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Integrated depositional model of the Carbonate Kirkuk Group of Southern Kurdistan-Iraq

Ala A. Ghafur

Natural Resources Engineering and Management-University of Kurdistan-Hawler (UKH)

30 Meter Avenue 44001, Erbil-Iraq

Abstract:

The carbonate Kirkuk Group succession hosts major hydrocarbon reserves in the southern Kurdistan-Northen Iraq. This is why investigations into this succession started a long time ago, especially for oil exploration.

In this research numerous microfacies were identified from the Kirkuk Group and interpreted as having been deposited in a ramp setting based on lateral variations of the microfacies; gradual deepening with no evidence of slope break or effective barriers. A depositional model has been generated from the overall palaeoenvironmental interpretations of the microfacies in which the analysed microfacies indicate palaeoenvironments ranging from terrestrial to open marine settings; nine major depositional environmental zones have been identified and correlated with the standard Cenozoic carbonate ramp model. These zones distributed across the ramp setting, dipping southwest, in which zone 1 is a terrestrial deposit; zone 2, 3, 4 and 5 belong to the inner ramp; zone 6, 7 and 8 belong to the middle ramp and zone 9 belong to the outer ramp and basinal settings.

Key words: Kirkuk Group, microfacies, Oligocene, Carbonate, Kurdistan, Iraq.

Introduction:

The Kirkuk Group represents a major part of the “Main Limestone” (Middle-Upper Eocene and Oligocene). The term “Main Limestone” is an informal term introduced to indicate the first main oil pay zone of the Kirkuk structure. It consists of the Avanah and Jaddala Formations of Eocene age and those nine Oligocene formations of the Kirkuk Group that occur in the Kirkuk structure (Bellen, 1956, Bellen et al, 1959 and Al-Naqib, 1960). The Early Miocene evaporite of the Fatha (formerly known as the Lower Fars) Formation (Burdigalian age ‘15.6-18.5 Ma’ according to Grabowski and Liu, 2009; 2010*)* acts as the cap rock for the reservoirs in the northern part of Iraq including the studied area.

The Kirkuk Group in the Low Folded Zone “LFZ” is recognized as a complete set of nine formations (Shurau, Sheikh Alas, Palani, Baba, Bajawan, Tarjil, Anah, Azkand and Ibrahim) in one stratigraphic package. The disappearances of certain formations of the Kirkuk Group may reflect the palaeo-configuration of the basin (Majid and Veizer, 1986). However in the High Folded Zone “HFZ” the Kirkuk Group formations are usually missing unless few places. This is evident due to the presence of conglomerates of variable thickness called Basal Fars Conglomerate (BFC) that are located between the Late Eocene (Pila Spi Formation) and Early Miocene (Fatha Formation). The implication of the possible partial presence of Kirkuk Group members in the High Folded Zone will certainly increase the potential of hydrocarbon in the studied area.

Most of previous studies have interpreted the depositional environment of the Kirkuk Group as a back reef/reef–fore reef–basinal succession. This group is bounded below by the Late Eocene Avanah Formation in most of the sections in the area studied while; the upper boundary is either the Early Miocene Jeribe Formation (early Burdigalian (18.5-19.6 Ma) or the Early Miocene Fatha Formation (middle-late Burdigalian (15.6-18.5 Ma) (Bellen, 1956; Bellen et al., 1959; Grabowski and Liu, 2010; Ghafur, 2012; Lawa and Ghafur, 2015).

Objective:

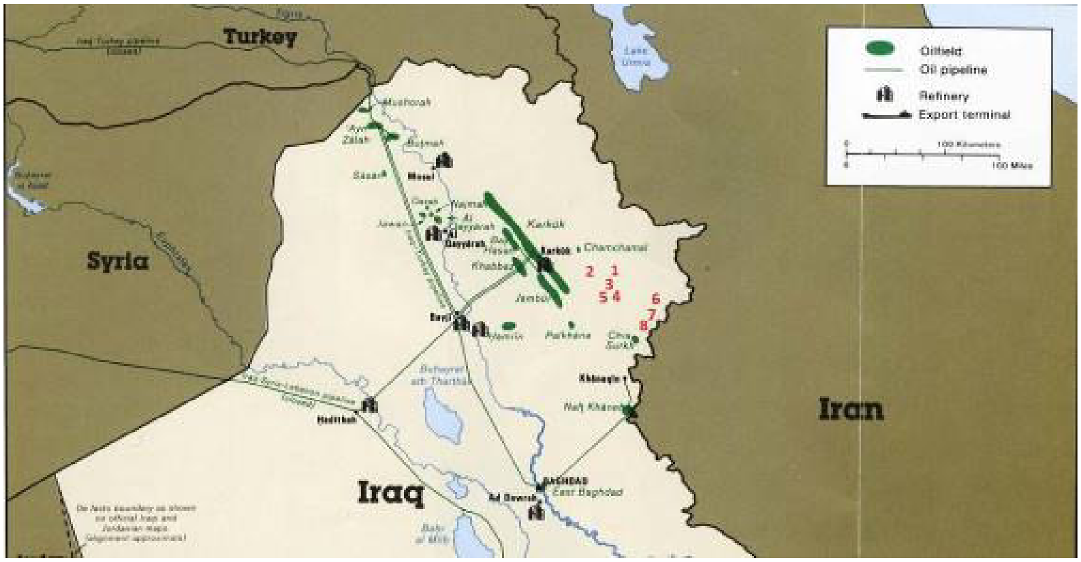
The main aim of this research is to document the different microfacies of the Kirkuk Group, facies relationships, and their environmental interpretations in order to produce an integrated depositional model and compare it with regional and global data.

Study area:

Despite the Kirkuk Group having been documented by several authors in different areas of Iraq, especially in the Kirkuk area, this study offers facies architecture of the Oligocene-Early Miocene Kirkuk Group, with some of the sections being studied for the first time, and based on studies of eight outcrops in southern Kurdistan and north-eastern Iraq. The study area is located in the southern part of Kurdistan bounded by latitude 34° 45’ to 35° 20’ and longitude 45° 15’ to 45° 50’ (Figure 1).

The study area covers eight outcrops in four main structures; the Sagrma, Aj-Dagh, Bamu and Sharwal-Dra anticlines in the south of the Sulaimani area. The total thickness of individual outcrops ranges between 26m to 186m in the areas studied, while the thickness of the Kirkuk Group only ranges between 4.5m to more than 122m.

Figure 1: Map shows the location of the studied area in northern Iraq.



Methodology:
Several field visits took place in the the southern Sulaimani area in northern Iraq. Eight localities were chosen for study in four different structures; Aj Dagh, Sagrma, Bamu and Sharwal Dra Anticlines. Samples were collected according to changes in the physical property of the limestone where obvious lithofacies changes occurred and or every one to two metres with no obvious change. The section was also logged during the sample collection. All the hand specimen samples were brought back to lab in order to saw the hand specimens to be ready for making thin-sections. In total over 300 hand specimen samples were prepared in the laboratory to finalize the preparation for making more than 300 thin-sections. In the last stage, the thin-sections were left un-covered in order to produce half stained thin-sections which is based on Dickson's (1965, 1966) procedure using Alizarin Red S (ARS) with Potassium Ferricyanide (PF) stains. Lasty the examination of thin-sections under transmitted light microscope were took place and stratigraphic columns were generated from SedLog software.

Microfacies descriptions:
Twenty-two different Microfacies/Sub-microfacies have been recognized in the eight field areas studied (see Table 1). They have been differentiated based on lithology, bioclasts and diagenesis. The most widely used classification of carbonate rock is by Dunham (1962). This classification was modified by Embry and Klovan (1971) to include the include reef textures. The classification was further revised by Wright (1992). In this study the latter classification scheme have been used for limestone classification. Moreover, the comparison charts after Baccelle and Boesellini (1965) has been used for estimating the percentage of each skeletal and non-skeletal grain in the microfacies.

Each Microfacies is described separately (See Table 1). Detailed microfacies description and sedimentary logs include: lithology, age, formation names, fossil content and facies are summarized in Appendix 1 and 2.

Table 1: Microfacies names with brief microfacies descriptions including percentage of each of the skeletal and non-skeletal grains with a number of figures.

Microfacies name	Microfacies descriptions:	Location no.	Figures
FT: Fatha microfacies:	GY: Gypsum: This microfacies is recognized by white, thick to massive bedded gypsum with chicken-wire structure, the total thickness is 5 metres thick.	1, 6	2, 3, 4
	GM: Marl: The GM microfacies is characterized by greyish green, thin bedded, rarely fine laminated marl, the total thickness is several of metres according to the location.	1, 6	
	RC: Claystone: RC microfacies is composed of red, thin bedded claystone, the thickness of this microfacies varies according to the locality, the total thickness several metres to tens of metres.	1, 2, 3, 4, 5, 6, 7	
JB: Jeribe microfacies:	OG: Ooidal grainstone: OG microfacies is characterized by thin bedded, fine laminated ooidal (average 35%) grainstone with bivalve fragments (20), peloids (7%). it has an average thickness of 1 metre.	4	5, 6, 7,
	PP: Peloidal packstone/grainstone: This microfacies is composed of thin bedded, fine laminated of (1) fine grain peloids (30%); (2) silt size, sub-angular to sub-round quartz (30%); (3) rare miliolids and bivalves (1-2%). It is approximately one metre thick.	2, 3, 4, 5,	8, 9, 10, 11
RR: Rotalids-Coralline red algae wackestone/packstone:	Microfacies RR has average thickness of 2-4 metres, composed of: (1) rotalids (average 4%) up to (10%); (2) red algae (average 5%); (3) echinoid fragment is (3-4%); (4) coral (5%); (5) rare miliolids, *Austrotrillina*, *Spirolina*, *Alveolina*; (6) un-recognizable fragments (average 15%).	8	11, 12, 13, 14
SP: Skeletal packstone/ grainstone:	SP-1: Skeletal packstone with brecciation: SP-1 microfacies has maximum thickness of 1.5 metres, composed of porcellaneous wall larger benthic foraminifera: (1) miliolids (average 15%); (2) *Austrotrillina* (average 10%); (3) *Peneroplis* (average 3.5%); (4) *Dendritina* (average 2.5%); (5) *Archaias* (average 2%); (6) *Praerhapydionina* (average 2.5%); (7) minor component include: *Biloculina (1%); Triloculina* (1%); *Quinqueloculina* (2%); and *Spirolina* is (1%). Common macrofaunal community are: (1) echinoid fragment (3.5%); (2) gastropods (3%); (3) bivalves (2.5%). Peloids (approximately 10%).	3, 5 1, 2, 4, 6	15, 16, 17 18, 19, 20, 21
	SP-2: Skeletal packstone with *Austrotrillina howchini*: The skeletal packstone of SP-2 microfacies is composed of 5 metres thick (average thickness), it has maximum thickness of 7 metres, contains porcellaneous larger benthic foraminifera, include: (1) miliolids (average 16.5%); (2) *Peneroplis* (average 4%); (3) *Austrotrillina* (average 7.5%); (4) *Dendritina* (average 2.5%); (5) *Archaias* (average 1.5%); (6) *Praerhapydionina* (average 2%); (7) minor component include: *Biloculina (1.5%); Triloculina* (1%); *Quinqueloculina* (2%) and *Spirolina* is (1%). A diverse macrofaunal community are: (1) echinoid fragment (average 4.5%); (2) gastropods (2%); (3) bivalves (3%). Peloids (average 10%).	2, 3, 4, 6	22, 23, 24, 25
	SP-3: Skeletal grainstone with *Praerhapydionina delicata*: SP-3 microfacies is grainstone, locally packstone, it has the average thickness of 11 metres with maximum thickness of 17.5 metres. Bioclasts are largely composed of larger benthic foraminifera, include; (1) miliolids (average 14.7%); (2) *Peneroplis* (average 4%); (3) *Austrotrillina* (average 6%); (4) *Dendritina*, *Archaias* and *Praerhapydionina* (2-3%); (5) *Biloculina (2%); (6) Triloculina* (1%); (7) *Quinqueloculina* (2%); (8) *Spirolina* is (1%); (9) minor component include: *Rotalia* and *Textularia* (less than 1%); (10) Other skeletal grain are; echinoid fragments (3-4%) with gastropods and bivalves (1-2%).		
MP: miliolids-*Austrotrillina*-*Peneroplis* packstone/ wackstone:	MP-1: peloidal, bioclastic packstone/grainstone: This microfacies is 1-3 metres thick, contains: (1) peloids (40%); (2) miliolids (average 11%), (3) *Austrotrillina* (10-12%); (4) *Peneroplis* (5%); (5) *Dendritina* (1-2%); (6) *Praerhapydionina* (2%); (7) *Archaias* (1-2%); (8) minor skeletal grains are: *Spirolina*, *Biloculina*, *Triloculina*, *Quinqueloculina* and echinoid fragments (1%).	2, 4	26, 27
	MP-2: peloidal wackestone/calcimudstone: The maximum thickness of MP-2 microfacies is 10 metres. The skeletal grains are micritized, include: (1) peloids (average 25%); (2) miliolids (average 5%), (3) *Austrotrillina* (2-4%); (4) *Peneroplis* (3%); (5) *Dendritina* (2%); (6) rare *Praerhapydionina*, *Archaias*, *Biloculina* and echinoid fragments (less than 1%).	3, 4, 5	28, 29, 30
CB: Coral bioherm:	The coral bioherm microfacies have various thicknesses; it has maximum thickness of 31	3, 4, 7, 8	31, 32, 33

