Sequence Stratigraphy of Upper Cretaceous Tanjero Formation in Sulaimaniya Area, NE-Iraq

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Abstract

On the basis of the sequence stratigraphy, the whole Upper Cretaceous succession is divided into two depostional sequences, named upper and lower sequences. About 80% of thickness of the Tanjero Formation is deposited in the upper sequence, which is bounded by SB1 and SB2 from below and above respectively. The rest (about 20%) of the formation belongs to the lower sequence. The SB1 is regarded as the major erosional and unconformity surface, which extended down the basin paleoslope from Chuarta area to Sharazoor plain. Thick conglomerate and sandstone wedges are deposited on this surface by forced regression. The regression is resulted from tectonically enhanced eustatic sea level fall. The formation ended by relatively thin conglomerate at the top of the formation and directly below Red Bed Series. This conglomerate, as an unconformity, exists only in some places and changes to correlative conformity in others. Therefore it is regarded as SMST, which is deposited as a result of basin fill (normal regression). Between the two-sequence boundaries and within upper sequence, LST, TST, HST and SMST are identified in addition to their surfaces.

The erosion of the shelf of the lower sequence shaped channels and incised valleys. More than four major incised valleys are found in the sediment of the previous HST (shelf and upper slope of lower sequence). The sediments of these valleys consist of low stand wedge of conglomerate and high stand red claystone. Above the sandstone wedge at Dokan, Chaqchaq valley, Sharazoor and Piramagroon plains the transgressive surface can be seen clearly which is represented by sudden change of clean sandstone to marl(Hemipelagic sediments) with some interbeded marly limestone. This surface is the starting point for the deposition of thick transgressive system tract on the shelf. On the slope and basin it is relatively thin (30- 90m), which is lithologically similar to the lithology of Shiranish Formation (marl and marly limestone), of deep marine environment. The maximum flooding surface and possible condensed sections are discussed in detail.

Keywords: sequence stratigraphy, Upper cretaceous, Tanjero Formation, Kurdistan geology, Sulaimaniya area.

Introduction

Tanjero Formation is an Upper Cretaceous (Campanian-Maastrichtian) unit, which crops out within the Imbricated and High Folded Zones in Northeastern Iraq (Buday, 1980)[1] and (Buday and Jassim, 1987) [2]. It stretches as narrow northwest-southeast belt near and parallel to the Iranian border (Fig. 1). The formation mainly consists of alternation of clastic rocks of sandstone, marl and calcareous shale with occurrence of very thick conglomerate and biogenic limestone (Bellen et al. 1959) [3].

Karim (2004) [4] studied sedimentary structures, lithology, and environment of the formation. On the basis of main lithological distribution, he divided the formation into three parts (lower, middle and upper parts).These parts are correlated across eight different sections, which represent the available outcrops in Sulaimaniya Governorate in addition to one section inside Iranian land (Fig.2 and photo1). His correlation is based on lithology and stratigraphic position of

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distinctive conglomerate and its derivative sandstones, which are discussed in detail in different localities. The lower part (lower regressive part) is mainly composed, on the lower slope and basin, of thick aggradation of sandstone (100-400m), whereas on the shelf it is dominated by 500m thick succession of conglomerate (in this study, it called Kato conglomerate). The middle part (middle transgressive part) is composed of 100-300m of bluish white marl and marly limestone on the slope and basin plain whereas it changes to calcareous shale on the shelf and to 20-50m thick of red claystone inside incised valleys at the area of coastal area.

The upper part (upper regressive part) is chiefly consisting of 50-200m thick mixed carbonate-siliciclastic successions (in this study, it is named Kat mixed carbonate-siliciclastic successions). The constituents of this succession are alternation of thick biogenic limestone beds and calcareous shale with miner amount of sandstone and conglomerate. In literature, only Minas (1997) [5] referred briefly to the sequence stratigraphy of Tanjero Formation.

