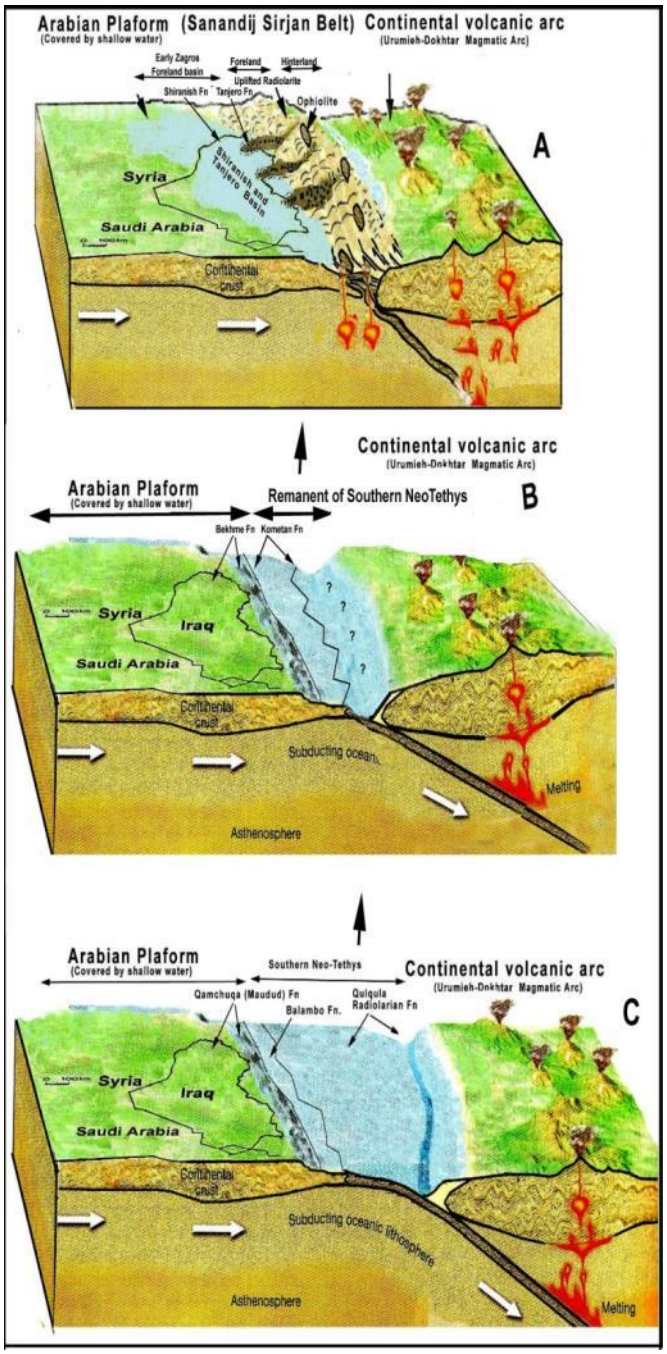

Geology of Iraq: Basic Principles

Description of stratigraphy, tectonics and boundary conditions of the some Rock units in Iraq and Kurdistan during Cretaceous and Tertiary. Prepared as a course for third year geology, 2008 revised in 2017

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1-Introduction

Definition:

The geology of Iraq and Kurdistan is subject which try to describe and divide systematically the outcropped and subsurface rock column into small stratigraphic interval (or parts or units) such as groups, formations, members and beds). These parts (units) are grouped according to tectonic development and depositional history of the region.

Why do we study the geology of Kurdistan and Iraq?

A-Academic purpose for: a- understanding history of the area, b- Writing geological reports
B-Practical purpose: for knowing, a- seismic risk of the area, b- finding groundwater and oil accumulation of an area.
C- Finding raw materials for cement, gypsum aggregates and metallic minerals
D-For understanding the engineering properties of formation (rocks) in case of dam and other large structure building.

1-1-The subject of the geology of Iraq depends on many facts and materials which are mentioned below as:

1-Language (used terms or wordology)

The most important factor for learning geology of Iraq is that The students must know that, as all sciences, the geology of Iraq has its language (wordology) which taken from the science of stratigraphy, petrology, tectonic and sedimentology. The student must know the definitions of the scientific words or terms in order to understand Geology of Iraq. Some of these terms are such as 1-Group, formation, member, beds, 2- Eon, Era, Period, Epoch, Age, 3-Eonothem, Erathem, System, Series, Stage. 4-Paleozoic, Mesozoic, Cenozoic, 5-Cambrican, Ordovician, Silurian, Devonian, Carbnoniferous, Triassic, Permian, Jurassic, Cretaceous, Paleogene, Neogene. 5-Ooid (Oolite), peloid, pellet, bioclasts, foraminifera, gastropod, pelecypod, rudist, bivalve, coral, algae. Other term such as pelagic, neritic, benthonic, planktonic, shelf, reef, littoral, sublittoral, thrust, overloading, isostasy, tectonics and others

2- Geology of Iraq deals mainly with formation as the main rock stratigraphic unit (lithostratigraphic units).

Definition of Formation

It is a lithostratigraphic unit (rock unit) which contain certain lithology and fossil and mapable. When new formation is found it is named by giving the name of geographic location with term of formation (such as Tanjero Formation, Pila Spi Formation). In a certain basin or certain tectonic activity many formations are deposited such as Maastrichtian Foreland basin in which Tanjero, Shiranish, Aqra, Digma and Tyiarat Formations are deposited.

3- Present structure of Iraq

The third issue that important of geology of Iraq is its dependence on the tectonics subdivision of Iraq in the present days. The whole Iraq can be consider as a large anticline (or anticlinorium) which has the trend of NW-SE and contain many small folds (syncline and anticlines). The northeastern limb of this anticline has suffered from recumbence, erosion and then thrusting over the southwestern limb. Because of colliding of Arabian and Iranian plates now Iraq is divided tectonically to , Western desert, Mesopotamian (Unfolded Zone), Low Folded, High Folded, Imbricated and Thrust Zones from southwest toward northwest (figs.1-1 and 1-2).

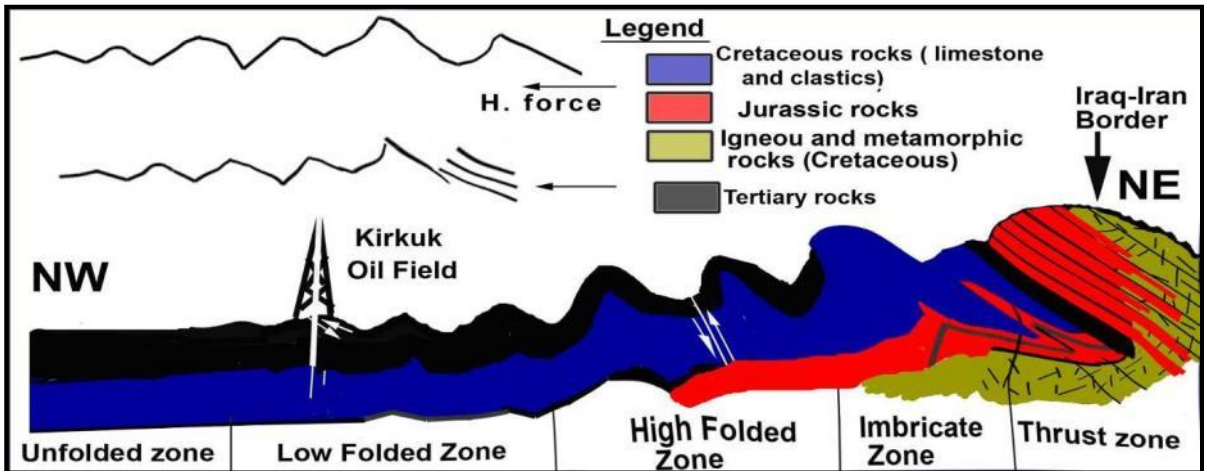

Fig.(1-1) Present days Tectonic subdivision of Iraq

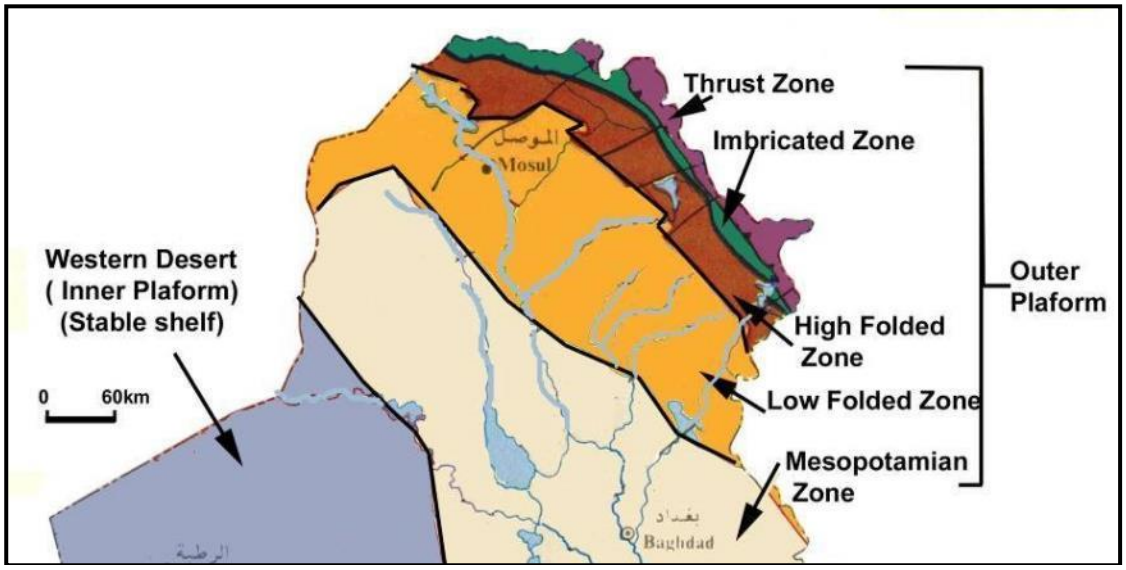

Fig.(1-2) Iraq map shows the most realistic (useful) tectonic subdivision of Iraq (Budy,1980 and Buday and Jassim,1987)

4-Time expanded stratigraphic (chronostratigraphic) column of Iraq.

For better understanding of depositional and erosional time of stratigraphic succession of the rock of Iraq, it stratigraphic column in which the lithology are indicated from older to younger from bottom to top respectively. The missing ages (those ages that have not representative lithologies) are expanded and shown on the column (see figure1-3).

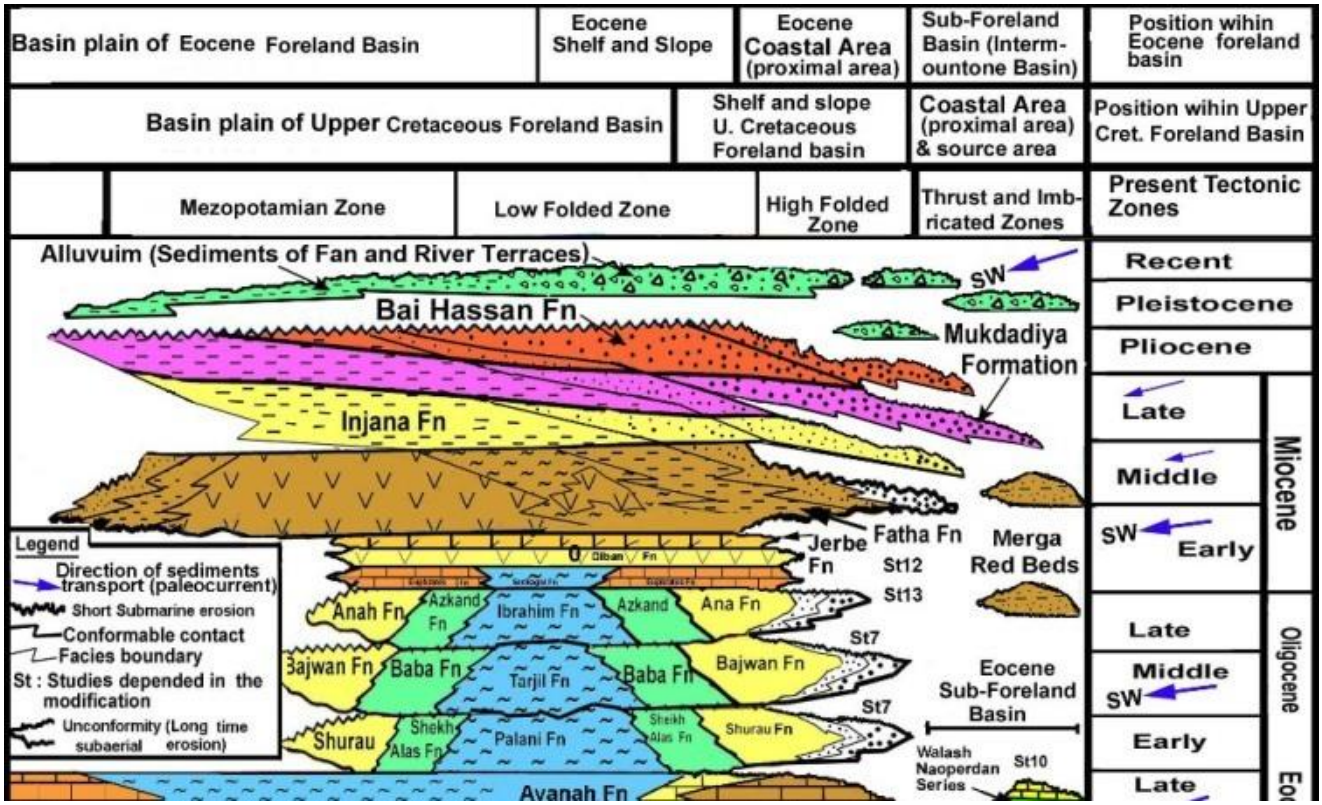

Fig. (1-3) time expanded stratigraphic column of Kurdistan during Tertiary (modified from Karim 2007 from Bellen et al (1959). It can be seen that the coastal area of the foreland basin contain several unconformities (right side of the figure)

5-Normal stratigraphic column

It is that type of stratigraphic column in which the age, lithology and thickness of the formsatioin are indicated from older to younger (from bottom to top respectively). The time of non-deposition or erosion is indicated by zig zag line only (Fig.1-4)

6-Facies maps (lithofacies maps)

These types of maps are useful in studying geology of Iraq and Kurdistan. They are those maps that show aerial (geographic) distribution of the certain formation with their thickness. They are very useful for understanding environment and tectonic of an area (see figure 1-3).

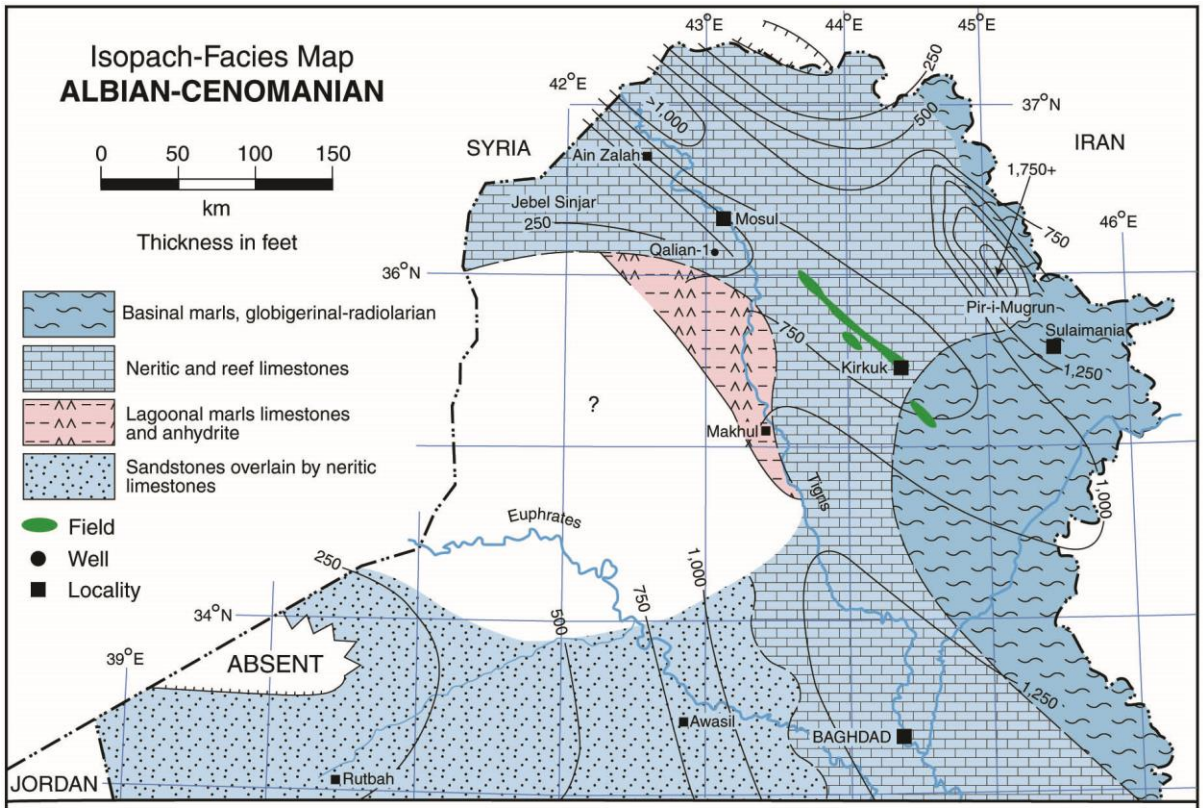

Fig.(1-3) Isopach facies map of Late Cretaceous (Dunnington, 1958) shows lithofacies and thickness distribution of Late Cretaceous (Maastricht Ian`).

7-<u>Field work</u>

The field work is the most important issue for the geology of Iraq and cannot be understandable without the field observation of: 1-lithologies and their colors, 2- bedding pattern, 3- thickness and fossil content, 4- nature of lower and upper contact, 5- Stratigraphic position. 6- Plotting the formation on prepared geological map. 7- Classification (division) of the existed rocks to stratigraphic units. Geologists use many tools during fieldworks such as hand lens (of 10X magnification) and compass (fig.1-5 and 6) in addition to hammer and camera.

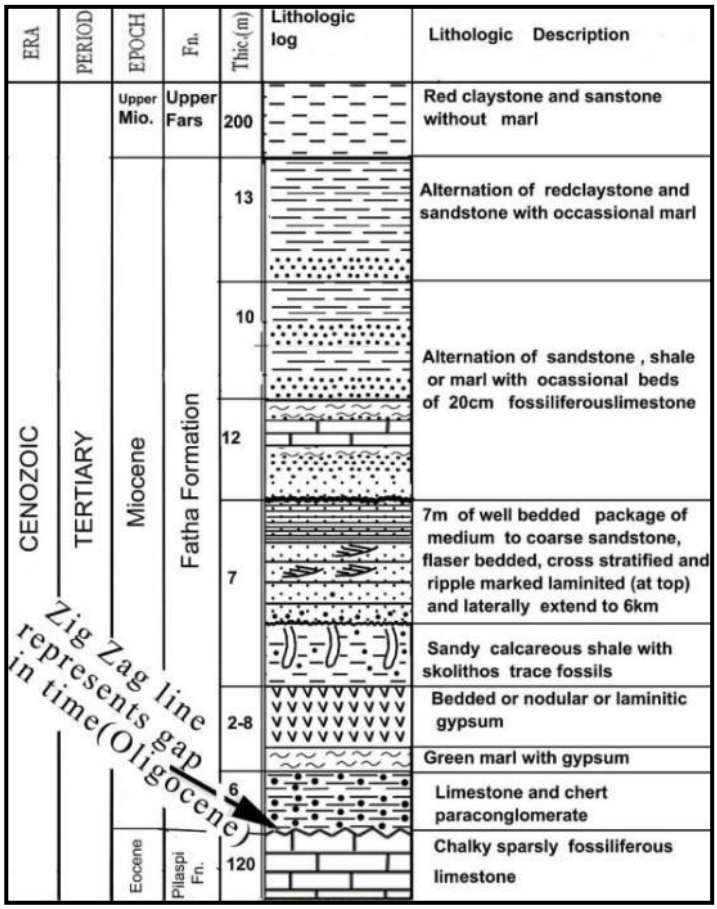

Fig.(1-4) Normal stratigraphic column of Kurdistan during Middle Eocene -Miocene in which Oligocene missed (has not representative rocks) (Ameen, 2007).

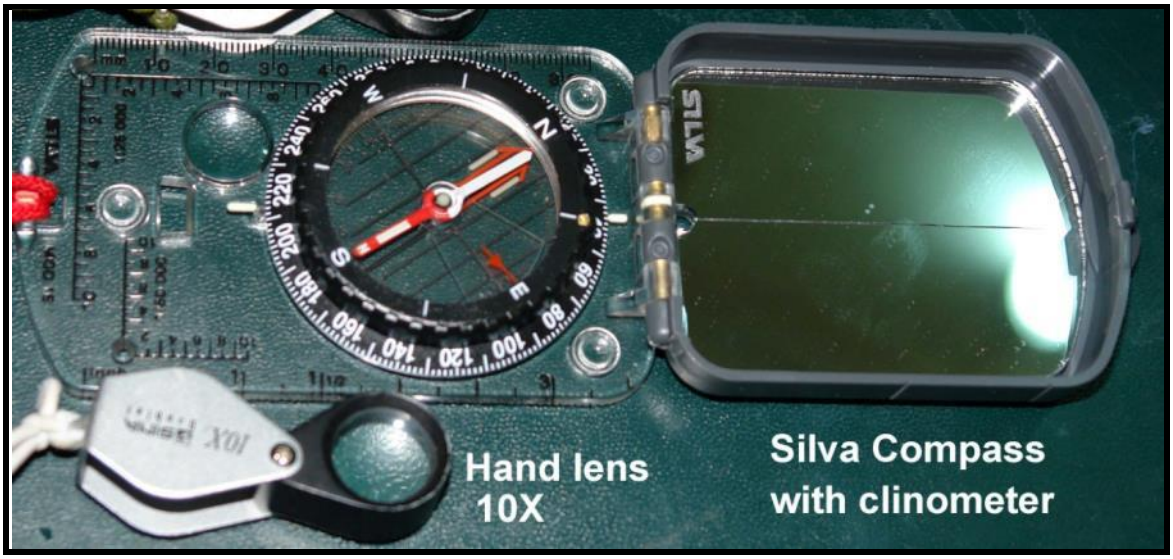

Fig. (1-5) Hand lense, hammer and compass are the most useful during the fieldworks

Fig. (1-4) field work by 4th year students (2003) on the border with Iran at the west of Mawat town

8- Boundary condition

In geology, the boundary conditions are highly variable and can be fixed. Any geological study, without indication and analysis of boundary condition cannot consider as precise scientific study. The most important feature or property of any formation is its boundary condition. This characteristic includes the vertical and lateral lithological and facies changes for tens and even hundreds of kilometers.

The vertical changes include conformable or unconformable upper and lower boundaries of the formation (or structure or Rocks). The boundary includes the nature of transitional zone when the boundary is conformable. The lateral changes must include the basin extent and location of the shoreline in the basin. On the outcrops, the indication of the boundary condition depends on the large scale fieldwork during which the sedimentology, sequence stratigraphy and structure of the area of the distribution of the formation are studied. In the subsurface it depends of the large numbers of wells and seismic reflection data.

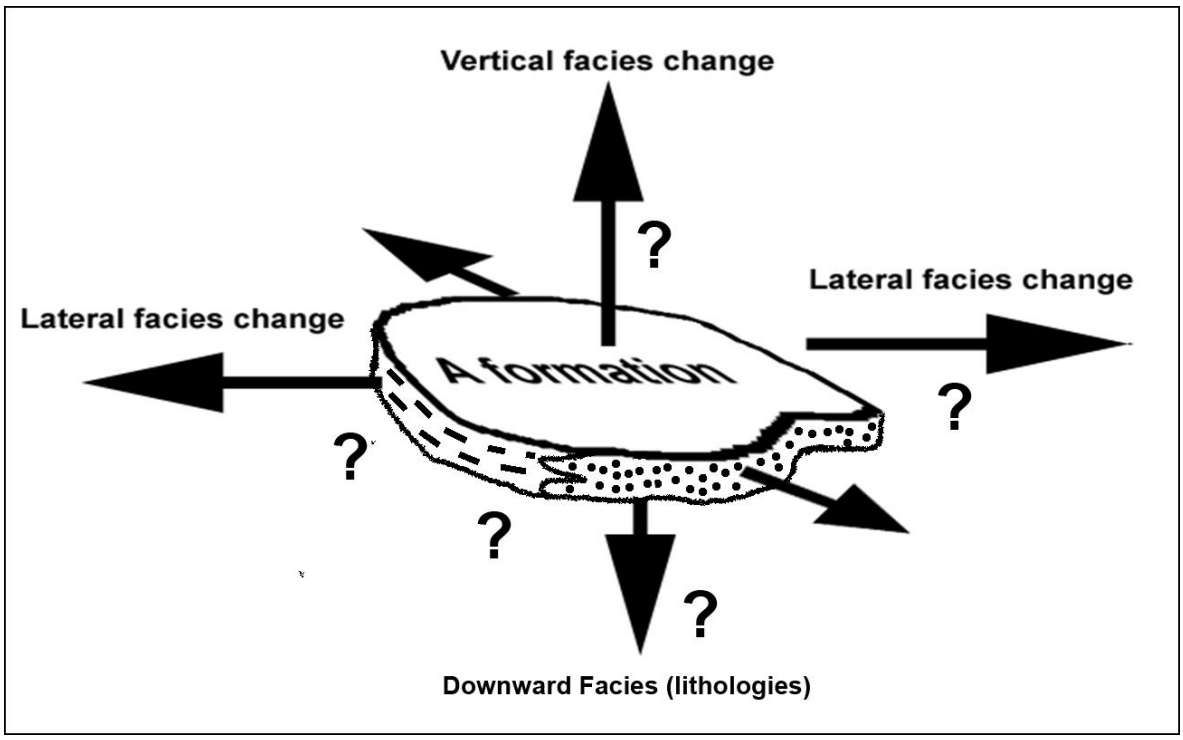

Fig. (1-5) boundary condition of a formation must be studied in all direction and may extend to tens or hundreds of kilometers far from formation border.

1-2-Neotethys Sea

It is that elongated and deep basin (ocean) that located between Arabian plate (or Afro-Arabian plate) and Iranian (Eurasia) Plate. It consists of two parts: 1-Southern Neo-Tethys and 2-Northern Neo-Tethys. The Southern one was covered Kurdistan, Iraq, and nearly half of the Iran (fig.1.2.1). The Neo-Tethys Sea has passed through two main phases:

1-2-1- oceanic phase

This phase existed during Jurassic and Early Cretaceous and the Neo-Tethys was consisted of relatively Deep Ocean in which radiolarites was depositing on its basin plain and trench while on its passive continental margin (platform) carbonate or evaporites were depositing (fig.1.2.1C).

2-2-Foreland basin phase (During Late cretaceous and Tertiary)

It is a basin that is formed in front of moving (advancing) orogenic belt (Frontal part of Iranian plate). It is formed on a stable area (former platform) by obduction (over thrusting) of Iranian Plate on Arabian one. Toward which the rocks of the orogenic belt were thrust or over folded. Generally, the foreland is a continental part of the crust and is the edge of craton or platform area. The reliefs (mountains) are created by uplifting of the orogenic wedge. The erosion of these mountains supplies detritus to fill the foreland basin (Fig.1-2-1B).

There are two types of Foreland basin:

2-3-Underfilled Basin or stage during late Cretaceous

In this stage, it is deep and underfilled (not filled) foreland basins in which turbidite or flysch is deposited: like basin of Tanjero and Kolosh Formations.

2-4-Overfilled basin (During Eocene and later ages)

It is the last stage of development of foreland basin in which molasses sediment are deposited such as basin of Red Bed Series, Gercus and Upper Bakhtiary Formations.

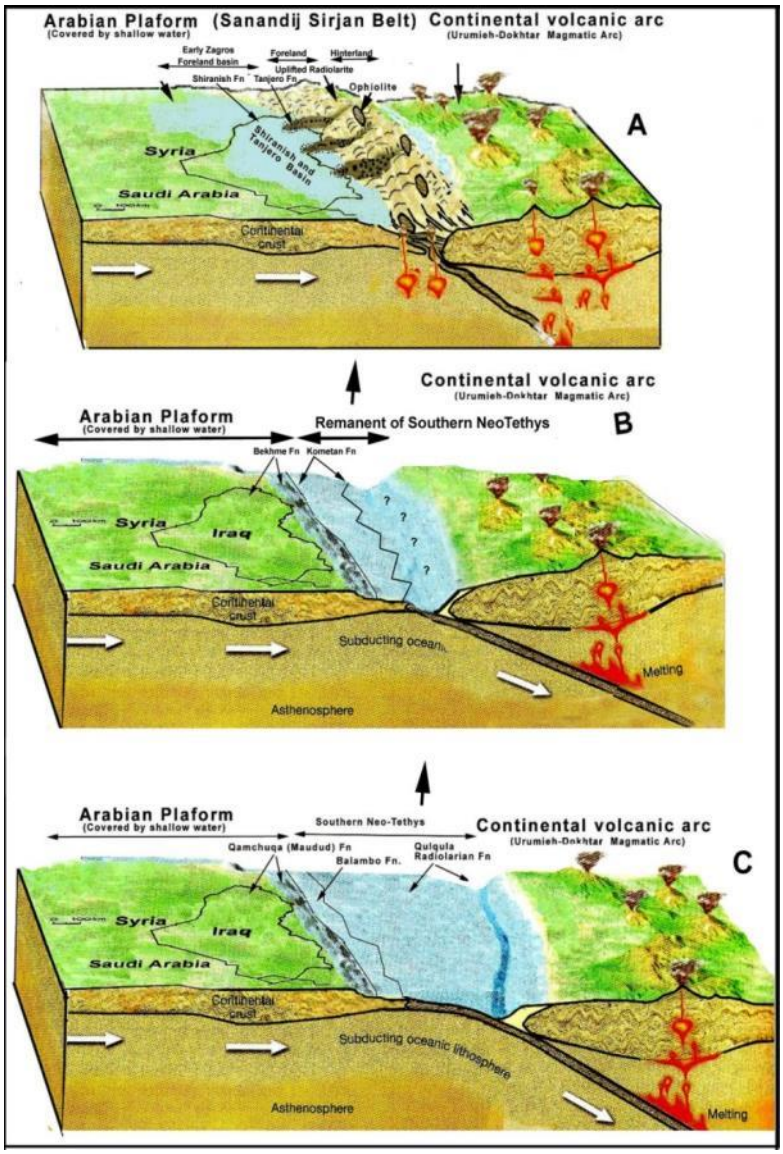

Fig.(1-2-1) Three different stages of the evolution of the Neo-Tethys, C) Oceanic stage which has the continental margin (Arabian platform) on which most Iraq and Kurdistan were located in Early Cretaceous. A) Foreland basin phase which started during late Cretaceous (Campanian) after closure of the southern Neo-Tethys. B) Transitional phase between the two above phase in which the Tethys became narrower and shallower than C phase.

