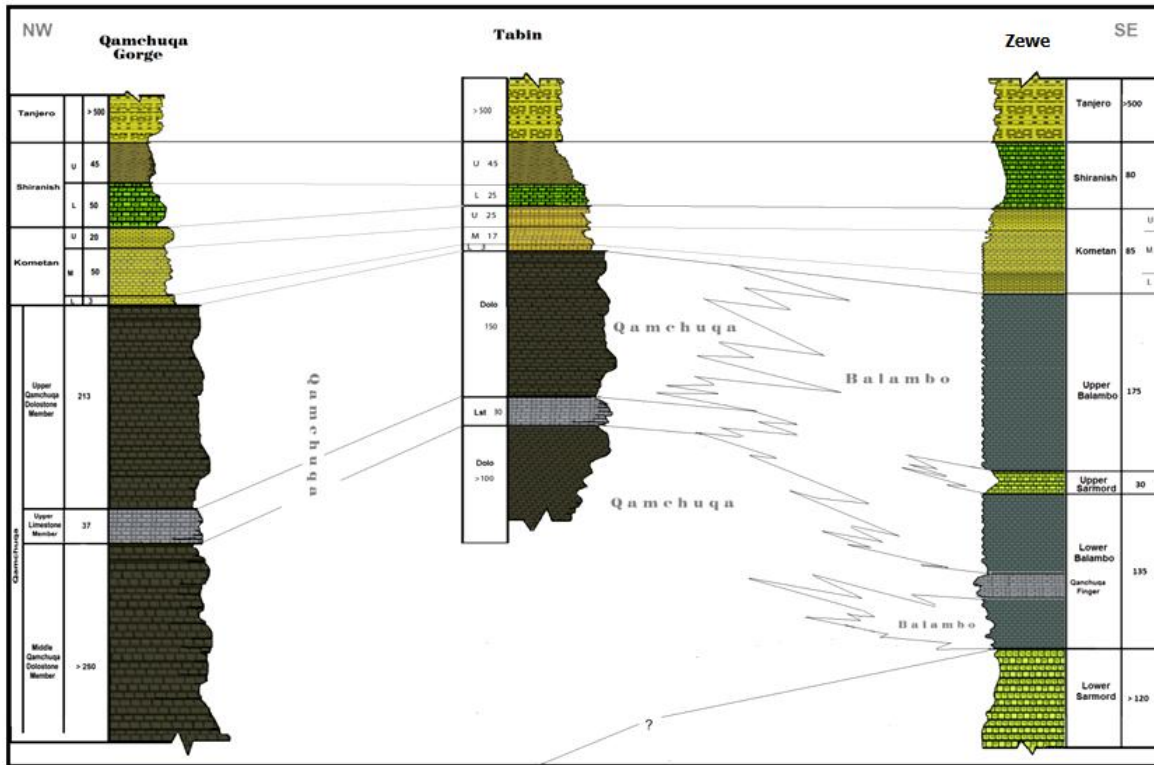


Fig. (20) Stratigraphic correlation across the studied sections.

Subsurface Stratigraphy

Subsurface data from three neighboring oil fields (Miran East, Bazian, and Chemchamal) were used here to show westward continuation of the examined stratigraphic units from Pira Magroon Mountain. These wells from northeast to southwest are: ME-1, Ba-1, Ch-2, (Fig. 1). Gama ray logs of these wells and lithologic interpretation by oil company's staff are shown in Figure (21). Gama-ray logs mark the boundaries between units clearly and indicate sharp contacts at some cases. The general stratigraphic sequence of the studied units especially at well ME-1 and Ba-1 are not much different from the surface geology which includes the Sarmord, Qamchuqa, Balambo, Kometan, Shiranish, and Tanjero Formations. The only difference is the occurrence of Dokan Formation at well Ch-2. This is resemble the stratigraphy of the Kirkuk area (AlShdidi, et al. 1995), owing to the location of well Ch-2 which is situated close to Kirkuk area rather than the studied outcrop area. The other explanation is related to the patchy distribution of the Dokan Formation. Moreover, the occurrence of the Dokan Formation at well Ch-2 matches the Azmar mountain stratigraphy (see Abawi and Hamoodi, 2010), or possibly misidentification of the lower part of the Kometan Formation.