Sequence stratigraphy

Sequence stratigraphy is defined as subdivision of sedimentary basin fill into genetic packages (depositional sequence) bounded by unconformity and their correlative conformities (Emery and Myers, 1996) [6]. In the present study, the method of Vail et al. (1977) [7] is used for division of the rock body of the formation into depostional sequences, this is because the unconformities and correlative conformities can be identified in studied succession. While the method of Galloway, (1989) [8] is not used because it is difficult to be applied on Tanjero formation. In order to indicate the sequence sequence stratigraphic position of the Tanjero Formation, the authors have tried to:

Study at least a part of the basin fill succession, which extend beyond Shiranish Formation. The time span and the related outcrops thickness which is treated in this paper, depends on the position of the closest overlying and underlying unconformities. When the unconformities are found the correlative conformities also encountered by us in the Tanjero Formation. It was found that one of the biggest sequence boundaries (SB1) is located within the Tanjero Formation. This means that the formation should be subdivided to two depostional sequences. This forced us to study and find the boundaries of both sequences wherever they are located. Therefore, for finding the type one or two sequence boundary (SB1 or SB2), the extent of this study, has gone vertically beyond underlying Shiranish and Kometan Formations and overlying Red Bed Series.

Although the boundaries of the above formations are studied previously, no correlation is done as concerned with traditional and sequence stratigraphy. For this, extensive lateral fieldwork is conducted to find all sedimentary facies deposited in response to relative sea level change. Finally, these facies are organized in system tracts (LST, TST, HST and SMST) and the associated sequence boundaries are identified. The systems and boundaries rarely can be seen in one continuous surface section. As the seismic sequence stratigraphy is not used in this study, therefore different surface sections are studied and combined to compensate to the seismic lack.

The first one who classified the formation in viewpoint of sequence stratigraphy is Minas, (1997) [5]. His study depended on the previous traditional stratigraphic studies. He included the lower part and middle parts as sediment of TST and HST respectively. As will be discussed later in this study the result is changed.

Before discussion of the system tracts, it is better to see the boundaries between Tanjero and adjacent formations. This is to find the certain starting point of sea level curve (relative sea level change) that enclosing Tanjero Formation in one or more of its cycles.