	metres thick, and composed of colonial coral replaced by calcite spar (aragonite in origin).		
CG: Conglomerate:	The CG microfacies is composed of massive, channelized conglomerate layer, the thickness laterally various between one to five metres, The average thickness is 3.5 metres comprises of sub-round shape, mixture of coble, pebble, very coarse to fine grains.	3, 5	34, 35, 36
PS: Palaeosols:	The palaeosols (calcretes) of this microfacies are composed of Alpha type, composed of dense micritic ground mass with features such as crystallaria including circumgranular cracks with floating quartz grains.	5	37, 38
PK: Planktonic foraminifera wackstone/calcite mudstone:	PK-1: Peloidal packstone with planktonic foraminifera: This microfacies is composed of thin bedded peloidal packstone. It has total thickness of 1 metre, the bioclasts in this microfacies: (1) Planktonic foraminifera (2%) and (2) ostracods (average 3%); (3) the non-skeletal component is peloids (average 40%). PK-2: Planktonic foraminifera calci-mudstone: The PK-2 microfacies is composed of thin bedded wackstone, locally calcimudstone. It has the total thickness of 80 metres, contains: (1) Planktonic foraminifera (average 12%); (2) *Dicocyclina* (2%); (3) *Nummulites* (1%); (4) rare *Pellatispira* less than 1%; (5) peloids (average 12%). PK-3: Planktonic-benthonic foraminifera wackstone: Microfacies PK-3 is medium to thin bedded wackstone, with total thickness of 32.5 metres, composed of: (1) *Nummulites* (average 5%); (2) *Dicocyclina* (8%); (3) planktonic foraminifera (average 11%); (4) unrecognizable fragments (average 20%); (5) rare echinoid fragments, *Pellatispira* and *Textularia* (less than 1%); (6) peloids (average 4%).	5 7, 8 6	39 40, 41, 42 43, 44
NR: *Nummulites-red algae-Discocyclina* packstone/wackstone:	NR-1: *Coralline* red algae-*Nummulites* wackestone: The NR-1 microfacies comprises of wackstone with *Nummulites* and red algae, it has thickness of 16 metres, bioclasts include; (1) *Nummulites* (average 5%); (2) *Asterigerina* (2%); (3) red algae (average 8%); (4) coral (1-2%) and (5) *Victorella* (1%). NR-2: Coralline red algae-*Nummulites-Discocyclina* packstone: NR-2 microfacies is massively bedded, average thickness is between 6-9 metres thick. This most common recognizable bioclasts of this microfacies are: (1) *Nummulites* (average 10%); (2) *Asterigerina* (4%); (3) red algae (3-6%); (5) *Discocyclina* (1-2%); (6) *Operculina* (2%); (7) Textularia (1%); (8) echinoid fragments (3-4%); (9) minor components are: miliolids, *Victorella*, *Pellatispira* (less than 1%), (10) peloids and micritized grains and fragments	6 4, 5, 6	45, 46 47, 48, 49, 50 51, 52, 53,
	approximately (18-22%). NR-3: *Nummulites-Dicocyclina* packstone: Microfacies NR-3 is also massively bedded, the maximum thickness is 10 metres, bioclasts are dominantly composed of benthic foraminifera: (1) *Nummulites* (average 30%); (2) *Dicocyclina* (average 15%); (3) *Asterigerina* (3-4%); (5) *Operculina* (2%); (6) *Textularia* (less than 1%). Other components are (7) echinoid fragments (3-4%); (8) red algae (1%); (9) echinoid fragments (average 3.5%) and (10) peloids (average 7%).	4, 5, 6	54, 55
PG: Peloidal, skeletal grainstone:	The peloidal, skeletal grainstone microfacies has varied thickness according to the locality, the maximum thickness is 25.3 metres, the rock is composed of peloidal, skeletal grainstone comprises of: (1) miliolids (average 15%); (2) *Orbitolites* (average 4%); (3) *Dendritina* (average 2%); *Quniquiloculina* (average 2%); (4) echinoid fragments (8%); (5) Rare skeletal grains are: *Biloculina*, *Triloculina*, *Textularia* and green algae (less than 1%) and (6) The non-skeletal grains include peloids (average 35%) and uncommon superficial ooids (1%) only in Hazar Kani village locality.	1, 2, 3, 4, 5, 6	56, 57, 58, 59, 60
NA: *Nummulites-Alveolina* packstone/grainstone:	This microfacies is approximately 100 metre thick, composed of: (1) *Nummulites* (average 5%); (2) *Alveolina* (8%); (3) *Orbitolites* (3%); (4) miliolids (2%); (5) *Asterigerina* (2%); (6) echinoid fragments (2%); (7) minor skeletal components are: *Biloculina*, *Triloculina* and *Quinqueloculina* (1%) and (8) the non skeletal components are peloids and micritized grains (average 25%).	6	61, 62, 63, 64, 65

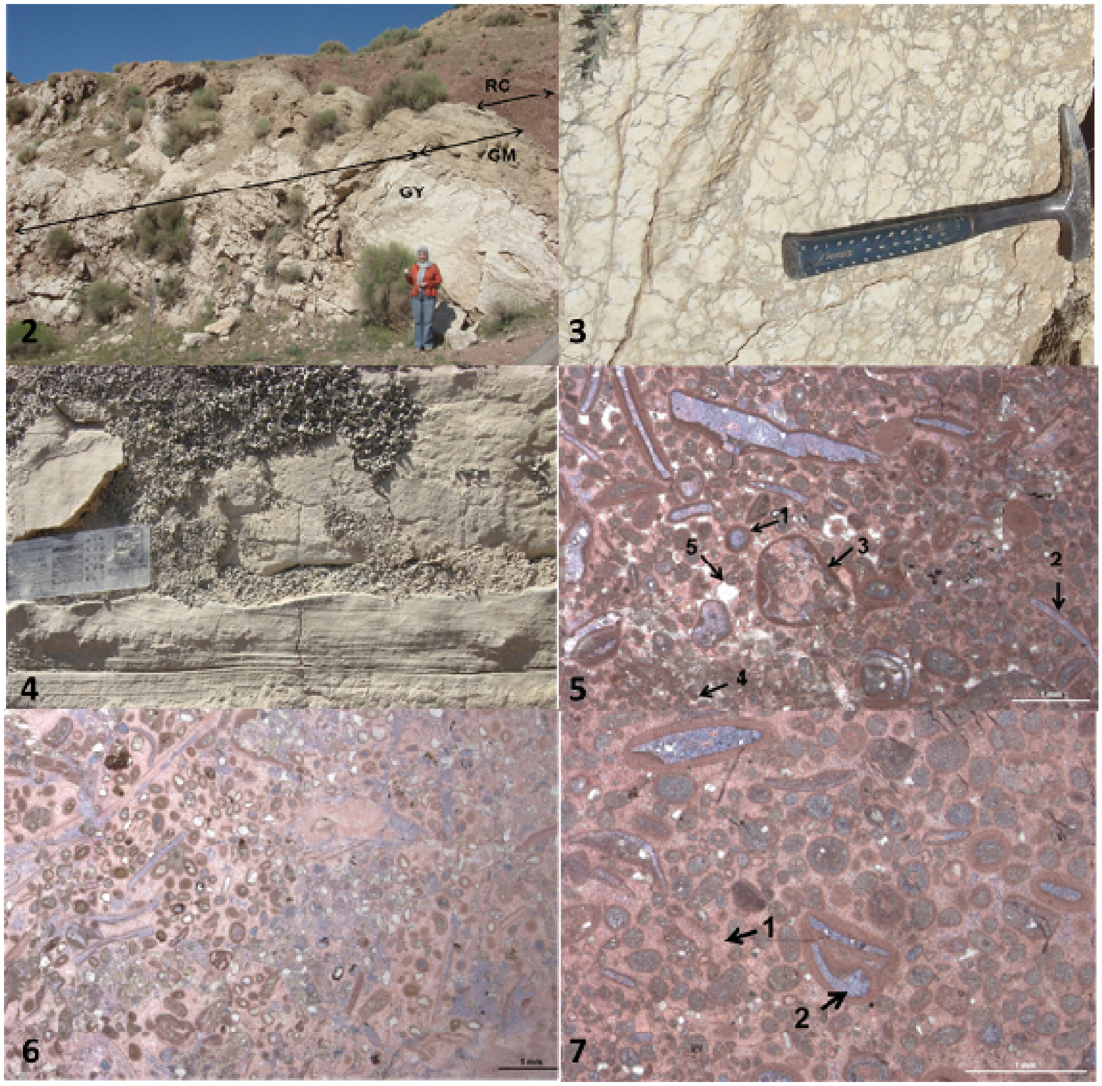


Figure 2: Field photograph for GY, GM and RC microfacies of Fatha Formation in the Bamu Gorge area.

Figure 3: Field photograph of gypsum (GY) microfacies with Chicken wire structure at Bamu Gorge locality.
Figure 4: Field photograph of fine lamination in GM microfacies located at Bamu Gorge locality. The scale bar is 15cm.
Figure 5: microfacies ooidal grainstone. (1) ooids, (2) former aragonitic bivalves, (3) sub-rounded intraclast, (4) peloids, (5) vugs. Photomicrograph of a stained thin-section from core of Aj Dagh Anticline (sample CA.32).

Figure 6: Sub-round to sub-angular quartz as nuclei for ooids (1), miliolid (2). Photomicrograph of microfacies OG, stained thin-section from core of Aj Dagh Anticline. (sample CA.33).

Figure 7: Non-ferroan intergranular calcite cement (1) and post aragonite dissolution moulds filled by ferroan calcite cement (2). Photomicrograph of microfacies OG. Thin-section is stained from core of Aj Dagh Anticline (sample CA.32).

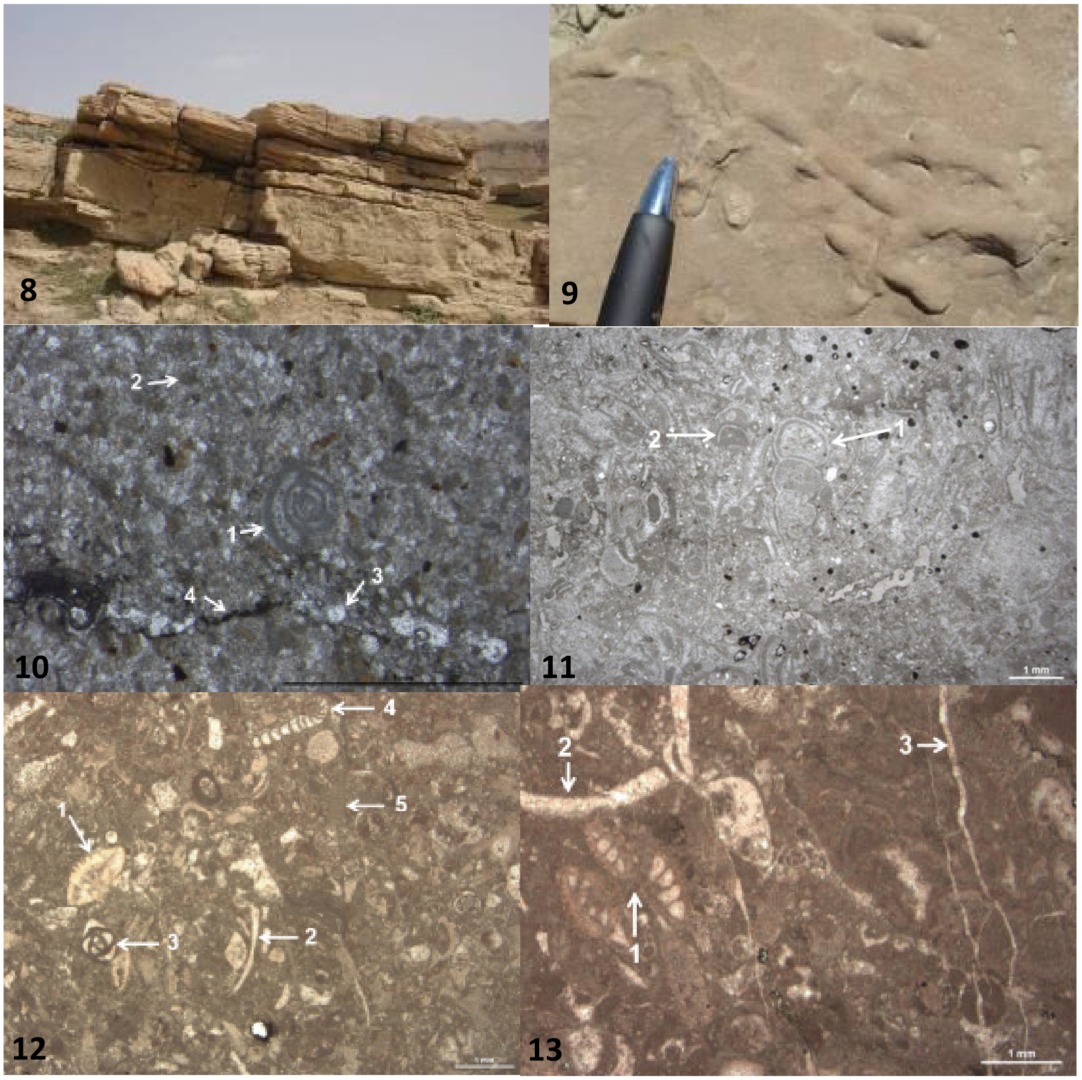


Figure 8: Field photograph of irregular lamination/bedding in PP microfacies from Awa Spi locality. Field of view is 2m wide.

Figure 9: Field photograph of horizontal burrowing on the surface of PP microfacies from Core of Aj Dagh Anticline.

Figure 10: Photomicrograph of peloidal packstone microfacies. (1) miliolids, (2) peloids, (3) quartz, (4) stylolite. Unstained thin-section from Hazar Kani village (sample AS. 10).

Figure 11: Photomicrograph of molluscan layer. (1) gastropod and (2) bivalve fragments with micritized envelope. Unstained thin-section from Zinana village area (sample Z. 31).