1-3-Recent and Pleistocene sediments

These sediments are covering the parent rocks (formations) and their differentiation is necessary for mapping and studding the formations. Alluvium sediments and soil cover most part of the Iraq that make identification surface formations (rocks) are difficult. Therefore, it is important to differentiate these sediments from older rocks (formations).

1-3-1-Colluvium or talus cone (or colluvial sediment)

It is unorganized (unstratified) and poorly sorted deposits at the base of a hill slope, formed by gravity.

Fig.(1-3-1) Several cones of colluvium sediments

1-3-2-Alluvial fans

Alluvial fans are gently sloping, fan-shaped landforms common at the base of mountain ranges in arid and semiarid regions such as frontal part of all mountains in Kurdistan. These are the products of two main depositional processes: debris flows and sheet flows. The deposits of alluvial fans reflect these processes. In the present days, alluvial fans are bodies of very course grained sediment. They have steep upper surfaces, ranging from 16°– 1.5°, with the slope decreasing towards the basin. The slope magnitude depends on the fan's provenance (muddy, gravelly) and tectonic setting. In contrast, river (fluvial) environments have grades of 0.5°– 0.01°. These are cone-shaped deposits of very coarse sediments, generally lacking finer silts and clays. They are built up by successive sheet-flow (sand-dominated) or debris-flow deposits, most often in desert semi-arid environments. But also it is noted in humid region. When alluvial fans coalesce (join together) along mountain fronts they form a bajada geomorphologic form (feature).

Alluvial fans are generally restricted in area, typically being no more than 1-10 km from their source. They form when there is a sudden change in a stream from a narrow confined channel with a steep gradient to the broad flat valley bottom or plain, which causes a sudden drop in the hydraulic power of the stream, and hence deposition.

The upper surface of an alluvial fan is dominated by braided streams, which typically have wide and shallow anastomosing channels that form in the upper reaches of streams where slope is greater and where flowing water is often choked with more sediment than the fluid can carry. During the highpoint in a flood water escapes the main channel and creates a sheet flood of well-sorted sand or fine gravel with little or no silt or clay (midfan sheets are typically well-sorted, well stratified, and cross-bedded).

Alluvial fan deposits (sometimes known as fanglomerates) typically coarsen upwards as the fan spreads out from the mountain range. That is the grain size in a fan generally decreases towards the valley. Surface of alluvial fans are covered with radiating systems of braided stream channels; each new flood cuts a new channel and fills existing channels with coarse gravels.

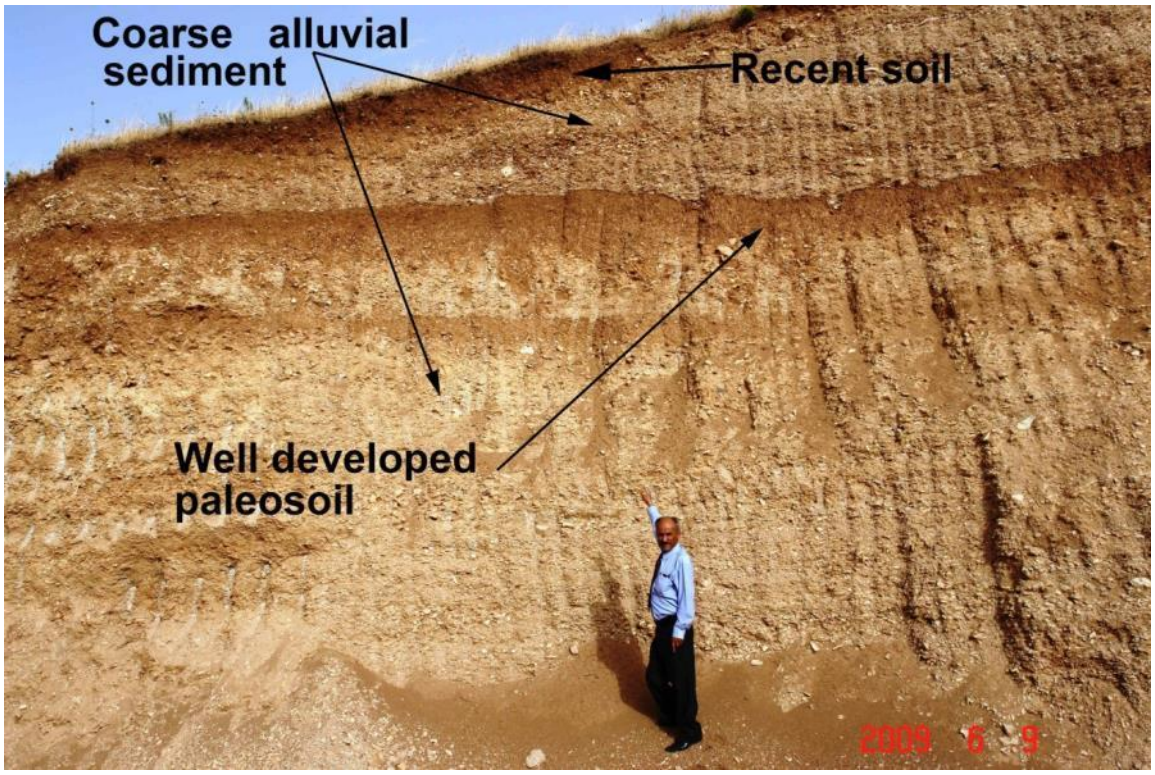

Fig. (1-3-2) Deposit of alluvium fan at north of Sulaimani city Interbedded with paleosoil.

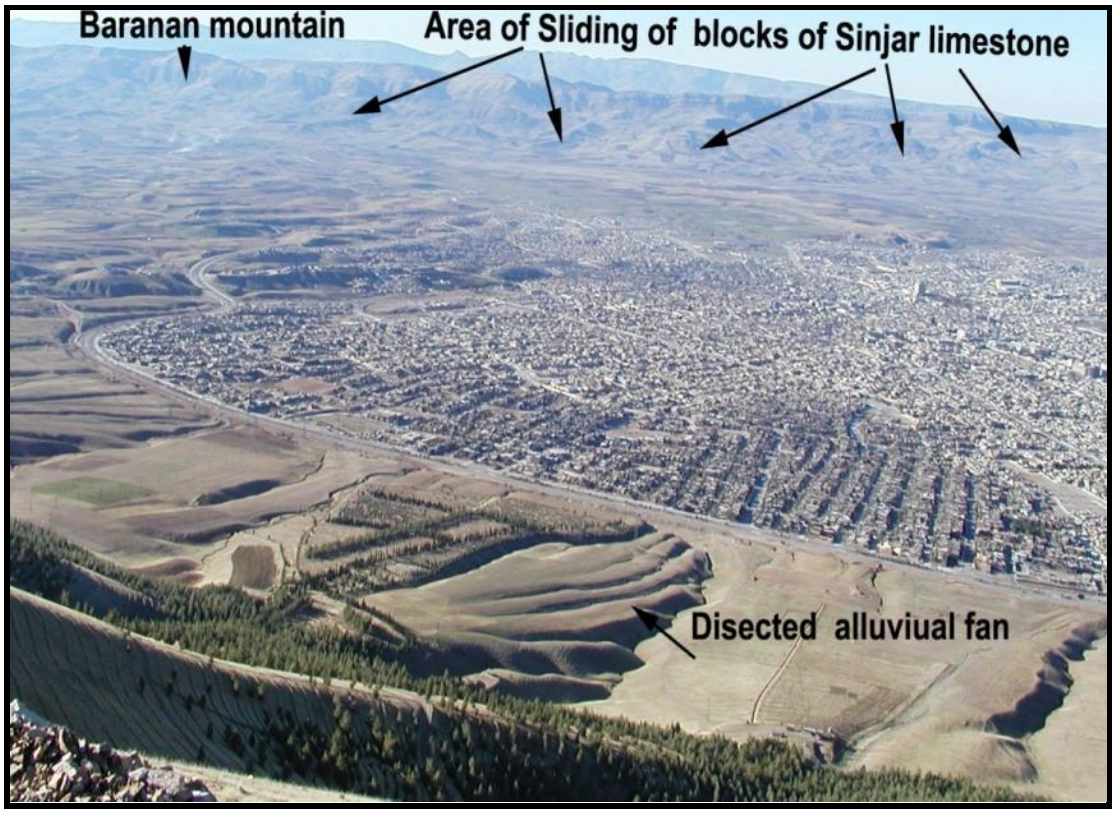

Fig. (1-3-3) Foreground: northeastern of Sulaimani city (pediment of Goizha Mountain) shows proximal part of several alluvial fans (Ali, 2007). Background: Baranan Mountain which contains several sliding of blocks of Sinjar Formation on Kolosh Formation.

Fig. (1-3-4) well sorted and rounded braided river deposits near Darbandikhan town which is mostly consist of gravel and boulder

2-Main tectonic steps (or phases) of development of the Geology of the Kurdistan

The present existed formations are deposited in different basins and reflect different tectonic setting and environments as cited below.

1-The southern Neo-Tethys was relatively small and narrow which was opened (at divergent Phase) during Triassic-Jurassic during which the Lower part of the Qulqula Radiolarite Formation is deposited (Fig.2.1).

2- The convergent phase is started at the beginning of the Cretaceous due to widening of the Northern Neo-Tethys, the pulling force was more than that of the southern one (See fig.2-2). By this pulling the Iranian plate had advanced toward southwest (toward Iraq).
3- The huge amount of the Radiolarites and Ophiolites (Trench materials) are accumulated in the trench between the two plates (See figure 2-3 and 2-4). This accumulation formed a forebulge on which Qamchuqa Formation was deposited

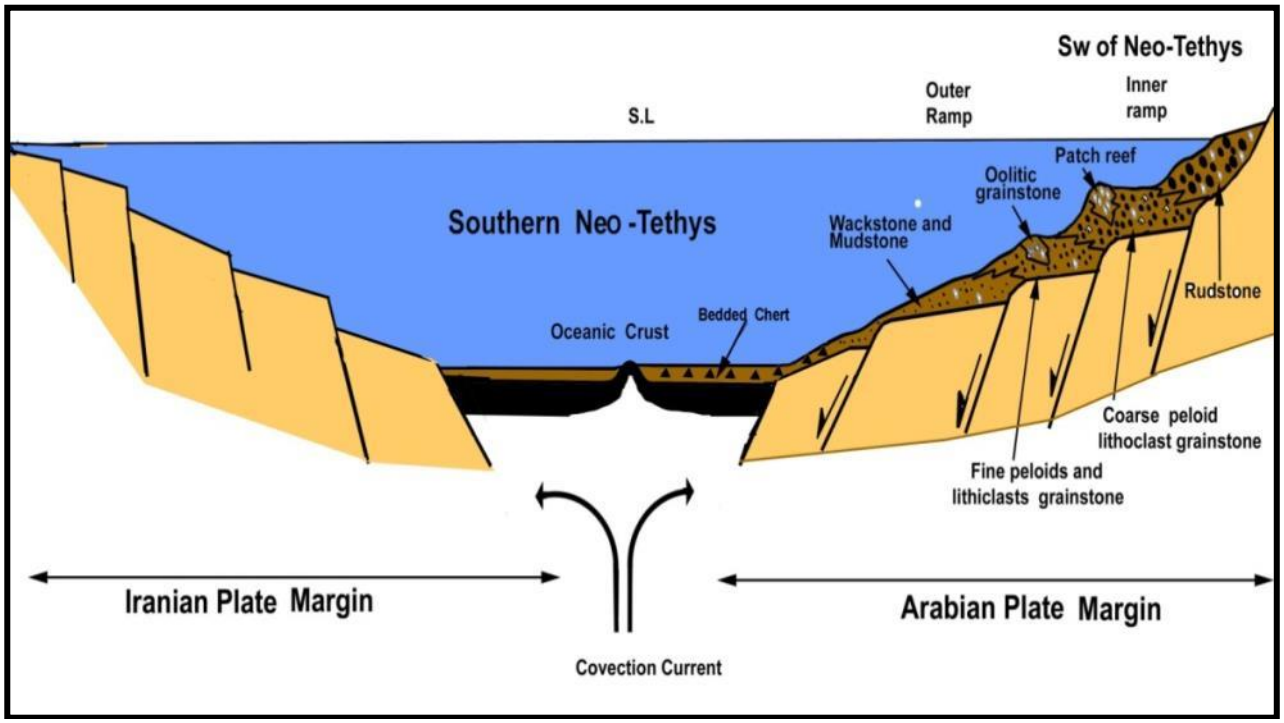

Fig. (2-1)Tectonic model of the Southern Neo-Tethys during Jurassic in which Lower part of Qulqula Radiolarian Formation is deposited (Baba Shekh, 2009). The basin was relatively small and narrow. At the beginning of Cretaceous, it had changed from divergent to convergent.

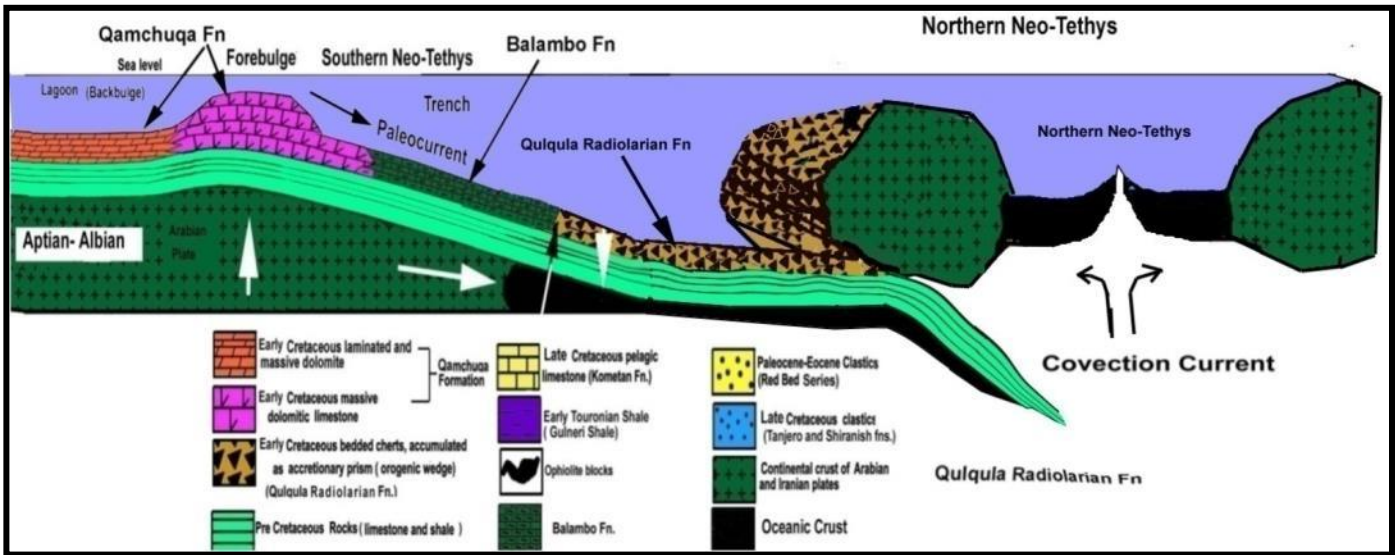

Fig. (2-2) this figure shows tectonic model of the southern and northern Neo-Tethys during Early Cretaceous upper part of the Qulqula Radiolarian Formation as equivalent of Balambo and Qamchuqa Formations. The basin was relatively small and narrow. At the beginning of Cretaceous, it had changed from divergent to convergent.

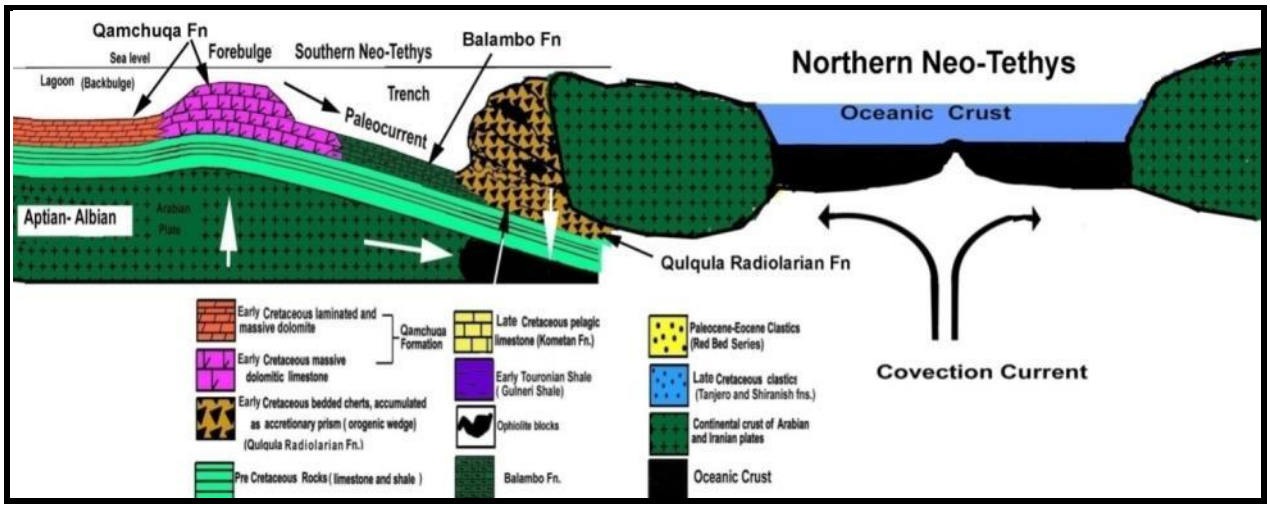

Fig.(2-3) The convergent of the southern Neo-Tethys is most possibly due to pushing stress of the Northern Neo-Tethys which was at the divergent phase.

4- The further advance and accumulation of the accretionary prism has forced the forebulge to subside (drown) during the downing Gulneri Formation is deposited. While after drowning the Kometan and Bekhme Formations are deposited (fig.2.6).

5- The further advance of the Iranian plate forced the accretionary prism to be thrown on to Arabian platform. This over throw of radiolarites and ophiolites on Arabian Platform had generated terrestrial land (as an island in mid of Neotethys). In tectonics this land is called foreland and basin that formed in front of it, called foreland basin which formed during Campanian (Fig.2.7). In this foreland basin, Tanjero, Shiranish and Aqra Formations are deposited

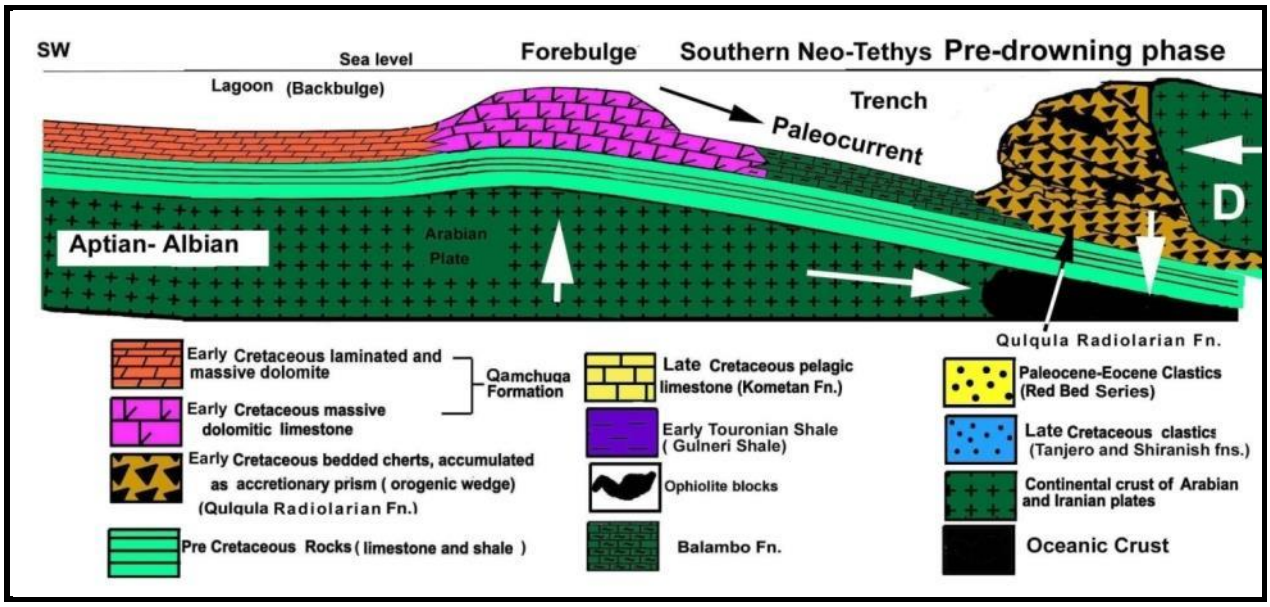

Fig.(2-4) Depositional history of Early Cretaceous basin in which Qamchuqa and Balambo and Qulqula Radiolarite Formations are deposited (Ameen, 2008). Under the load of the trench materials (accretionary materials), the Arabian plate is suffered from flexure which is formed forebulge (submerged high). On this paleohigh Qamchuqa Formation is deposited as reefal and lagoonal sediments.

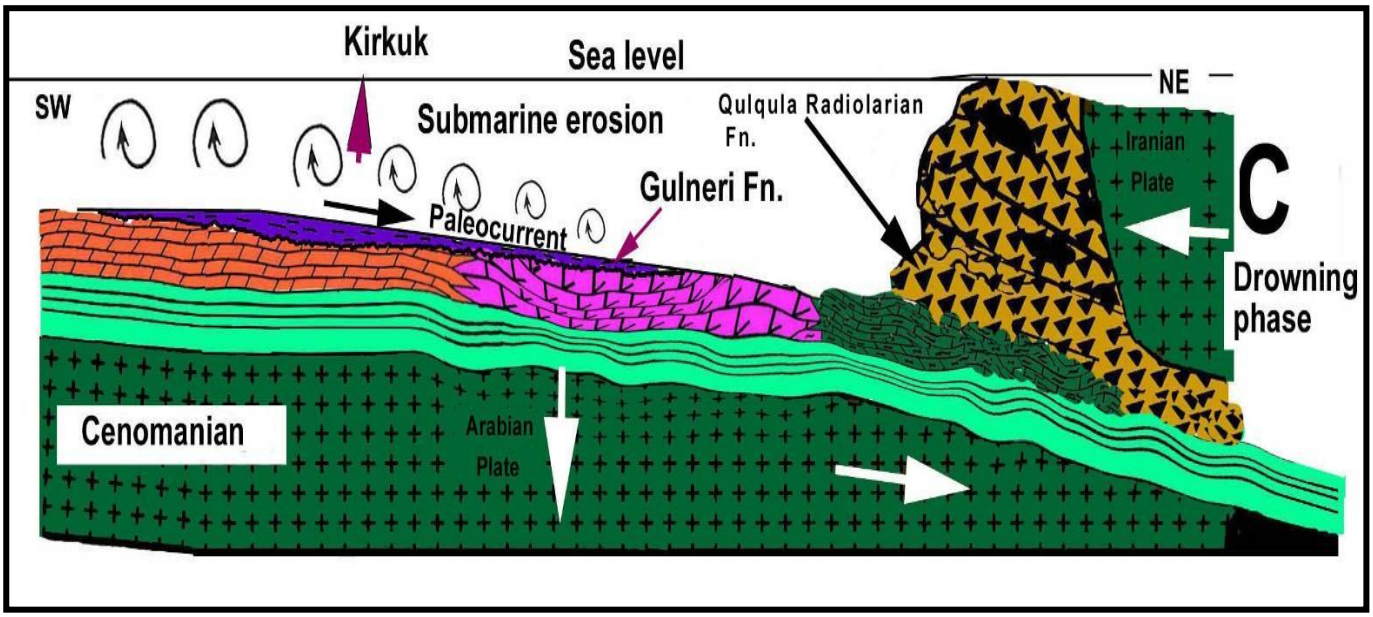

Fig. (2-5) Tectonic and depositional model of the Upper (Late) Cretaceous (Cenomanian) basin in which Kometan and Bekhme fms are deposited. The Kometan Formation is deposited after drowning of the Arabian Platform (Qamchuqa Formation) under the load of the Trench material (accretionary prism materials) and Iranian plate. The forebulge is subsided and during subsiding Dokan and Gulneri Formations are deposited as Transitional facies (as sediments of intermediate depth between shallow (Qamchuqa) and deep (Kometan) facies (Taha, 2008)

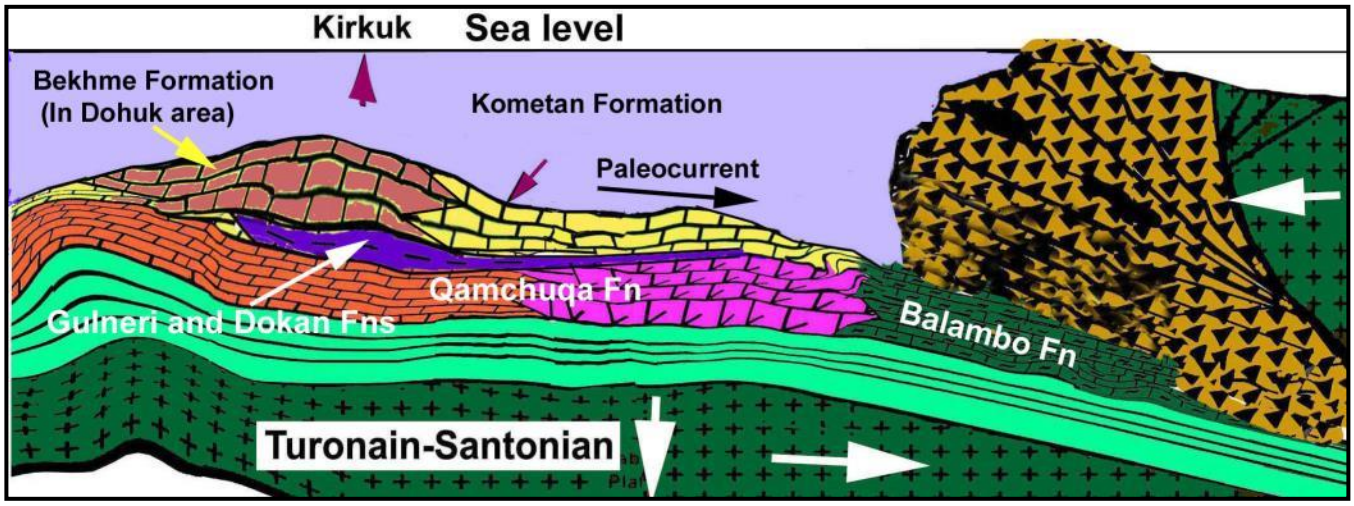

Fig.(2.6) Tectonic and depositional model of the Upper (Late) Cretaceous (Turonian-Campanian) basin in which Kometan and Bekhme Formation are deposited. The Kometan Formation is deposited after drowning of the Arabian Platform (Qamchuqa) Formation under the load of the both Trench materials (Accretionary prism materials) and the Iranian plate, forebulge subsided (deepened). The paleocurrent was toward northeast. On this forebulge Qamchuqa Formation is deposited.

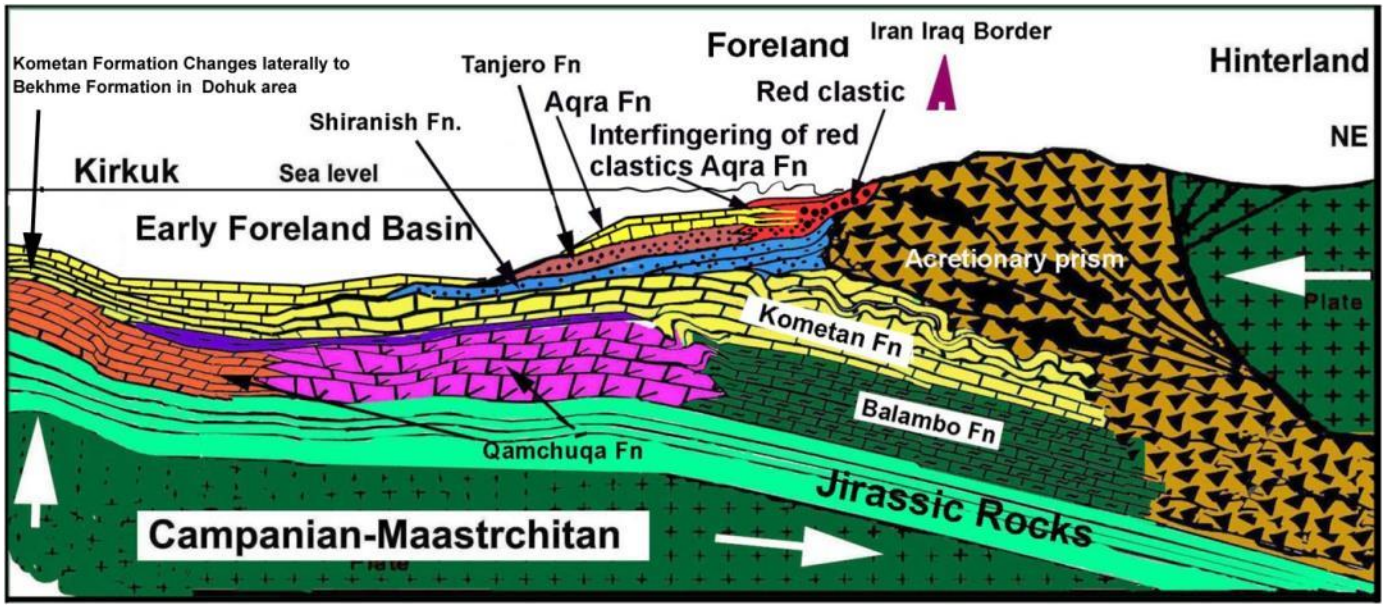

Fig.(2.7) Combination of tectonic and depositional setting of Upper (Late) Cretaceous basin in which Shiranish, Aqra and Tanjero Formation are deposited (Karim, 2008). During Campanian the Continental parts of the Iranian and Arabian plates are collided. By this, the trench materials (Accretionary materials) are thrown (pushed on to) the Arabian Platform. Due to this colliding a terrestrial land had generated during Campanian and the paleocurrent is reversed toward southwest. In addition to that a Foreland basin is formed in front of the Iranian Plate as can be seen from figure above (Karim, 2004).