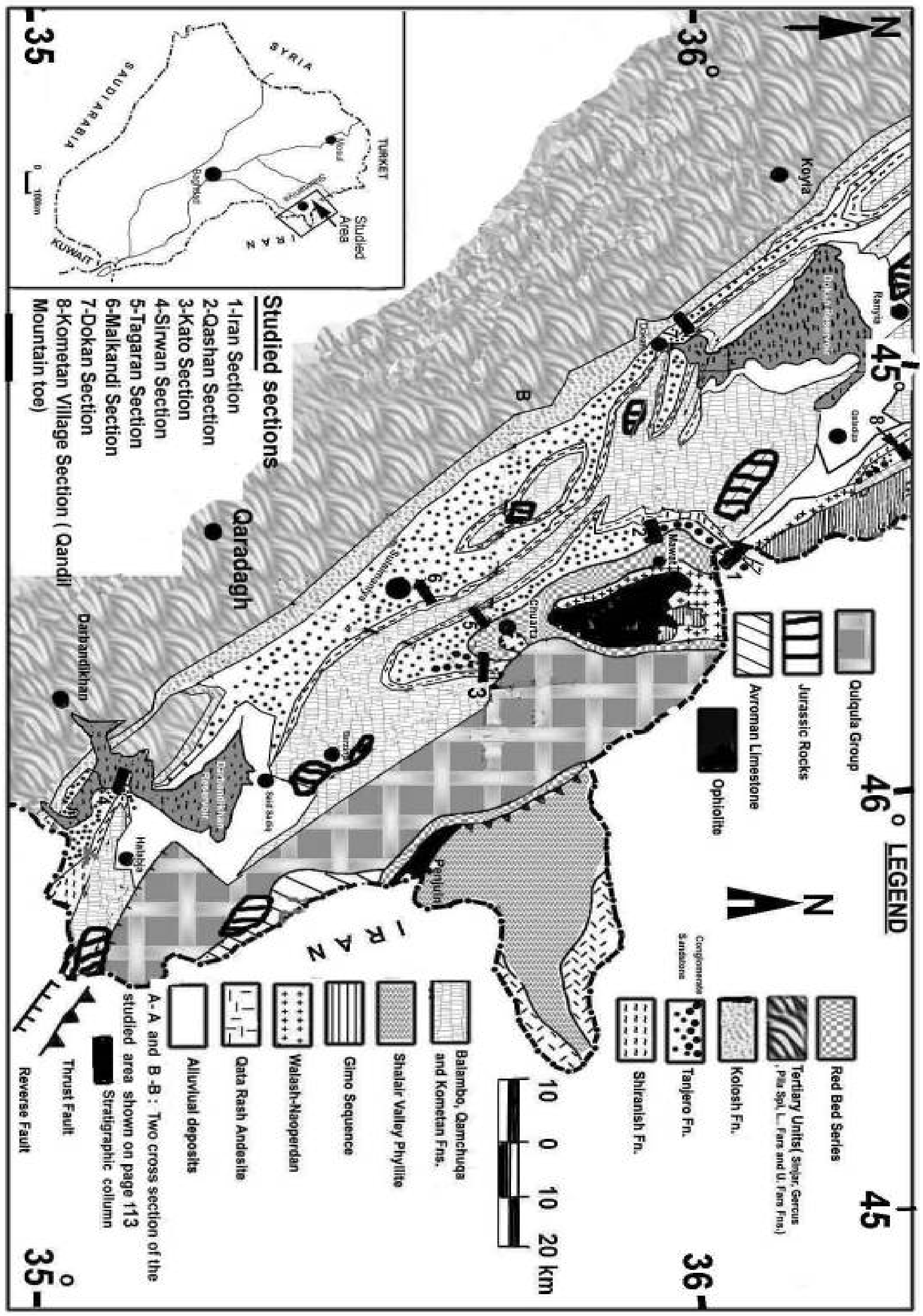


Fig. (1) Geological map of the studied area (modified from Jassim and Al-Hassan, 1977)[9]

Boundary between Shiranish and Tanjero Formation

In all previous studies concerned with the two formations such as Bellen, et al. (1959) [3] and Buday (1980) [1], it was recoded that the contact between the two formations is gradational. But in the present study, at least in one locality, it was found that the contact is unconformable, as shown below:

Iran Section

This section is located inside Iran near the border with Iraq (Fig.1 and 2) on the left bank of the Do Awan River (upstream of Little Zab River) about 4km to the west of Awa Kurte village and about 20 km to the northwest of Mawat Town at the intersection of N 35^{0} 37^{-} $20.6^{=}$ and E 45^{0} 35^{-} $16.4^{=}$. At this locality the Shiranish Formation (Bluish white marl and marly limestone) is overlain directly by 13 to 150m of conglomerate then comes Red Bed Series exist at the top of the conglomerate. Field study showed that the conglomerate belongs to Tanjero Formation because which is correlated and traced laterally with Kato conglomerate (Fig.4). Moreover, both have similar lithological constituents. The contact between Shiranish and the conglomerate is sharp and erosional. This is also true for one location at the toe of Qandil Mountain (Photo 3). In spite of these two localities, in this study, yet the boundary between the two formations is not regarded as unconformable. This is because the erosional contacts are attributed to position of section where all sediments finer than conglomerate are removed due to elevation of the area in the coastal area and incision by rejuvenated streams. The conglomerate represents onlap on the steep head of the incised valleys. The boundary between the two Formations is conformable in all other localities in side the basin. The conglomerate represents sequence boundary. Emery and Myers (1996, p.98) [6] mentioned that the type one sequence boundary is associated with superimposition of shallow or non-marine deposit on deeper one (when the conglomerate regarded as non-marine or shallow marine deposits and the marl as deep one).

Contact between Shiranish and Kometan Formations

All the sections inspected in the studied area (Sulaimaniya Governorate) have gradational contact. So, primarily appear that there is no major break in the sedimentation of Upper Cretaceous except the one inside the Tanjero