Figure 12: Photomicrograph of microfacies RR (1) *Rotalia*, (2) bivalve fragment, (3) miliolids, (4) *Spirolina*, (5) red algae. Stained thin-section from Sharwal-Dra locality (sample SD.29).

Figure 13: Photomicrograph of microfacies RR (1) *Rotalia*, (2) bivalve fragment filled with non-ferroan calcite cement, (3) fracture filled with non-ferroan calcite cement. Stained thin-section from Sharwal-Dra locality (sample SD.29).

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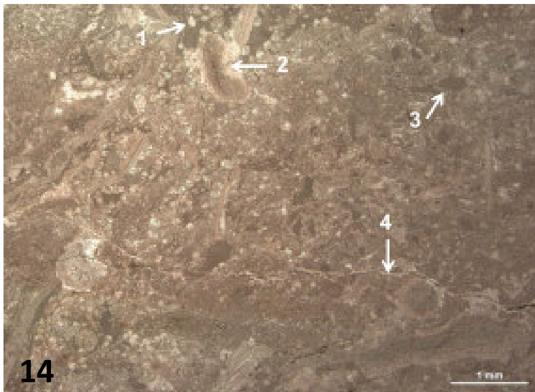


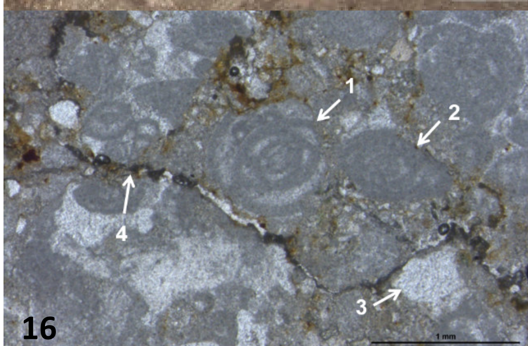


Figure 14: Photomicrograph of euhedral dolomite texture (1), echinoids fragment (2), red algae (3) fracture (4). Stained thin-section from Sharwal-Dra locality (sample SD.8).

Figure 15: Field photograph of SP-1 microfacies overlying the MP-2 microfacies in the Awa Spi locality.

Figure 16: Photomicrograph of brecciated packstone (SP-1) with porcellaneous benthic foraminifera. (1) *Austrotrillina*, (2) *Archaias*, (3) echinoid fragments, (4) brecciation line filled with clay residue. Unstained thin-section from Awa Spi locality (sample DS.12).

Figure 17: Photomicrograph of brecciated packstone (SP-1 microfacies) with (1) *Triloculina*, (2) *Quinqueloculina*, (3) calcite filled fracture, (4) clay seams. Unstained thin-section from Hazar Kani village locality (sample AS.9).

Figure 18: Field photograph of horizontal borrowing in the Sagrma locality.

Figure 19: Field photograph of macro fossil of gastropod in Sagrma locality.

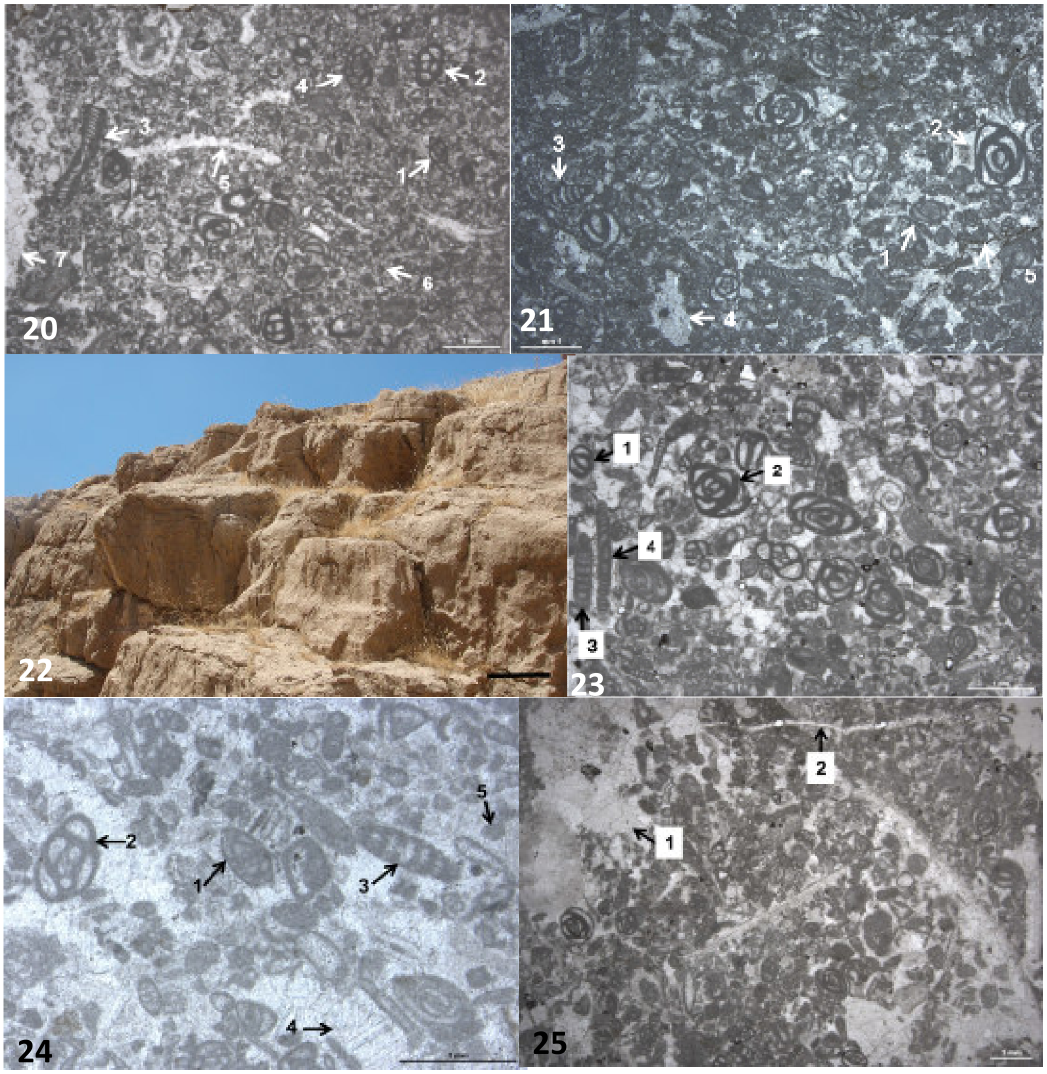


Figure 20: Photomicrograph of SP-2 microfacies (1) miliolids, (2) *Austrotrillina*, (3) *Peneroplis*, (4) *Dendritina*, (5) bivalves, (6) peloids, (7) vugs filled with calcite cement. Unstained thin-section in the Zinana village locality (sample Z.28).

Figure 21: Photomicrograph of SP-2 microfacies with (1) miliolids, (2) *Austrotrillina*, (3) *Praerhapydionina*, (4) echinoid fragments, (5) low amplitude stylolites. Unstained thin-section from the Sagrma locality (sample SG.27).

Figure 22: Field photograph of very thick bedded of skeletal grainstone in Zinana area. Scale bar is 50 cm.

Figure 23: Photomicrograph of skeletal grainstone of SP-2 microfacies with (1) miliolids, (2) *Austrotrillina*, (3) *Praerhapydionina*, (4) *Peneroplis*. Unstained thin-section from the Zinana village locality (sample Z.18).

Figure 24: Photomicrograph of SP-3 microfacies with (1) *Dendritina*, (2) *Austrotrillina*, (3) *Praerhapydionina*, (4) echinoid fragments (5) peloids. Unstained thin-section in the Hazar Kani village locality (sample AS.8).

Figure 25: Photomicrograph of skeletal grainstone, partially packstone (1) dissolution filled with blocky calcite spar (2) calcite filled fracture. Unstained thin-section from the Zinana village locality (sample Z.21).

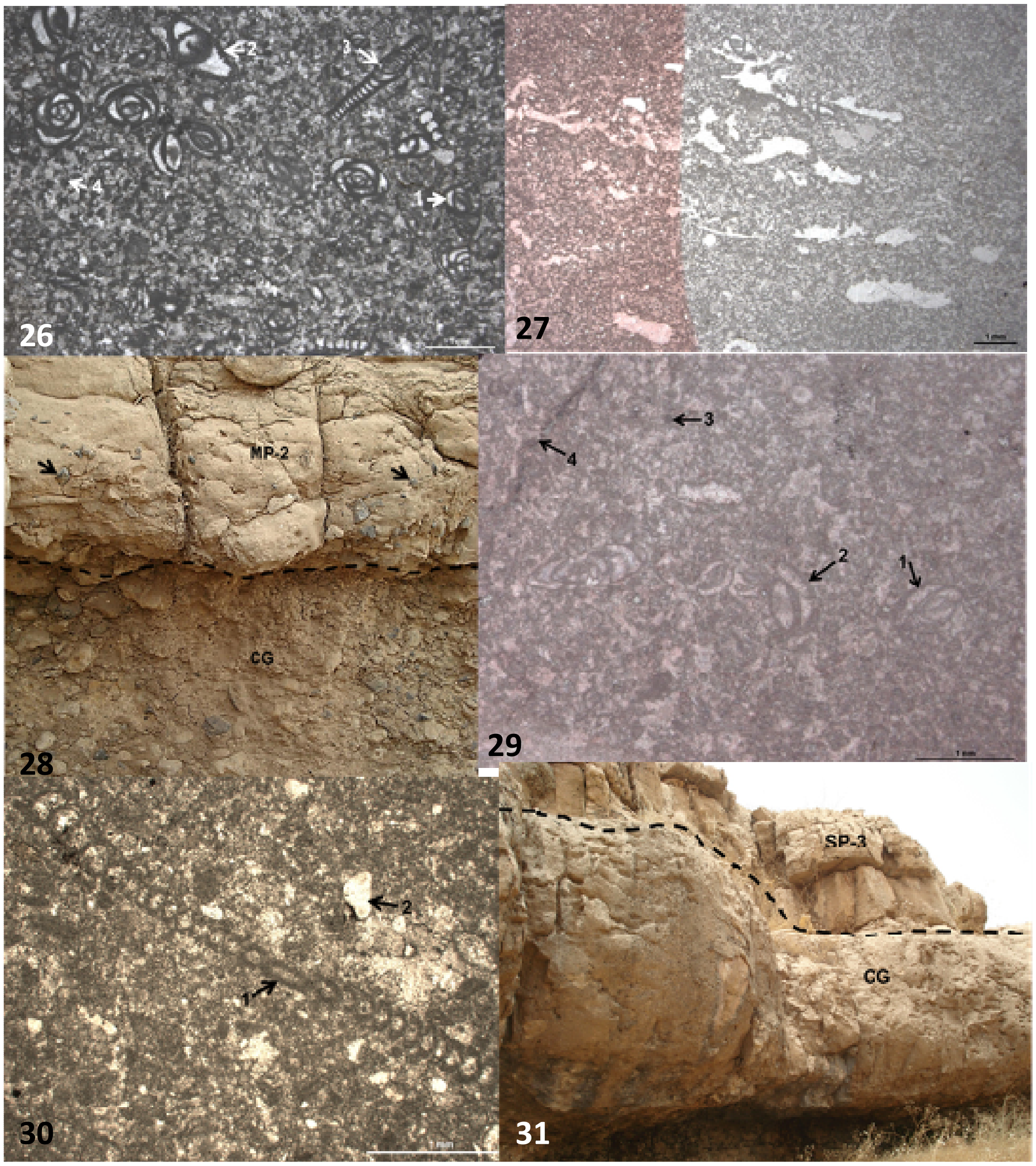


Figure 26: Photomicrograph of MP-1 microfacies (1) miliolids, (2) *Austrotrillina*, (3) *Peneroplis*, (4) peloids. Unstained thin-section from Zinana village section (sample Z.17).

Figure 27: Photomicrograph of fenestral pore filled with non-ferroan calcite cement. The thin-section is half stained from the core of Aj Dagh Anticline (sample CA.16).

Figure 28: Field photograph of MP-2 microfacies overlying the CG microfacies, note the quartz pebble at the lower part of MP-2 microfacies selected by arrow. Location is Awa Spi area. Field of view is 50cm wide.

Figure 29: Photomicrograph of peloidal wackestone of MP-2. (1) miliolids, (2) *Austrotrillina*, (3) peloids, (4) clay seam. Stained thin-section of core of Aj Dagh Anticline (sample CA.18).

Figure 30: Photomicrograph of peloidal calcimudstone of MP-2. (1) peneroplids, (2) quartz grain. Un-stained thin-section of core of Awa Spi locality (sample DS.8).

Figure 31: Field photo of CB microfacies overlain by SP-3 at core of Aj Dagh Anticline. Field of view is 3 metres wide.