6- The further advance of the Iranian plate forced the accretionary prism to be thrown on to Arabian platform. This throw of radiolarites and ophiolites on Arabian Platform had formed a continental land and foreland basin in front of the land during Campanian (Fig.2.7).

7- During Paleocene, the geological setting of the foreland basin was very similar to that of Campanian-Maastrichtian. In the foreland basin the Kolosh Formation is deposited in the deeper part of the basin as lateral facies change of Red Bed Series. In the coastal area of the basin Red Bed Series are deposited in continental environment which was rich in oxygen. Aliji is deposited in deeper part of the basin toward southeast (Fig.2.8).

7- During Eocene, the geological setting of the foreland basin was very similar to that of Paleocene except for more advance of the front of the orogenic wedge toward southeast. The source had suffered from some subsidence and the basin becomes shallower due to filling with sediments. The basin topography had changed by which some submerged paleohigh raised and on these highs the Sinjar (Khurmala) Formation was deposited in between Red Bed Series and Jaddala Formations (Fig.2.9).

8- During Middle Eocene the foreland basin was divided to two parts, in the northeastern part Walash-Nauperdan was deposited while in the southwestern one Pila Spi (Avanah) Formation were deposited (Fig.2.10)

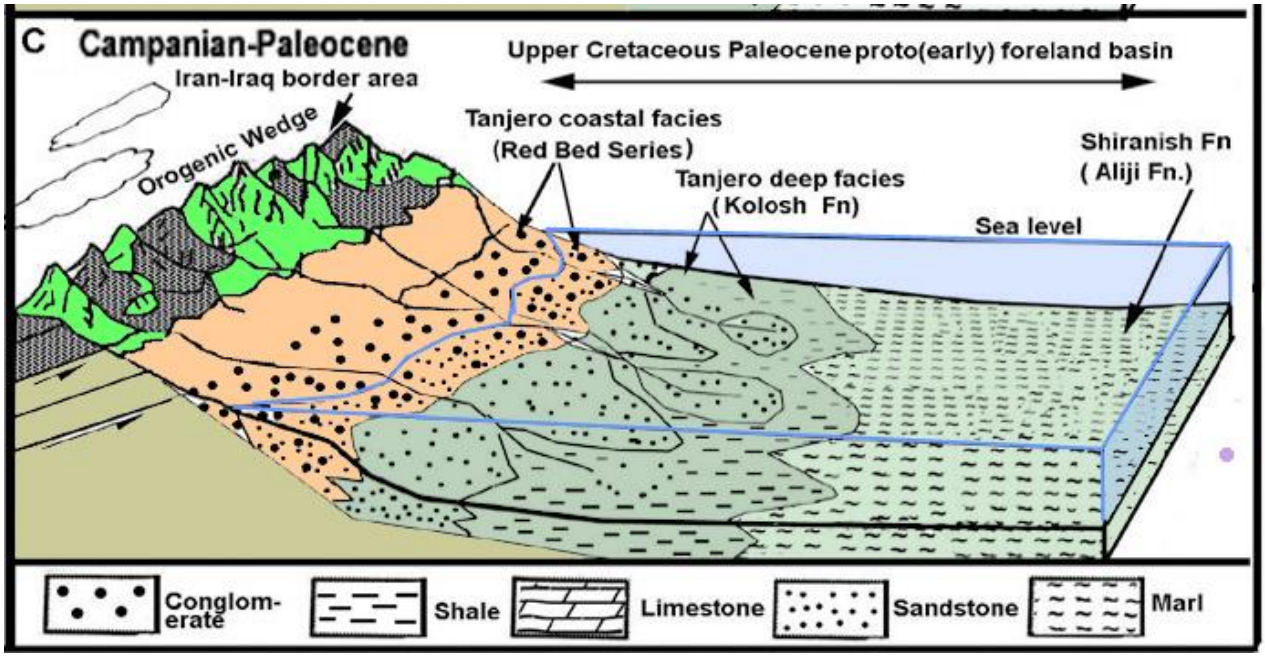

Fig.(2.8) Tectonic and depositional model which is fit (suitable) for both Upper (Late) Cretaceous and Paleocene basins in which Tanjero and Kolosh formations and Red Bed Series are deposited during Maastrichtian and Paleocene respectively (Karim, et al, 2008).

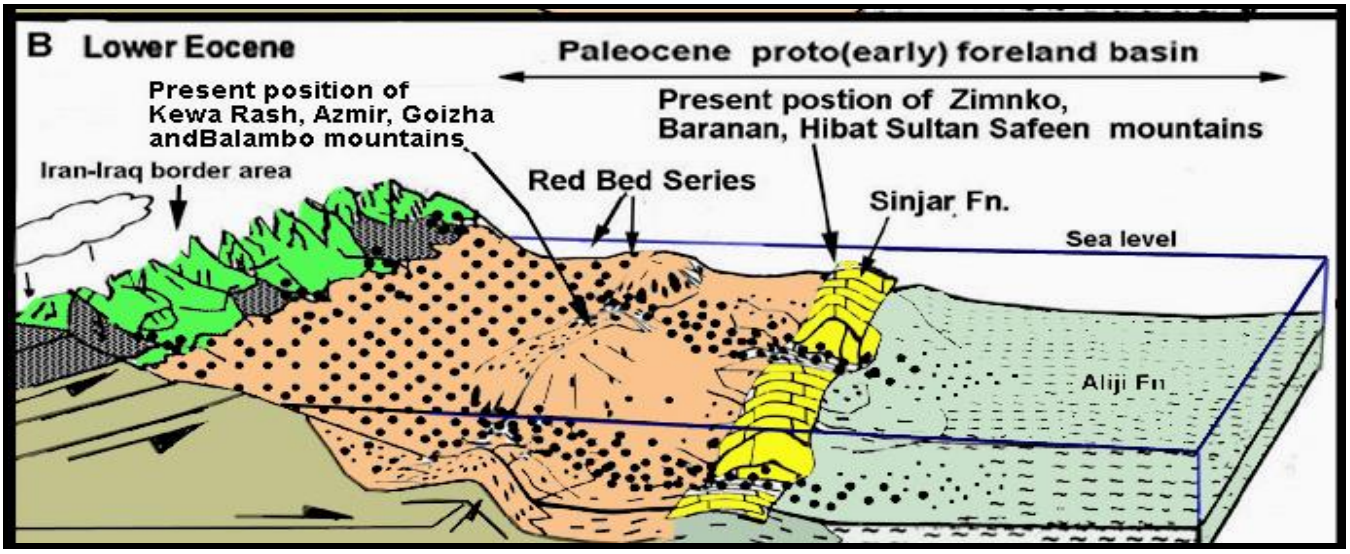

Fig.(2.9) Tectonic and depositional history Paleocene basins which is nearly similar to that of the Paleocene except for existence of some submerged highs on which Sinjar Formation is deposited as seen in the figure above (Karim, et al, 2008).

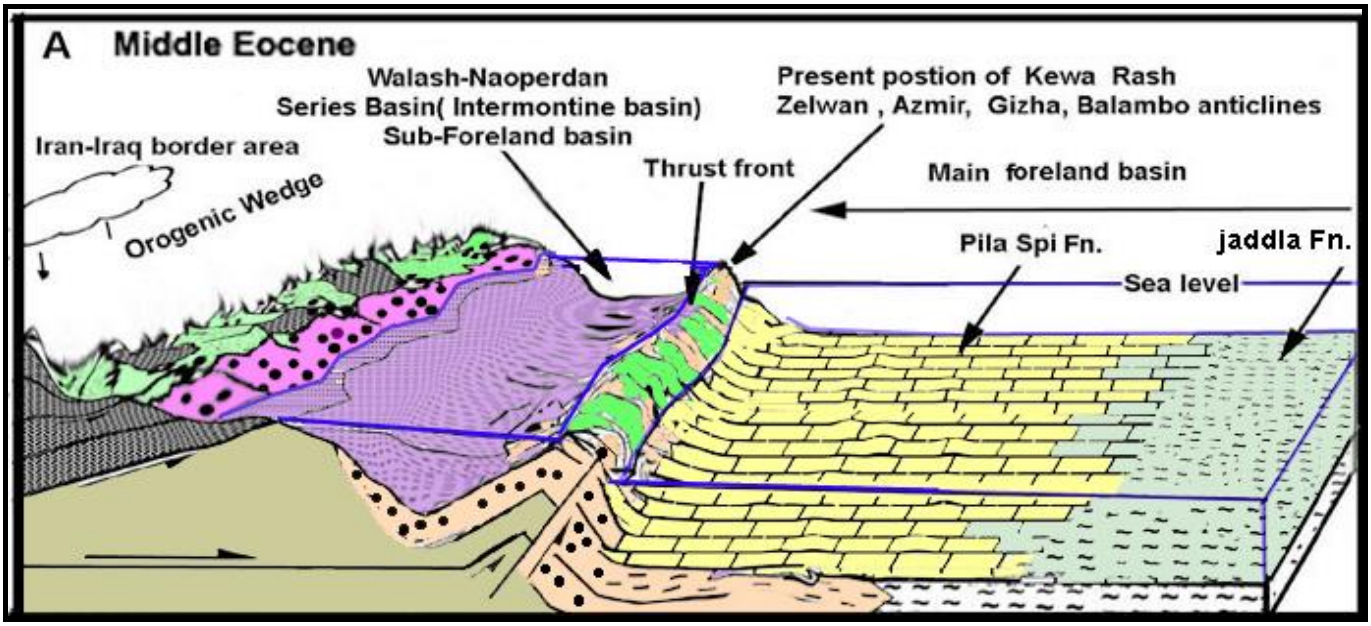

Fig.(2.10) Tectonic setting of Middle Eocene basins in which the Zagros Foreland basin is separated into two smaller basin in which Walash-Naoperdan Series and Pila Spi Formation are deposited in the northern and southern basin respectively as seen in the figure above (Karim, et al, 2008).

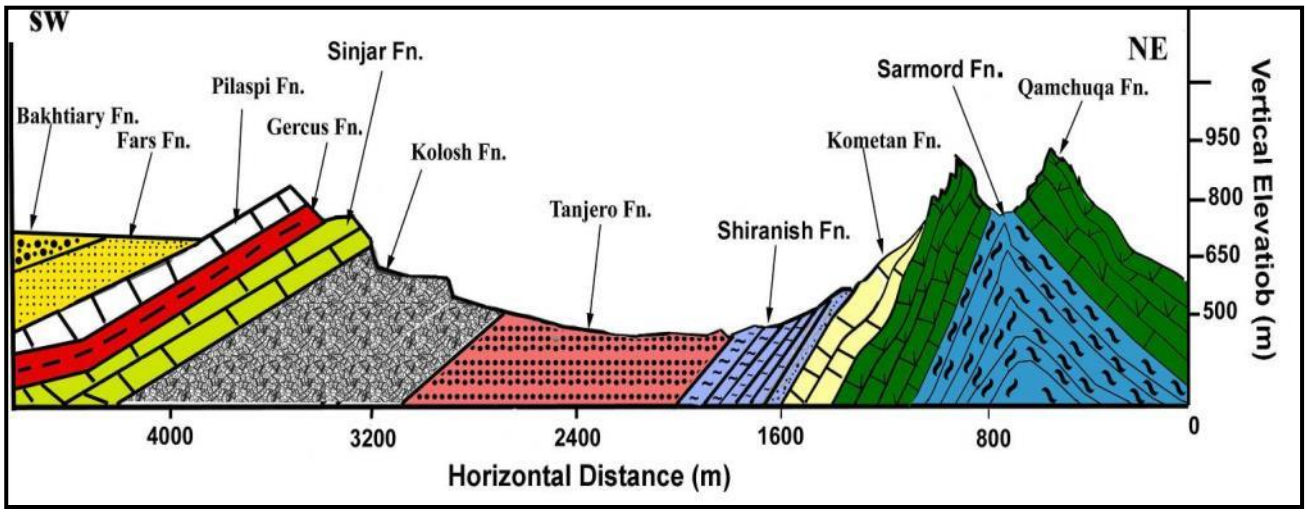

Fig.(2.11) Geologic Cross section of the Piramagroon anticline, Jarmaga Valley and Chaqizh mountains (Taha, 2005).

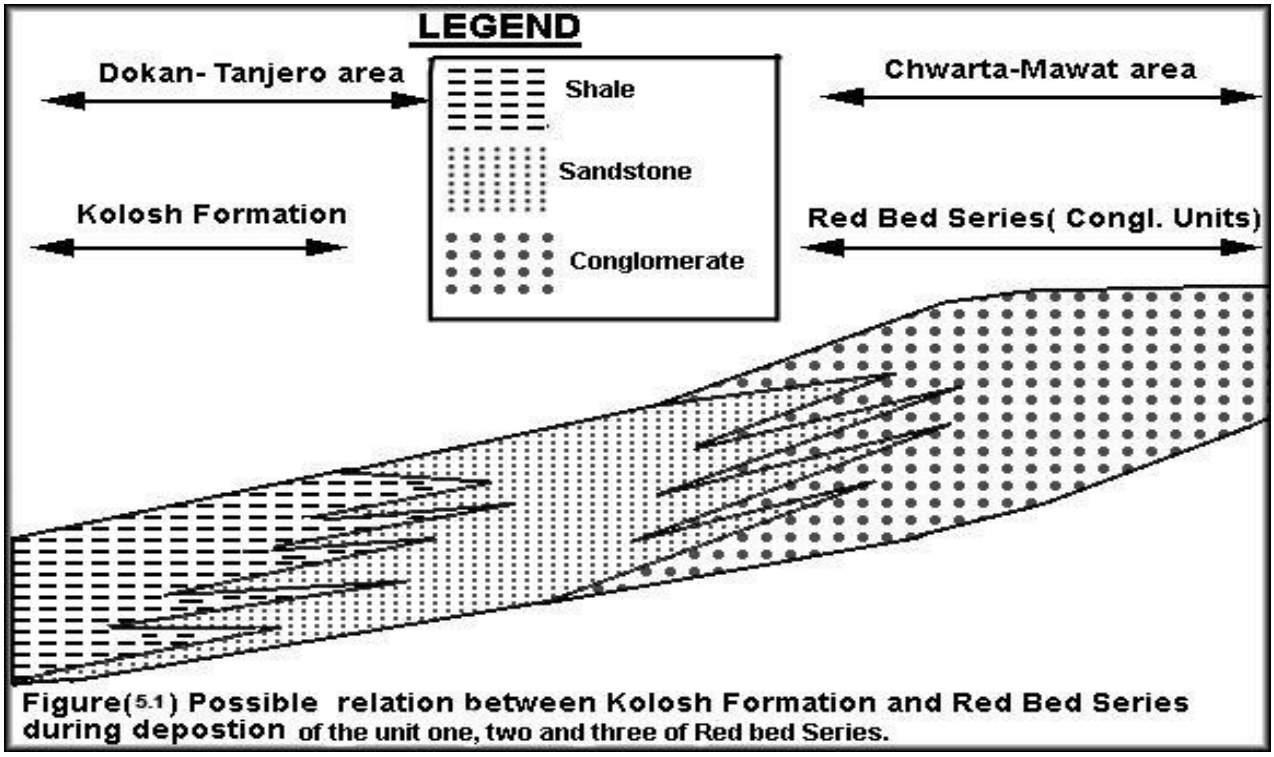

Fig.(2.12) Diagram shows relation between unit one and two of Red Bed Series and Kolosh Formation (Al-Barzinjy, 2006).

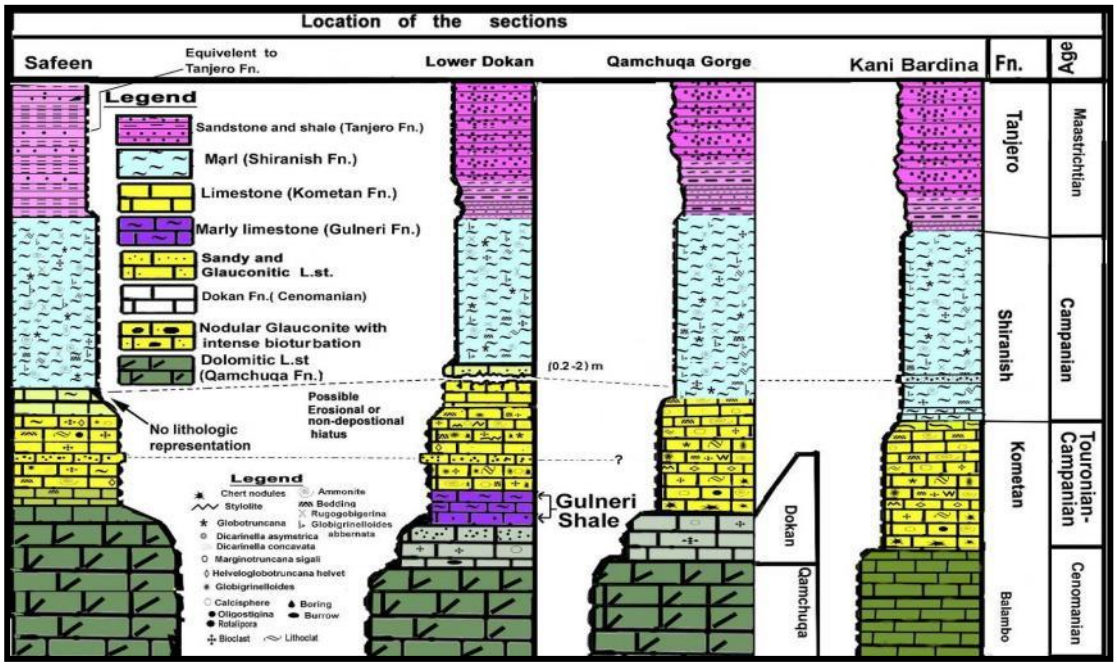

Fig.2.14: Stratigraphic column of the different areas (as indicated above each column) of the Lower and Upper Cretaceous units. It also shows that the contact between Kometan and Shiranish Formations is conformable (Modified from Karim, et al 2008).

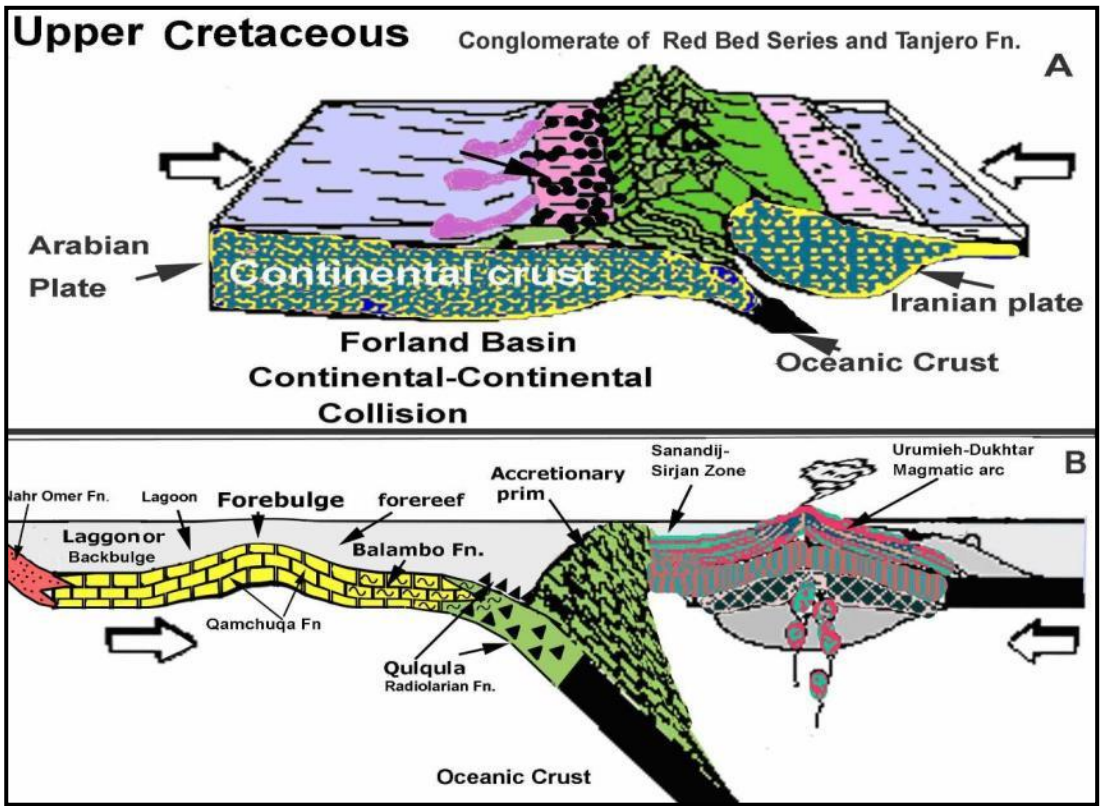

Fig.(2.15) Tectonic setting and position of the indicated formations within: A: Late Cretaceous Foreland Basin, B: Early Cretaceous Southern Neo-Tethys.

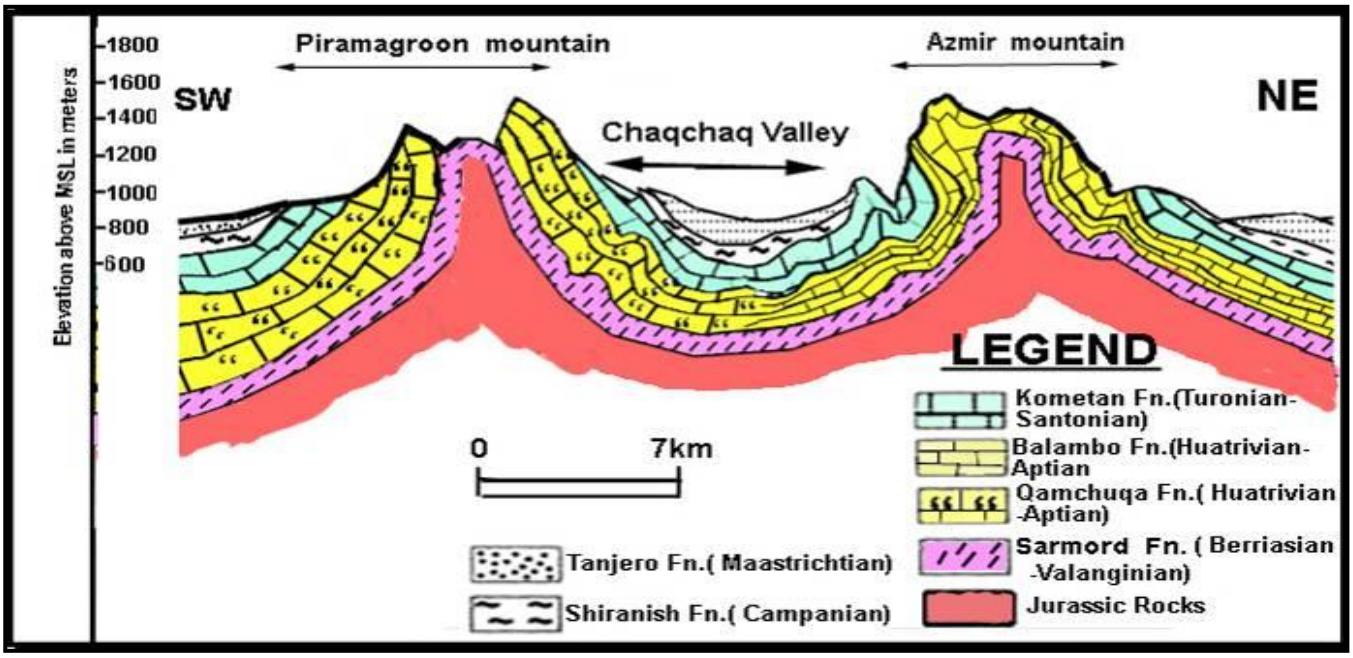

Fig. (2.16)Geologic cross section of Azmir and Piramagroon anticlines showing main lithostatigraphic units (formation) (Ali, 2007).

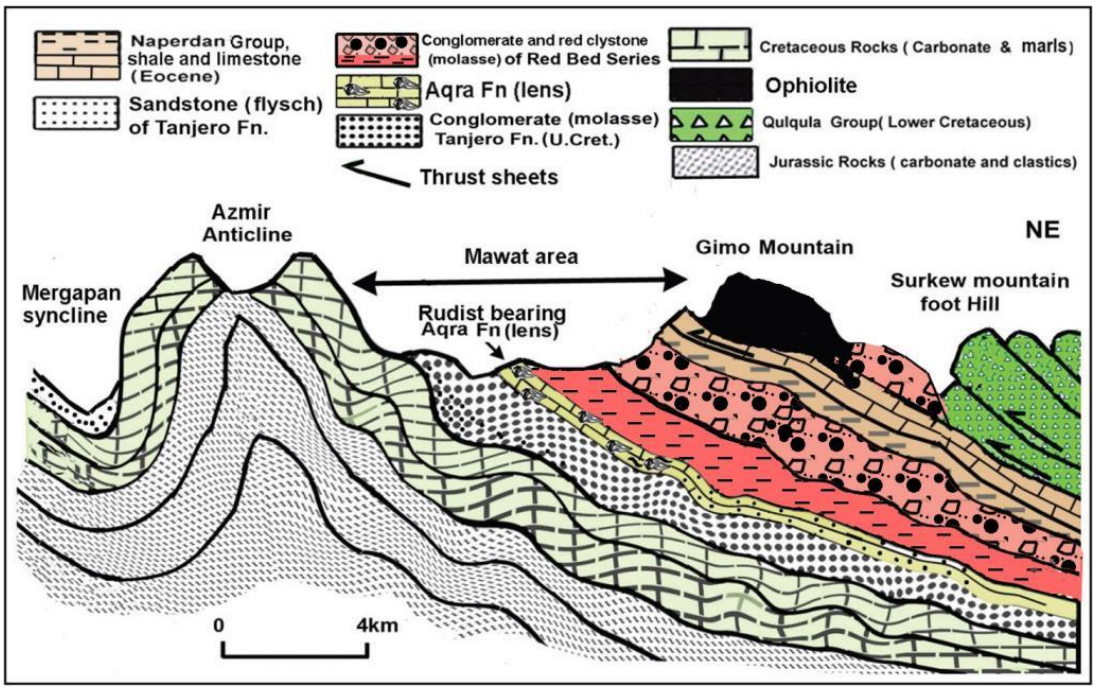

Fig.(2.17)Simplified geologic cross section passing through Chaqzh, Piramagron and Surkev Mountain

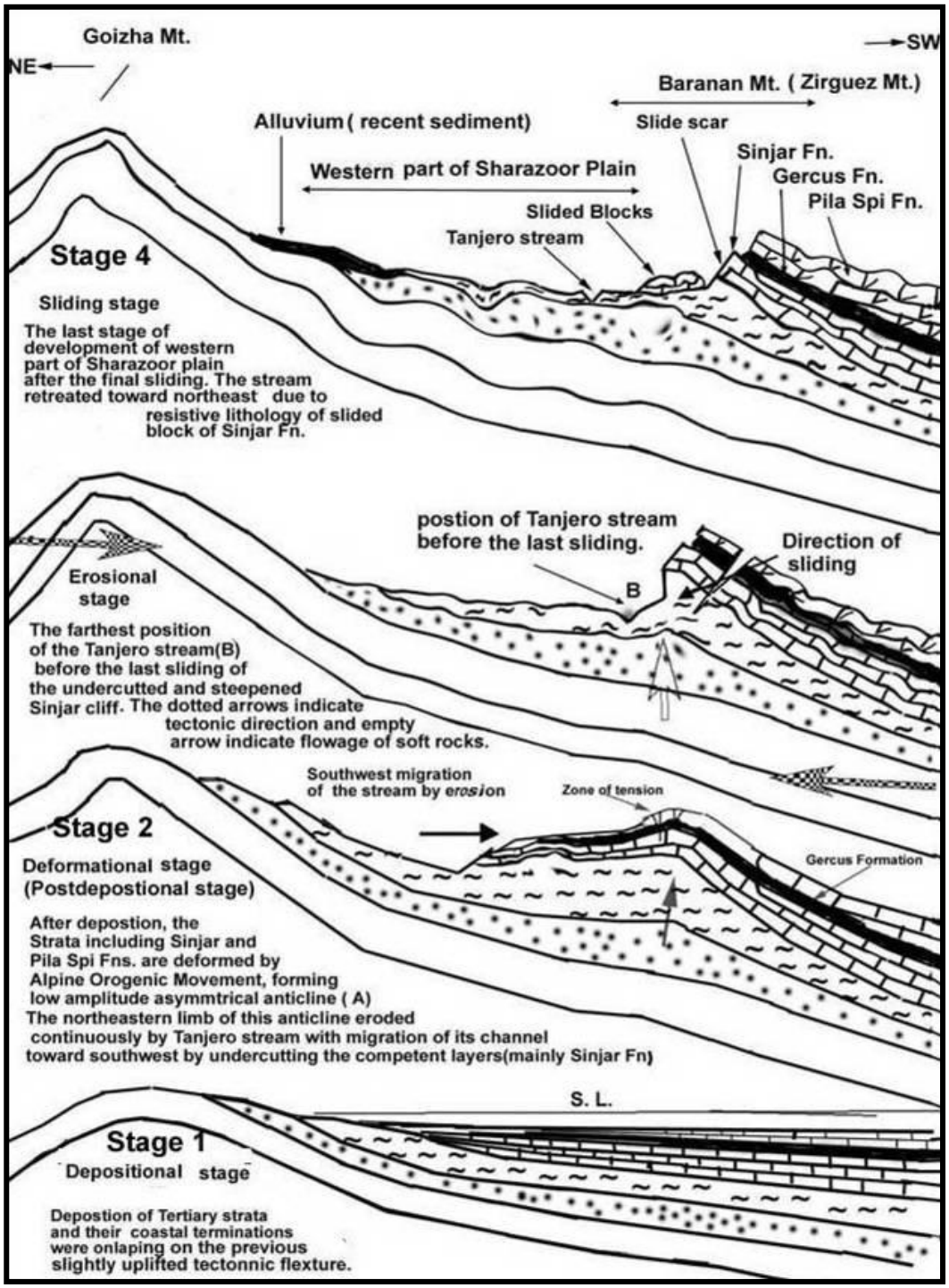

Fig.(2.19) shows how western part of Sharazoor plain are developed through different stages by tectonic stress, sliding and stream erosion from middle Miocene to present (Karim and Ali, 2005).