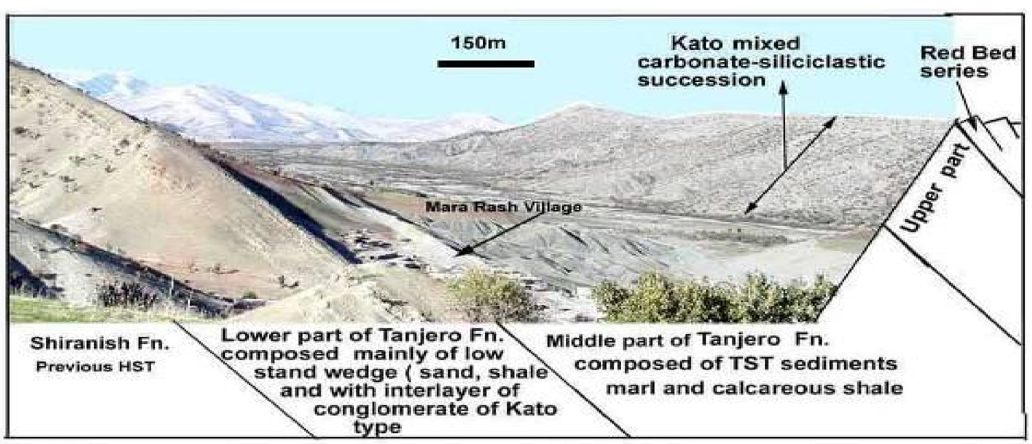


Photo (1) The three part of Tanjero as outcropped along the left bank of Mokaba stream, 15 km west og Chuarta town. The section pass through Mara Rash village , direcrtly at west the connectiong point of Khewatw and Qalla Chullan streams .

Formation which represented by Kato conglomerate and its equivalent lithologies.

System Tracts of Tanjero Formation

The subdivision of the formation is depended on the factors such as three-dimensional lithological correlation and facies changes (Fig. 4) in addition to finding marker beds and stratigraphic position of the formation between older and younger units. The main system tracts of formation are as follows:

Lowstand-system tract of Tanjero Formation

It is most probable that the typical lithology of the Tanjero Formation (lower part of the new division) is deposited as lowstand system tract. This is deduced from field study in the proximal area Chuarta and Mawat, Qaladiza and Qandil mountain toe area. In these areas when one cross the upper part of Shiranish Formation, Tanjero Formation begins as alternation of thin sandstone beds and thick dark green calcareous shale. Theses lithologies suddenly change to thick succession (500m) of boulder and pebble conglomerate beds (Kato Conglomerate). This type of upward lithological change represents incised valley sediment overlying the fine sediment of previous HST unconformably.

The Kato conglomerate is deposited during late stage of LST when sea level slowly rises. This is because it is equivalent to the low stand wedge on the slope toe. During this slow rise, coarse conglomerate is deposited which shows aggradations stacking pattern demonstrated by 500m of coarse conglomerate beds of nearly same thickness and grain size. The erosional surface below the conglomerate (Fig.2 and photo 2) is a major unconformity of the Upper Cretaceous.