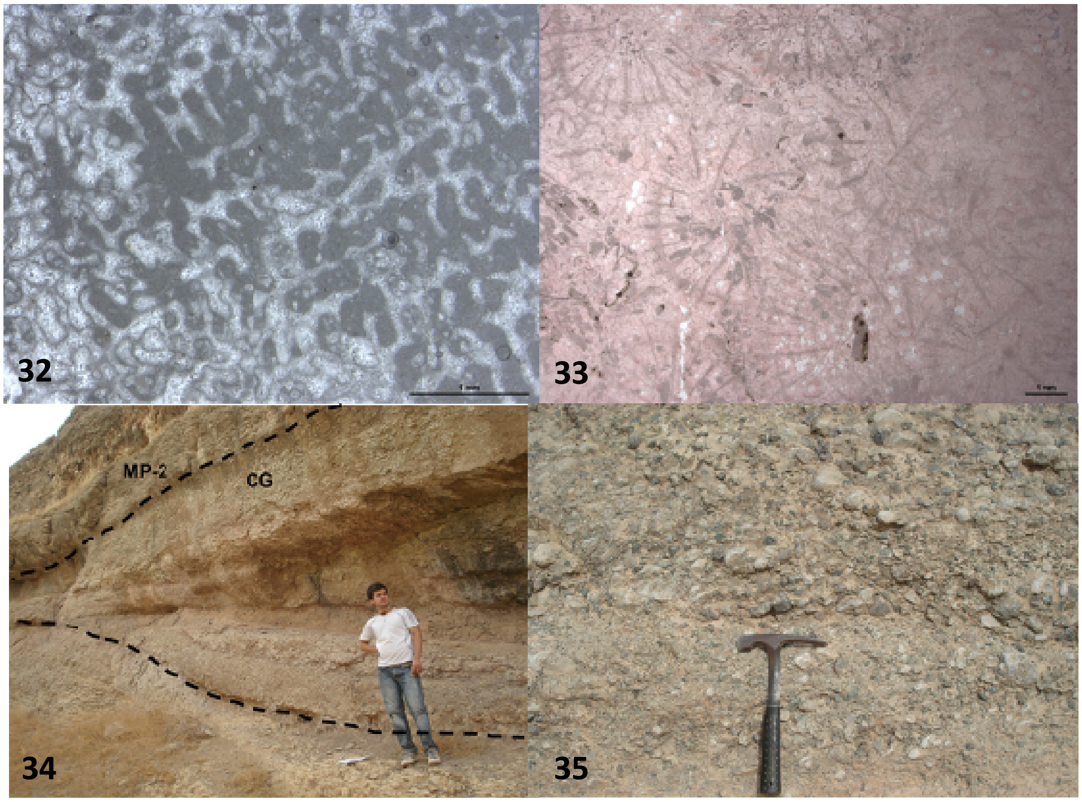


Figure 32: Photomicrograph of colonial coral, with aragonite replaced by non- ferroan calcite cement, the intra-skeletal pores filled by micrite. Un-stained thin-section of Hazar Kani village (sample AS.6).

Figure 33: Photomicrograph of colonial coral replaced by non-ferroan calcite cement. Stained thin-section of core of Aj Dagh locality (sample CA.19).

Figure 34: Field photo of CG microfacies at Awa Spi locality, note the thinning at the margin of this unit.

Figure 35: Field photo of CG microfacies at Hazar Kani village.

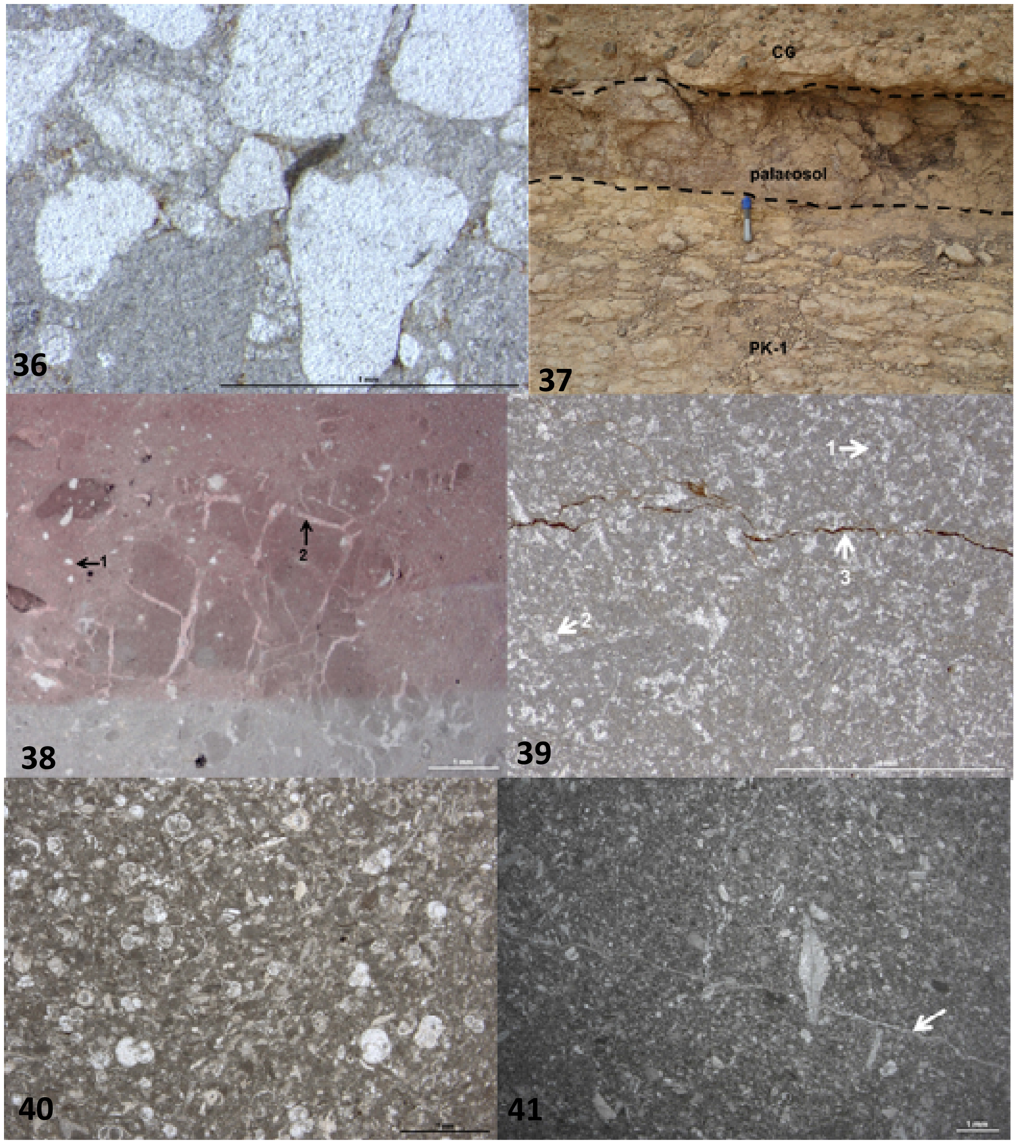


Figure 36: Photomicrograph of CG microfacies composed of sub-round to sub-angular quartz clasts in clay matrix. Unstained thin-section. Hazar Kai village (Sample AS.2).

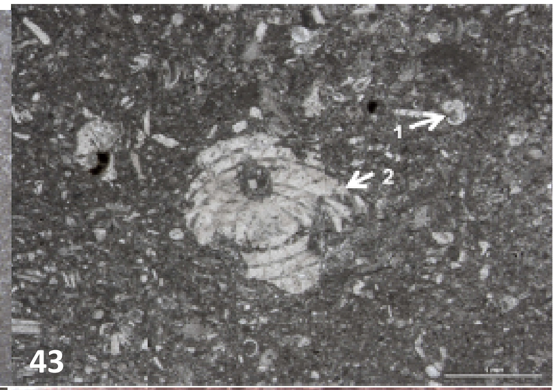
Figure 37: Field photo of paleosols underlies by PK-1 microfacies and overlies by CG microfacies at Awa Spi locality.

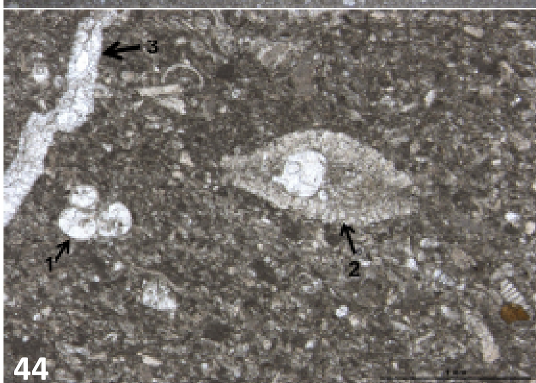
Figure 38: Photomicrograph of paleosols. (1) floating quartz, (2) fine irregular fractures some circumgranular cracks. The thin-section is half stained. Awa Spi locality (sample AW.18).

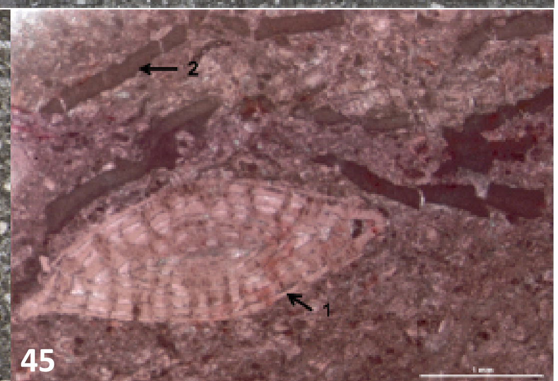
Figure 39: Photomicrograph of peloidal packstone. (1) peloids, (2) planktonic foraminifera, (3) low-amplitude stylolites. Unstained thin-section from Awa Spi area (sample AW.16).

Figure 40: Photomicrograph of wackestone with planktonic foraminifera. Unstained thin-section from Bellula Gorge locality (sample BL.26).

Figure 41: Photomicrograph of PK-2 with presence of calcite filled fracture (arrowed). Unstained thin-section from Bellula Gorge locality (sample BL. 43).







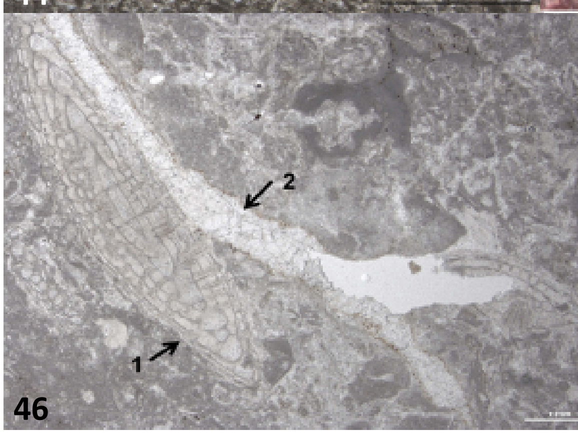


Figure 42: Photomicrograph of PK-2 with clay seams (arrowed). Unstained thin-section at Bellula Gorge locality (sample BL.32).

Figure 43: Photomicrograph of PK-3. (1) planktonic foraminifera, (2) broken *Nummulites,* Unstained thin-section from Bellula Gorge locality (sample BL.51).

Figure 44: Photomicrograph of PK-3. (1) planktonic foraminifera, (2) *Discocyclina,* (3) calcite filled fracture. Unstained thin-section at Bellula Gorge locality (sample BL.31).

Figure 45: Photomicrograph of NR-1. (1) *Nummulites*, (2) red algae. Stained thin-section at Bellula Gorge locality (sample BL.56).

Figure 46: Photomicrograph of NR-1. (1) *Nummulites*, (2) calcite filled fracture. Unstained thin-section at Bellula Gorge locality (sample BL.59).

Figure 47: Field photograph of NR-2 microfacies at the Awa Spi locality with presence cavity. The height of the outcrop is 8m.

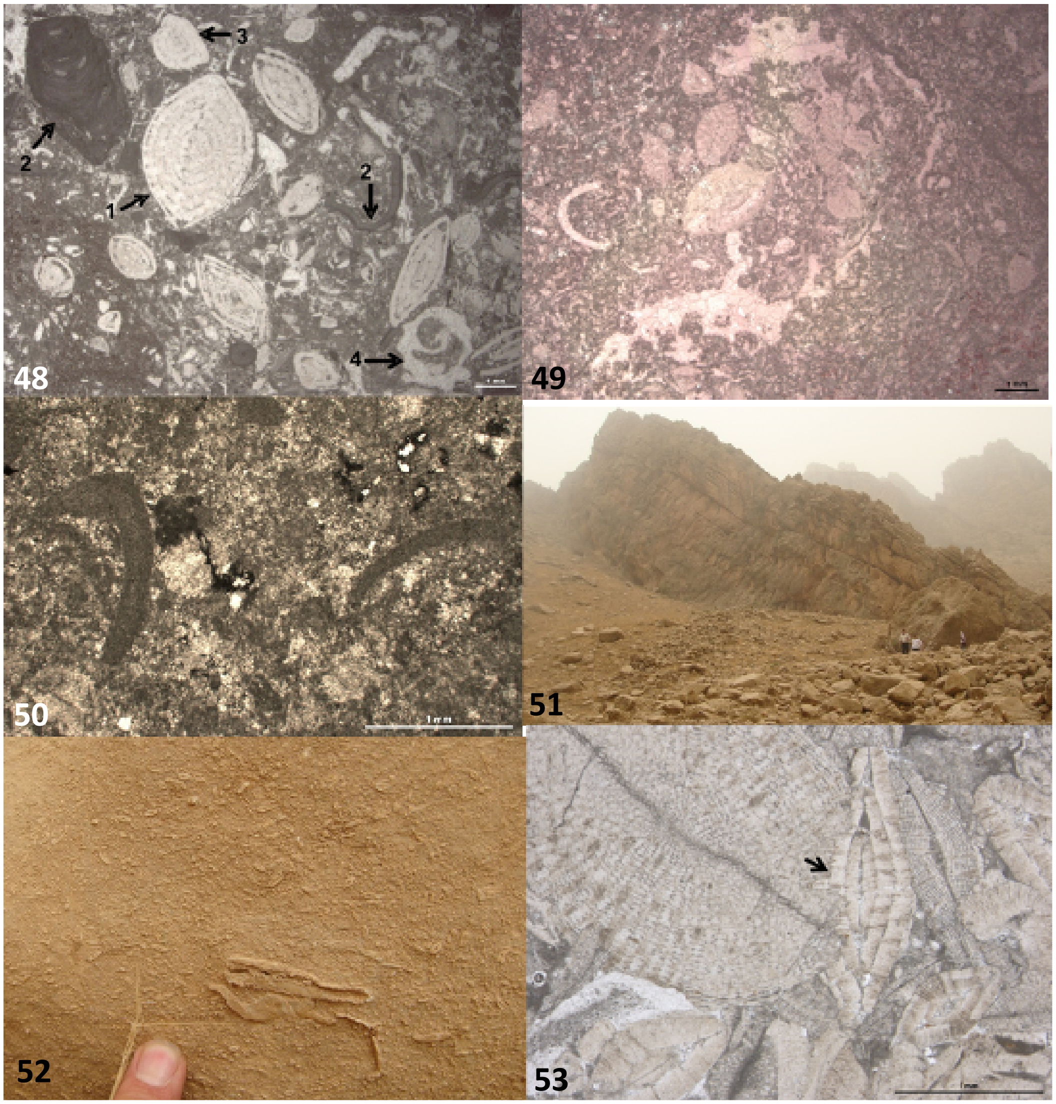


Figure 48: Photomicrograph of NR-2. (1) *Nummulites*, (2) red algae (3) *Asterigerina*, (4) gastropod. Unstained thin-section of microfacies SP-2 from Awa Spi locality (sample AW.10).