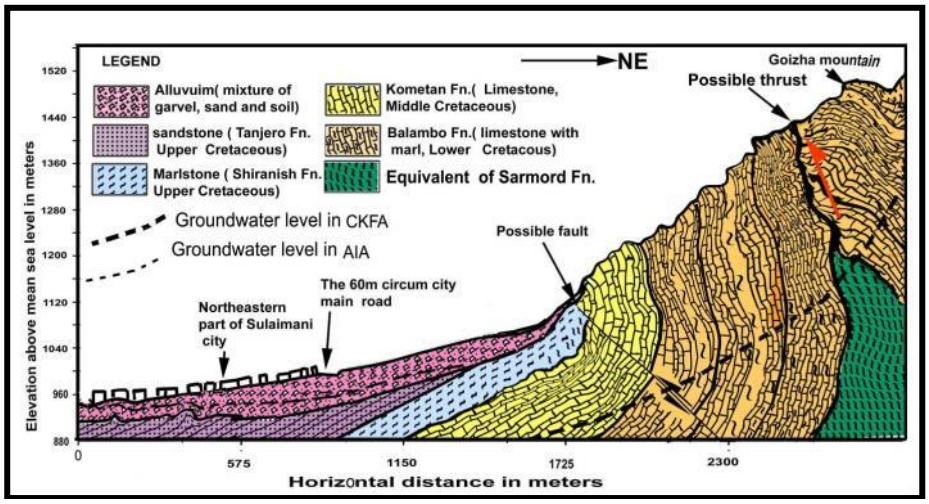

Fig.(2.23) Simplified geologic cross section of southeastern limb of Goizha anticline that is passing through Sulaimani city showing lithostratigraphic units (formations).

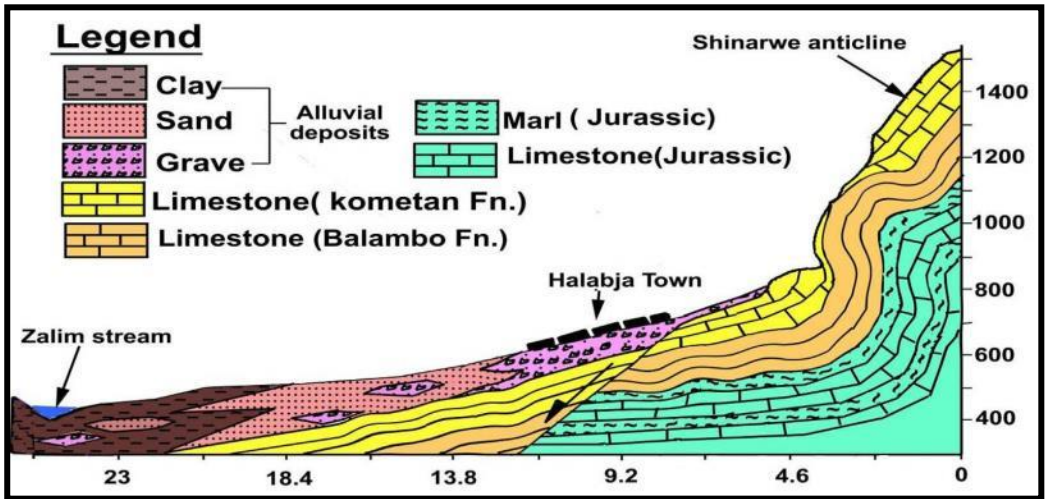

Fig.(2.20) Simplified geologic cross section of Shinarow mountain that pass through Halabja town(Ali, 2007).

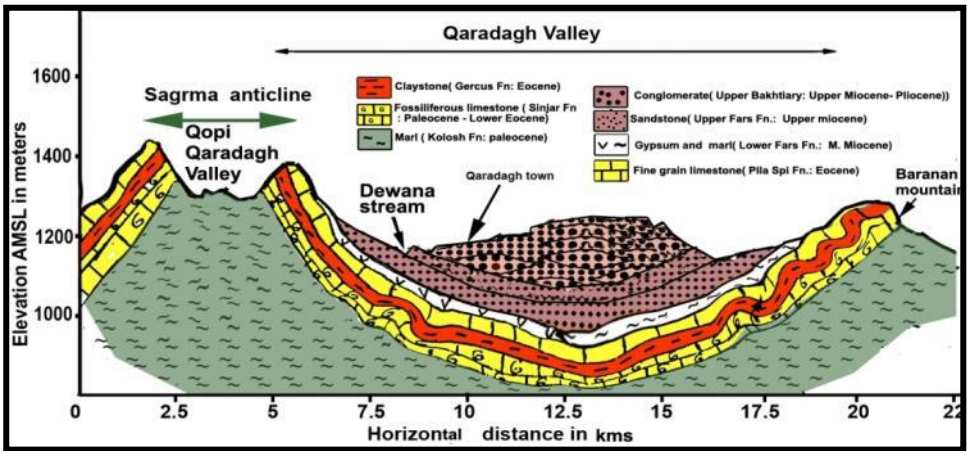

Fig.(2.21) Simplified geologic cross section Qaradagh area showing structures and lithostratigraphic units (formations).

Fig.(2.22) Burning of bitumen in Aqra area. The name Aqra (or Agre) is come from fire or (Agir).

Fig.(2.23) Hot bitumen comes out from Khurmala Fm and forms volcanic–Like flow structures due to burning of bitumen in Aqra area . The name Aqra (or Agre) is come from fire or (Agir).

Fig. (2. 24) a limestone conglomerate at the contact between Khurmala and Aqra formations at area near Saru Kani Village

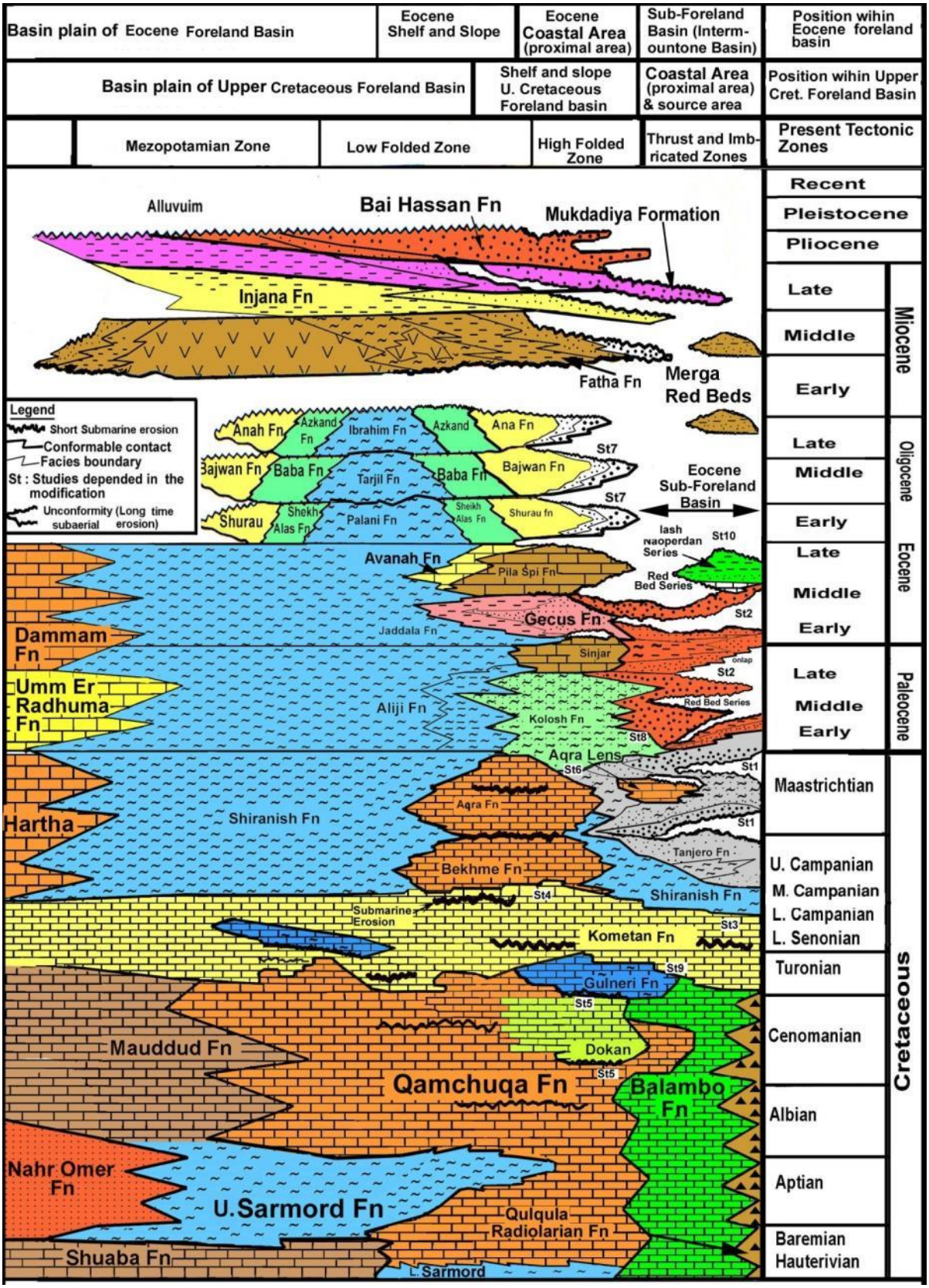

Fig. (2.25) Chronostratigraphic column (time-rock column) of Kurdistan during Cretaceous and Tertiary (Karim, 2009, in press) in which the dependent studies are shown as (St).

3-Stratigraphic units

3-1-Quaternary deposits

3-1-1-Alluvium deposits

Alluvium sediments and soil cover most part of the Iraq that make identification and mapping of the surface formation (rocks) difficult. Therefore, it is important to differentiate these sediments from older rocks (formations).

Definition

They are all loose sediments that deposited by running water which include:

1-Alluvuial fan deposits (boulder, gravel, and sand silt and clay deposits)

Kurdistan contains high mountains which made up of different type of limestones and bedded chert, sandstone and igneous rocks. These mountains dissected by tens of the perennial and emepheral streams. These streams scored more or less deep valleys in the rocks of the mountains by erosion and with the aid of mass wasting. The products of erosion and weathering consisted of angular clasts which are accumulated in the steep valley sides and in the valley bottoms. The accumulated rock fragments are transported seasonally by stream floods during heavy rainfall. Then huge quantities of boulder, gravel and sands are carried to downstream and deposited on the plains and lower slopes of mountain sides.

Tens of large and small alluvial fans start from the feet of the High Mountain such as Piramagroon, Azmir, Goizha, Avroman, Surren, Shinarwe and Balambo. These fans elongate from the mouths (outlets) of large or small valleys of these mountains into the lowland of Sharazoor and Piramagroon plains (Fig.1-3-3). The fans are formed when the heavy loaded flood or debris flow reach the narrow outlets of the deep valleys and in this outlet the flow attain high thickness. Then when pass through tight passage and reach the plain the debris flow spread over downstream plain as fan shaped deposits. The spreading is due to decrease of both slope and channel depth (abrupt widening) as compared to steep slope and lightness of the valleys.

Most of the large fans are prograded into the central part of the Sharazoor plain. Now these fans hardly can be distinguished from their fan-like shape. This is because they dissected by several small emepheral streams which modified the shape. Another reason is that the adjacent fans are coalesced (joined) laterally so that single fan cannot be separated. Nevertheless these fans can be distinguished from their sediment which is consisted of heterogeneous, unsorted and angular rock fragments and clay. In rare case the alluvial fan can be identified from map and Images of Earth Google. These fans are very common in the areas that have semi-arid climate and has intermittent seasonal rain fall. The absence of weak vegetation and loose soil cover are main factor for generation of alluvial fans.

3-1-2-Recent limestone

Many caves, streams and few lakes contain limestone rocks, such as those exist in the Kona Ba cave at southeast of Darbandikhan town and in the Ganau Lake at the southeast of Ranyia Town. The caves limestone consists of laminated and coarse crystalline fresh water calcite (travertine). In the Ganau Lake the recent limestone consists of about 2m of detrital, oolitic and stromatolitic limestone which shows cross lamination. The grains (allochems) of the limestone mainly consist of fragments of characea algae which bindded by bacteria secreted lime materials (Fig.3.1.2).

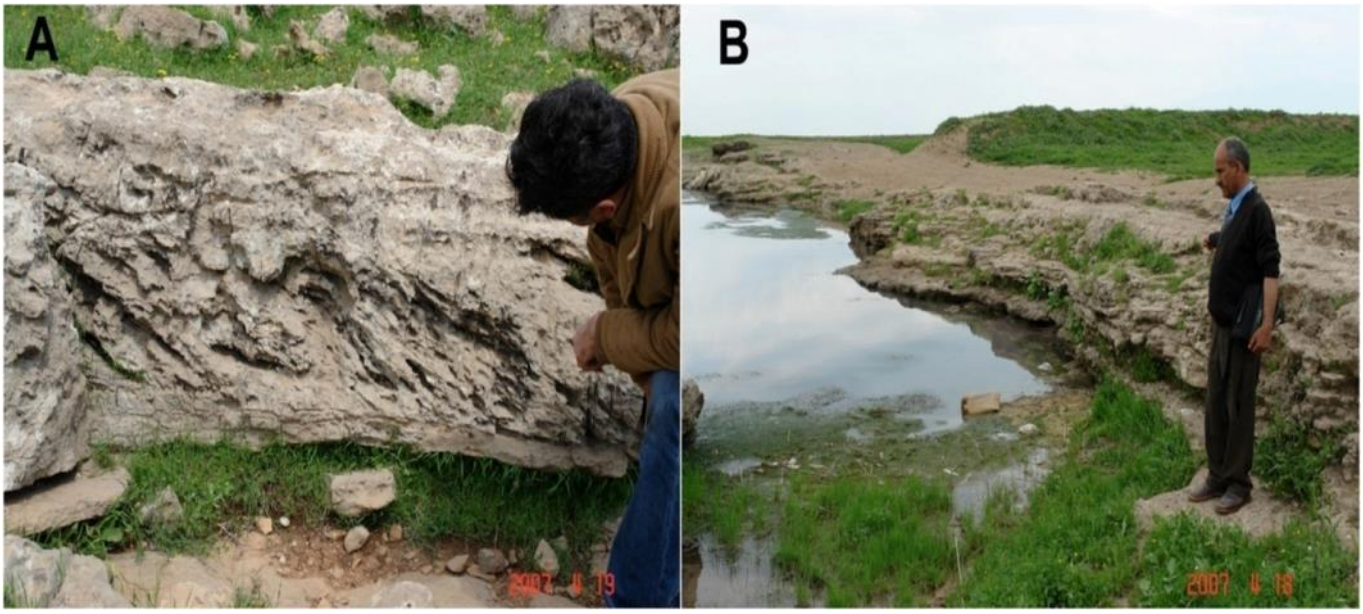

Fig. (3.1.2) Cross bedded ooids (micro-oncoids) on the southwestern bank of the Ganau lake. B) Bedded and laminated ooids limestone, contain both stromatolite and thrombolites.

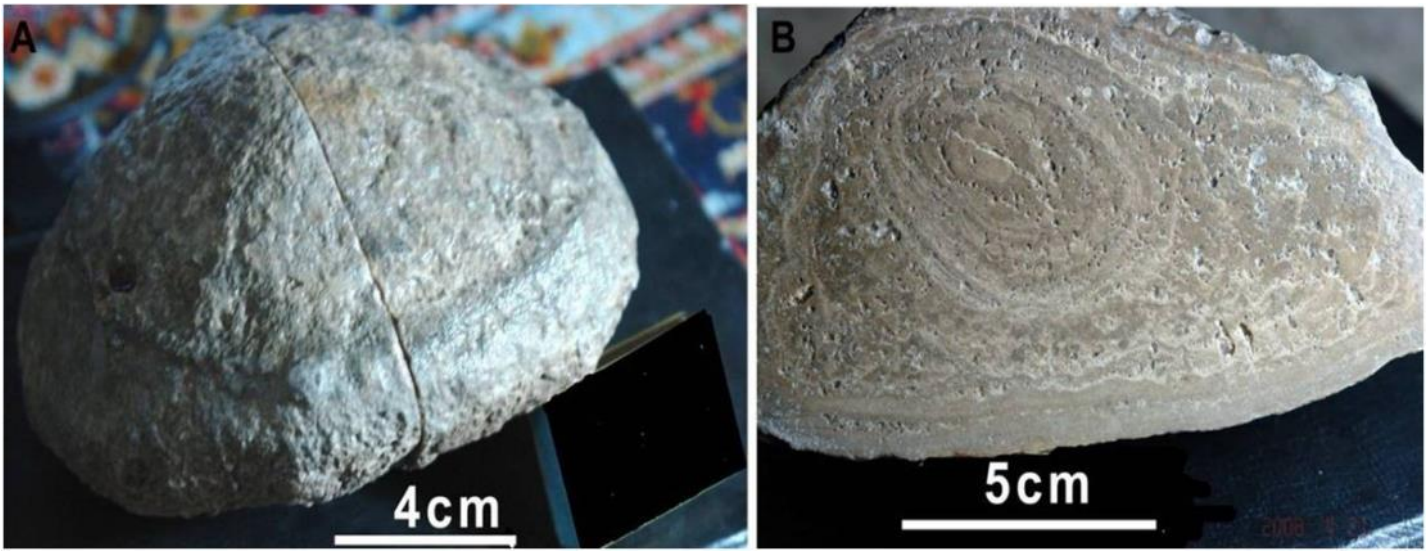

Fig. (3.1.3) large saucer-sized oncoids on the periodically flooding side of the lake. B) Polished surface (A) after cutting into two equal halves showing internal structure of the left side which shows development of a lager oncoids around an older smaller one.

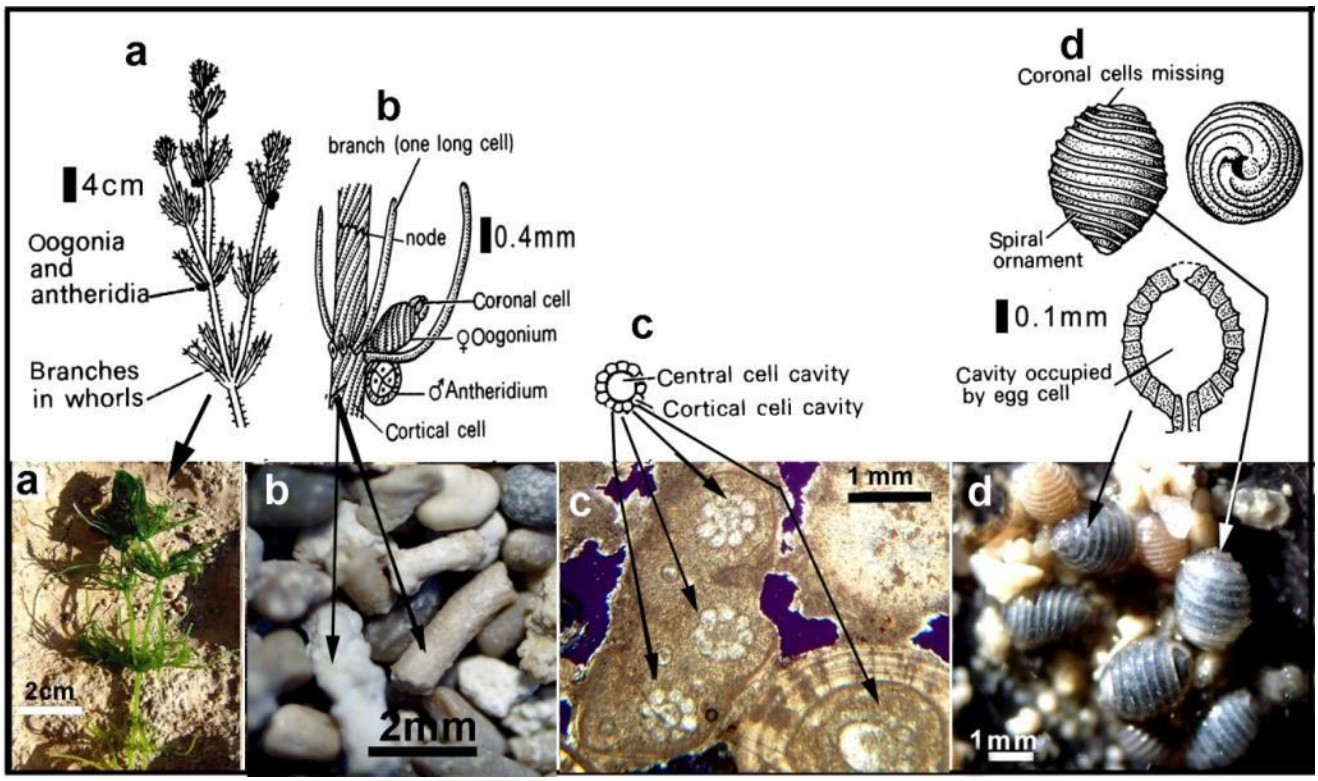

Fig. (3.1.4) comparison of the chara fragments (as photos) of the present study with sketches of similar parts given by Brasier 1980 and Flügel 2004. a) Chara plant; b) stem and node fragments replaced by calcite ; c) thin section of laminated limestone rock shows cortical cell and central cell cavity; d) light and dark coloured gyrogonites (female reproductive organs).

3-2-Late Miocene-Pliocene

3-2-1-Upper Bakhtiary (Bai Hassan) Formation

Lithology: Very thick alternation of polygeneic and polymictic orthoconglomerate, sandstone and red claystone. In Dokan area it consists of limestone conglomerate which has thickness of about 300 and studied by Karim and Taha (2012)
Age: Pliocene
Tectonic condition: Deposited on the foot of the uplifted mountain range and plains that bordered the Late Zagros Foreland basin during the maximum uplift of Kurdistan
Environment: deposited in braided river and delta environments.
Thickness: about 500-1000m
Area of distribution: mainly in the Low Folded and Mesopotamian Zones and occur in localized area of the High Folded Zones
Fossil content: Trace fossil and vertebrate skeletons
Sedimentary structures: bedding, Cross bedding, imbricated pebble, traverse and longitudinal bars
Stratigraphic position: Located between Lower Bakhtiary Formations and alluvium at the base and top respectively.
Boundary condition: It is conformable laterally and vertically with underlying Lower Bakhtiary Formation while is unconformable with Quaternary alluvial deposits
Sequence stratigraphy: deposited as sediment of Low stand Fan delta

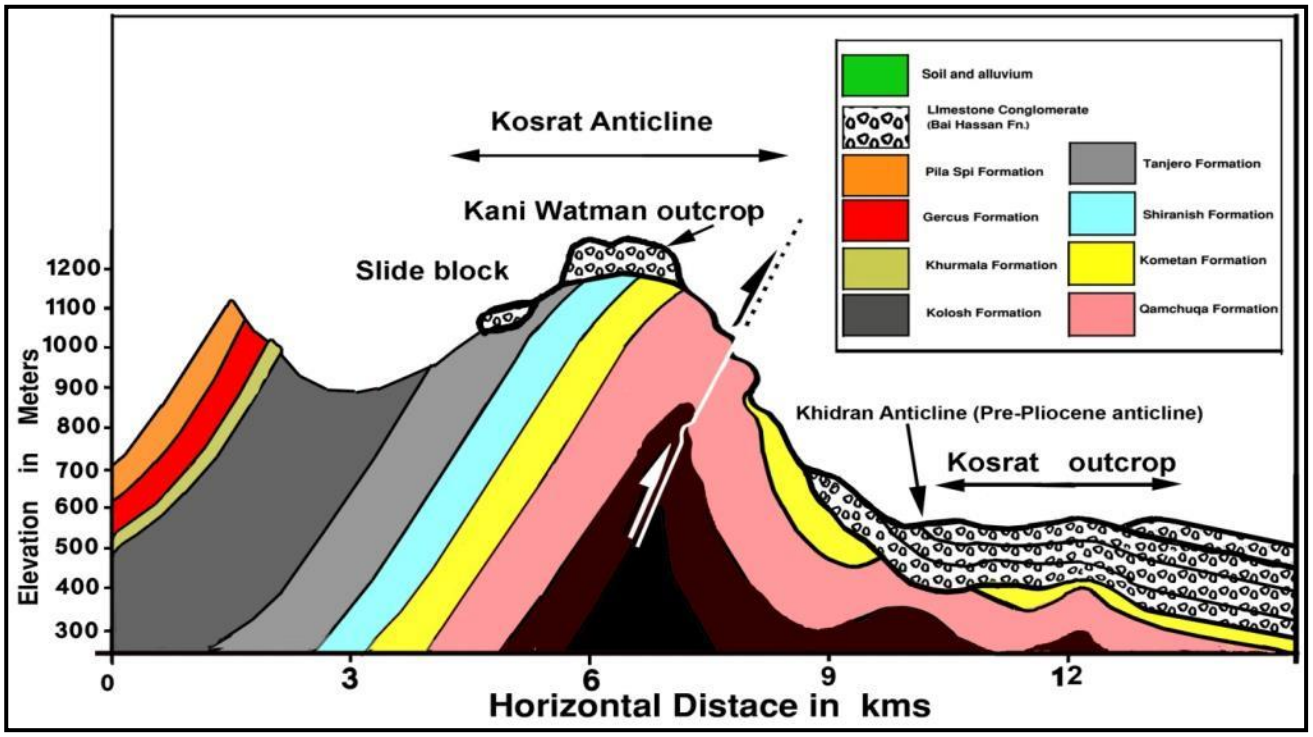

Fig.(3-2-1) geologic cross section of the northwestern part of Kostrat anticline show limestone conglomerate (Dokan conglomerate or Upper Bakhtiary Fm)

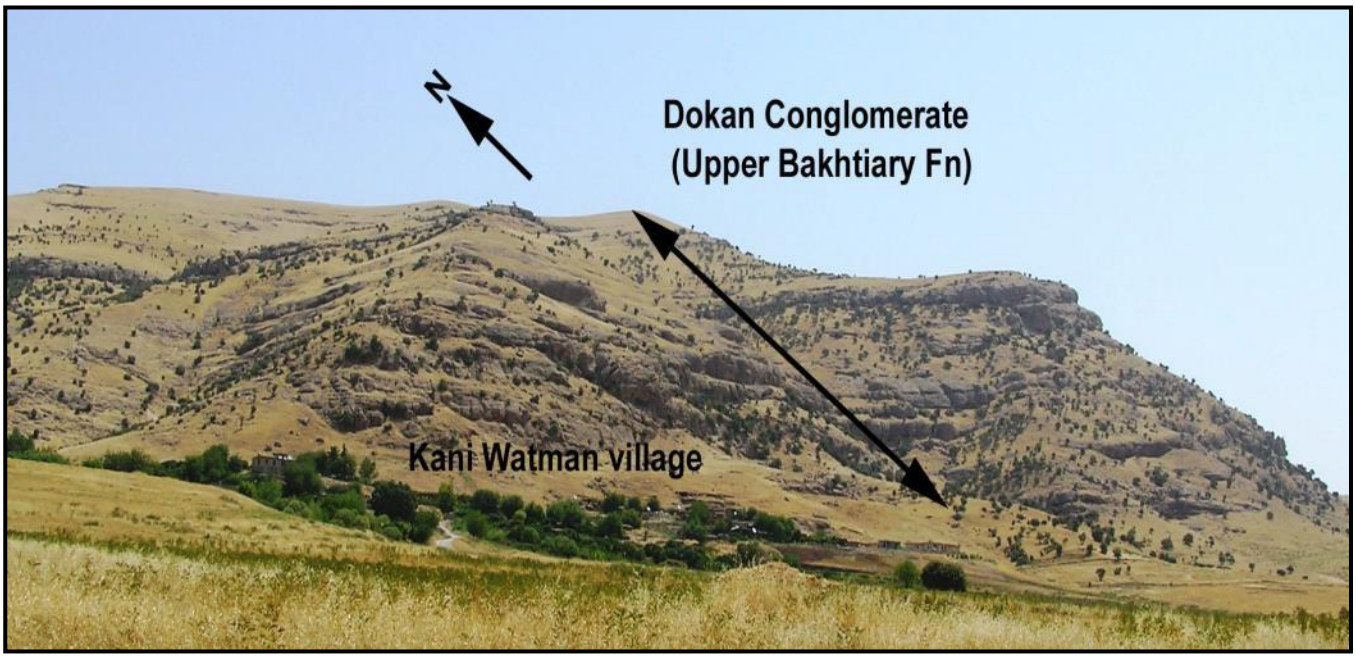

Fig.(3-2-2) Northwestern part of Kostrat anticline show limestone conglomerate (Dokan conglomerate or Upper Bakhtiary Fm) at the northeast of Kani Watman village.

3-2-2-Lower Bakhtiary (Mukdadyia) Formation

Lithology: Very thick alternation of red claystone and Pebbly sandstone
Age: Upper Miocene- Early Pliocene
Tectonic condition: Deposited on the plains that were bordering the Late Zagros Foreland basin at the final stage of the uplifting of Kurdistan
Environment: High energy deltaic and fluvial environments.
Thickness: about 500-1000m
Area of distribution: Low Folded and Mesopotamian Zones
Fossil content: Trace fossil and vertebrate skeletons.
Sedimentary structures: bedding, lamination, Cross bedding and trace fossils
Stratigraphic position: located between Upper Fars and Upper Bakhtiary (Bai Hassan) Formations at the base and top respectively.
Boundary condition: It is conformable laterally and vertically with underlying Lower Fars and overlaying Upper Bakhtiary Formation
Sequence stratigraphy: deposited as sediment of Low stand Fan delta

3-2-3-Upper Fars (Injana) Formation

Lithology: Very thick alternation of red claystone and sandstone
Age: Upper Miocene
Tectonic condition: Deposited during final uplift of Kurdistan and deposited in coastal area of Upper Miocene Foreland basin
Environment: High energy deltaic plain and prodelta environment.
Thickness: about 500-1000m
Area of distribution: Low Folded and Mesopotamian Zones
Fossil content: plant debris and ostracods
Sedimentary structures: bedding, lamination, Cross bedding and trace fossils
Stratigraphic position: located between Lower Fars and Lower Bakhtiary (Mukdadyia) Formations at the base and top respectively.
Boundary condition: It is conformable laterally and vertically with underlying and overlying lower Bakhtiary and Lower Fars Formations respectively
Sequence stratigraphy: deposited as sediment Flood plain of Low stand fan delta.