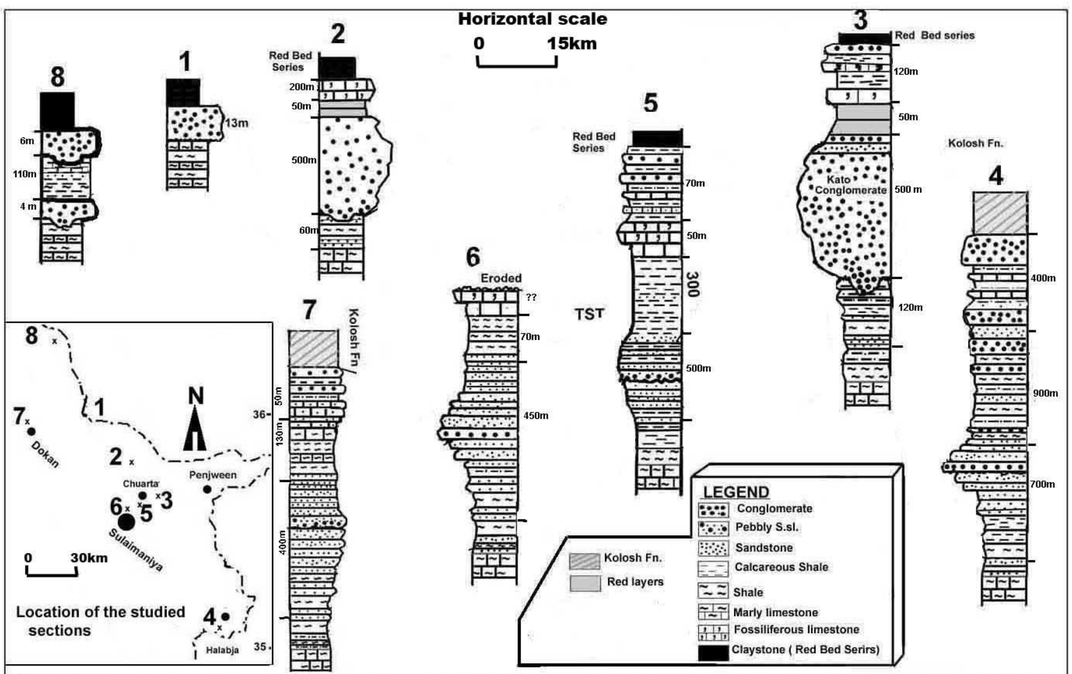


Fig. (2) Location and collumn of the studied section, 1) Iran section, 2) Qashan section, 3) Kato section, 4) Sirwan section, 5) Tagaran section, 6) Malkandi section, 7) Dokan section, 8) Kometan village section(Qandil Mountain toe) (after Karim, 2004)

It also stands for a type one-sequence boundary (SB1) on which the huge quantity of sediments are bypassed from the coastal area of prograding fan delta to prodelta slope and basin plain during relative sea level fall. This surface can be identified from Kato Mountain to south of Sulaimaniya city at distance of 25km. This distance is equal to about 30km if folding shortening is eliminated.

Near Tanjero stream it changes to correlative conformity, which changes to coarse and fine sandstone. In the toe of northeastern limb of the Goizha and Azmir and Daban anticlines also can be seen in certain places, such as Azimra Bichkola valley, north of Bnawella village in addition to Mararash village. The sediments above the erosional surface show that the shoreline and facies belt is probably shifted basin ward from the mountain to the north of Sulaimaniya city during Upper Cretaceous sea fall. The sea level fall most probably supported by tectonic and eustatic sea level changes.

All mentioned for the area between Kato Mountain and Sulaimaniya city is also true for the following areas:

A. The area between Mawat Town and Kizlar Village in the Chaqchaq valley.

B. The area at Qandil mountain toe and Dokan area.

C. Type section at Sirwan valley and Khurmal town. The proximal area inferred indirectly to be near Khurmal town by applying the distance of the two areas of A and B.

The proximal sediments (conglomerate) do not exist in the Khurmal area due to later erosion. But their positions are inferred for the sediments of distal area in Sirwan valley and Dokan area. At the distal area such as Dokan, Sharazoor and Piramagroon plains, when one crosses the boundary between the two formations, bluish white marl changes to sandstone and calcareous shale. Emery and Myers (1996) [6] regarded this type of change is regarded as indication of lowstand system tract in deep marine environment.

In the present study, the environment of boundary between Shiranish and Tanjero Formations can be regarded as deep environment. The further advance into Tanjero Formation, the sandstone increases and changes to a thick succession (100-400m) sandstone wedge, the base of which consists of clean succession 4-20m thick of sandstone with cross lamination and skolithos escape structures. This succession is equivalent to the erosional surface under the Kato conglomerate (for simplicity it can be assumed as time equivalent of lower part of Kato conglomerate and represent the deposit of the extreme shallowing during lowstand system tract. The whole sandstone wedge is equivalent or derived from Kato conglomerate (Fig.2 and 5).

Components of lowstand system tract

A. Lowstand fan

The lowstand system tract consists of two parts; lowstand wedge and lowstand fan. Low stand fan in turn is divided into slope fan and basin floor fan Emery and Myers (1996) [6]. Tanjero Formation, as has limited outcrops, so the lowstand fans are not clear. But some dirty sandstone beds exist which may represent basin floor fan. These beds exist at Sirwan, Chaqchaq valleys and Dokan area. In these areas, there are two beds of either coarse dirty sandstone or paraconglomerate near the transition zone between Shiranish and Tanjero Formations. These beds are isolated in the marls or calcareous shale. The position of these beds in the succession of the formation and relative sea level change suppose that they deposited during early phase of low stand time when the relative seal level fall was at its maximum rate.