Figure 49: Photomicrograph of NR-2. (1) *Nummulites*, (2) *Asterigerina,* (3) vug filled with non-ferroan calcite cement. Stained thin-section from core of Aj Dagh Anticline (sample CA.10).

Figure 50: Photomicrograph of NR-2 microfacies. Showing red algae with hooked structure. Unstained thin-section from Awa Spi locality (sample AW.12).

Figure 51: Field photograph of NR-3 microfacies at Bellula Gorge locality.

Figure 52: Field photograph of skeletal packstone of NR-3 microfacies from Bellula Gorge locality.

Figure 53: Photomicrograph of sutured contact between grains (marked by arrow), left is *Discocyclina* and right is *Nummulite*. Unstained thin–section of NR-3 microfacies from Bellula Gorge locality (sample BL.3).

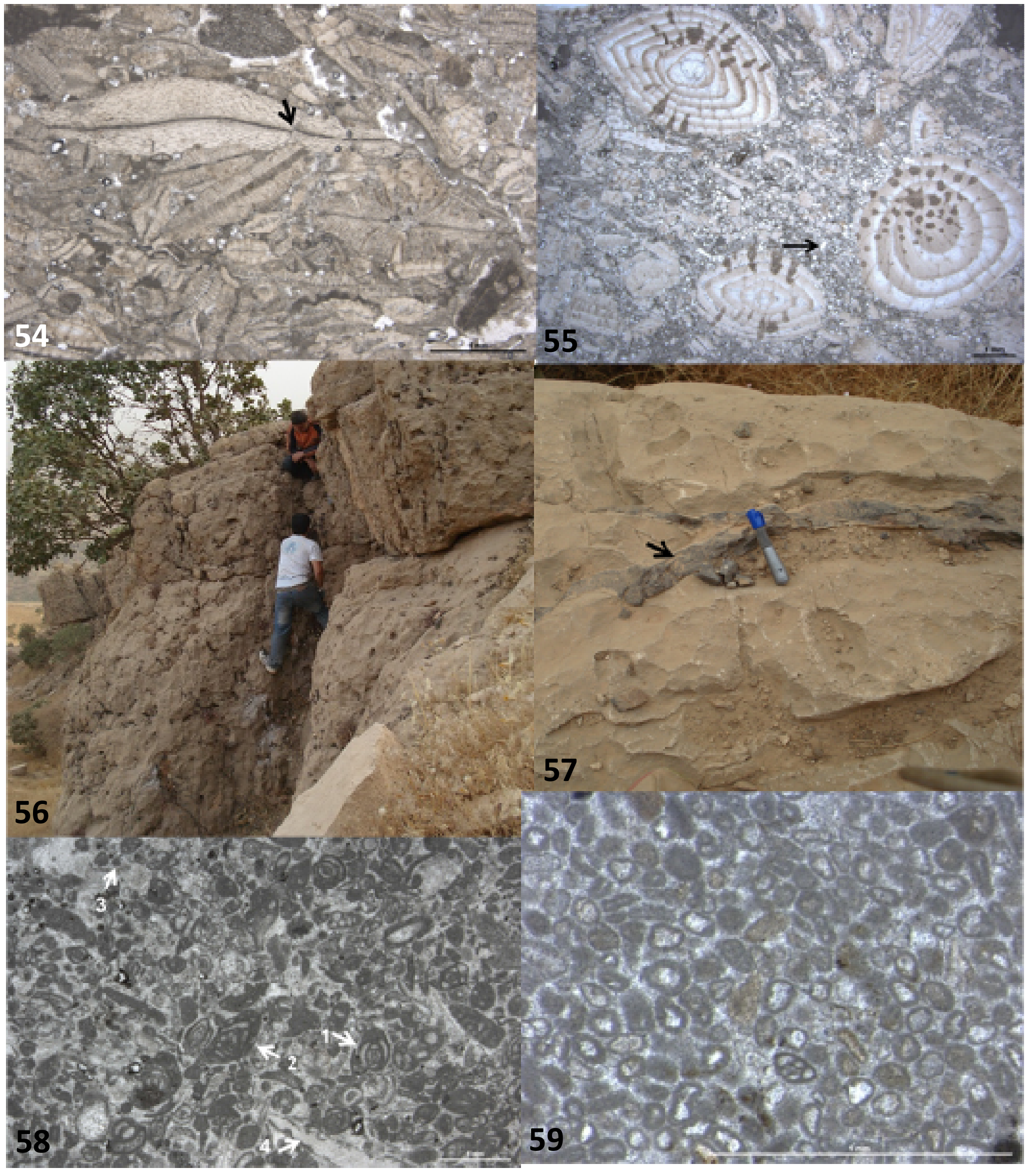


Figure 54:

Photomicrograph of mechanical compaction inside grain (marked by arrow) in NR-3 microfacies. Unstained thin-section from Bellula Gorge locality (sample BL.2).

Figure 55: Photomicrograph of idiotopic dolomite rhombs (marked by arrow) in NR-3 microfacies. Unstained thin section from Bellula Gorge locality (sample BL.5).

Figure 56: Field photograph of PG microfacies from Sagrma locality.

Figure 57: Field photograph of silicification (arrowed) in PG microfacies from Awa Spi locality.

Figure 58: Photomicrograph of peloidal, skeletal grainstone (PG) microfacies. (1) miliolids, (2) ?*Dendritina*, (3) peloids, (4) echinoid fragments. Unstained thin-section from Zinana village locality (sample Z.7).

Figure 59: Photomicrograph of very fine sand grade superficial ooids in PG microfacies. Unstained thin-section from Hazar Kani village locality (AS.1).

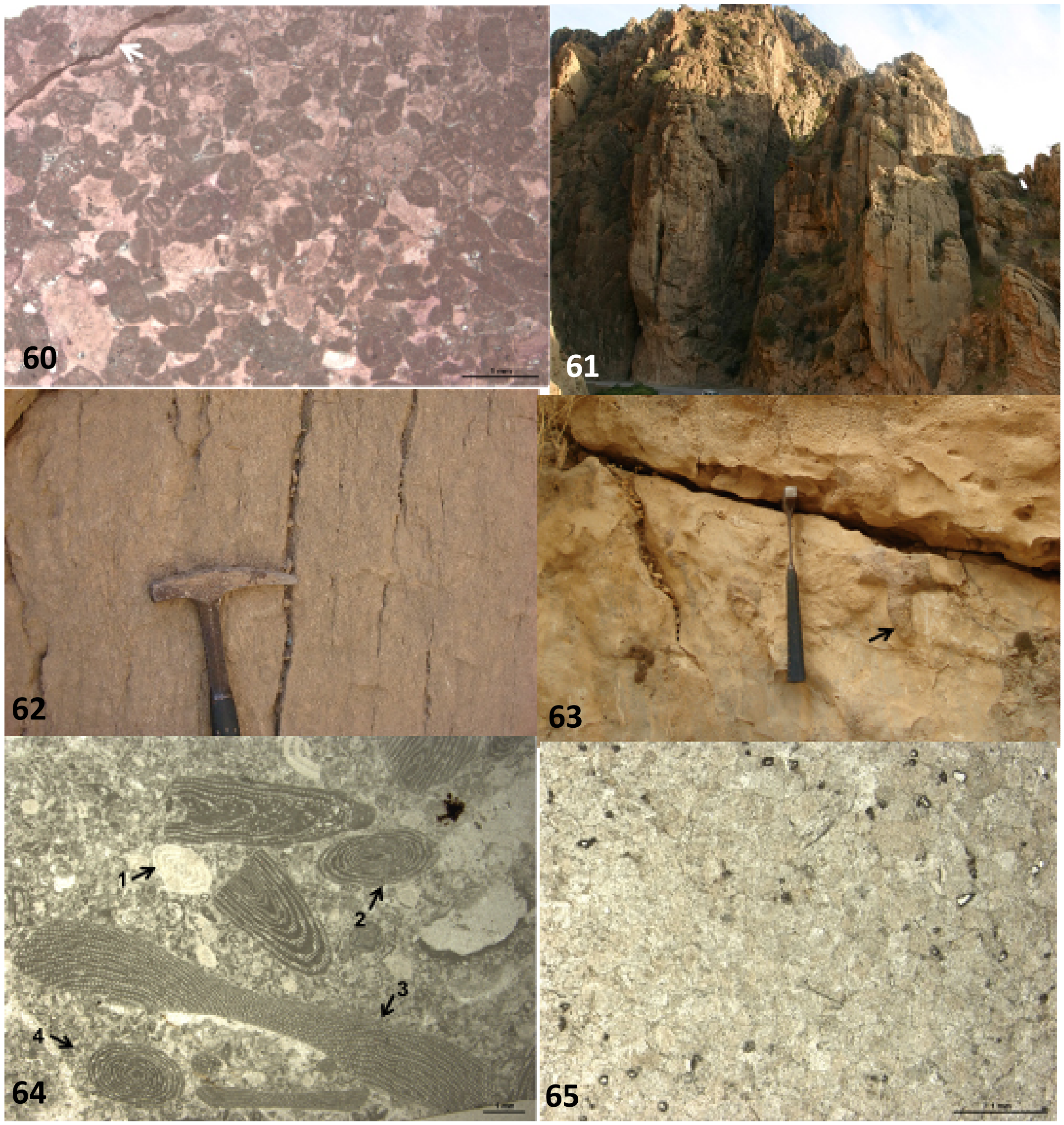


Figure 60: Photomicrograph of low amplitude stylolites (arrowed) present in PG microfacies. Stained thin-section from core of Aj Dagh Anticline locality (sample CA.5).

Figure 61: Field photograph of NA microfacies from Bamu Gorge locality.

Figure 62: Field photograph of skeletal packstone/rudstone of NA microfacies from Bamu Gorge locality.

Figure 63: Field photograph of burrowing (arrowed) on the surface of the bed of NA microfacies, from Bamu Gorge locality.

Figure 64: Photomicrograph of peloidal, skeletal packstone/rudstone.(1) *Nummulites,* (2) *Alveolina*, (3) *Orbitolites*, (4) peloids. Unstained thin-section of microfacies NA from Bamu Gorge locality (sample BS.8).

Figure 65: Photomicrograph of Idiotopic dolomite in NA microfacies. Stained thin-section from Bamu Gorge locality (sample BS.2).

Microfacies interpretation:

Interpretation for each microfacies is based on the distribution of foraminifera; planktonic faunas dominate the deeper, open marine segments, whereas the intervening shallower segments are characterized by an abundance of benthonic foraminifers. The microfacies analysis indicates palaeoenvironments ranging from terrestrial to open marine settings (down-ramp) in nine microfacies zones (Table 2). Buxton and Pedley's (1989) model for

Cenozoic carbonate ramps (Figure 66) strongly correlates to the current study's microfacies, based on the distribution of foraminiferal associations across the ramp setting over time (Figures 67 and 68).

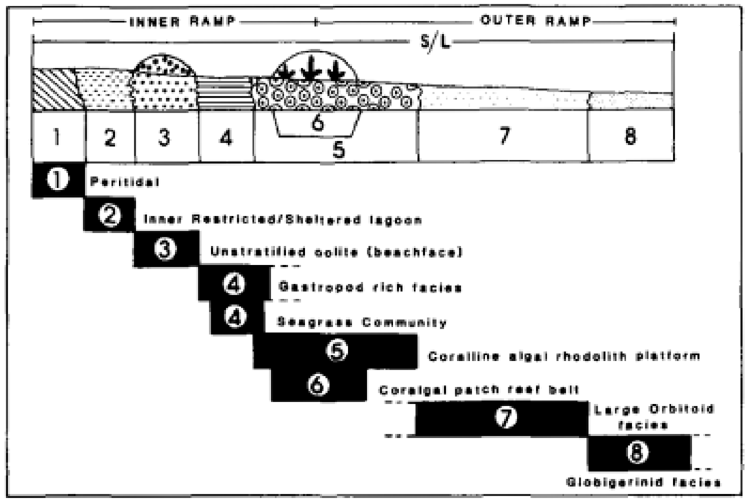


Figure 66: Profile of standard Cenozoic ramp model showing down-ramp facies distribution (Buxton and Pedley, 1989).