Other minor differences are related to lateral facies changes and local lithologic variations. The correlation between lithologic characters and thickness are fairly uniform. The possible occurrences of the Balambo Formation at the upper part of Qamchuqa Formation at both well ME-1 and Ba-1 is conceivable and reported at both wells (Fig. 21). This stratigraphic relation is quit correlatable with Zewe section stratigraphy which

shows the interchanging of the Balambo Formation with the Qamchuqa Formation. Further westward and in most of the wells of Kirkuk area oil fields, the Qamchuqa Formation becomes the only representative of the Aptian-Albian sequence. At this area the lower part of the Qamchuqa Formation, especially, at well Ch-2, as well as the Kirkuk oil field wells (AlShdidi et al. 1995) display better inter-fingering relation with the Sarmord Formation (Fig. 21).

Regional Stratigraphy and Petroleum Accumulation

The detailed examination of the outcrop sections from the Pira Magroon and Surdash mountains and the cross-correlation with the subsurface sections shows a close similarity in thicknesses and lithologic characters, however, gave the opportunity to detailed differentiation of these formations into subdivisions and members. For example the Shiranish and Kometan Formations at the outcrop sections are differentiated into further lithologic units or members (Figs. 4, 5 and 6). The partly covered Tanjero Formation at the three localities limits its lithostratigraphic differentiation. The striking difference is the replacement of Balambo Formation by the Qamchuqa Formation. This is noticed as we move northwestward from Zewe to Qamchuqa gorge section, whereby the foraminiferal-Oligostigial argillaceous limestone of the Balambo Formation at the Zewe section is replaced by the alternating units of Dolostone and limestone of the Qamchuqa Formation at Tabin and Qamchuqa Gorge localities (Figs. 4, 5, 6). This difference is also noticed when correlating outcrop section of Zewe locality with the subsurface sections to the west of the outcrop area (Fig. 22). The Balambo Formation of the Zewe section is changed into Qamchuqa Formation with influences of Balambo Formation in the upper part as in the litholog of wells ME-1 and Ba-1 (Fig. 21). Further westward into the Kirkuk area the Formation is completely changed into Qamchuqa Dolomite and limestone (Al-Shdidi, et al., 1995, and Al-Qayim et al., 2010). This interesting stratigraphic relation has being previously reported by many workers including Henson (1950), Bellen et al., (1959) Ameen and Karim (2008) Abdul Hassan et al., (2011) and Al-Hakari, (2011). Owing to the relatively short distance between Zewe and Tabin localities on one side, and the distance between Zewe and the well ME-1 on the other side, the lateral transition zone between the two formation seems to be rapid and narrow. The Qamchuqa Formation sediments represent wide spectrum of platform carbonate representing shallow marine conditions of shelf environments (Ameen, 2008 and Al-Qayim, 2015). The Foraminiferal- Oligostegial, and sometimes radiolarian marlstone and limestone of the Balambo Formation represent a deep marine and basinal facies extends towards the south east of the Qamchuqa carbonate platform. This transitional zone is extended in the study area for 10-15 kilometers and run in a general in a northeast-southwest trend (Fig. 23). This map is constructed using this study data in addition to the examined sections a barrowed stratigraphy from final well reports of three additional wells including (Kirkuk-109, Jambour-16, and Khor Mor- 9). This zone is believed to represent a narrow and steep cliff of a possible normal fault scarp along which the Balambo trough is stepping down rapidly. The fairly uniform width and narrow extension, and the rapid facies change across this zone from shelf to deep marine (pelagic) support such inference. This stratigraphic relation become an interesting issue as oil-charged reservoirs of the Qamchuqa dolostone and limestone being discovered from several fields located next (northwestwards) to this transitional zone (Fig. 23). These oil fields includes: Jambour, Bai Hassan, Khabbaz, Kirkuk, Taq Taq, Chemchamal, and Miran, (Al-Qayim and Rashid, 2012). Thus this zone could play an important role in the development of the Cretaceous petroleum system of northeast Iraq.