3-3- Lower and Middle Miocene

3-3-1-Lower Fars (Fatha) Formation

Lithology: Very thick alternation of Gypsum (or anhydrite), Salt, marly limestone in the basin center while it may contain fossiliferous and oolitic limestone, sandstone and red claystone in the basin periphery.
Age: Middle Miocene dominated by periodic influx of fresh (from surrounding terrestrial area) and marine water from Mediterranean +Sea
Tectonic condition: closed Foreland basin
Environment: restricted and evaporatic shallow and deep Laggonal environment
Thickness: about 100-800m
Area of distribution: Mostly in Low Folded and Mesopotamian Zones

Fossil content: Planktonic and benthonic forams, pelecpod and ostracod
Sedimentary structures: bedding, lamination, trace fossils
Stratigraphic position: located between Pila Spi and Upper Fars (Injana) Formation at the base and top respectively in the High folded Zone while it located between Kirkuk group or Jerbe (at the base) and Upper Fars formations (at the top) in the Low Folded Zones. In
Boundary condition: It is conformable with overlying and underlying but in some place unconformable with Kirkuk group and Pila Spi formation in High and Low Folded Zones
Sequence stratigraphy: deposited as sediment of High Stand system tract

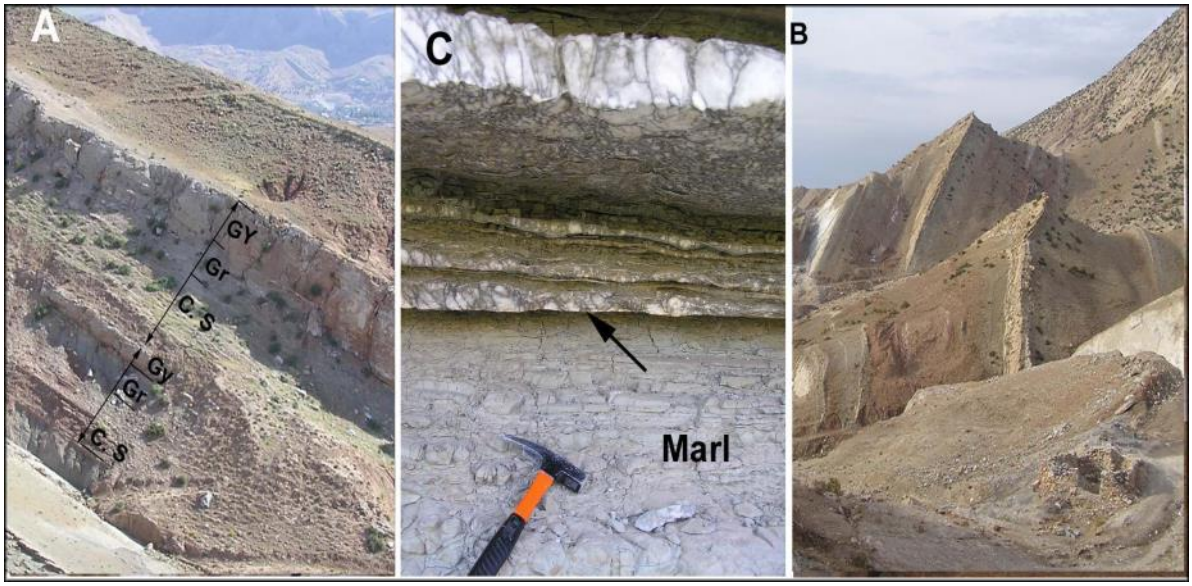

Fig. (3.3.3) A: Two ideal cycles of depositions of Lower Fars Formation: red claystone (C.S), green marl (Gr) and gypsum (GY) at southeastern plunge of Sagrma anticline. C: Gradational contact between marl and gypsum, which is manifested by alternation of laminae of marl and gypsum (above the arrow). B: Common geomorphologic feature (iron flats) formed by limestone and gypsum beds (southeast limb of Qishlagh anticline.

3-3-1-Govanda Formation

Lithology: alternation of biogenic (coral, algal, faraminifera) limestone, fine and coarse grain detrital limestone and silty marl. (Fig.3.3.4 and 3.3.5)
Age: Middle Miocene
Tectonic condition: remnant Foreland basin
Environment: Shallow open marine (shoal and for reef)
Thickness: 20-120m
Area of distribution: Mostly in Thrust Zone
Fossil content: benthonic forams, pelecypod and gastropod, coral, echinoderm and red algae
Sedimentary structures: bedding, lamination, trace fossils
Stratigraphic position: located between Qulqula Radiolarian Formation at the base and Merga Red Bed at the top.
Boundary condition: unknown all boundaries may be tectonic

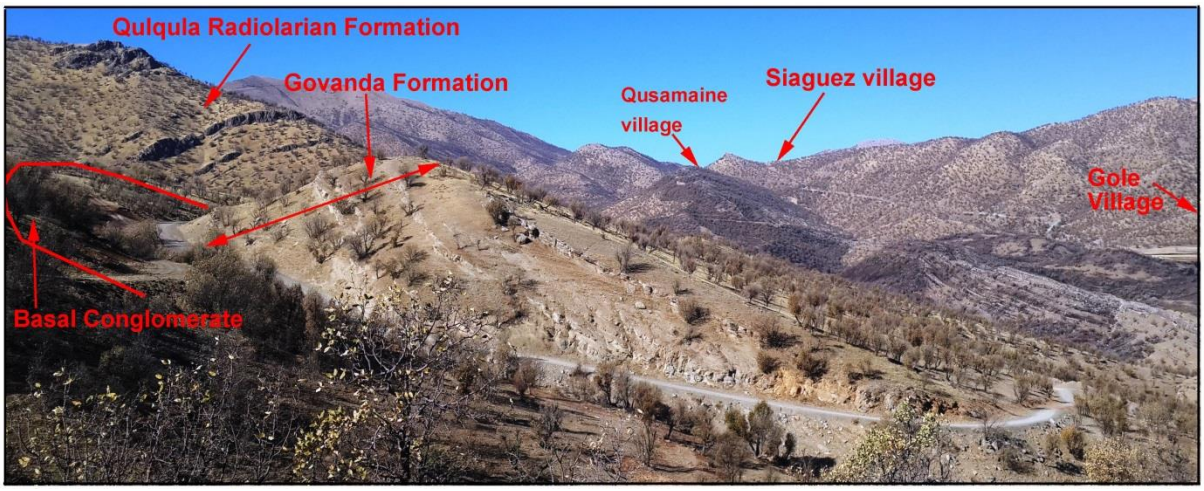

Fig. (3.3.4) an outcrop of Govanda Formation at 200m west of Bahe village, southwestern boundary of Shalair valley, Penjwin area.

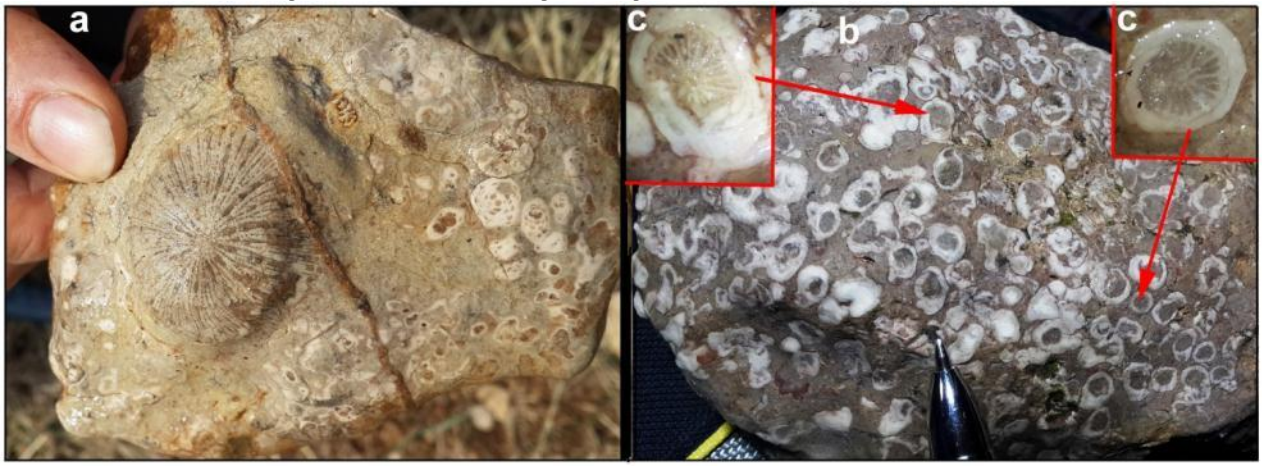

Fig. (3.3.5) a) Coral and rudstone consist of broken fragment of scleractinian coral colony near Taza De village on the Rashan outcrop, b) detail of the coral under stereoscope microscope.

3-4-Oligocene

3-4-1-Kirkuk Group

The Kirkuk Group is nine formations that are deposited during Oligocene. These nine formations can be grouped into three types according to environment. 1- Basinal (deep marine) formation, they are: Ibrahim, Palani and Tarjil Formations. 2- Lagoonal and reefal Formations, they are: Anah, Bajwan and Shurau Formations, 3- Reefal and forereefal Formations: Azkand, Baba and Shekh Alas Formations (Fig.3.4.1 and 3.4.2).

These formations are deposited in relatively small normal marine basin in Kirkuk, Dohuk, south of Sulaimani and Ramadi areas. The shape of this basin was elongate and trended northwest-southeast which was opened to open marine (ocean) from south and west. The reef and fore reef formations are good reservoir for oil accumulation and actually they now penetrated for oil production. Recently Khanaqa et al. (2009) have extended the distribution of the group to the inside High Folded Zone (Fig.3.4.3)

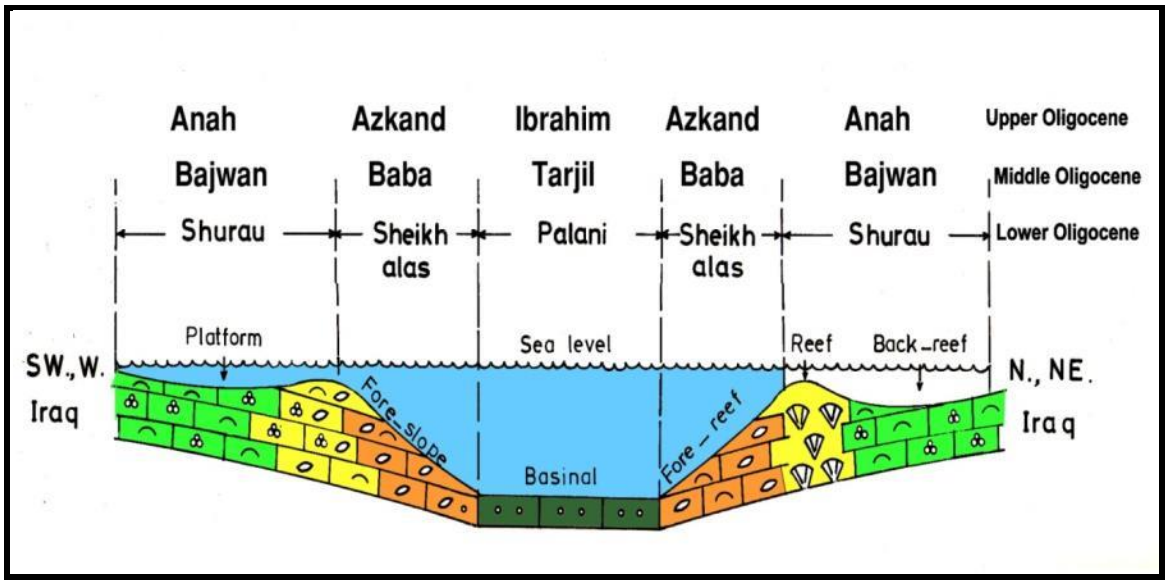

Fig.(3.4.1) Geologic cross section of Oligocene showing formations of Kirkuk Group (Al-Hashimi and Amer, 1986).

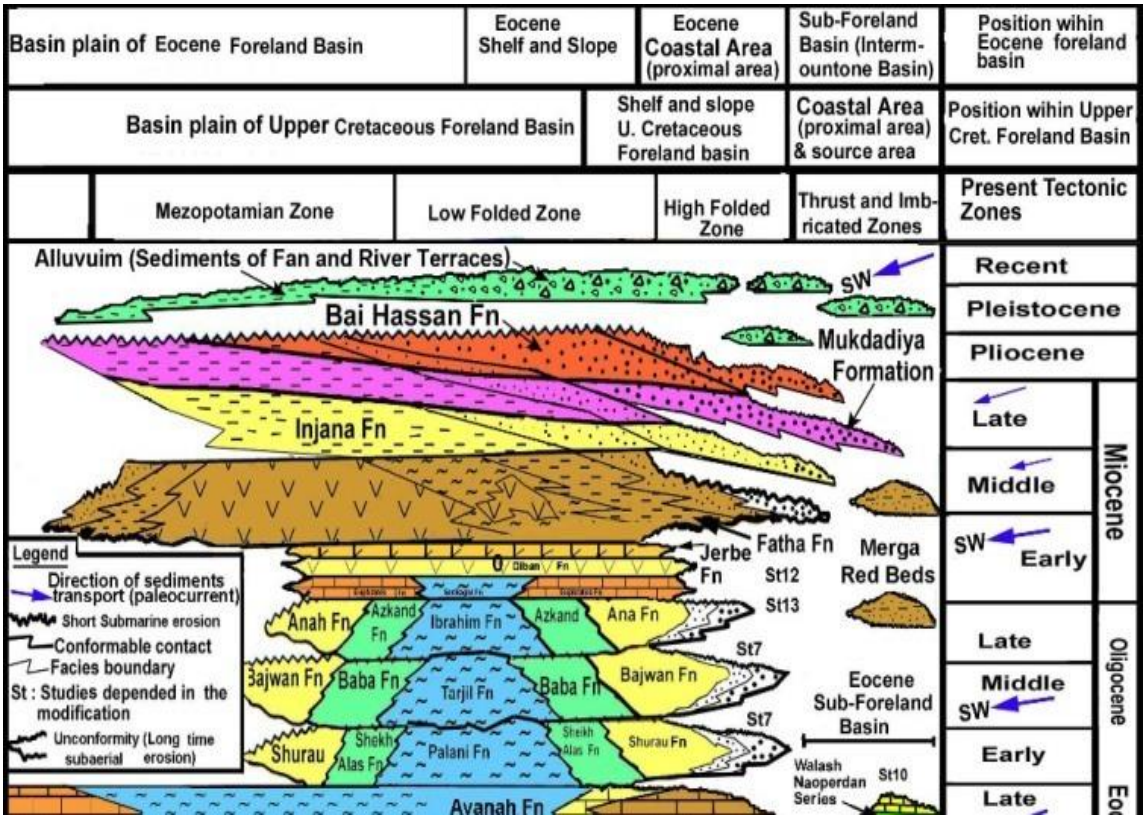

Fig. (3.4.2) Chronostratigraphic column of Late Tertiary and Quaternary 6Shows Kirkuk Group (Karim, 2010)

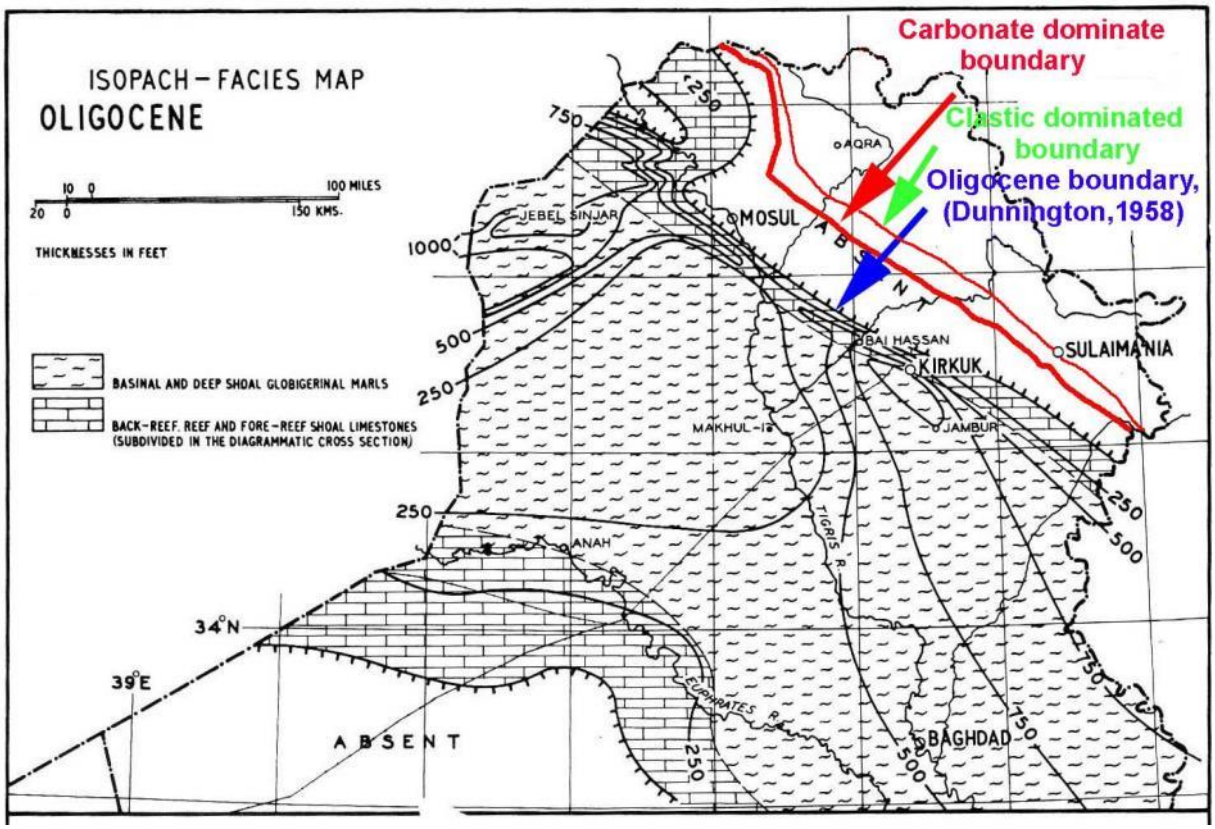

Fig. (3.4.3) Facies map during Oligocene showing basinal, and reefal facies (formations) of the Kirkuk Group with northeast southwest cross section of the basin.

3-5-Eocene

3-5-1-Pila Spi Formation

Lithology: white or milky limestone or dolomitic limestone
Age: Middle-Upper Eocene
Tectonic condition: Deposited after separation of the Zagros Foreland basin into two basins (main foreland basin in which Pila Spi Formation is deposited) and Sub-foreland basin in which Walash-Naoperdan Series is deposited
Environment: mainly deposited in semi-restricted lagoon and partly in reef environments
Thickness: about 40-150m
Area of distribution: High Folded Zones and Low Folded Zones
Fossil content: green algae, bryozoa, miliolids, alveolina, pelecypod and gastropods (Fig.3.5.1).
Sedimentary structures: bedding, lamination, trace fossils
Stratigraphic position: located between Gercus and Anah or Lower Fars Formations at the base and top respectively.
Boundary condition: It is unconformable with overlying Lower Fars formation but it is conformable with underlying Red Bed Series. It changes laterally to Avanah and Jaddala formations toward southwest
Sequence stratigraphy: deposited mainly as sediment high stand system tract

Fig.(3-5-1) Polished slab of chalky limestone of Pila Spi Formation of Glazarda Area showing Algae and Bryozoa.

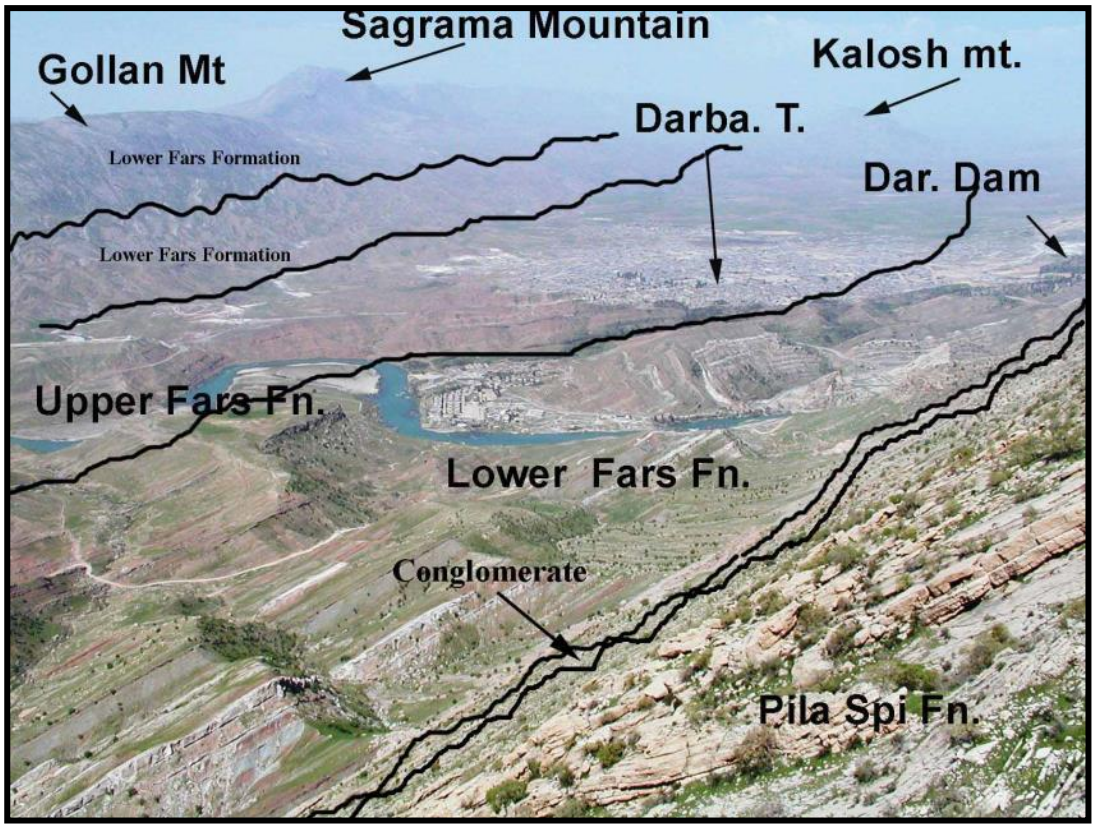

Fig. (3-5-2) The area around Darbandikhan town showing the exposed formation.

3-5-2-Gercus Formation

Lithology: Red or grey sandstone, claystone and conglomerate (Fig.3.5.3)
Age: Lower Eocene
Tectonic setting: Deposited in near shore area of Eocene Foreland basin as distal alluvial fan, delta plain and front in high tectonic activity phase.
Environment: distal alluvial fan, delta plain and delta front deposit i
Thickness: about 40-70m
Area of distribution: High Folded Zones
Fossil content: rare
Sedimentary structures: bedding, lamination, cross bedding, parting lamination and imbricated pebbles.
Stratigraphic position: located between Kolosh and Pila Spi Formations at the base and top respectively.
Geographic distribution: Low and High Folded Zone
Boundary condition: It is unconformable with overlying Pila Spi formation but it is conformable with underlying Sinjar (or Khurmala) Formation. It changes laterally to Jaddala or Avanah formations toward southwest and to Red Bed Series toward northeast
Sequence stratigraphy: deposited mainly as sediment low Stand system tract on low stand delta plain

Fig.(3-5-3) An outcrop of Gercus Formation near Mirade village along eastern side of the main road between Sulaimani city and Darbandikhan town. Grey, yellow, and red colors are sandstone, conglomerate and red claystone s respectively

3-5-3-Avanah Formation

Lithology: milky to grey fossiliferous limestone with some dolomitic limestone
Age: Upper Eocene
Tectonic condition: A barrier reef in the Eocene Foreland basin
Environment: slightly restricted to normal shallow marine environment
Thickness: about 50-250m
Area of distribution: Low Folded and Mesopotamian Zones
Fossil content: Algae, coral, benthonic foram such as alveolina, nummulites and miliolids
Sedimentary structures: bedding, lamination, trace fossils
Stratigraphic position: located between Khurmala Formations and Anhan Lower Fars Formation at the base and top respectively.

Boundary condition: It is unconformable with overlying Pila Spi and underlying Gercus formations. It changes laterally to Jaddala Formations toward southwest and to Gercus or Plia Spi toward northeast
Sequence stratigraphy: deposited mainly as sediment of different system tracts (high and Low)

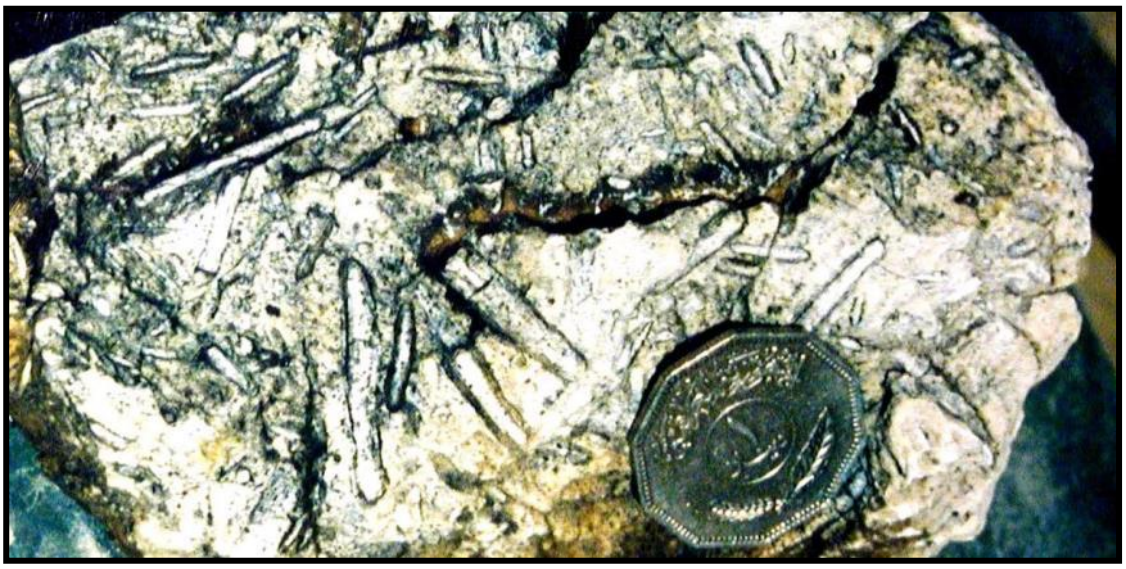

Fig.(3.5.4)Weathered milky limestone of Avanah Formation shows Alveolina forams in Sartak Bamo Area.

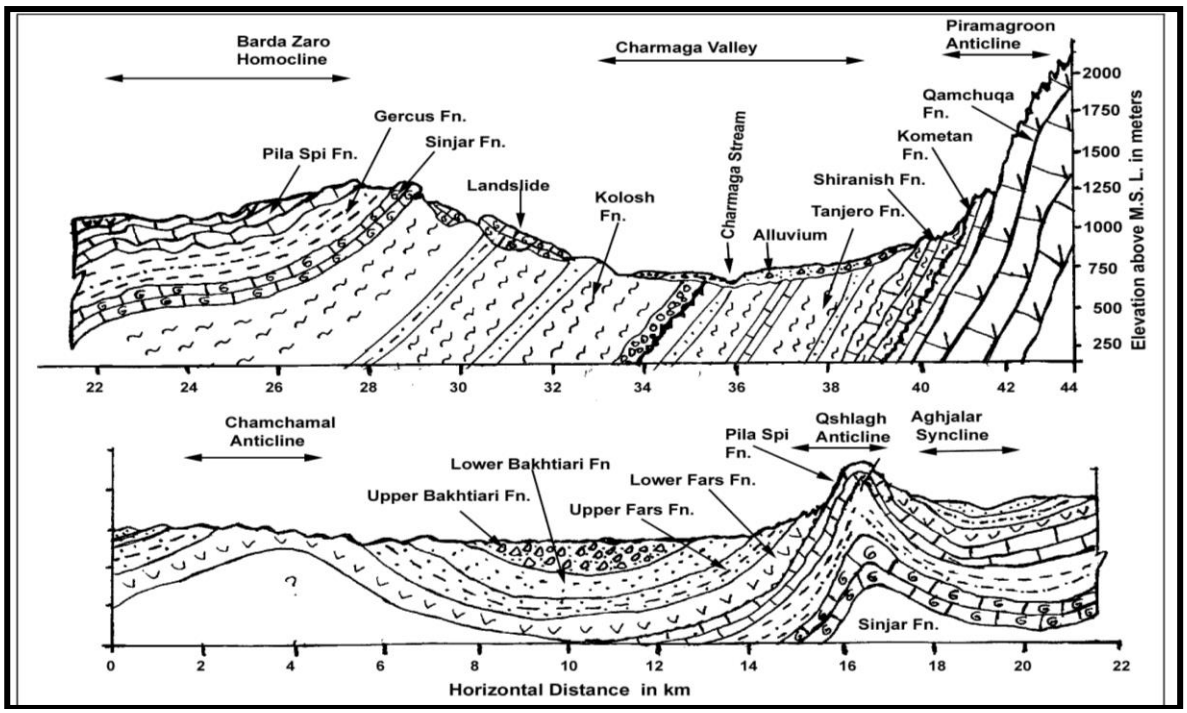

Fig. (3.5.5) two geologic cross sections passing through southwestern limb of Piramagroon (northeast) Qashlagh anticline and Chamchamal town. The two sections can be combines together at 22km distance.