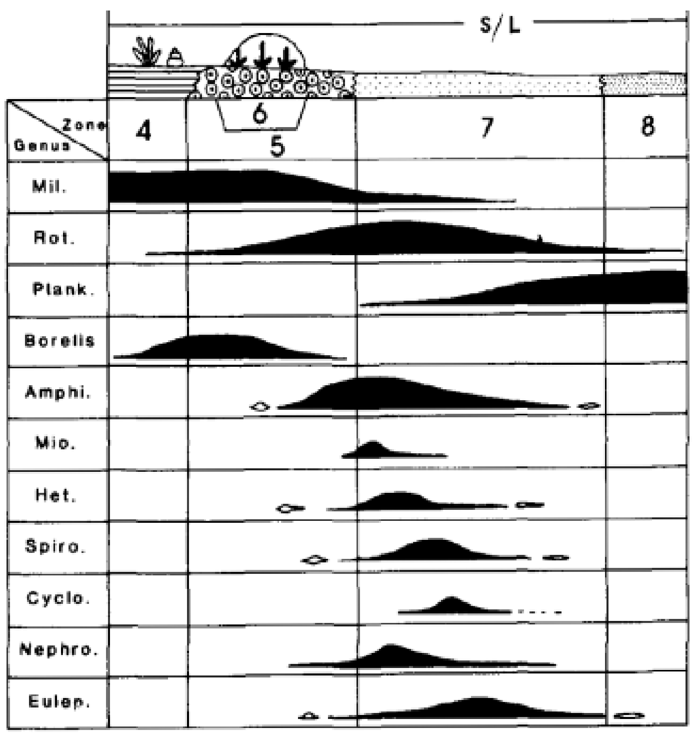


Figure 67: Foraminiferal distribution of Middle-Upper Oligocene Tethyan ramps (Buxton and Pedley, 1989). Mil: Miliolids; Rot: Rotaliids; Plank: Planktonic foraminifera; Amphi: *Amphistegina*; Mio: *Miogypsinoides*; Het: *Heterostegina*; Cyclo: *Cyclocltpeus*; Nephro: *Nephrolepidina* and Eulep: *Eulepidina*.

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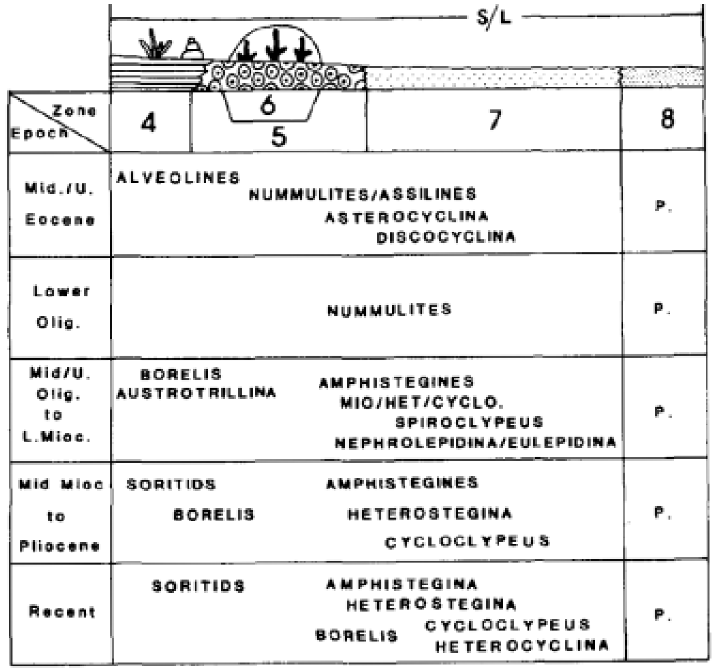

Figure 68: Distribution and evolution of Tethyan foraminiferal associations over time (Buxton and Pedley, 1989). P: Planktonic foraminifera.

Ramp zones	Micro-facies	Sub-microfacies	Buxton and Pedley's (1989) facies distribution
1	FT	Gypsum/Marl/Claystone	-
	CG	Conglomerate	
	PS	Palaeosol	
2	MP	MP-1: peloidal, bioclastic packstone/grainstone	1
3		MP-2: peloidal wackestone/calcimudstone	2
	PG	Peloidal, skeletal grainstone	
	JB	PP: Peloidal packstone/grainstone	
4		OG: Ooidal grainstone	3
5	SP	SP-1: Skeletal packstone with brecciation	4
		SP-2: Skeletal packstone with *Austrotrillina howchini*	
		SP-3: Skeletal grainstone with *Praerhapydionina delicate*	
	NA	*Nummulites-Alveolina* packstone/grainstone	
6	CB	Coral bioherm	6
7	RR	Rotalids-coralline red algae wackestone/packstone	5
	NR	NR-1: Coralline red algae-*Nummulites* wackestone	
		NR-2: Coralline red algae-*Nummulites-Discocyclina* packstone	
8	NR	NR-3: *Nummulites-Discocyclina* packstone	7
9	PK	PK-1: peloidal packstone with planktonic foraminifera	8
		PK-2: Planktonic foraminifera calcimudstone	
		PK-3: Planktonic-benthonic foraminifera wackestone	

Table 2: Distribution of the depositional environment zones by comparison to Buxton and Pedley's (1989) ramp model.

Although foraminifera are one of the main components for the interpretation of microfacies, the texture of the rock with a presence and absence of micrite matrix is also a major consideration. Detailed interpretations for each ramp zone are listed below:

1. Zone 1:

1.1. FT Microfacies interpretation:

Gypsum layer is one of the main microfacies of Lower Fars (Fatha) Formation. Fatha Formation was studied in many localities in Iraq, Syria and Iran (Bellen, 1959; Ctyrocky and Karim, 1971; Behnam, 1975, 1977; Ponikarov et al., 1967; James and Wynd, 1965), but only few of them discussed the depositional environment. In

Syria this formation was deposited in a littoral environment (Ponikarov et al., 1967). In Iraq, in Jazera and Duhok-Ain Zalah area it was deposited in the shallow, near shore lagoons or coastal lagoons of tropical to subtropical waters, where lagoons were periodically isolated from sea water (Behnam, 1975; 1977). Jassim and Goff (2006) interpreted the Fatha Formation as being deposited in a rapidly subsiding sag basin that periodically became evaporitic with the formation of sabkhas and salinas. The presence of a chicken-wire structure suggests displacive growth as in such a supratidal sabkha environment.

1.2. **CG Microfacies interpretation:**

The conglomerate layer is composed of a single storey unit with a complex internal geometry. It comprises of a central thick conglomerate body, thinning at the edges with lateral extent of few tens of metres, which suggests an incised valley. The detrital mineralogy of the valley fill exhibits a different composition and provenance to surrounding strata suggesting the clasts were reworked from a different origin. Furthermore, poorly sorted, subround-round shape clasts refer to transport from the source moderately. No marine faunas were found in the matrix suggesting a non-marine, likely alluvial environment.

1.3. **PS microfacies interpretation:**

Calcretes result from the progressive calcification of the soil due to the precipitation of calcite within the soil profile (Wright and Tucker, 1991). The nodular carbonate textures in paleosols are referred to as glaebular textures. The disorthic type nodules described by Wieder and Yaalon (1974) are similar to the type 2 nodules because of the sharp contacts separating them from the surrounding matrix suggesting possible shrinkage and the swelling of the soil matrix. The presence of circum-granular cracks suggests the cracking of the soil, including wetting and drying (Brewer, 1964).

2. Zone 2:

2.1. MP-1 microfacies interpretation:

The nature of bioclasts in MP-1 microfacies suggests very shallow marine water. The low diversity of bioclasts in this microfacies, such as miliolids, *Austrotrillina* and *Peneroplis* with few other porcellaneous foraminifera (Figure 4.25), is indicative of restricted, very shallow marine environment (Geel, 2000) (for details see 4.3.5a). Furthermore, the depositional environment of the packstone/grainstone texture suggests a relatively moderate to high energy regime, likely waves and currents influenced.

The origin of peloids is commonly uncertain, although many appear to be highly abraded, totally micritized ?miliolids. However a few may be ?faecal pellets, based on their shape and aggregate nature (Pusey, 1975). In a modern shallow marine environment, faecal pellets are produced in large quantities, especially by worms and gastropods; faecal pellets account for most soft pellets within muddier low energy areas such as the south Florida Shelf (Enos, 1977).

Fenestrae indicate subsequent exposure in a tidal flat environment, while the evidence of exposure is generally absent (Hardie, 1977).

The cements, including cement filled fenestrae, are composed of non-ferroan calcite cement (figure 4.26) with no trace of ferroan calcite to indicate burial diagenesis.

This microfacies is analogous to standard microfacies 1 peritidal of the Cenozoic carbonate ramps of Buxton and Pedley (1989). The microfacies MP-1 is also similar to standard microfacies SMF21 of Flügel (2004).

The overall characteristics suggest a very shallow marine setting above a fair-weather wave-base in a relatively high energy intertidal environment receiving skeletal grains from a somewhat restricted setting.

3. Zone 3:

3.1. MP-2 microfacies interpretation:

The nature of the bioclasts of MP-2 represents a very shallow marine setting. They are mostly the same as MP-1 but with lower diversity of miliolids, peneroplids and *Austrotrillina* (for more details see 4.2.5b and 4.3.5a). Low diversity of organisms suggests a restricted lagoonal environment (Tucker and Wright, 1990). Partial micritization in the skeletal grains mostly in benthic foraminifera represents a shallow marine environment. According to Perry (1998) the highest degree of grain infestation occurs within a shallow (less than 18 metres), low energy environment and one of most susceptible grain for infestation is foraminifera. The occurrence of matrix in wackestone/calcimudstone beds indicates lower energy conditions with no effect of waves or currents. Furthermore, a low energy regime is indicated by the presence of poorly sorted sub-angular quartz which comes from the erosion of the underlying conglomerate bed. The cements are composed of non-ferroan with no evidence of burial cements.

This microfacies is analogous to standard microfacies 2, restricted lagoonal, of the Cenozoic carbonate ramps of Buxton and Pedley (1989).

Majid and Veizer (1986) described similar facies in the Kirkuk Group, in the Kirkuk Oil Field in northern Iraq. They proposed a tidal flat/mud flat as the environment of depositional. Subsequently, Bassi and Nebelsick (2010) logged similar microfacies in the Upper Oligocene shallow water carbonates in the Venice area, noth-east Italy and interpret it as a proximal inner ramp environment.

The overall characteristics suggest a very shallow, restricted lagoonal environment in inner ramp setting.

3.2. **PG Microfacies interpretation:**

The bioclasts of PG microfacies comprises of mostly porcellaneous benthic foraminifera suggesting a shallow water marine setting. Shallow water depth is supported by the abundance of miliolids which when found in a lagoonal environment (Geel, 2000) indicates a connection to the open ocean (Chassefiere et al., 1969). *Orbitolites* lives in a ranges of environments and it has been interpreted as a restricted environment between *Nummulites* banks and the shoreline by Serra-Kiel and Reguant (1984); shallow inner ramp by Racey (1994) and "well-flushed" back-reefs and other carbonate facies free of mud in less than 40 metres water depth by Geel (2000).

The dominant grainstone texture of this microfacies with un-common superficial ooids, indicates a deposition in a relatively high energy environment under the action of waves and currents. The grainstone texture may suggest wave winnowing in shallow, broad lagoon by Kendall and Skipwith, (1969). Colby and Boardman (1989) described the windward, high-energy lagoon in Graham's Harbor, Bahams and they presumed that the packstone/grainstone texture is one of these facies which receive the greatest wave energy in the lagoon.

This microfacies may be an analogous to standard microfacies 2, lagoonal facies of Buxton and Pedley (1989). Furthermore, the faunal association of this microfacies may be correlated to the shallowest faunal association of an Eocene carbonate ramp described by Beavington-Penny and Racey, (2004).

The overall a characteristics suggest a restricted biota in wave winnowing in a very shallow, broad lagoon.

3.3 **PP Microfacies interpretation:**

The nature grains in the PP microfacies suggest a very shallow restricted lagoonal environment. The abundant peloids indicate that the depositional environment was a very shallow water setting as a lagoon (Tucker and Wright, 1990). Presence of micrite matrix and packstone texture suggest low energy regime, is not affected by waves or currents. Furthermore, a low energy environment may also be inferred from the presence of sub-angular/angular poorly sorted quartz that comes from aeolian. The fine irregular lamination/bedding suggests a lack of bioturbation (Tucker and Wright, 1990). Micritization and micrite envelope indicator for shallow marine environment less than 18 metres (Perry, 1998). In addition the presence of very few bioclast, is indicative of a restricted environment.

Non-ferroan calcite cement is evidence that cementation occurred before burial in an oxygenated diagenetic fluid. Subsequently, compaction includes stylolites formed during burial diagenesis (Flügel, 2004).

This microfacies is analogous to standard microfacies 2, inner restricted lagoon of the Cenozoic carbonate ramps of Buxton and Pedley (1989).

The overall characteristics suggest low energy, very shallow water in a restricted lagoon in an inner ramp setting.

4. Zone 4:

4.1. OG Microfacies interpretation:

Ooids are the main components of this microfacies, which are found in very shallow settings, in areas where tidal wave/foreshore processes retain the grains in the environment. Although ooids are capable of being transported by storms and sediment gravity flows into deeper waters, the absence of these features suggests that these oolitic grainstones are effectively *in situ.* The dominant grainstone texture and the absence of fine micrite matrix indicate deposition in a high energy, well-winnowed environment under the effect of waves and currents. High energy settings may be inferred from the well-sorted grains as well.

The cement is composed of both ferroan and non-ferroan calcite, which is evidence that cementation continued during burial. Most of the interparticle cements are non-ferroan, while the dominant ferroan cement is restricted to ooid nuclei, mostly from bivalve fragments. The cement in the intraclasts looks similar to the rest of the rock.

The absence of a range of sedimentary structures, allowing a more specific flow regime to be identified prevents further interpretation.

This microfacies can be correlated with standard microfacies 3 of Buxton and Pedley (1989), and also standard microfacies RMF 29 of Flügel (2004). It is common in bank and sand shoal environments.

Ooid skeletal grainstones in the Qom Formation in Iran were interpreted as a shoal environment (Shakeri et al., 2007). Also, similar microfacies were recorded in the Rupelian, Umm Ad Dahiy Formation in South Sirte Basin, Libya by Imam and Galmed (2000).