These beds are generally massive and dirty (matrix supported) so they, most probably, deposited by debris flow and slumping of the shelf edge (shelf break).

Above these two beds comes very clear lowstand wedge. The base of this wedge consists of 4-20m thick package of coarse and clean sandstone. This package is in most case associated with thin bed of conglomerate. The position of this package between basin floor fan and lowstand wedge possibly comprises the slope fan. The beds of this fan contain such sedimentary structures that indicate the shallowest environment of the formation during deposition of the lower part (LST) of formation. Karim (2004, p.38-57)(4) discussed in detail these sedimentary structures (large scale cross bedding, hummocky cross stratification plant debris, cruziana and skolithos trace fossils.

B. Lowstand wedges

In contrast to lowstand fans, lowstand wedges are very clear as these wedges make up 70% of the whole succession of the lower part of the formation (Photo2). The typical lithology of Tanjero formation (alternation sandstone and shale) consists of these wedges and the slope fans. The wedge is conglomerate-rich in the proximal area, which is represented by 500m of Kato conglomerate. But they are sandstone-rich in the distal area (at Chaqchaq and Shadalla valleys and along foothill area of Azmir and Goizha mountains). The distal sandstone wedge is correlative to the Kato conglomerate.

Einsele (1998, p.338 and 339) [10] mentioned that during late lowstand the lowermost portion of incised valley is filled with coarse fluvial sediment (gravel in case of Tanjero Formation) of braided stream. Therefore all thickness of Kato conglomerate (conglomerate wedge) and most of distal sandstone wedges are mainly deposited during late lowstand time when the sea level fall stabilized for considerable time and subsequent slow rise. The thickness and grain size of the wedges are depending on the distance from the shoreline and limit of downward shift of coastal onlap. The wedges show aggradation to progradation stacking patterns with nearly same thickness of the layers.

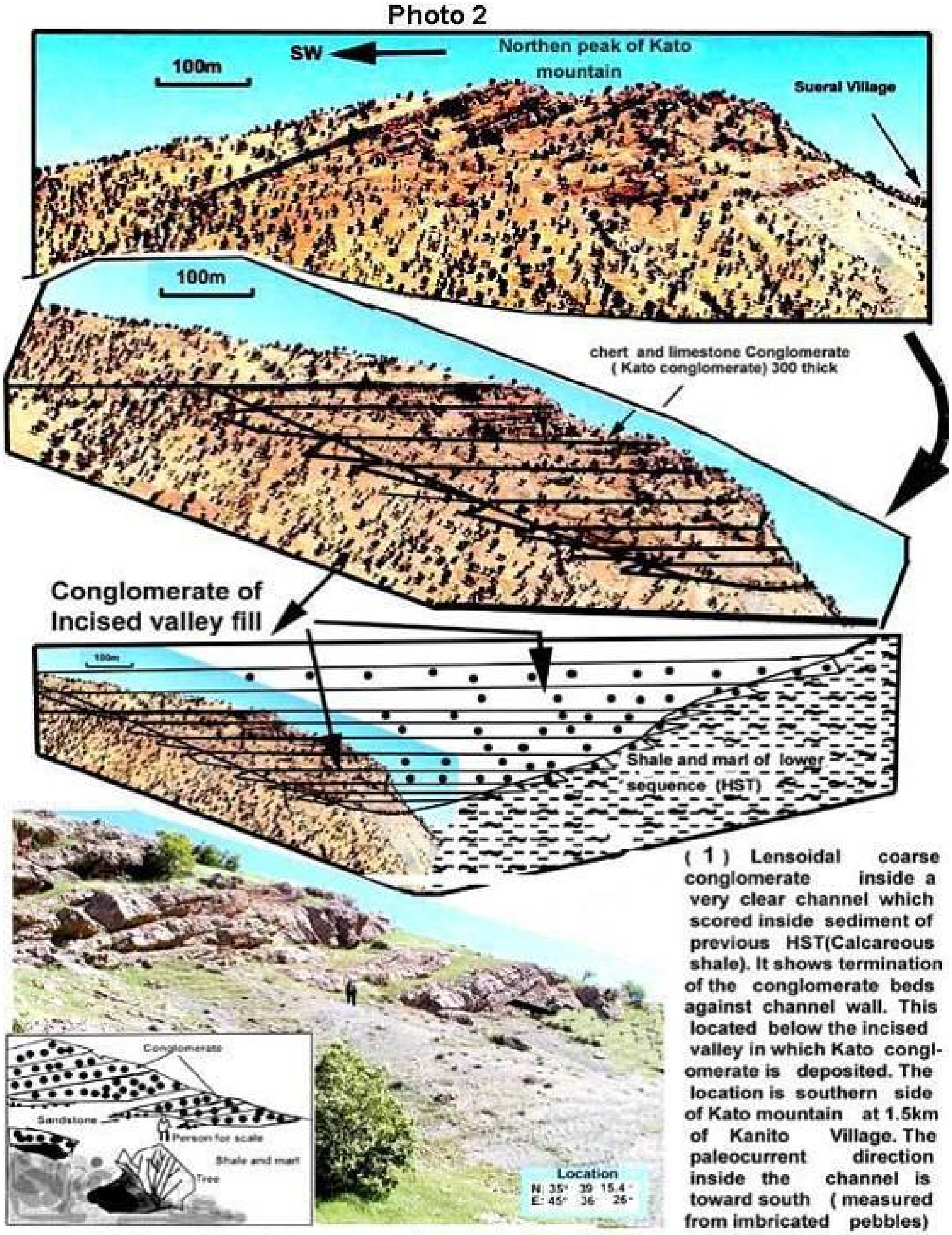
The most important characteristics of sandstone wedge are their abundant content of plant debris on surface of sandstone beds. These plant fragments are derived from plants grown inside incised valleys and on the surface of the sediments of the alluvial fans during middle Maastrichtian. They were then, eroded by severe current of sediment influx from hinterland by river. The incised valleys of the shelf and upper slope are flooded during early slow rise of sea level and during late lowstand forming some swamp and estuaries with possible plant growth.