3-5-4-Sinjar Formation

Lithology: mainly consists of grey coarse grain detrital and fossiliferous limestone and partly contain some dolomitic limestone (Fig.3.5.5)

Age: Upper Paleocene – Lower Eocene
Tectonic condition: Deposited on submerged highs in the near shore area of Tertiary Foreland Basin
Environment: reef, fore reef and lagoon environments
Thickness: about 70-200m
Area of distribution: Low and High Folded Zones
Fossil content: Algae, coral, brayozoa, nummulite, alveolina (Fig.3-5-5) miliolids, gastropod and pelecypods
Sedimentary structures: bedding, lamination, trace fossils and concretions
Stratigraphic position: located between Kolosh and Gercus Formations at the base and top respectively.
Boundary condition: It is conformable with overlying Gercus and underlying Kolosh Formations. In Sinjar area It is unconformable with underlying Shiranish Fm and conformable with Jaddala Formation. It changes laterally to Jaddala formations toward southwest and to Red Bed Series toward northeast (Fig.3.5.7)
Sequence stratigraphy: deposited mainly as sediment of high system tracts

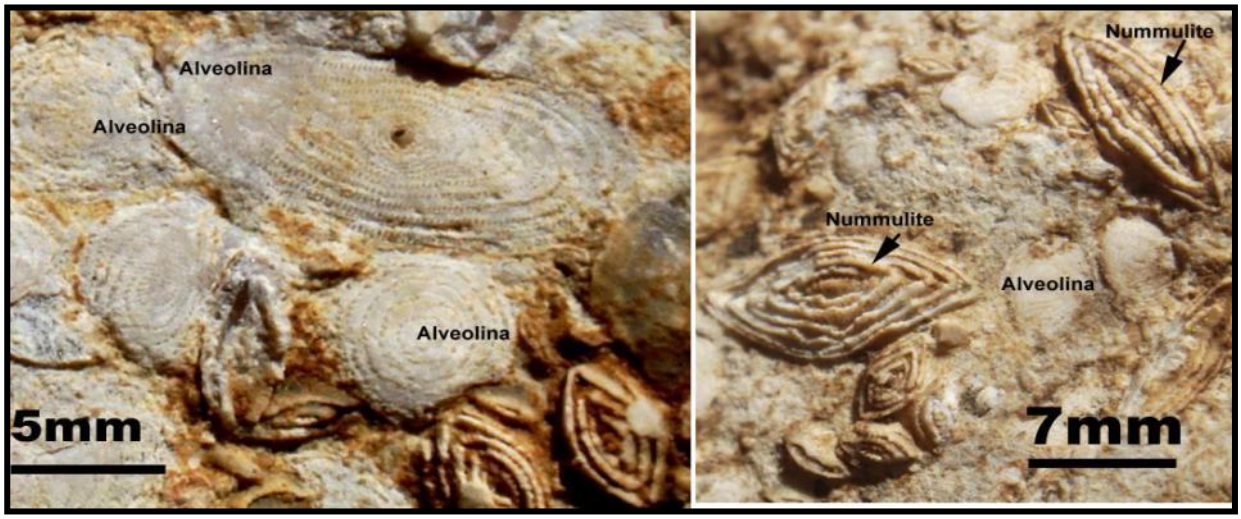

Fig.(3.5.5) Weathered outcrop of Sinjar Formation in Sartak Bamo Area showing Nummulite and Alveolina forams.

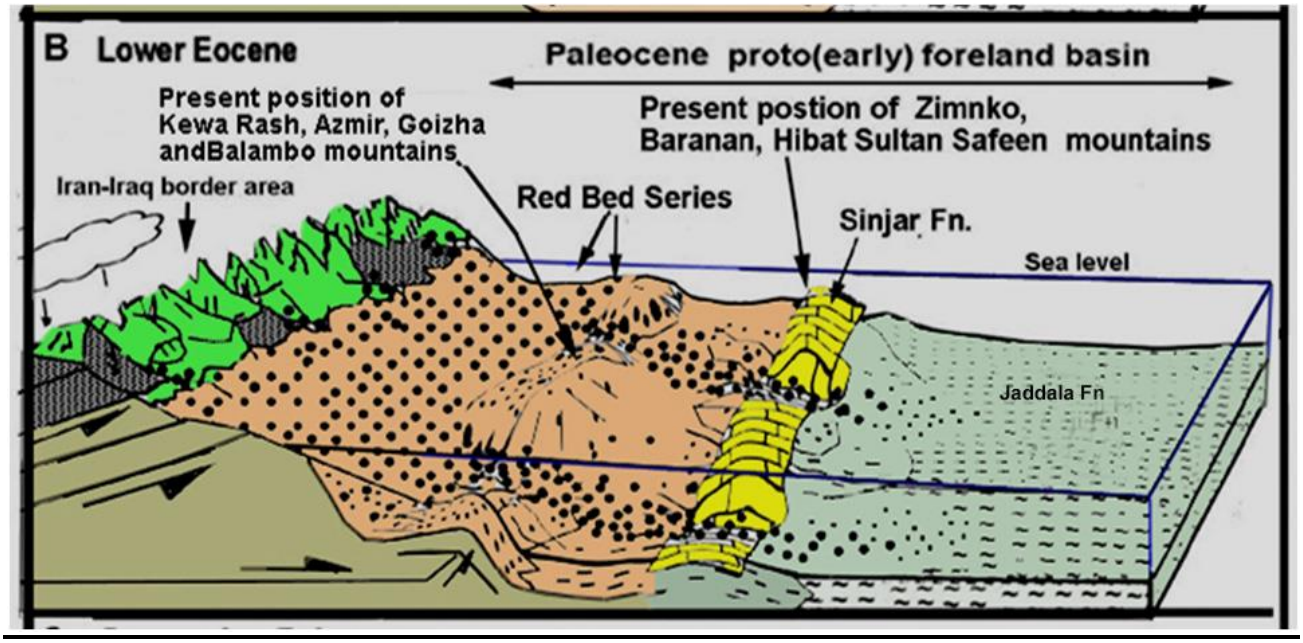

Fig.(3.5.6) Tectonic setting of the Foreland basin during Paleocene-Early Eocene shows the environment and lateral changes of Sinjar Formation

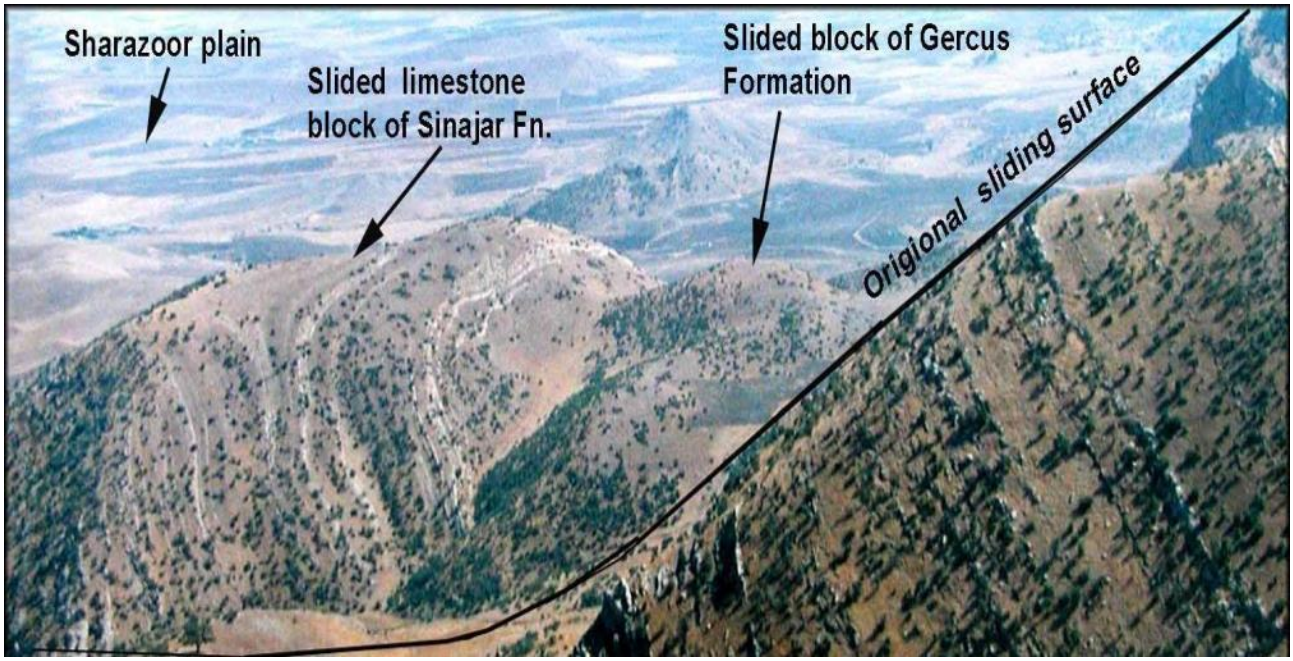

Fig.(3.5.7) Photo of part of northeastern side of Baranan mountain (Glazarda mountain) at south of Sulaimani city showing large landslide (weighted more than 200,0000 tons)Karim and Ali, 2004).

3-5-5-Khurmala Formation

Lithology: Grey dolomitic limestone and marly limestone

Age: Upper Paleocene – Lower Eocene

Tectonic condition: Deposited in Tertiary in Foreland Basin

Environment: Lagoon (back reef)

Thickness: about 20-70m

Area of distribution: Low and High Folded Zones

Fossil content: algae, large forams, pelecypods and gastropods

Sedimentary structures: bedding, lamination, trace fossils

Stratigraphic position: located between Kolosh and Gercus Formations at the base and top respectively in Sulaimani and Arbil areas while it is located between Aqra and Gercus Formation in some places of Duhok area.

Boundary condition: It is conformable with overlying Gercus and underlying Kolosh Formations. It changes laterally to Jaddala formations toward southwest and to Red Bed Series toward northeast and to Sinjar or Kolosh Formations toward southeast (Fig.3-5-8).

Sequence stratigraphy: deposited mainly as sediment of high system tracts

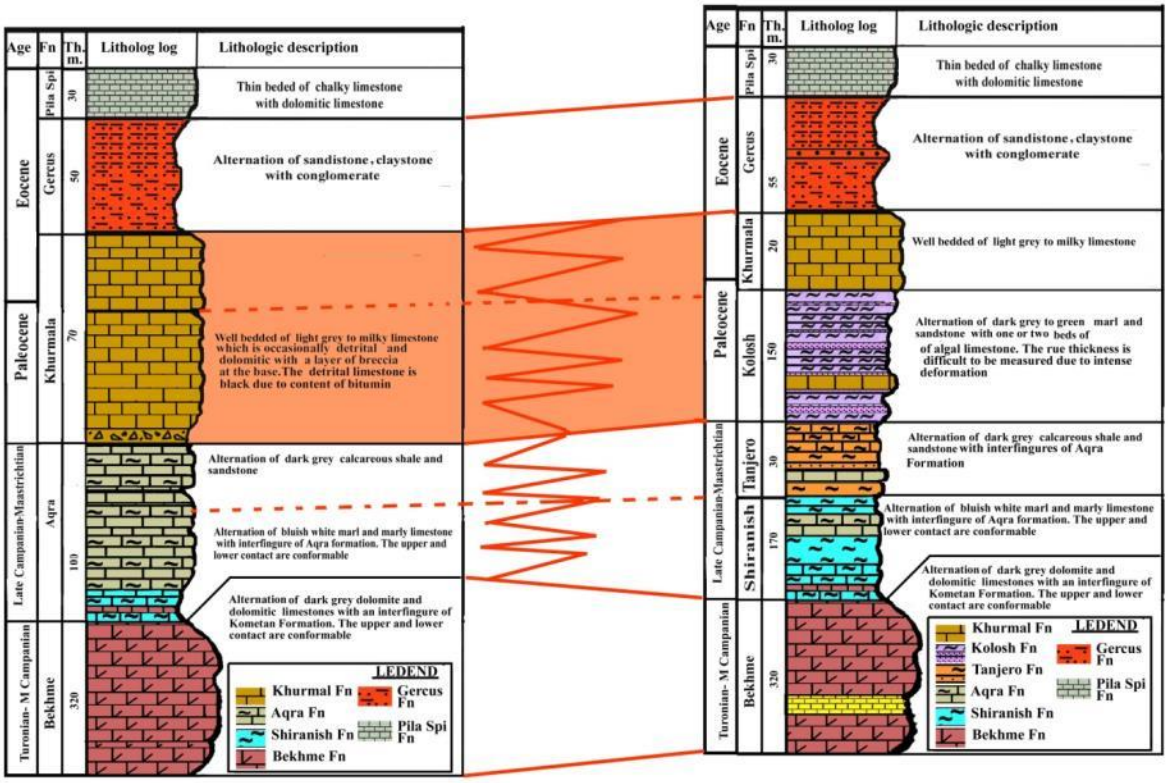

Fig. (3.5.8) a correlation of Bekhme and Saru Kani sections which shows the total lateral facies change of Kolosh (green marl) to Khurmala formations

3-5-6-Jaddala Formation

Lithology: Marl and marly limestone
Age: Eocene
Tectonic condition: Basin plain of Eocene Foreland basin mainly far from tectonic activities.
Environment: Basin plain (Offshore).
Thickness: About 350m
Area of distribution: Low Folded and Mesopotamian Zones
Fossil content: Planktonic foram (globogerina)
Sedimentary structures: bedding, lamination, trace fossils
Stratigraphic position: located between Aliji Formations and Kurkuk Group at the base and top respectively.
Boundary condition: It is conformable with overlying Kirkuk group and underlying Aliji Formations. It changes laterally to Gercus, Sinjar, Khurmala and Pila Spi formations toward northeast
Sequence stratigraphy: deposited mainly as different system tracts

3-6-Paleocene

3-6-1-Kolosh Formation

Lithology: Alternation of sandstone and calcareous shale with rare interbeds of conglomerates

Age: Paleocene
Tectonic condition: Slope and basin plain of Tertiary Foreland basin in front of southwest advancing of Iranian Plate front (Fig.3-6.1).
Environment: slope and basin plain of the Foreland basin
Thickness: about 400- 1200m
Area of distribution: Mainly High Folded Zones
Fossil content: Planktonic and benthonic forams, plant derbis, and gastropods with Nereite, skolithos trace fossils
Sedimentary structures: tool marks, flute casts, cross bedding, graded bedding.
Stratigraphic position: located between Tanjero (or Aqra) Formation at the base and Sinjar (or Khurmala) Formation the top. In Some case the overlaying formation is Gercus formation such near Mirade village (Fig. 3-5-2).
Boundary condition: It is conformable with overlying Sinjar Formation and underlying Tanjero Formation at distal areas. But it may be unconformable in proximal area in some places. It changes laterally to Red Bed Series toward northeast while it changes to Aliji Formation toward southeast (Fig.3.6.1 and 2).
Sequence stratigraphy: Deposited mainly as low system tracts

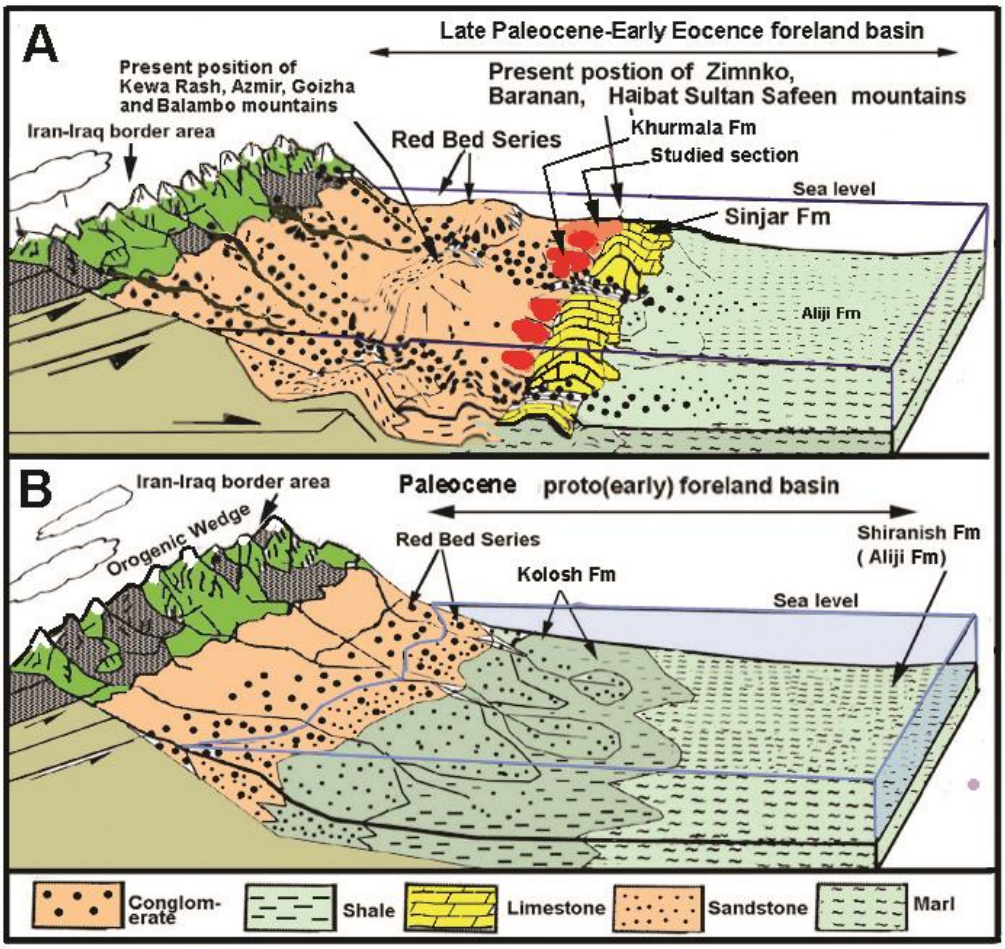

Fig.(3.6.1) Tectonic setting of the Foreland basin during Paleocene shows the environment and lateral changes of Kolosh Formation. The same model is applicable for Maastrichtian when both Red bed series and Shiranish Fms are replaced by Tanjero Formation

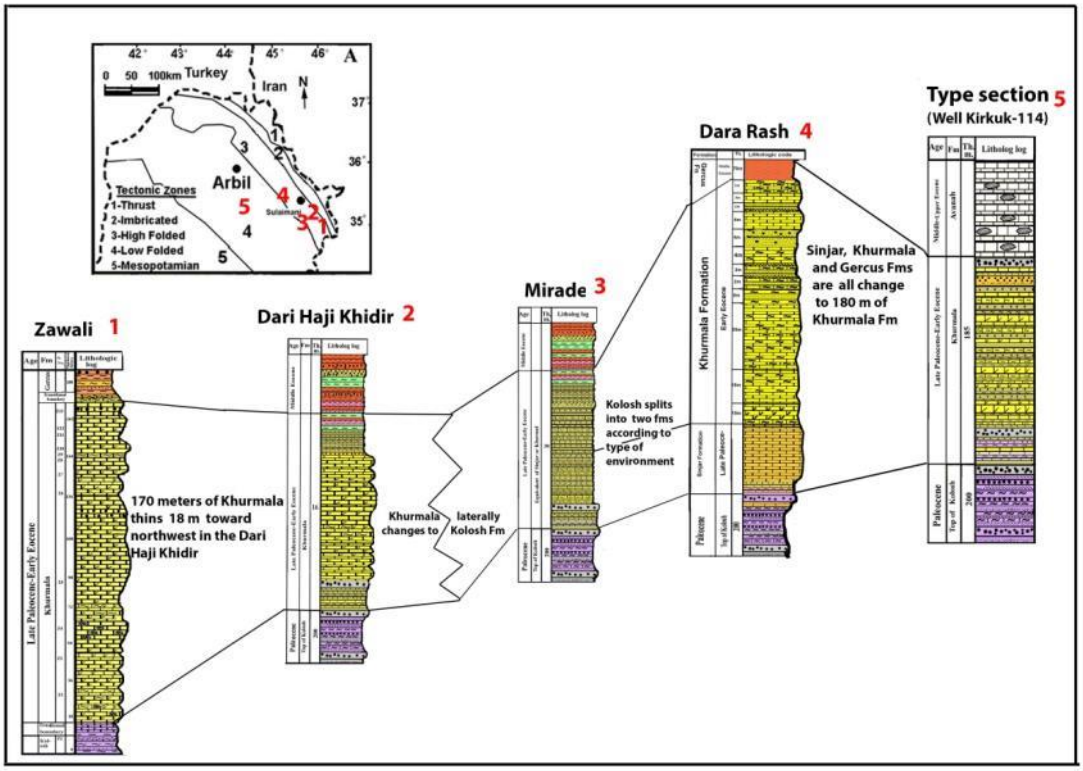

Fig.(3.6.2) Correlation of the four-studied section with the type section of the Khurmala Formation.

3-6-2-Aliji Formation

Lithology: Marl and Marly limestone
Age: Paleocene
Tectonic condition: Basin plain of Paleocene Foreland basin away from tectonic activities.
Environment: basin plain
Thickness: about nearly 100-300m
Area of distribution: Low Folded and Mesopotamian Zones
Fossil content Planktonic foram (globigerina)
Sedimentary structures: bedding and lamination
Stratigraphic position: located between Shiranish and Jaddala Formations at the base and top respectively.
Boundary condition: It is conformable with both overlying and underlying formations formation in the High Folded Zones.
Sequence stratigraphy: deposited as sediment of low stand system tract

3-6-3-Red Bed Series

Lithology: Thick successions of red or grey sandstones, claystones and conglomerate
Age: Paleocene-Eocene
Tectonic condition: Costal area of large Tertiary Foreland basin in front of southwest advancing of Iranian Plate. It is equivalent to Kolosh, Sinjar and Gercus Formation in lateral facies and in age.
Environment: continental Alluvial fan, fan delta and delta front environment
Thickness: about 1500m
Area of distribution: Imbricated Zone and thrust Zone

Fossil content: Mostly reworked fossils
Sedimentary structures: imbricates pebbles, longitudinal bar, cross bedding and lamination and tool marks
Stratigraphic position: located between Tanjero Formation at the base and but its overlying unit is unknown.
Boundary condition: It is conformable in some place and unconformable in others with both underlying Tanjero Formation. it is laterally changes to Kolosh, Sinjar and Gercus Formations toward southwest
Sequence stratigraphy: Deposited as sediment of mainly low stand system tract with minor high stand system tract (Fig.3.6.2)

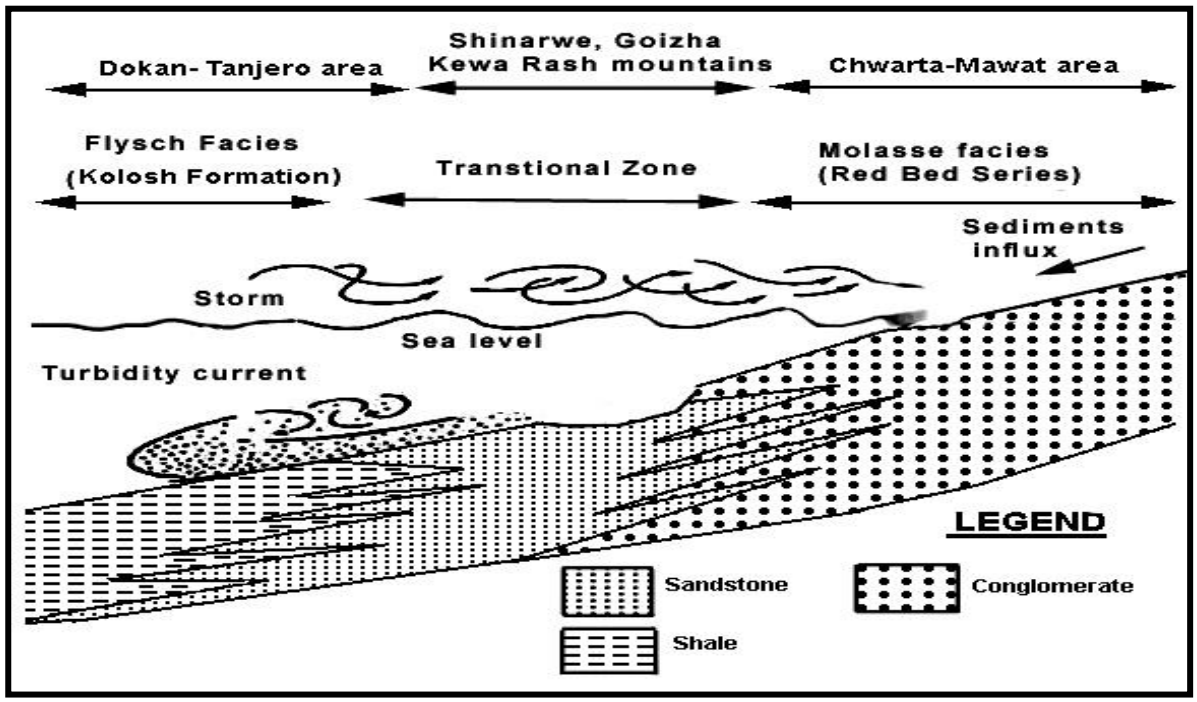

Fig.(3.6.3) Both Kolosh Formation and lower part of Red Bed Series are deposited in same foreland basin in basin plain and coastal area respectively. There is a transitional Zone (environment) between the two facies but now it is eroded

3-7-Maastrichtian-Campanian

3-7-1-Aqra Formation

Lithology: Reefand forereef massive grey limestone
Age: Maastrichtian-Campanian
Tectonic condition: deposition on submerged paleohigh (forebulge) of Early Cretaceous Foreland basin in front of southwest advancing of Iranian Plate
Environment: reef, forereef and lagoon
Thickness: 30- 350m
Area of distribution: Low and High Folded Zones in addition to and Imbricated Zone
Fossil content: rudist, Pelecypod, large forams (omphalocyclus, luftusia orbituids) coral, Echinoderms, gastropods.
Sedimentary structures: bedding and lamination
Stratigraphic position: located between Kolosh Formation at the top and Tanjero Formation at the base in Sulaimani area. In Duhok areas it located between Khurmala (at the top) and Bekhme Formation at the base.

Boundary condition: It is conformable in some place and unconformable in others with both overlying Red Bed Series and underlying Tanjero Formation. it is laterally changes to Shiranish and Tanjero Formation toward southeast
Sequence stratigraphy: Deposited as sediment of both low and high stand system tracts (Fig.3.6.2).

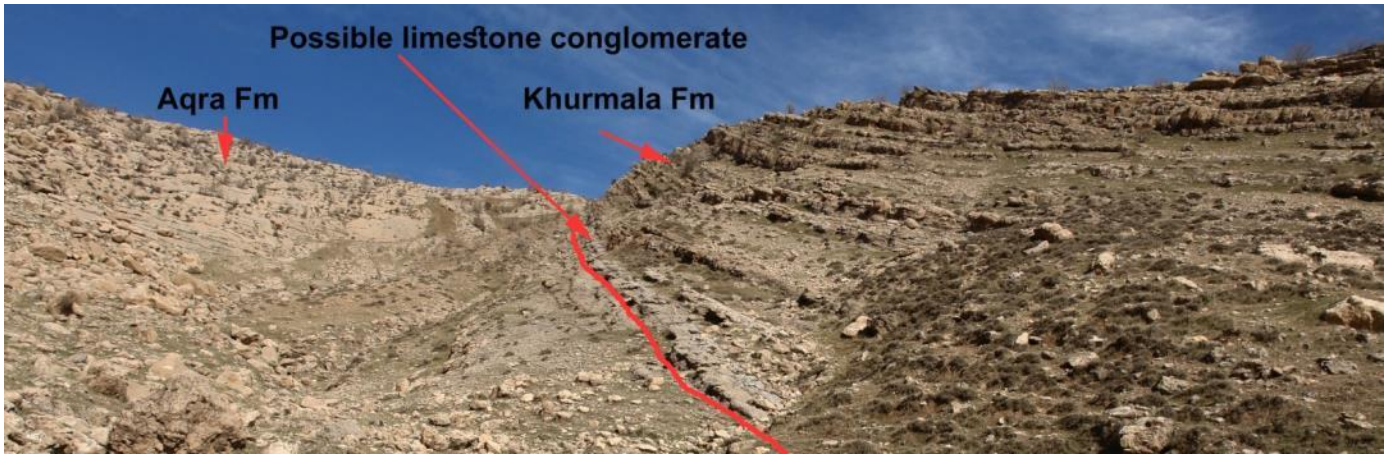

Fig.(3.6.4) a Possible limestone conglomerate at the contact between Aqra and Khurmal Formations at area near Saru Kani village

3-7-2-Tanjero Formation

Lithology: Alternation of sandstone and calcareous shale on the slope and basin plain while changes to conglomerate and biogenic limestone on the shelf and coastal (Chuarta and Mawat Area) area (Fig.)
Age: Maastrichtian
Tectonic condition: Near shore area of Cretaceous Foreland basin in front of southwest advancing of Iranian Plate
Environment: Delta, high turbid shelf, slope and basin plain
Thickness: about 50- 600m
Area of distribution: Thrust, Imbricated and High Folded Zones
Fossil content: Pelecypod, planktonic forams, large forams, rudist (in Aqra lens) and gastropods with Nereite, skolithos and planolites, Paleodictyon trace fossils.
Sedimentary structures: tool marks, flute cast, groove cast, cross bedding, graded bedding
Stratigraphic position: In Sulaimani Governorate, it is located between Kolosh and Red Bed Series at the top and Shiranish Formation at the base. In Duhok area, it located between Shiranish and Khurmala Fms.
Boundary condition: It is conformable with both overlying Red Bed Series and underlying Tanjero Formation. It is laterally changes to Shiranish and Aqra Formations toward southeast and west
Sequence stratigraphy: Deposited as sediment of both low and high stand system tracts (Fig. 3.6.1 and 3.7.1 and 2).

Fig.(3.7.1) outcrop Tanjero Formation after rain at 5 km west of Rawandoz town

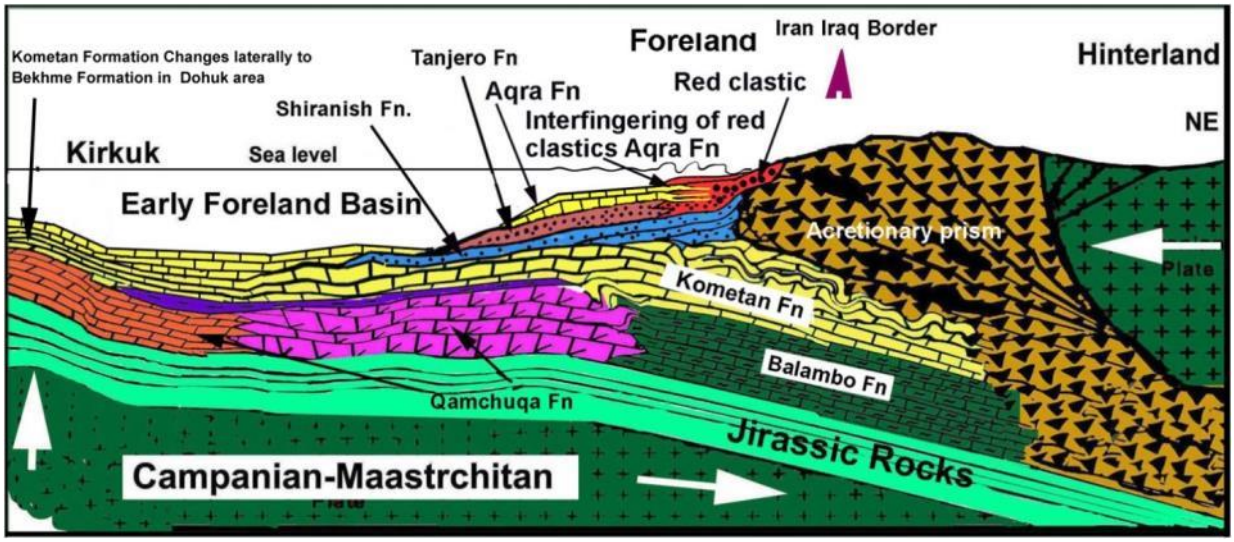

Fig.(3.7.2)Combination of tectonic and depositional setting of Upper (Late) Cretaceous basin in which Shiranish and Tanjero Formation are deposited (Karim, 2008).