The overall characteristics suggests high energy, very shallow marine shoal environment.

5. Zone 5:

5.1. SP-1 Microfacies interpretation:

The nature of the bioclasts of SP-1 suggests a shallow water environment, and this is deduced from the abundance of porcellaneous benthic foraminifera (for details see 4.2.4a). Peneroplids are estimated to inhabit water shallower than 30 metres deep (Beavington-Penney and Racey, 2004) and they prefer a relatively low energy water environment (Brasier, 1975a). They are common in lagoon setting, and it is believed that the foraminifera do not normally live on the sediment surface in these environments but their dead remains were transported some distance prior to burial (Murray, 1965, 1966).

Furthermore, a shallow depth of water is supported by the abundance of miliolids, which live in a variety of very shallow water environments, from subsaline to hypersaline, preferably in low turbulence water in lagoonal and/or backreef environments (Geel, 2000). *Praerhapydionina* is another component of this microfacies, largely found with lime-mudstone in a very shallow water platform interior accompanied by abundant miliolids, and may indicate a sheltered low energy backreef environment. In contrast, *Austrotrillina,* generally associated with miliolids, lived under somewhat higher environmental energy conditions compared with *Praerhapydionina,* in very shallow water less than 30m deep in a platform interior (Geel, 2000). Furthermore, the shallowest part of the photic zone, in inner ramp, is characterized by *Austrotrillina* and *Archaias* (Bassi et al., 2007). The presence of a large number of porcellaneous foraminiferal tests may point to the depositional environment being slightly hypersaline (Vaziri-Moghaddam, 2006; Brandano et al., 2009).

The dominant packstone texture of this microfacies indicates deposition in a relatively low energy environment, with the effect of waves or currents not being obvious.

Cementation occurred before burial and is composed of non-ferroan calcite cement.

Chemical compaction, including stylolites and organic-rich seams along the brecciation lines, formed during the burial diagenesis (Flügel, 2004). The presence of common irregular fractures within this microfacies gives the rock a brecciated appearance; tectonic may cause this brecciation.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a protected embayment in a shallow subtidal ramp (microfacies 4). It represents lagoonal environment in the standard microfacies types described by Wilson (1975) and Flügel (1982, 2004).

The overall characteristics represent shallow water protected environment, in shallow subtidal zone.

5.2. **SP-2 Microfacies interpretation:**

The nature of the bioclasts of SP-2 suggests shallow water setting. This assemblage is mostly composed of porcellaneous benthic foraminifera, miliolids; *Peneroplis*; *Austrotrillina*; *Praerhapydionina, Dendritina* are the most commons (for bioclasts interpretations see 4.3.5a). The occurrence of large numbers of imperforate foraminifera in wackestone-packstone-grainstone represents restricted shallow sub-tidal environments with relatively low current energy (Geel, 2000; Romero et al., 2002). The dominant packstone texture suggests deposition in a low energy environment, although the partial grainstone texture indicates a relatively higher energy environment than SP-1 microfacies.

Both horizontal and vertical burrowing creates an extensive burrow of networks which represent a wide variety of environments.

Cements are precipitated in an oxic fluid before burial and are composed of non-ferroan calcite. Rare chemical compaction represents burial diagenesis (Flügel, 2004).

In accordance with the standard microfacies type in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as microfacies 4, protected embayment in a shallow subtidal ramp.

A similar microfacies was described as a shelf lagoon environment by Okhravi and Amini (1998) from Miocene in Central Bain, Iran; by Vaziri-Moghaddam et al. (2006) at Oligocene-Miocene Asmari Formation in south-west Iran and by Brandano et al. (2009) at the Late Oligocene Attard Member in Malta.

The overall characteristics represent a shallow protected environment above the normal fair-weather wave base in an inner ramp setting.

5.3. SP-3 Microfacies interpretation:

The nature of the bioclasts of SP-3 suggests a shallow water marine setting. It comprises shallow marine biota with abundant porcellaneous benthic foraminifera as miliolids, peneroplids, *Austrotrillina, Praerhapydionina, Dendritina* and *Archaias* are dominant (for bioclasts interpretations see 4.3.5a).

The grainstone texture suggests deposition in a high energy environment with the depositional setting being influenced by waves and currents. In addition, the partial packstone texture indicates intervals with a relatively low energy. Overall, this microfacies is higher energy than SP-1 and SP-2 microfacies.

The open, uncompacted texture is characteristic of rocks that were substantially cemented in early diagenesis (Adams and MacKenzie, 1998), with non-ferroan calcite cement formed before significant burial.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a microfacies 4, protected embayment in a shallow subtidal ramp. This microfacies is analogous to the standard microfacies SMF18 of Flügel (2004).

Similar microfacies were described by Vaziri-Moghaddam et al. (2006) from the Oligocene-Miocene Asmari Formation in south-west Iran as a lagoon close to nearby tidal flat.

The overall characteristics represent shallow environments above the normal fair-weather wave base in an inner ramp.

5.4. NA Microfacies interpretation:

The nature of bioclasts of NA suggests a shallow marine setting. Alveolinids are one of the more abundant components and have been found in a variety of shallow subtidal environments down to approximately 80m water depth, although their maximum abundance occurs in depths of less than 35m (Reichel, 1964; Bandy, 1964; Hottinger, 1973). Moreover, *Orbitolites* is common down to 40 metres (Geel, 2000). *Nummulites* is another component, the shape and size of which can be used as an environmental indicator. The shape and thickness of the test of the larger foraminifera is strongly influenced by water turbulence and light. The species which live in either more turbulent environments or higher levels of light, produce thicker tests than specimens from less turbulent environments and lower light levels (Hallock, 1979, 1983; Kuile and Erez, 1984; Hallock and Glenn, 1986). Furthermore, the modern amphisteginids from the Gulf of Aqaba show that interspecific changes in diameter to thickness (D/T) ratio of some species may be related to the level of incoming light (Larsen, 1976), a general tendency towards increasing D/T ratio with depth was observed. In addition to Beavington-Penney and Racey, (2004) interpretation of foraminiferal test shape, *Nummulites,* as example, that have ovate tests with thick walls are produced in shallow water, while the flatter tests with thinner walls are produced with increasing water depth (for more detail of *Nummulites* environment interpretation see 4.3.7b).

Nummulites in this microfacies are composed of small to medium size lens shaped forms, which; according to the above interpretations suggest growth in a shallow water environment, in relatively medium-high level of light.

The co-occurrence of hyaline, perforates benthic foraminifera from normal marine and imperforates one suggests that sedimentation took place in a lagoon with no effective barrier to separate them (Geel, 2000; Romero et al., 2002).

The Micrite matrix with a packstone texture is evidence that the deposition took place in a relatively low energy condition.

The cement in this microfacies is composed of non-ferroan calcite cement without any evidence of burial.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a protected embayment in a shallow subtidal ramp (microfacies 4). It is similar to the ramp microfacies type RMF14 of Flügel (2004) which was interpreted as restricted to open marine environments. Moreover, the faunal association of this microfacies may be correlated to the *Nummulites-Alveolina-Assilina* faunal association of the Eocene carbonate ramp which were described by Beavington-Penney and Racey, (2004).

The overall characteristics suggest a shallow marine environment in an open lagoon setting with no effective barriers.

6. Zone 6:

6.1. CB Microfacies interpretation:

This microfacies, representing in-situ coral reef bioherm, either represents a barrier reef which separated the open marine from a restricted lagoon, or patch reefs, which are common in open (non-restricted) lagoons (Tucker and Wright, 1990).

Individual coral heads are difficult to see in the field due to the massive nature of the outcrop and to recrystallization (Figure 4.30) and it is interbedded with skeletal grainstone (SP-3), coralline red algae-*Nummulites* wackestone (NR-1) and rotalids-coralline red algae wackestone/packstone (RR) with almost metre scale that makes it behave like a patch reef rather than a barrier one.

The main component of CB microfacies comprises different coral genera with different shapes, along with the muddy matrix. Corallite was originally composed of aragonite which was completely dissolved and replaced by sparite cements, but morphology has been conserved by micritization of the outer surface.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a microfacies 6, coralgal patch-reef belt (shallow ramp build-up).

Similar microfacies have been reported by Amirshahkarami et al. (2007) as in-situ organisms of organic reefs of mid ramp origin in the Asmari Formation-southwest Iran. Furthermore, the coral boundstone in the Qom Formation (central Iran) generates both barrier reef and patch reefs (Shakeri et al., 2007).

According to the lateral distribution of facies in the Lower Oligocene Gornji Gard Beds (Slovenia), the coral facies lived in a deeper marine environment relative to foraminiferal-coralline algal facies (Nebelsick et al., 2000).

The overall characteristics suggest in-situ coral reef bioherm in the form patch reef belt in a middle ramp setting.

7. Zone 7:

7.1. RR Microfacies interpretation:

The nature of the bioclasts in the RR microfacies suggests a shallow open marine setting. One type of bioclast is composed of non-articulated, fruticose with few crustose coralline red algae, with a rare “hooked” form or curved shape (improper hooked structure), which may be evidence of sea grass growth in a vegetated environment (Beavington-Penney et al., 2004) (Figure 47 and 48). Fossil seagrasses are rarely found in the geological record, yet it has been suggested that seagrasses first appeared in the Late Cretaceous which originated from Tethyan and became wide spread during Eocene (DenHartog, 1970; Brasier, 1975b; Eva, 1980). Furthermore, during the Late Eocene period when many larger benthic foraminifera became distinct, numerous seagrass-dwellers disappeared and Oligocene became uncommon in the seagrass-dweller. Therefore, it is difficult to suggest that the distribution of the seagrass communities may have been present during the Oligocene pwroid. Although, in Bembridge, Isle of Wight, *Cymodocea* has been recorded during Oligocene (Chesters et al., 1967).

Wolf and Conolly (1965) pointed out that algae are generally good indicators for shallow water because photosynthesis is depth controlled. Rotalids is another component that represents shallow turbulent water of 0-40 m water depth in the shore zone, on reefs and inter-reef areas (Geel, 2000).

The packstone and wackestone textures suggest a low energy regime, in a depositional environment not influenced by waves or currents. Moreover, the matrix is indicative of a deposition within low water energy conditions. The cements in this microfacies are non-ferroan calcite precipitated in an oxic fluid before burial.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as microfacies 5, rhodolith platform facies.

A similar microfacies found in the Qom Formation in central Iran has been interpreted as indicating a proximal open marine environment (Shakeri et al., 2007). Moreover, Amirshahkarami et al. (2007) reported the same microfacies in the Asmari Formation, south-west Iran, as indicating a shallow open marine environment or being near fair weather wave base on the proximal side of a mid-ramp environment.

The overall characteristics suggest a shallow open marine setting, just below a fair-weather wave-base.

7.2. NR-1 Microfacies interpretation:

Nummulites and coralline red algae are the most common bioclasts in NR-1 microfacies which suggest an open marine setting. The depositional environment of *Nummulites* is clearly related to size and form, but it is difficult to interpret, because the authors drew different conclusions as it has been interpreted from shallow nearshore, inner ramp shore face to mid and outer ramp or shelf within 30-60 metres water depth (Moody, 1987; Aigner, 1983; Racey, 1994; Bassi, 1998; Gilham and Bristow, 1998; Sinclair et al., 1998; Loucks et al., 1998; Luterbacher, 1998; Nebelsick et al, 2000; Racey, 2001). Moreover, Racey (2001) concluded that *Nummulites* occupied a broad range of open marine environments, on both ramps and shelves, where restricted water is absent. In addition, Geel (2000) concluded that *Nummulites* could live in various environments, except for very restricted areas, and that they could form banks on swells. He mentioned that large flat *Nummulites* proliferated on the seaward side of the shallow shelf and the upper part of the deeper shelf at 50-80m water depth, but the small and medium-sized lens shaped *Nummulites* lived in a platform interior (for more detail on *Nummulites* shape see 4.3.5d).

Another component is red algae, mostly composed of *Lithothamnium* (for more detail on red algae see 4.3.7a). Pomar (2001) concluded that the presence of larger foraminifera with red algae generating a distally steepened ramp platform.

According to these interpretations of the environment, *Nummulites* can be interpreted as shallow open marine setting; because of the lens shape, coarse sand sized *Nummulites* are accompanied by abundant coralline red algae.

The matrix in wackestone beds suggests a low energy condition, so the environment was not influenced by waves or currents. The open uncompacted texture suggests that cementation began during early diagenesis, before any compaction (Adams and MacKenzie, 1998). The only form of cement present is non-ferroan calcite, with no evidence of burial cement.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as microfacies 5, rhodolith platform facies.

The overall characteristics suggest a shallow open marine setting, just below the fairweather wave base in a proximal part of the mid-ramp.

7.3. NR-2 Microfacies interpretation:

The nature of bioclasts of NR-2 suggests an open marine setting. They are composed of *Nummulites,* and red algae with uncommon *Discocyclina* (more detail on *Discocyclina* is in 4.3.8a). The bioclasts are more diverse and relatively deeper than NR-1 microfacies. The medium to large lens-shaped *Nummulites*, in addition to its association with *Discocyclina,* are indicative of an open marine setting (more detail is in 4.3.5d and 4.3.7b) relatively deeper than NR-1. *Operculina* is another component of this microfacies which can live in environments with water depths of 15-150m (Geel, 2000).

The texture of packstone with the presence of micrite matrix is evidence that the deposition was in a low energy conditions without the effect of waves or currents. The cement in this microfacies is only non-ferroan calcite, without evidence of burial cement. The cement can be described as early cement because the grains are open-packed.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a microfacies 5, rhodolith platform facies. A similar microfacies is reported in an open marine environment in Middle Eocene-Early Oligocene shallow water carbonate by Nebelsick et al. (2005). Furthermore, *Nummulites* from same microfacies in Aj Dagh Anticline were described by Aqrawi et al. (2010) as Early Oligocene *Nummulites vascus* "with question mark" of Sheikh Alas Formation, but they also mentioned that no *Lepidocyclina* were found which indicative of the Early Oligocene age. Whereas, this study reveals that these *Nummulites* are belong to Late Eocene Avanah Formation, because they associate with *Discocyclina* and *Pellatispira* which they are indicators for the Late Eocene age.