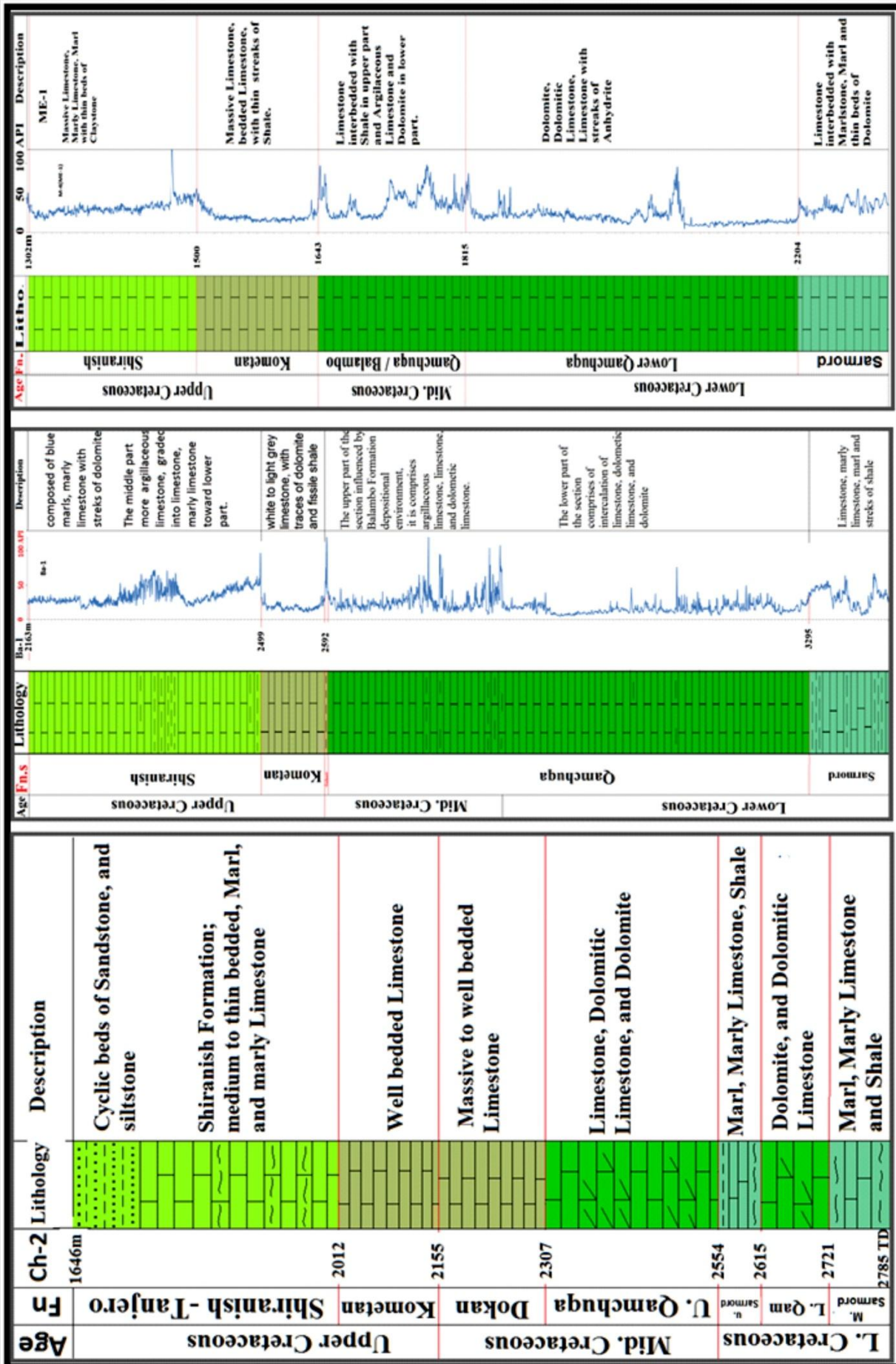


Fig. 21. Subsurface stratigraphic correlation of the studied sequence at three selected wells.