Erosional surfaces and unconformities below and inside the wedges

As previously mentioned a major erosional surface (SB1) exists below the Kato conglomerate. This surface is formed after the exposure of the shelf (Mawat and Chuarta areas). According to Van Wagoner et al (1988) [11] type one sequence boundary is characterized by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation.

This erosional surface, as an unconformity, changes to several unconformities toward south and southwest down dip. This occurred during gradual fall of sea level, overlain by more or less thick beds of conglomerate (Fig.4 photo 2). The down dip extension of this surface, with associated conglomerate, reaches the middle part of Sharazoor and Piramagroon plains (to positions beyond

Photo 2



(1) Lensoidal coarse conglomerate inside a very clear channel which scored inside sediment of previous HST(Calcareous shale). It shows termination of the conglomerate beds against channel wall. This located below the incised valley in which Kato congl-omerate is deposited. The location is southern side of Kato mountain at 1.5km of Kanito Village. The paleocurrent direction inside the channel is toward south (measured from imbricated pebbles)

(2) Upper photo shows cross section of tilted beds of Kato conglomerate directly to the west of Suerala Village, The conglomerate suposed to be deposited in an incised valley. The Middle photo shows the beds when the amount of tilt is corrected to the rigional postion of depostion. Lower photo and the sketch shows, the form right side of the valley (or canyon) is constructed on the basis of the pattern of the beds of the left side. The photo and the sketch shows only part of the valley.

Arbat and Piramagroon towns respectively). In the literature similar type of unconformities are cited by Potter and Pettijohn (1977) [12] in basin margins, they called them "compound unconformity".

In some places, in the plains, the surface becomes correlative conformity. These places represent interfan areas (Fig.5) where the conglomerate changes to sandstones. The sandstones, near the base of the wedge, have coarse and clean texture with high thickness. Both thickness and grain size decrease downward and upward of the sections. Downward, the lithology changes to bluish marl of Shiranish Formation and to marl of Middle part at the top of the wedges.

Incised valleys and their sediment fill

Incised valleys are developed during negative accommodation, Mail (2002, p.1209) [13]. This is true for Tanjero Formation which during sea level fall (negative accommodation) the shelf and upper slope of the Tanjero Formation is exposed to subaerial erosion and fluvial incision. The evidences for exposure is the Kato conglomerate and Kato red layers in addition to trace fossils and sedimentary structures (see Karim 2004, p.38-56) [4].