3-7-3-Shiranish Formation

Lithology: Alternation well bedded bluish white marls and marly limestone
Age: Campanian-Maastrichtian
Tectonic condition: off-shore area of Cretaceous Foreland basin in front of southwest advancing of Iranian Plate
Environment: slope and basin plain
Thickness: about 100- 200m
Area of distribution: Thrust, Imbricated and High, low Folded Zones and Mesopotamian Zone
Fossil content: Planktonic forams, ammonites, pelecypods
Sedimentary structures: bedding and lamination

Stratigraphic position: located between Tanjero Formation at the top and Kometan Formation at the base. In Sinjar area, it overlain by Sinjar Formation unconformably
Boundary condition: It is conformable with both overlying Tanjero Formation and underlying Kometan Formation. It is laterally changes to Tanjero and Aqra Formations toward southeast
Sequence stratigraphy: Deposited as sediment of early low stand system tracts (Fig.3.7.1)

Hartha Formation

Lithology: Reefal and lagoonal limestone with some dolomite and terrigenous sandstone with some oolitic limestones.
Age: Maastrichtian and Campanian (equivalent to Shiranish and Tanjero Formations)
Tectonic condition: Deposited in the foreland basin.
Environment: reef, forereef and lagoon
Thickness: about 200m
Area of distribution: Mesopotamian and Western Desert Zones
Fossil content: Rudist, Pelecypod, large forams, gastropods and pelecypods.
Sedimentary structures: Bedding and lamination
Stratigraphic position: Located between Saadi (at the base) and Tayarat at the top)

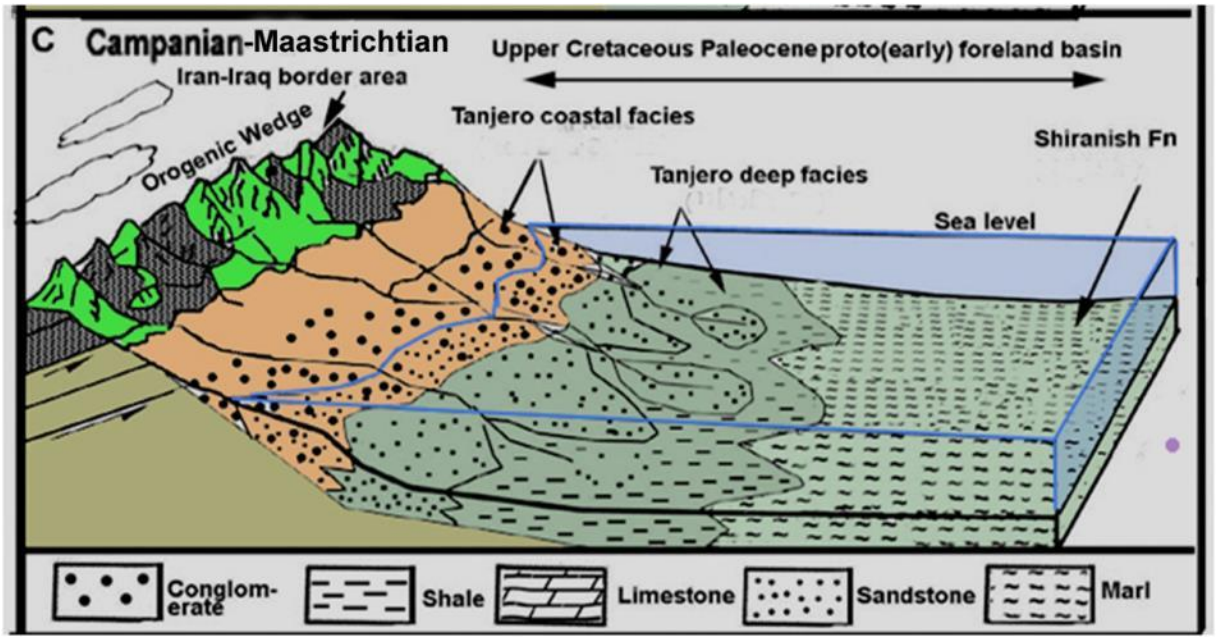

Fig.(3.7.3)Combination of tectonic and depositional setting of Upper (Late) Cretaceous basin in which Shiranish and Tanjero Formation are deposited (Karim, 2008).

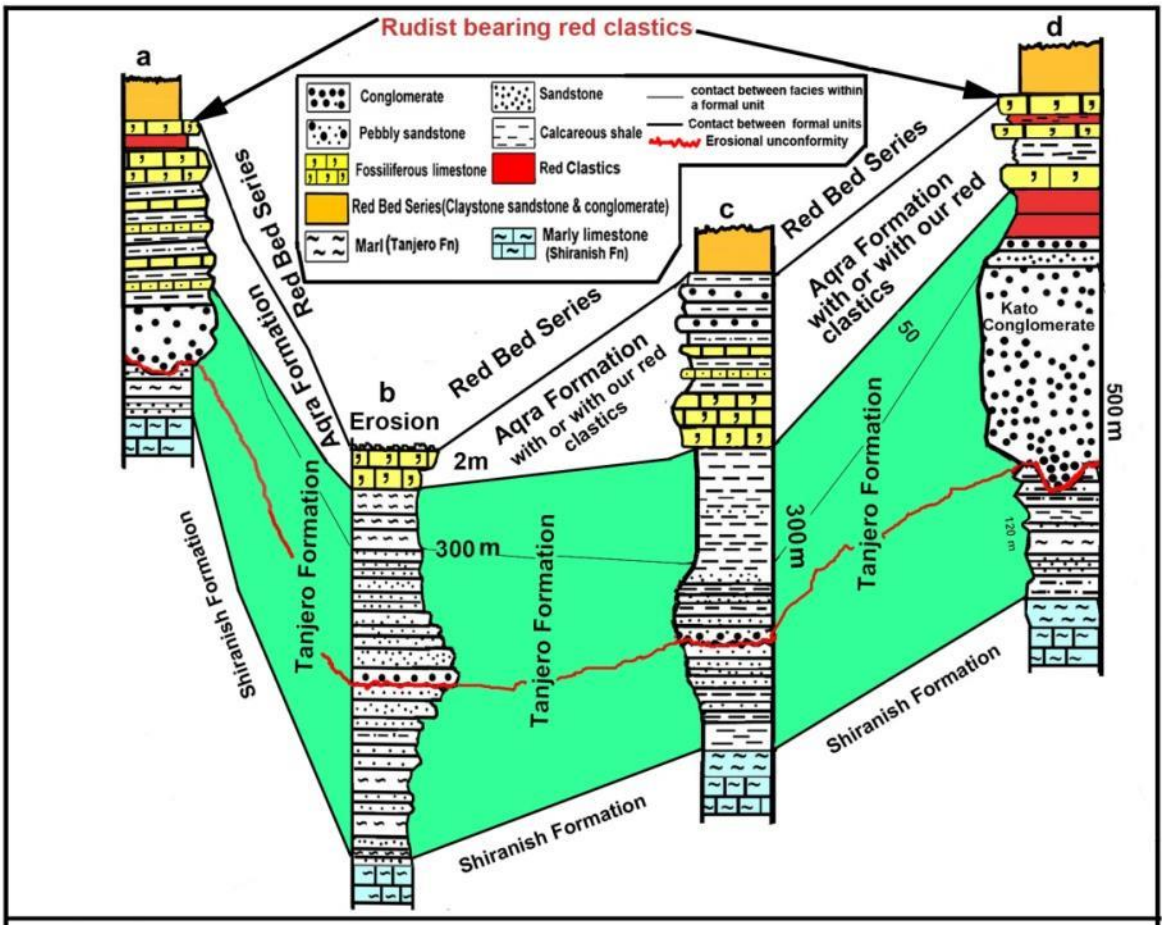

Fig. (3.7.4) Correlation of the Campanian-Maastrichtian formation in the Sulaimani area (modified from Karim, 2004)

3-8- Campanian-Turonian

3-8-1-Bekhme Formation

Lithology: Reefal and lagoonal massive dolomite and dolomitic limestone
Age: Middle Campanian-Turonian
Tectonic condition: Deposited on the continental margin (or oceanic margin) of Neo-Tethys basin
Environment: reef, forereef and lagoon
Thickness: about 300m
Area of distribution: Imbricated, Low and High Folded Zones
Fossil content: Rudist, pelecypod, large forams, gastropods and pelecypods.
Sedimentary structures: Bedding and lamination
Stratigraphic position: Located between Aqra (and Shiranish) Formation at the top and Qamchuqa Formation at the base.
Boundary condition: It is conformable with both overlying Shiranish Formation and underlying Qamchuqa Formation. It is laterally changes to Kometan Formation Formations toward southeast

Sequence stratigraphy: Deposited as sediment of both High stand system tracts (Fig.3.7.1)

3-8-2-Kometan Formation

Lithology: White well bedded fine grain limestone (pelagic limestone)
Age: Turonian- Middle Campanian
Tectonic condition: Deposition on the continental margin (or oceanic margin) of Neo-Tethys basin before foreland generation
Environment: Slope and forereef
Thickness: about 70-120m
Area of distribution: Imbricated, High Folded, and Low Folded Zones
Fossil content: Planktonic Forams, its upper part contains ammonite
Sedimentary structures: Bedding, lamination and chert nodules
Stratigraphic position: Located between Qamchuqa Formation at the base and Shiranish Formation at the top.
Boundary condition: It is conformable with both overlying Shiranish Formation and underlying Gulneri (or Qamchuqa or Dokan Formations). It is laterally changes to Bekhme Formation toward northwest.
Sequence stratigraphy: Deposited as sediment of High stand system tracts (Fig.3.8.1, 3.8.2 and 3.8.2)

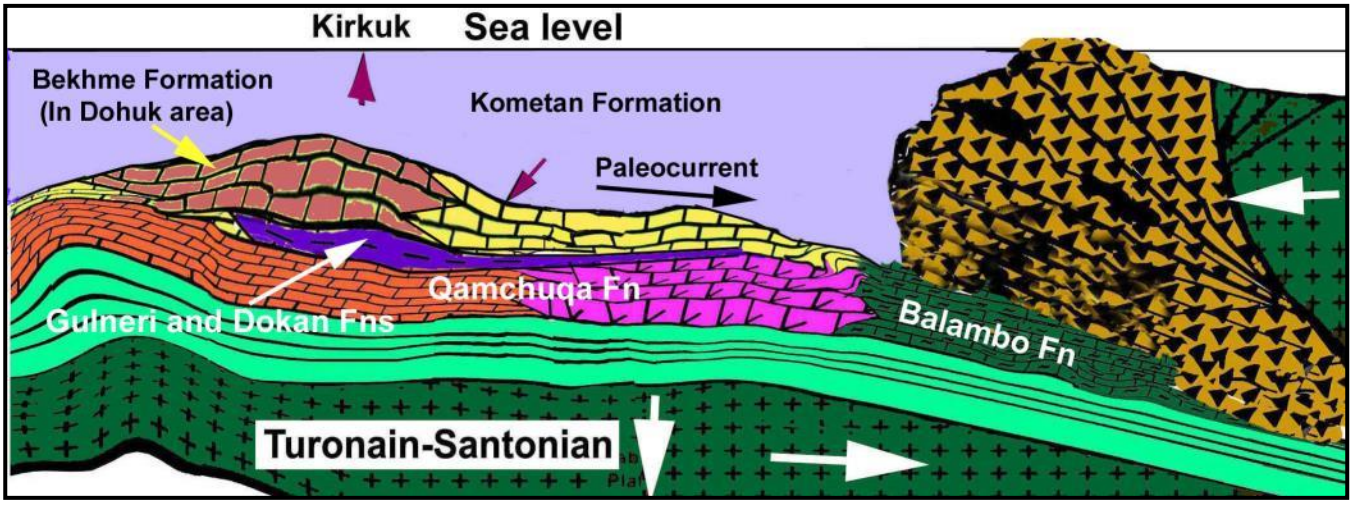

Fig.(3.8.1) Combination of tectonic and depositional setting of Upper (Late) Cretaceous basin in which Kometan is deposited (Modified from Karim, 2013 and Taha, 2008).

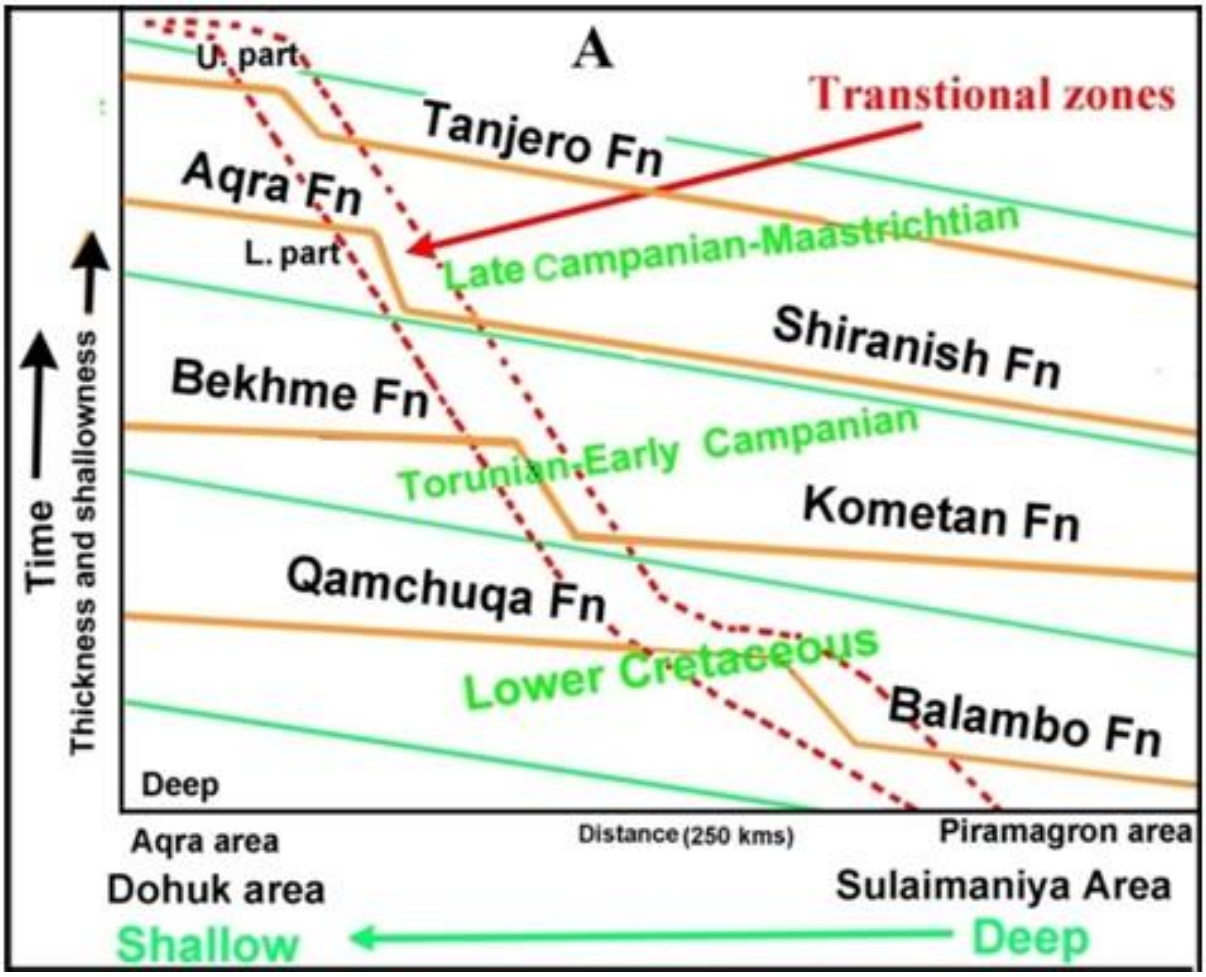

Fig.(3.8.2) Relation between deep and Shallow Facies (formations) during Cretaceous in Dohuk and Sulaimani Governorates (Karim et al., 2013)

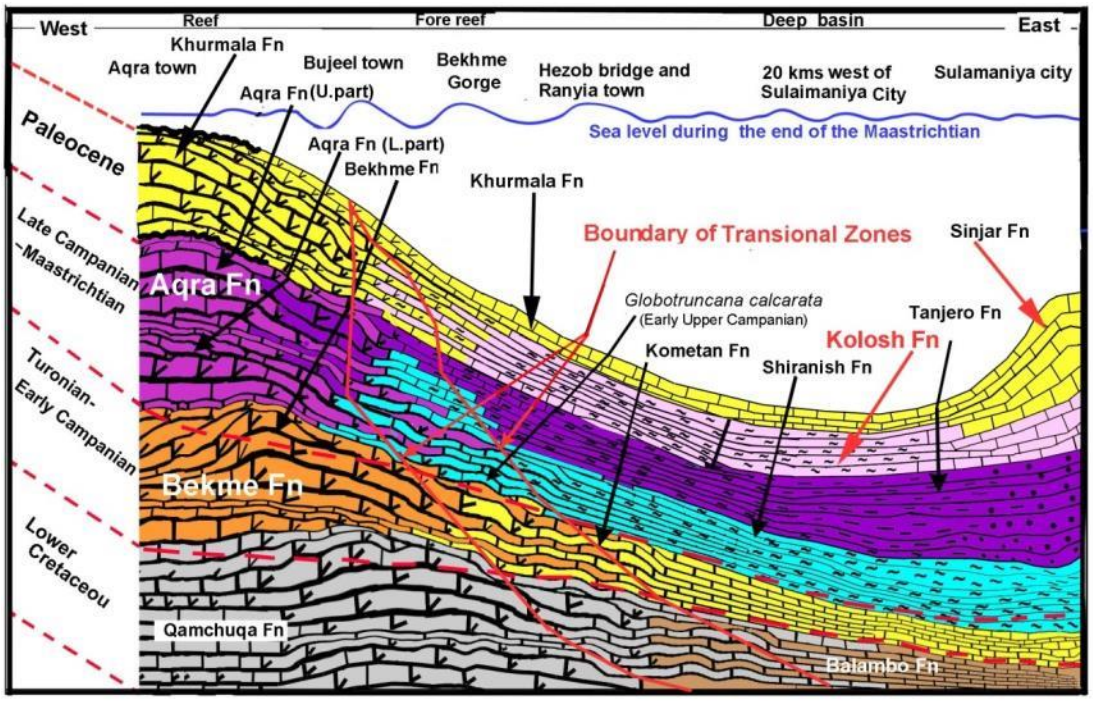

Fig.(3.8.3) Relation between deep and Shallow Facies (formations) during cretaceous in Dohuk and Sulaimani Governorates (Karim et al., 2013)

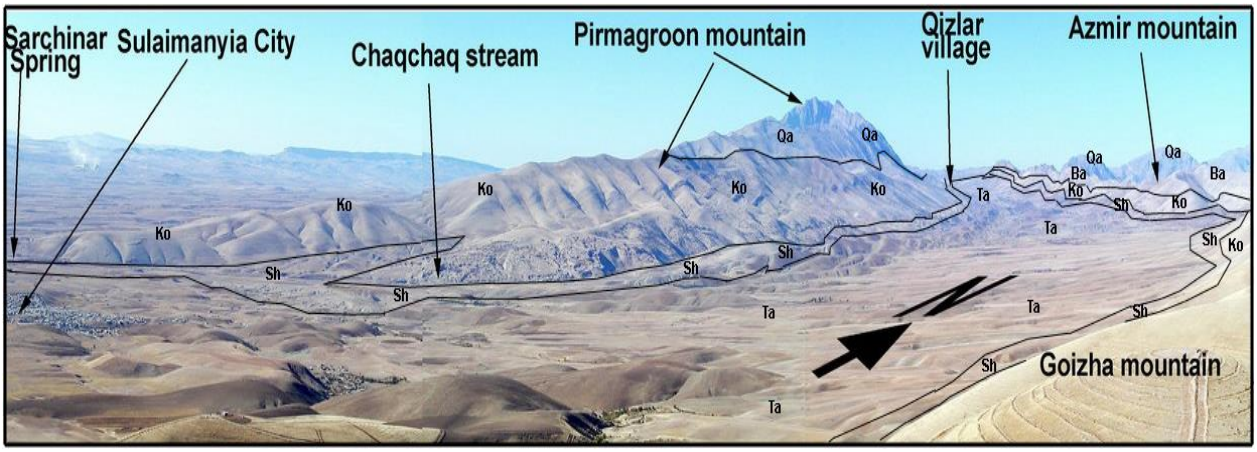

Fig.(3.8.4) Chaq Chaq valley (Dolla Root) valley showing Lower and upper Cretaceous Formations (Ali, 2007).

3-8-3-Gulneri Formation

Lithology: Grey, black or pink of highly deformed marl and marly limestone
Age: Late Cenomanian- Early Turonian (fig. 3.8.6)
Tectonic condition: Deposition on the continental margin (or oceanic margin) of Neo-Tethys basin
Environment: Slope and basin plain
Thickness: about 1.5-4m
Area of distribution: Imbricated, High Folded, and Low Folded Zones
Fossil content: Planktonic forms and nannofossils,
Sedimentary structures: Bedding, lamination and ball and pillow
Stratigraphic position: Located between Kometan Formation at the top and Qamchuqa (or Dokan) Formation at the base.
Boundary condition: It is conformable with both overlying Kometan Formation and underlying Dokan (or Qamchuqa) Formations. It is laterally changes to Kometan Formation or Qamchuqa or Balambo Formations
Sequence stratigraphy: Deposited as sediment of High stand system tracts (Fig.3.8.5 and 3.8.1).

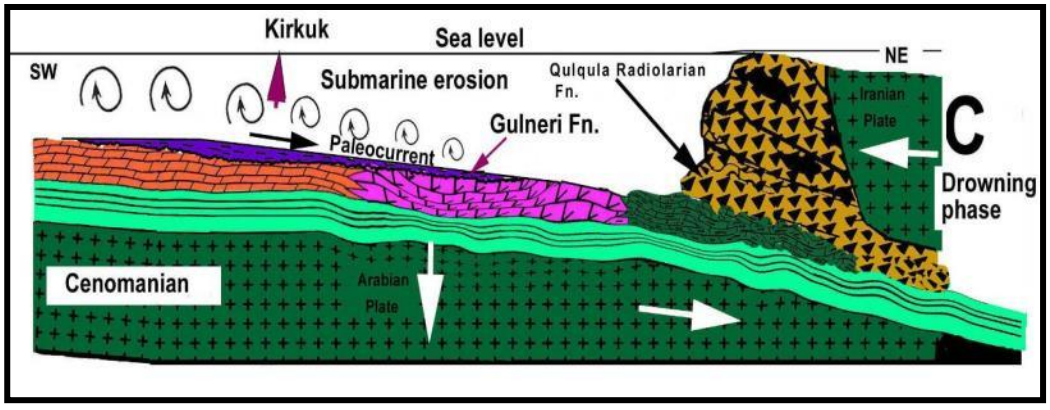

Fig.(3.8.5) Combination of tectonic and depositional setting of Middle Cretaceous basin in which Gulneri Formation is deposited (Taha,2008)

Fig.(3.8.6) Gulneri Formation on the Salta Re Hill at north of Sulaimani city show pink marl and marly limestones

3-8-4-Dokan Formation

Lithology: Grey thick bedded oligostiginal limestone
Age: Middle Cenomanian
Tectonic condition: Deposition on the continental margin (or oceanic margin) of Neo-Tethys basin
Environment: forereef (intermediate in depth between Kometan and Qamchuqa Formations
Thickness: about 5m
Area of distribution: High Folded Zone
Fossil content: Planktonic forms (oligostigina)
Sedimentary structures: Bedding, lamination
Stratigraphic position: Located between Gulneri Formation at the top and Qamchuqa Formation at the base.
Boundary condition: It is conformable with both overlying Gulneri Formation and underlying Qamchuqa or Balambo Formations. It is laterally changes to Kometan Formation or Qamchuqa or Balambo Formations. It is represent transitional facies from Qamchuqa Formation to Kometan Formation
Sequence stratigraphy: Deposited as sediment of early low stand system tracts (Fig.3.8.5 and 3.8.2).

3-9-Early Cretaceous

3-9-1-Qamchuqa Formation

Lithology: Reefal and lagoonal massive grey limestone
Age: Aptian- Early Cenomanian
Tectonic condition: Deposition on submerged paleohigh (forebulge) of Lower Cretaceous continental margin (or oceanic margin) of Neo-Tethys basin
Environment: reef, forereef and lagoon
Thickness: about 600m
Area of distribution: Imbricated, thrust, High Folded, Low Zones and Mesopotamian Zone (Shuaiba and Mauddud as equivalent of Qamchuqa Formation in the southern Iraq.
Fossil content: Rudist, pelecypod, coral, algae, gastropods and pelecypods.

Sedimentary structures: bedding, lamination and stromatolite (Fig. 3.9.3)
Stratigraphic position: located between Kometan or Bekhme Formation at the top and Sarmord Formation at the base
Boundary condition: It is conformable with both overlying Dokan Formation and underlying Sarmord Formations. It is laterally changes to Balambo Formation.
Sequence stratigraphy: Deposited as sediment of high stand and low system tracts (Fig.3.9.1 and 3.9.2).

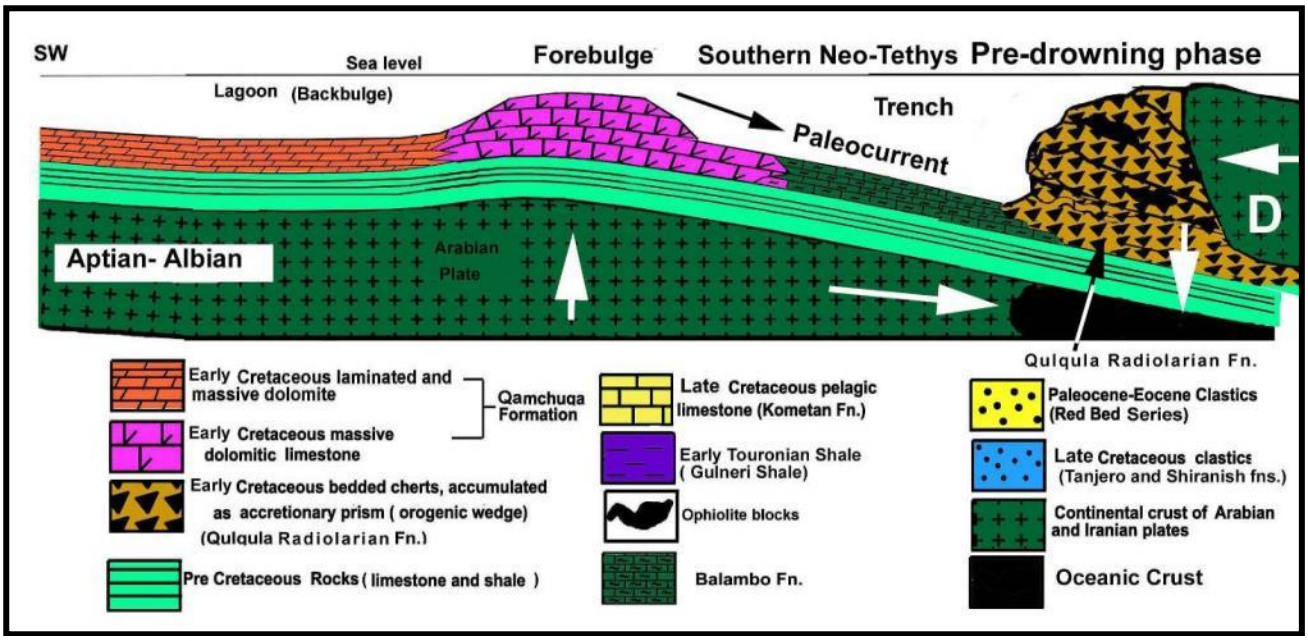

Fig.(3.9.1) Combination of tectonic and depositional setting of Lower (Early) Cretaceous basin in which Balambo, Qamchuqa and Qulqula Radiolarian Formations are deposited (Ameen,2008).

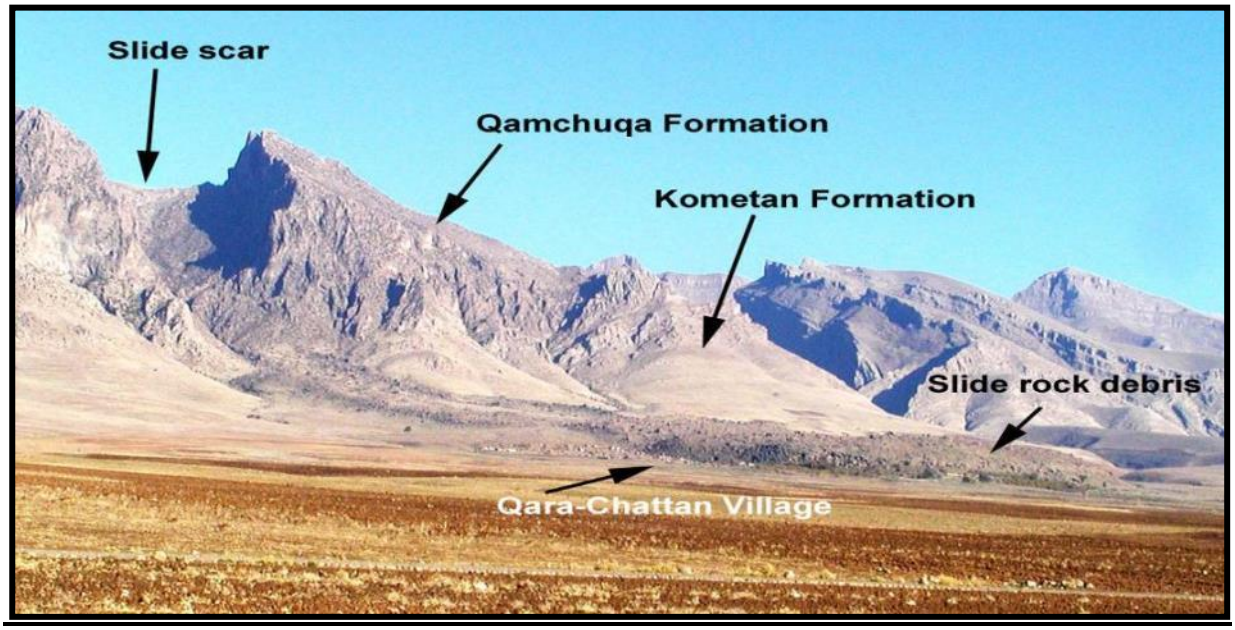

Fig. (3.9.2) Southwestern limb of Piramagroon anticline shows the exposed formations and Qara Chattan Rock slide.