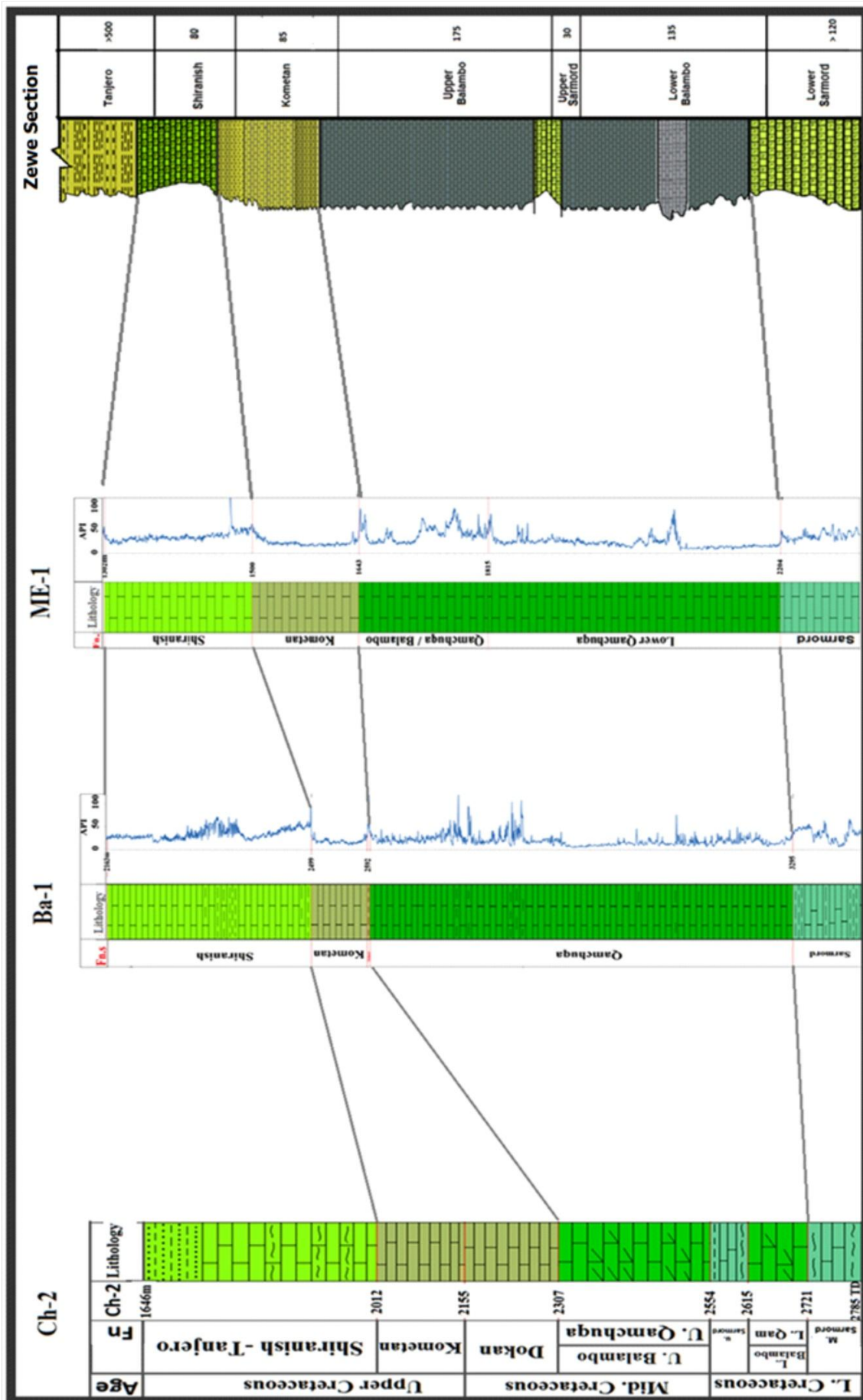


Fig. 22. Stratigraphic correlation of surface and subsurface sections of the study area