The overall characteristics suggest an open marine setting above the storm wave base in a mid-ramp setting.

8. Zone 8:

8.1. NR-3 Microfacies interpretation:

The bioclasts of NR-3 represent an open marine setting deeper than NR-1 and NR-2. The dominant bioclasts are *Nummulites* and *Discocyclina. Nummulites* are mostly large flat shaped *Nummulites* which are associated with *Discocyclina*; the environment of deposition can be described as a distal part of the shallow shelf and the upper part of a deeper shelf at water depths of 50-80m according to Geel's (2000) conclusion.

Discocyclina is one of the most common components of this microfacies. Numerous studies have interpreted *Discocyclina* as having lived in a broad spectrum of environments within the photic zone, including shallow fore-reef/fore-shoal environments (Henson, 1950a; Racz, 1979; Anketell and Mriheel, 2000) and deeper outer ramps (Racey, 1994; Gilham and Bristow, 1998). Meanwhile Ghose (1977) studied *Discocyclina* from the Palaeogene of north-east India and concluded that *Discocyclina* had lived in both fore-reef and back-reef environments. Both Loucks et al. (1998) and Sinclair et al. (1998) concluded that the ovate form can be found in shallow marine settings above the fair-weather wave base in inner ramps, while the flattened form is below the fair-weather wave base in mid to outer ramp settings. According to Geel (2000), *Discocyclina* is an indicator of normal marine water and can be found down to water depths of 100m. In NR-3 microfacies, the *Discocyclina* is more likely to be large and flat in shape and can be assigned to nearby outer ramp settings.

The texture of packstone is evidence of low energy conditions and the effects of waves and currents are not present. Only non-ferroan calcite cement is present, while both chemical and mechanical compactions are obvious. The chemical compaction is clear between grains as grain-to-grain contact, concave-convex contact and suture contact which indicates burial diagenesis, while the mechanical compaction is indicative of a lack of early cement in this microfacies (Figures 4.51 and 4.52).

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a microfacies 7, large foraminifera 'orbitoid' facies.

Similar microfacies were reported as an open marine by Amirshahkarami et al. (2007) in the Asmari Formation in south-west Iran.

The overall characteristics suggest low energy; open marine setting in the proximal part of deeper marine.

9. Zone 9:

9.1. PK-1 Microfacies interpretation:

The bioclasts in PK-1 microfacies suggest an open marine outer ramp/basinal environment. The bioclasts are composed of rare planktonic foraminifers with small fragments of ostracods. Planktonic foraminifers live in open marine water and their abundance increases seaward. Where larger benthic foraminifers are absent, the water depth is assumed to have been more than 200m in slope and basin environments (Geel, 2000). Furthermore, open marine deposition is suggested by the presence of pelagic foraminifera.

The occurrence of matrix in packstone beds indicates a low energy regime, thus suggesting deposition in an environment not affected by waves or currents. This indicates a deposition below the normal wave base (Wilson, 1975; Flügel, 1982, 2004).

The cements comprise non-ferroan calcite with no evidence of burial cementation. Meanwhile, the clay seams and low amplitude stylolites are indicative of burial diagenesis.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as being a microfacies 8, planktonic foraminiferal facies. It represents the standard microfacies SMF2 deep sea of Flügel (2004). It is the deepest deposit in the succession.

Similar microfacies have been described by Amirshahkarami et al. (2007) in the Asmari Formation in south-west Iran and have been interpreted as an outer ramp facies.

The overall characteristics suggest an open marine environment below the storm wave base in the outer ramp towards a basinal setting.

9.2. PK-2 Microfacies interpretation:

The nature of bioclasts of PK-2 suggests an open marine setting. The lack of benthonic foraminifera and the abundance of planktonic ones suggests an open marine setting down to more than 200m of slopes and a basinal environment (Geel, 2000).

The absence of any micritization of the bioclasts indicates deposition at a depth of more than 18 metres, and below a fair-weather wave-base (Perry, 1998). Furthermore, the matrix-rich texture of calcimudstone is indicative of a lower energy regime without the influence of waves or currents. The low energy hydrodynamic regime indicates a deposition below the normal wave base (Wilson, 1975; Flügel, 1982, 2004).

Only non-ferroan calcite cement precipitated in this microfacies, with no burial cement, while the presence of clay seams indicates burial diagenesis.

The microfacies PK-2 is equivalent to the 'facies (8) planktonic foraminifera' in the standard model of the Cenozoic carbonate ramp generated by Buxton and Pedley (1989), and to the standard microfacies SMF3, deep water basin of Flügel (2004); the deposition environment is interpreted as being a slope and basin setting. A similar microfacies were reported on the outer slope toward a basin environment in the Oligocene-Miocene Asmari Formation in south-west Iran by Vaziri-Moghaddam et al. (2006).

The overall characteristics represent an open deep marine setting on the outer ramp of a basinal environment.

9.3. PK-3 Microfacies interpretation:

The nature of bioclasts of PK-3 suggests an open marine setting. The presence of both allocthonous benthonic and autochthonous planktonic foraminifera suggests a transition from a shallow to a deep marine environment above 200m of water depth. So, it can be interpreted as a shallower microfacies relatively to PK-1 and PK-2.

The absence of the micritization of bioclasts indicates deposition at a depth of more than 18 metres, below the fair-weather wave-base (Perry, 1998). Moreover, the matrix-rich texture of wackestone indicates a lower energy condition and deposition in an environment not influenced by waves or currents, below a normal wave base (Wilson, 1975; Flügel, 1982, 2004). However high energy is indicated by the abundance of larger benthic foraminiferal debris, including fragments of *Nummulites* and *Discocyclina*. This may suggest this debris was driven from a different environmental setting during a storm event or by geostrophic currents. There is no evidence of sediment gravity (slope-related) flows.

The only cement precipitated is non-ferroan calcite cement, with no evidence of burial cement, while the presence of stylolites and clay seams indicates burial diagenesis.

In accordance with the standard microfacies types in a Cenozoic carbonate ramp which were described by Buxton and Pedley (1989), this microfacies is interpreted as microfacies 8, planktonic foraminiferal facies.

A similar microfacies was interpreted as an outer slope environment by Pedley (1996) on the Maltese Tortonian ramp, and also by Vaziri-Moghaddam et al. (2006) in the Asmari Formation in southwest Iran.

The overall characteristics suggest an open marine setting below the storm wave base in an outer ramp setting nearby basin.

Integrated depositional model:

Shallow marine carbonate sediments can occur in three different settings: platforms, shelves and ramps (Tucker, 1985). Platforms regionally composed of extensive environments of shallow subtidal and intertidal sedimentation; shelves have relatively narrow depositional environments, recognized by a distinct break of slope at the shelf margin, while ramps are composed of a gentle slope from intertidal to basinal depths, with no major change in facies gradient. This study considers that deposition took place on a carbonate ramp, because of lateral variations in microfacies; gradual deepening with no evidence of a steep slope suggest that there was no effective barrier or slope break, and only minor patch reefs have been detected. The distribution of foraminiferal assemblages allows the ramp to be divided into three parts: inner ramp; middle ramp and outer ramp (Burchette and Wright, 1992).

Depositional model has been generated from the overall palaeoenvironmental interpretations of the microfacies. Nine major depositional environmental zones have been identified from the twenty two different microfacies and have been correlated to the standard Cenozoic ramp model of Buxton and Pedley (1989) (more detail is in Table 2). These zones distributed across the ramp setting, dipping southwest, zone 1 is a terrestrial deposit; zone 2, zone 3, zone 4 and zone 5 belong to the inner ramp; zone 6, zone 7 and zone 8 belong to the middle ramp and zone 9 belongs to the outer ramp and basinal setting. In addition to the evolution and changes in associated foraminifera across the ramp, it has been separated into two time intervals, Late Eocene foraminiferal association and Oligocene-Early Miocene foraminiferal association (see Figure 69).

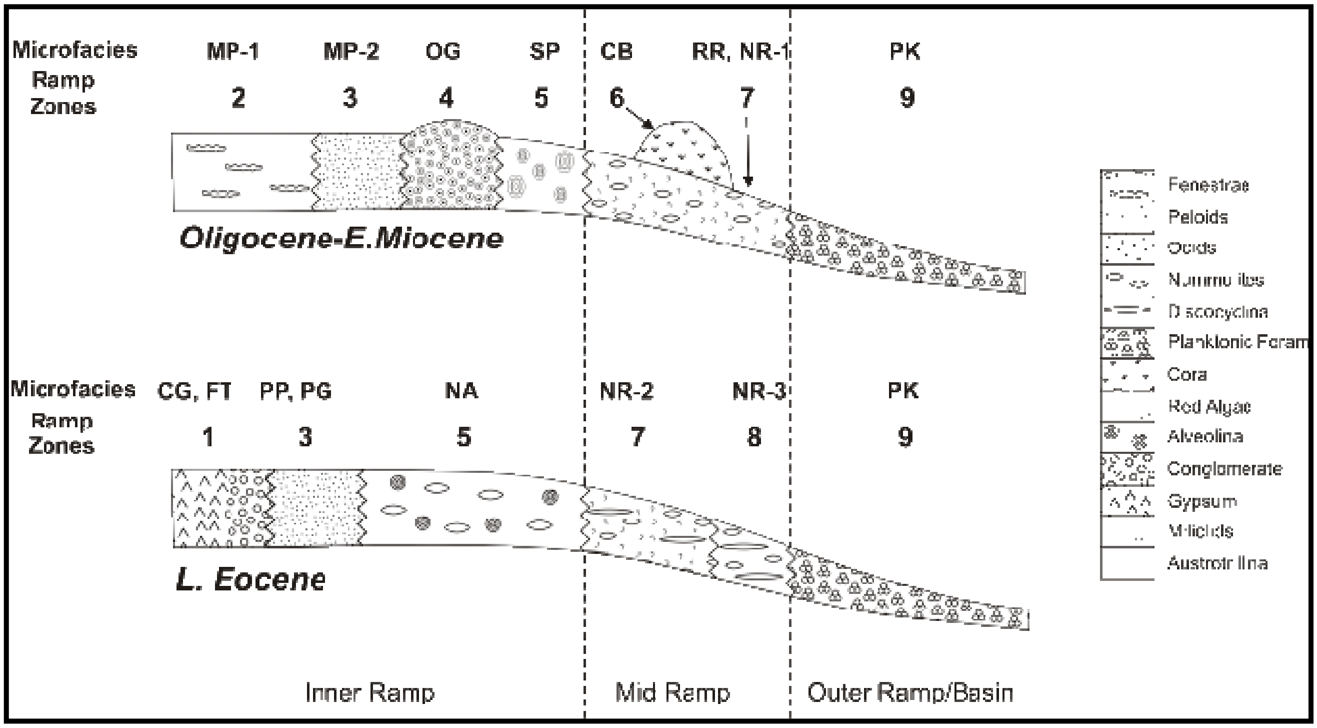

Figure 69: Depositional model and microfacies change across the ramp, during Late Eocene and Oligocene-Early Miocene in the study area.

Discussion and conclusion:

Although the previous study (Henson, 1950a) established the depositional environment of the Kirkuk Group as reefal, this study considers that deposition took place on a carbonate ramp. The above interpretations show that the depositional environment represents a ramp setting, as the lateral facies changes gradually with depth, and also there is no evidence of a rimmed shelf and steep slope.

According to the distribution of foraminiferal associations, nine dipositional environment zones were determined ranging from terrestrial to open marine settings distributed across inner, middle and outer ramp settings (see Figure 69) where the microfacies gypsum/marl/claystone (FT), conglomerate (CG) and palaeosol (PS) are located in ramp zone one which belongs to a terrestrial environment; microfacies peloidal, bioclastic packstone/grainstone (MP-1) is in ramp zone two; microfacies peloidal wackestone/calcimudstone (MP-2), peloidal, skeletal grainstone (PG) and peloidal packstone/grainstone (PP) are in ramp zone three; microfacies ooidal grainstone (OG) is located in ramp zone four; microfacies skeletal packstone with brecciation (SP-1), skeletal packstone with *Austrotrillina howchini* (SP-2), skeletal grainstone with *Praerhapydionina delicata* (SP-3) and *Nummulites-Alveolina* packstone/grainstone (NA) are in ramp zone five. These four ramp zones, from two to five, belong to an inner ramp setting. Microfacies coral bioherm (CB) is in ramp zone six; microfacies rotalids-coralline red algae wackestone/packstone (RR), coralline red algae-*Nummulites* wackestone (NR-1) and coralline red algae-*Nummulites-Discocyclina* packstone (NR-2) are in ramp zone seven; microfacies *Nummulites-Discocyclina* packstone is in ramp zone eight. The ramp zones six to eight belong to a middle ramp setting. In addition to microfacies peloidal packstone with planktonic foraminifera (PK-1), planktonic foraminifera calcimudstone (PK-2) and planktonic-benthonic foraminifera wackestone (PK-3) are located in ramp zone nine in which this ramp zone belongs to an outer ramp to the basinal setting (see Figure 68).

This study's microfacies can be correlated to the Cenozoic ramp facies which were described by Buxton and Pedley (1989) where Late Eocene foraminiferal association is dominant in *Alveolina, Nummulites* and *Discocyclina*; Early Oligocene foraminiferal association is *Nummulites* dominant and finally at Late Oligocene to Early Miocene the foraminiferal association changed to dominant in miliolids, *Austrotrillina, Peneroplis, Praerhapydionina* and *Dendritina*.

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