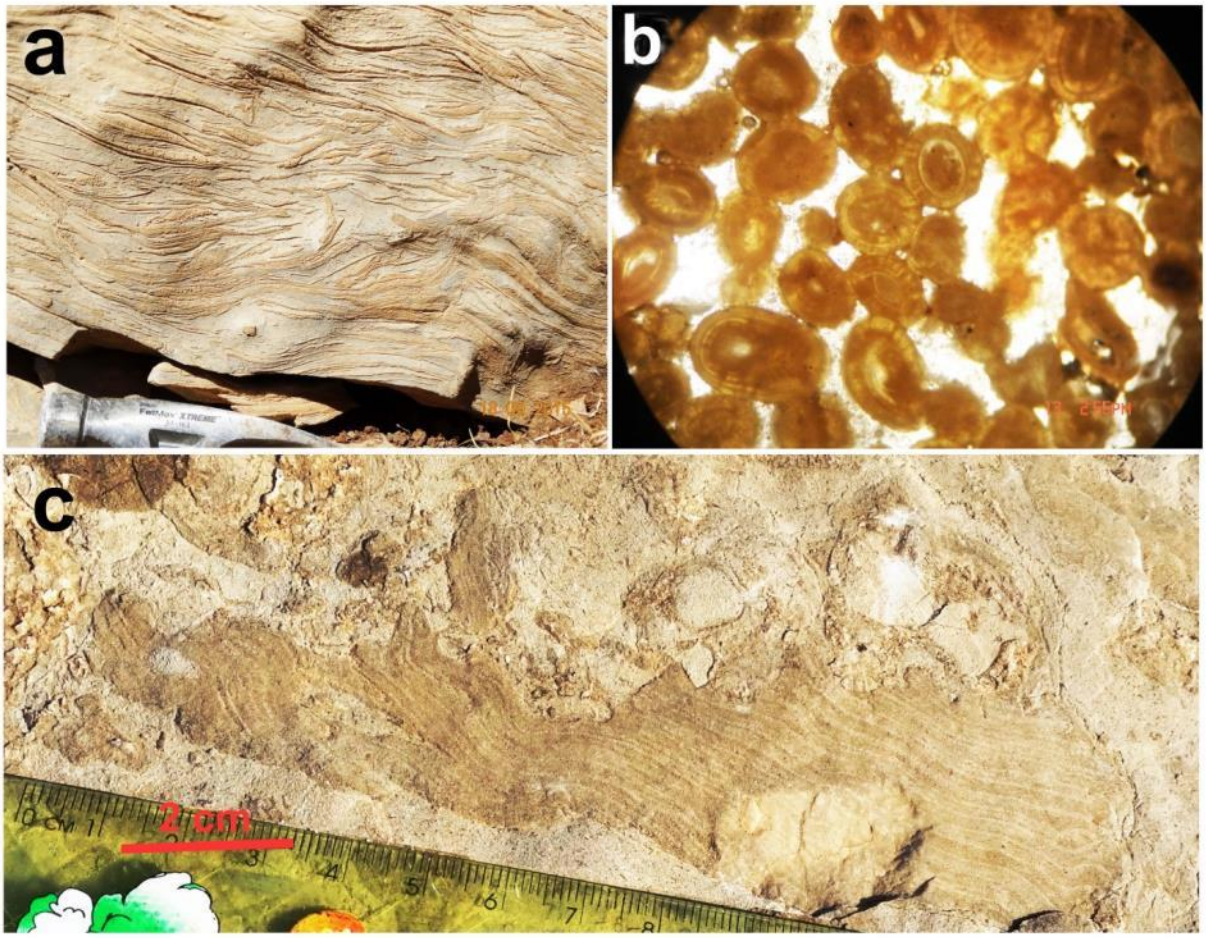

Fig. (3.9.3) some lithologies of Qamchuqa Formation, a)parallel and horizontal accumulation of thick rudist bed (shell debris) forming biostrome (bioclast rudstone) on Asos anticline 5km north of Bingrd town. b) oolitic limestone (oolitic grainstone) on Babo mountain at 3 km southwest of Sargalu village, c) current truncated and fragmented stromatolite on the latter mountain, located 10m below the oolite.

3-9-2-Balambo Formation

Lithology: light grey or milky well bedded limestone and marly limestone with local dolomitic limestone beds. In most place contain detrital limestones as calciturbidite in Sulaimani Governorate
Age: Aptian-Cenomanian
Tectonic condition: Deposition in slope and basin plain of Southern Neo-Tethys slope and basin of Arabian passive margin or platform) during convergence of Arabian and Iranian Plates. We can say that it deposited on the slope of the continental margin of Neo-Tethys Ocean
Environment: slope and Basin plain (Deep basin)
Thickness: about 200- 350m
Area of distribution: certain areas of Thrust, Imbricated, Low, High Folded Zones
Fossil content: ammonite (Fig. 3.9.5), planktonic forams, nannofossils, pelecypods ,
Sedimentary structures: bedding, lamination and chert nodules
Stratigraphic position: located between Kometan (and Gulneri) Formation at the top and Sarmord or Chia Gara Formation at the base.
Boundary condition: It is conformable with both overlying Kometan Formation (or Gulneri) Formation (Fig. 3.9.4) and underlying Sarmord Formations. It is laterally changes to Qamchuqa Formation toward west and to Qulqula Radiolarian Formation toward northeast.

Sequence stratigraphy: Deposited as sediment of high stand system tracts (Fig.3.9.1 and 3.9.2).

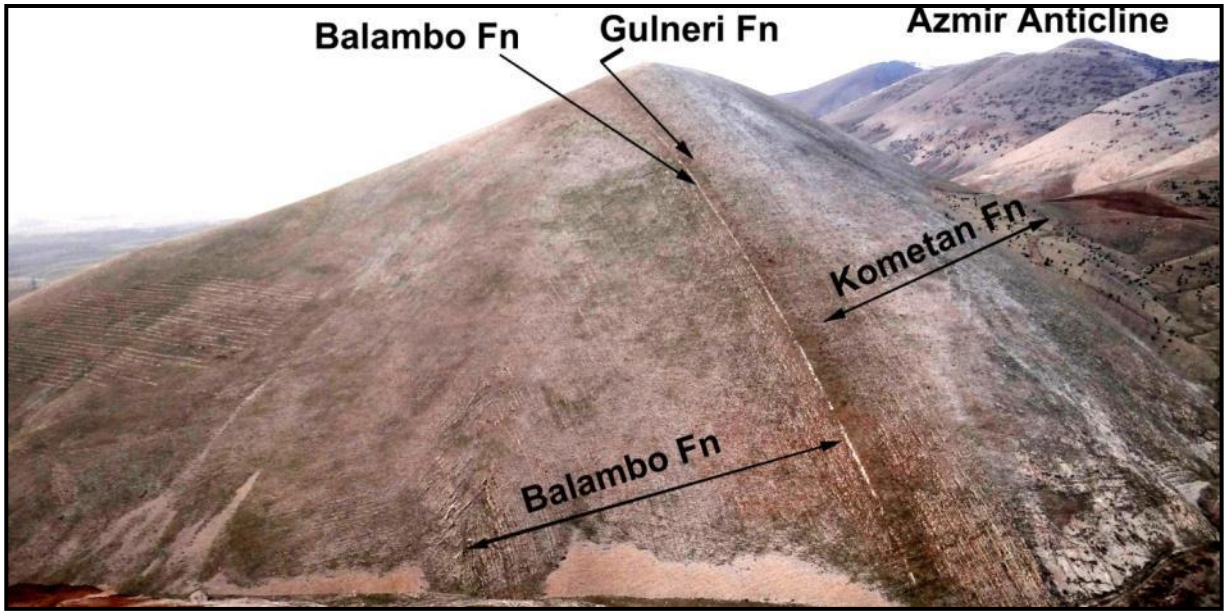

Fig. (3.9.4) Southwestern limb of Azmir anticline shows exposed formation on the Naugrdan hill which located 300m to the west of the southern end of the Azmir tunnel. There are no any sign of the unconformity between the formations

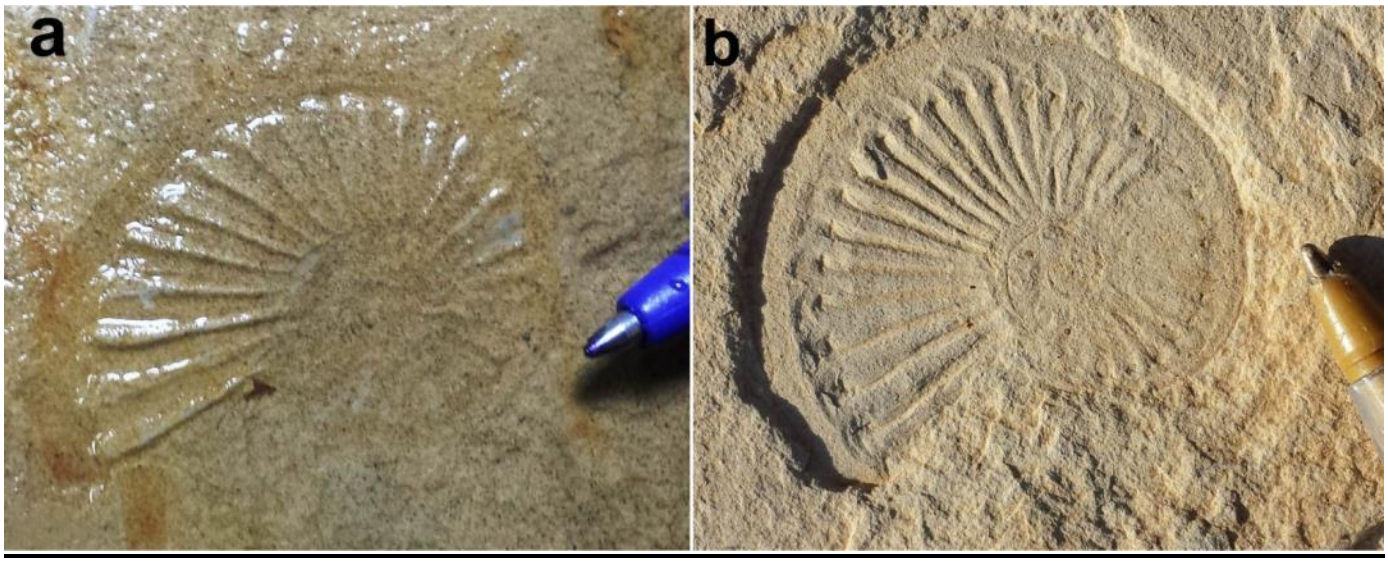

Fig. (3.9.5) two different species of ammonite in basin plain calciturbidite in the Balambo Formation a) in the Middle part and b) in the lower part, at the east and south of Weladar village respectively.

3-9-3-Sarmord Formation

Lithology: light grey marl and marly limestone with local pelagic fine grain limestone
Age: Valanginian-Aptian
Tectonic condition: Deposition in southern Neo-Tethys before converging of Arabian and Iranian Plates. We can say that it deposited on the slope of the continental margin of Neo-Tethys Ocean
Environment: Fore reef and slope.

Thickness: about 350m
Area of distribution: Imbricated, High Folded Zones
Fossil content: Orbitolina formas, Planktonic formams, nannofossils
Sedimentary structures: bedding, lamination
Stratigraphic position: located between Qamchuqa Formation at the top and Chia Gara Formation at the base
Boundary condition: It is conformable with both overlying Qamchuqa (and Balambo) Formation and underlying Chia Gara Formation. It is laterally changes to Nahr Umer toward south and to Qulqula Radiolarian Formation toward northeast.
Sequence stratigraphy: Deposited as sediment of high stand system tracts (Fig.3.9.1 and 3.9.2).

Fig. (3.9.6) two different species of ammonite in basin plain calciturbidite in the Balambo Formation a) in the Middle part and b) in the lower part, at the east and south of Weladar village respectively.

3-9-4-Qulqula Conglomerate Formation

This formation is refused by many authors and must be abandoned, see (www.kurdistan-Geology.com) for the evidence of refusing. It was the conglomerate of Tanjero Formation or Red Bed Series that was considered as Qulqula Conglomerate Formation

3-9-5-Qulqula Radiolarian Formation

Lithology: Alternation of bedded chert, marl, shale and well bedded limestone
Age: Jurassic- Early Cretaceous
Tectonic condition: Deposition in southern Neo-Tethys in the trench or basin plain between Arabian and Iranian Plates.
Environment: Deep basin (Trench or Basin plain)
Thickness: about 1500m
Area of distribution: Thrust Zones
Fossil content: Radiolaria and foraminfera in the limestone beds
Sedimentary structures: bedding, ripple marl, flute cast, cross lamination and chert nodules

Stratigraphic position: not known as both lower and upper contacts are tectonic (thrust surface)
Boundary condition: most possibly laterally changes to Sargelu, Chia Gara, Sarmord and Balambo Formation toward south.
Sequence stratigraphy: Deposited as sediment of both high and low stand system tracts (Fig.3.9.1 and 3.9.2).

3-9-6-Chia Gara Formation

Lithology: marl and marly limestone
Age: Late Jurassic- Early Cretaceous
Tectonic condition: Deposition in southern Neo-Tethys before converging of Arabian and Iranian Plates.
Environment: Slope and basin plain
Thickness: about 30-100m
Area of distribution: Imbricated, High Folded Zones
Fossil content: Ammonite and Planktonic forams
Sedimentary structures: bedding, lamination
Stratigraphic position: Located between Barsarine and Sarmord Formation at the base and top respectively.

3-9-8- Barsarine Formation

Lithology: Thin and thick bedded partially crystallized stromatolitic limestone, (Fig.3.9.7)
Area of distribution: High Folded and Imbricated Zone
Age: Late Jurassic
Tectonic condition: Deposition on Passive margin of the southern Neo-Tethys converging of Arabian and Iranian Plates.
Environment: warm and restricted lagoon
Thickness: about 20-50m
Area of distribution: High Folded and Imbricated Zone
Fossil content: Pelecypod (Posidonia, fig. 3.9.7)) and ammonite
Sedimentary structures: bedding, lamination and all types of Stromatolite
Stratigraphic position: Located between Chia Gara and Naokelekan at the top and base respectively.
Boundary condition: it is conformable with underlying Naokelekan and overlying Chia Gara Formations. Lateral change is not known

Fig. (3.9.7)Stromatolite in the Barsarine 10 km east of Barzinja town near Chinara village Formation

Fig. (3.9.7) posidonia pelecypod on the broken surface of outcrop of the Barsarine Formation, 10 km east of Barzinja town near Chinara village Formation

3-9-8-Naokelekan Formation

Lithology: alternation of black shale, sandstone and recrystallized mottled limestone (dolomitized stromatolite)
Age: Late Jurassic
Tectonic condition: silicicalstic dominated lagoon
Thickness: about 10-30m
Area of distribution: High Folded Zones and Imbricated Zones
Fossil content: Pelecypod (Posidonia and ammonite

Sedimentary structures: bedding, lamination
Stratigraphic position: Located between Barsarine and Sargelu Formation at the base and top respectively.
Boundary condition: it is conformable with underlying Sargelu and overlying Barsarine Formations. Lateral change is not known

Fig. (3.9.8)black bituminous sandy shale contain ball of crystalized detrital Limestone

3-9-9-Sargelu Formation

Lithology: Thin and well bedded detrital limestone, Calcareous shale and bedded cherts
Age: Middle Jurassic
Tectonic condition: Deposition on slope of southern Neo-Tethys passive margin before converging of Arabian and Iranian Plates.
Environment: Slope and basin plain
Thickness: about 30-100m (Fig. 3.9.9)
Area of distribution: High Folded Zones, Imbricated, and it occur in all other parts of Iraq in subsurface.
Fossil content:
Sedimentary structures: bedding, lamination
Stratigraphic position: Located between Naokelekan and Sehkanian Formation at the base and top respectively.

Boundary condition: it is conformable with overlying Naokelekan and underlying Sehkanian Formation. Lateral change is unknown

Fig. (3.9.9) Type section of Sargelu Formation consists of relatively thin beds of detrital limestone and calcareous shale and bedded cherts

3-10-Older Formation

3-10-1-Khabour Quartzite Formation

Lithology: Thick alternation of sandstone and shale (Fig. 3-10-1)
Age: Ordovician
Tectonic condition: Deposited during high tectonism during Ordovician
Environment: shallow and deep environment
Thickness: about 800m
Area of distribution: Thrust, Imbricated and High Folded, Zone
Fossil content: Pelecypods and Trilobite.
Sedimentary structures: bedding, lamination and Cruziana trace fossils
Stratigraphic position: not certain
Boundary condition: it is conformable with overlying Pirispiki Red Bed Formation while lower boundary is not unknown

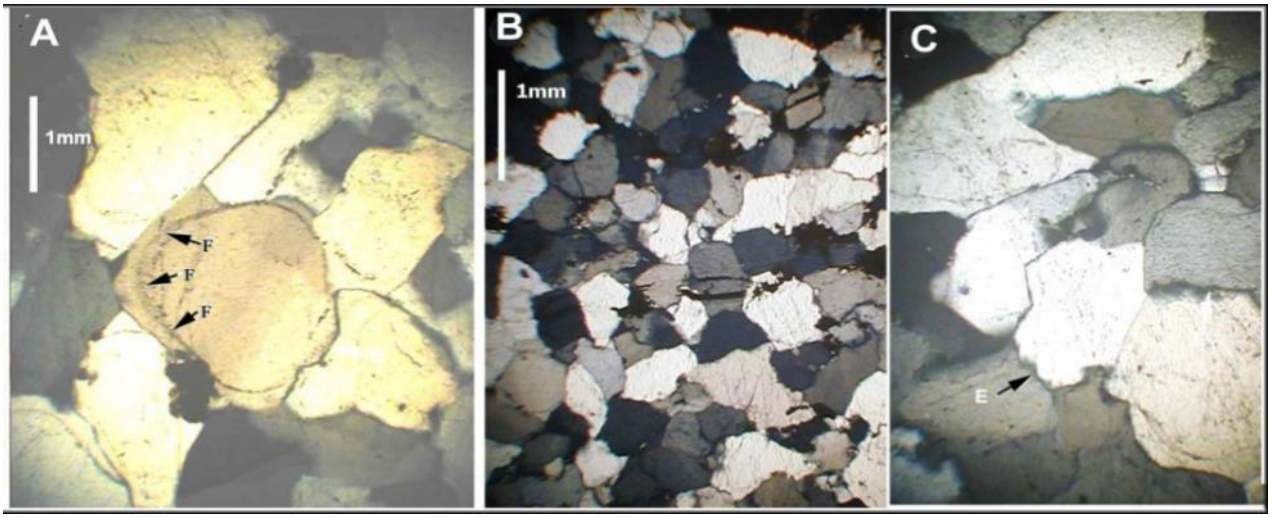

Fig. (3-10-1) Three thin sections (under plane polarized light) of the Khabour sandstone. Arenite of Khabour Formation composed mainly of quartz grains with well-developed sutured contacts (E) and grains overgrowth (F).

Fig. (3-10-2) out crop of Khabour Formation (Sandstone and calcareous shale) along road cut at its type locality near Kaista village in Khabour valley.

Fig. (3-10-2) A part of cruziana trace fossil in Khabour Formation in its type locality near Kista village in Khabour valley.

Pirispiki red beds formation

Lithology: thick beds of white or brown sandstone and red silty red claystone (Fig. 3-10-3) and rare conglomerate
Age: Ordovician
Tectonic condition: Deposited during high tectonism during Ordovician
Environment: shallow marine and continental terrain
Thickness: about 83m
Area of distribution: Thrust Zone
Fossil content: unknown
Sedimentary structures: bedding, lamination, cross bedding
Stratigraphic position: not certain
Boundary condition: unknown

Fig. (3-10-3) out crop Pirispiki Red Bed Formation (white and brown sandstone with silty red claystone) along road cut at its type locality near Kista village in Khabour valley.

Avroman Formation

Lithology: Thick alternation well bedded to massive gray fossiliferous limestone
Age: Triassic
Tectonic condition: Deposited on Isolated Platform
Environment: shallow reef and fore reef environment
Thickness: about 600m
Area of distribution: Thrust Zone on the border with Iran and form part of Avroman Mountain
Fossil content: Pelecypods and foram, algae, foram, echinoderm.
Sedimentary structures: bedding, lamination and stromatolite (oncoid) see below figures
Stratigraphic position: Not known.

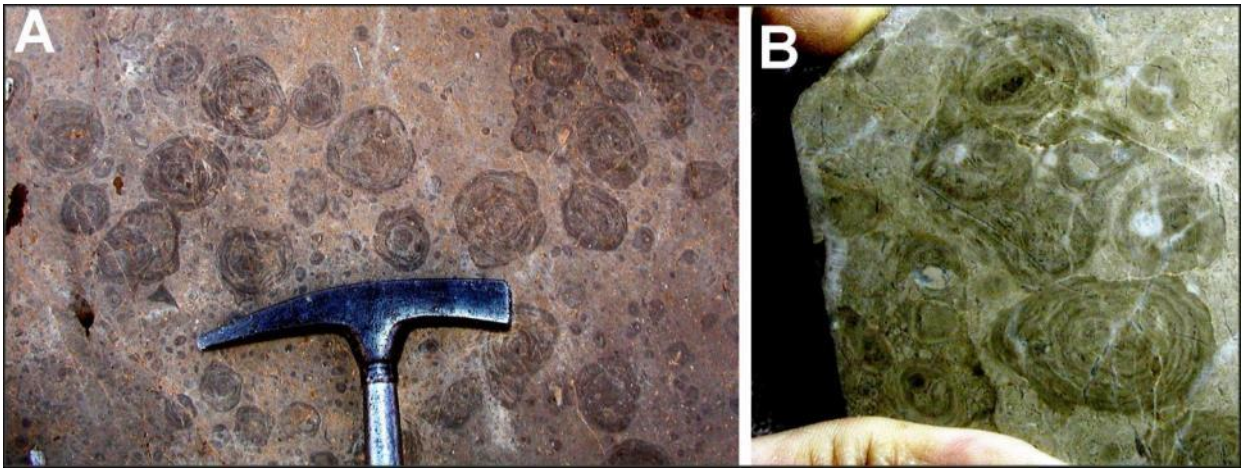

Fig. (3-10-2), A: Simple and composite oncoids in the limestone of the Avroman Formation as seen in polished slabs, B: the well-developed laminae can be seen, sometime disrupted by post positional fracturing.

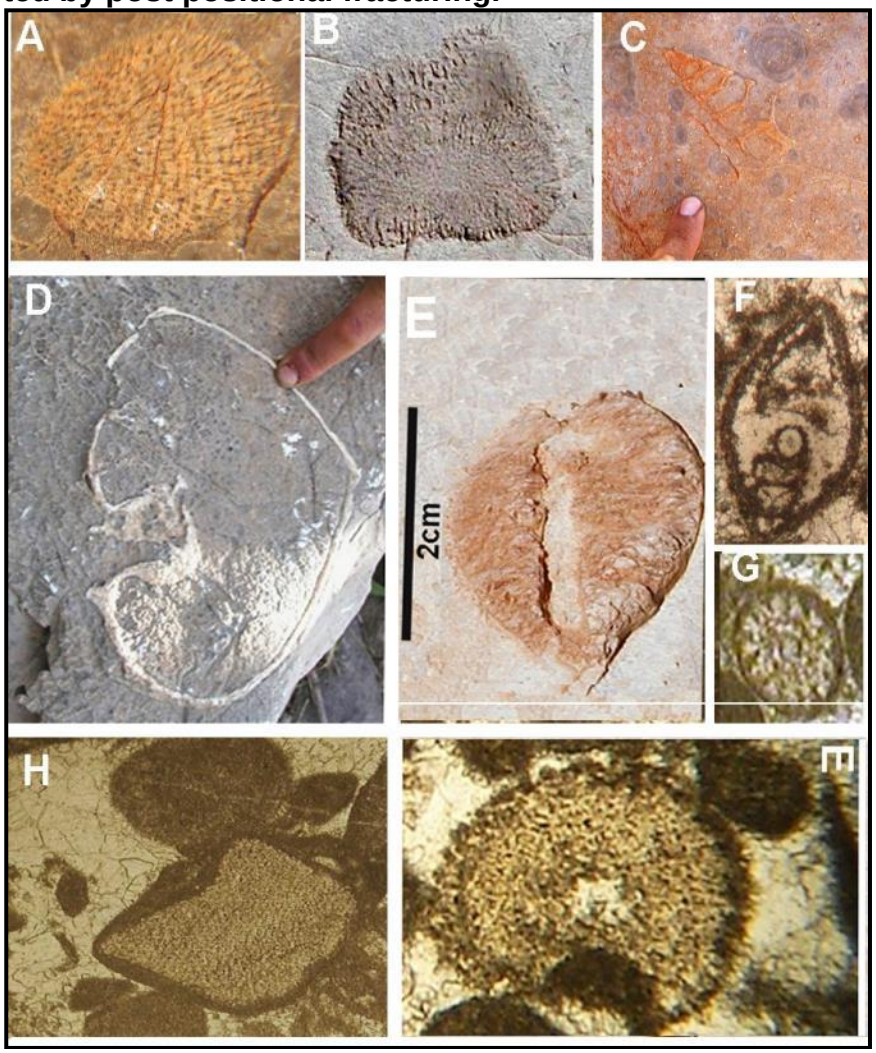

Fig. (3-10-3) Different types of fossils and their bioclasts in Avroman Formation. A and B) solitary colony of green algae, X5. C: Gastropod shell in oncolites bearing limestone. D and E) two different type of echinoderm. F) Unknown foraminifera, X20, PPl. G: Cross section of green algae steam, X30, PPL. H and I) Echinoderm plate and spine cross section, PPL X30, X50.

Equivalent of the formations in Iraq and southwestern Iran

During Jurassic, Cretaceous and Tertiary the southwestern Iran and Iraq was covered by one large basin. This basin was called Southern Neotethys which consisted of foredeep (a basin consisted of trench) during Lower Cretaceous while it was changed to foreland basin at the beginning of Campanian and remained so till the present. Therefore, the formations in the southwestern Iran (Khuzistan and Ilam governorates) and Iraq are nearly the same with some minor differences. Only the name of the formations is different due to independent geological survey in the two countries by different oil companies. Another reason for the similarities of the formations is that the irregularities in the Neotethys are parallel to the trend of the oil field (present trend of Zagros Fold Thrust belt).Below a table shows equivalent name.

Name of the formations in Iraq	Name of the formations in Iran	Name of the formations in Iraq	Name of the formations in Iran
Upper Bakhiary (Bai Hassan)	Bakhiari	Aliji	Pebdah
Lower Bakhtiary (Mukdadyia)	Aghajari	Aqra	Seymare or Tarbur
Upper Fars (Injana)	Mishan	Tanjero	Upper part of Gurpi
Lower Fars (Fatha)	Gachsaran	Shiranish	Lower Part of Gurpi
Kirkuk Group	Kalhur and Shahbazan		
Euphrates	Asmari	Kometan	Ilam
Pila Spi	Jahrum	Dokan and Gulneri	Surgeh
Gercus	Kashkan	Upper Qamchuqa (Mauddud)	Sarvak
Avanah	Pebdah	Lower Qamchuqa (Shuaba)	Darian
Jaddal	Pebdah		
Sinjar	Teleh Zang	Balambo	Garau or Kazhdumi
Kolosh	Amiran	Sarmord	Gadvan

3. Main modifications (changes) of Geology of Kurdistan which are achieved in Department of Geology

Many modifications (changes) are achieved in the geology of Kurdistan during the recent years. Most of the changes are published in specialized geological journal in Iraq and Kurdistan. Some of the modifications are taken from MSc and PhD thesis that are achieved in Department of Geology, University of Sulaimani. The main modifications are as following:

1-Refusing the unconformity between Shiranish and Kometan formations
2- Refusing the unconformity between Qamchuqa and Bekhme formations.
3-Refusing the unconformity between Qamchuqa and Kometan Formations
4-Refusing the Qulqula Conglomerate Formation and combining it with Red Bed Series.
5-Refusing unconformable contact between Dokan and Qamchuqa formations and changing it to conformable contact.
6-Refusing the unconformable contact between Gulneri Formation and both Kometan and Dokan Formation.
7-Refusing that Gulneri and Dokan Formation are deposited in relict and euxinic basin but they are included in the Tethys basin. They are deposited on the continental margin of the basin.
8-Indicating the tectonic position of Qulqula Radiolarian Formation as deposits of trench and later accumulated as accretionary prism between the two plates.
9- Refusing existence of mio- and Eu-geosyncline in Kurdistan during Cretaceous and Tertiary and changing them to foreland basin.
10- Proving that the collision of continental part of Iranian and Arabian is occurred at Campanian not in Eocene as indicated before.
11-Proving that the paleocurrent was toward south and southwest during Upper Cretaceous and Tertiary.
12-Proving that western part of Sharazoor basin is formed by erosion and sliding which both activated by Tanjero stream.
13- Finding four incised valleys in the topography of Upper Cretaceous during deposition of Tanjero Formation for the first time in Iraq.
14-Lower part of the Tanjero Formation contains 500m of conglomerate instead of Upper part as suggested before.
15- Putting both Kolosh Formation and Red Bed Series in one foreland basin considering them as lateral facies changing of each other.
16- Putting both Upper parts of Red Bed Series with Gercus Formation in single foreland basin and considering them as lateral facies changing of each other.
17- Proving that there are no any paleohighs between Kolosh Formation and Red Bed Series during Paleocene.
18- Proving that the Ball-and pillow structures in Tanjero and Kolosh Formations are not sedimentary structures (as considered before) but they are tectonic or diagenetic structures.
19- Proving that Chuarta–Mawat area consist of a large graben.
20-Finding foot prints of birds and mammals in Lower Bakhtiary Formation (10m.y) before present
21-Proving that Qamchuqa Formation is deposited on a forebulge formed by tectonic load of Iranian plates.
22-Refusing that Gulneri formation is composed of shale, but composed of limestone and marl.

23-Refusing most of the cycles of the Cretaceous and Tertiary that are previously established. The number of these cycles (cycles of uplifts and subsidence) is more than ten in Buday (1980) but most of them refused.

24-New chronostratigraphic column are drawn for Cretaceous and Tertiary which is completely different from previous one.

25- Changing the age of the Bekhme from Campanian to Turonian – Middle Campanian. Bekhme Formation is equivalent to Kometan Formation in age and deposited in the same basin.

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