The Cretaceous petroleum system is the most important in Iraq and includes important parts of the AP8 and AP9 megasequences (Aqrawi, *et al.*, 2010). The Lower Cretaceous units seem to form the major components of this system. The thick basinal sediments of the Garague, Sarmord and the Balambo Formation are forming potential source rocks for charging fractured carbonate reservoir to the north and west anticlinal structures. One of the charging source rocks to these structures is believed to be the Balambo/Sarmord Formations of the Hautervian-Cenomanian of the southeastern trough.

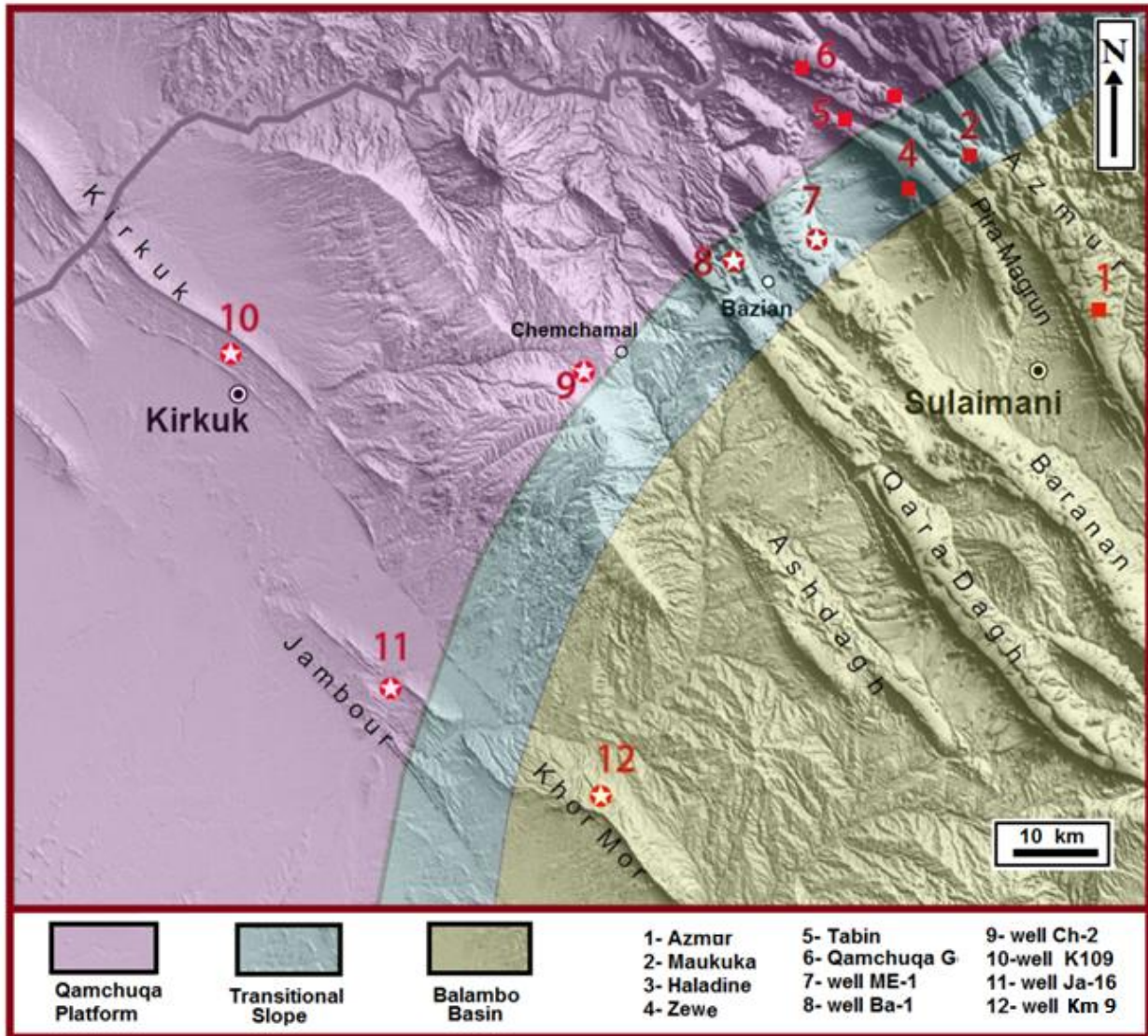


Fig. 23. Paleofacies map of the study area sketching the lateral stratigraphic relationship between the Qamchuqa platform carbonate facies and the basinal marlstone of the Balambo Formation.

Potentiality of the Balambo-Sarmord basinal facies as a good source rocks for the Lower-Upper Cretaceous carbonate reservoirs of north Iraq is noticed by (Ibrahim, 1983, Aqrawi, *et al.*). The lower part of the Balambo Formation has TOC value of 0.9% in Pulkhana-5 well, but average value in Kirkuk area reaches 1.2 - 8.8% (Habba and Abdulla, 1989). This and the thick section of the Balambo Formation makes it a major source for the reservoirs of the Kirkuk embayment (Sadooni and AlSharhan, 2003, Sadooni, 2004). The formation is believed to enter the oil window by the Oligocene time (Ibrahim, 1983) prior to the major folding phase of northeast Iraq. The Qamchuqa Formation's carbonates, on the other hand, forms the major Cretaceous reservoirs in several fields located to the north and north west of the Balambo-Sarmord Basin such as Taq Taq, Miran West, Bazian, Chemchamal, Kirkuk, Bai Hassan, Jambour, and Khabbaz oil fields (Fig. 24). Moldic- intergranular porosities of these platform carbonated are greatly accentuated by

Conclusions

The integrated examination of the stratigraphic units of the Lower- Upper Cretaceous interval from Sulaimani area of Kurdistan Region of northeast Iraq, reveal important points regarding their lithologic characterization, stratigraphic status and associations. The correlation with subsurface equivalents in the westward direction gives insight regarding hydrocarbon accumulation. These points summarized as follow.

- 1) The stratigraphic examination and microfacies analysis of outcrop sections from Pira Magroon–Surdash Mountain shows similar stratigraphic status for the Late Cretaceous Units (Kometan, Shiranish, and Tanjero) to the other localities of northeast Iraq. The units of the Early Cretaceous time (Balambo, Qamchuqa and Sarmord) shows interesting differences in lithology and microfacies and lateral stratigraphic relations.
- 2) Correlation of the outcrop stratigraphic sections with equivalent sequence from subsurface sections of neighboring oil fields especially in the westward area shows general similarities and little differences in stratigraphic characters.
- 3) Microfacies analysis of the examined units range between basinal foramineferal- oligostigonal grainstone to wackestone (Balambo, Sarmord, Kometan, Shiranish, and parts of the Tanjero Formations) to biclastic -foramineferal grainstone-packstone to wackestone of the Qamchuqa Formation. The dolostone of the Qamchuqa Formation is well developed and characterized by medium to coarse crystalline planar-e to planar-s type dolomite mosaic.
- 4) An interesting lateral stratigraphic relation between the Qamchuqa carbonate platform and the Balambo basinal marlstone and limestone is recognized and discussed within the framework of the Cretaceous petroleum accumulation. The lateral replacement of the first by the second in the southeast direction passes through transitional zone of 10- 15 km in extension and characterized by inter-fingering zone of both units. This zone could furnish the required path for lateral oil migration from the source area (Balambo basin) up dip into the dolostone reservoirs of the Qamchuqa platform in a northwest direction.

Acknowledgments

The authors would like to thank the directorate of the geological survey of Sulaimani for their support in providing assistance in field transportation and thin –section making.

Well Logs for this work and other well data were provided by the Ministry of Natural Resource to whom the authors express their gratitude.

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