The erosion is initiated as the stream base level is lowered. At least, four incised valleys are indicated (Fig.3). Each one is associated with its prograding lowstand fan in front the valleys. When they fans directly entering the sea, they called lowstand fan delta. Most quantity of the sediment is reworked from the delta front to the deep basin through the by turbidity currents forming submarine fans.

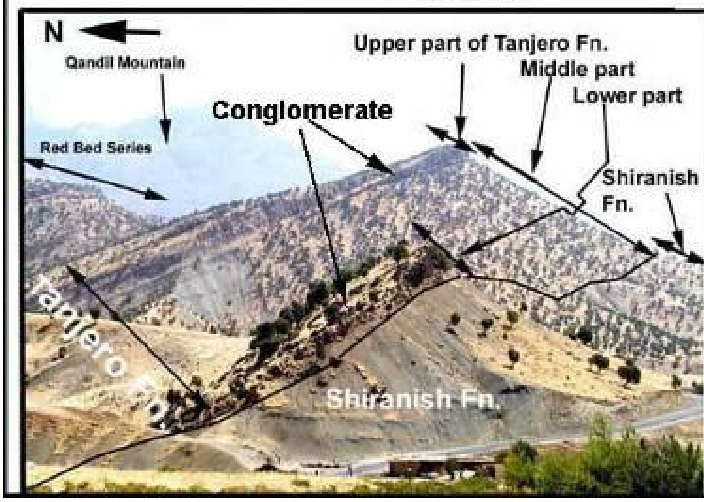
The valleys were filled by different sediments when reversal of accommodation from negative (valley cutting) to positive (valley filling occur (Mail, 2002) [13]. This is exactly what happened during filling of incised valley of Tanjero Formation which are filled by conglomerate during slow rise of see level. Three of valleys are discovered and mapped (depending on availability of outcrops) in the field from shoreline (proximal area) till the distal (basin) area. The characteristics of the three mapped valleys are used for inferring other one. This forth valley is deduced from the lithology of the formation in the basin-distal area at Sirwan valley. At this area the lithology and sedimentary structures are compared with the lithologies of mapped ones at the equivalent locations.

These valleys with submarine fans descend from north and northeast toward south and southwest. The first one starts from the area around Mawat area, passing by Qizlar Village at the head of Chaqchaq valley and end at the area around Tasluja Town in the Piramagroon plain. The second mapped one starts from the east of Chuarta town and descends to the south and southeast and ends at the Sharazoor plain at the southwest of Arbat Town near Damirkan Village (6km southwest of the Town). The other one extend from Suwais Village (Qandil mountain toe) to Dokan area (Fig.3). Many evidence exist that the fan associated with this valley has many lobes the largest one delivered thick alternation of conglomerate and sandstone beds to the north of Sulaimaniya city.

The width of these valleys is more than 2km and their lengths are more than 9 km. These valleys filled, on the previous highstand shelf area, with 500m of Kato conglomerate and about 50 m of red layers (photo 5.5).

The thickness and grain size of this conglomerate changes rapidly and laterally in distance of one or few

Photo 3



Two thick coarse conglomerate bed in the Naudasht valley (Qandil Mountain toe). The photo is taken from inside Kometan Village toward east. They stand for lower and upper sequence boundary of the upper sequence. Both showing sudden lateral thickness changes.The three parts of this study are very clear espicially the two regressive parts

kilometers (Photo 2). In some cases the thickness change, along the depositional strike, from 500 to 10m in distance of two kilometers and grain size change to sandstone in the same distances. This sedimentological phenomena also observed by Karim (1997) [14] in Gercus Formation in Sartaq-Bamo area. The hard and well lithified conglomerate of these valleys, now, forms high mountains such as Kato, Gaza and Talishk Mountains. These mountains are formed by reciprocal of topography. The conglomerate of Tanjero formation is deposited during late lowstand system tract. In this connection Haq (1991)[15] mentioned that during low stand system tract when the relative sea level begins to rise slowly the stream incision is stopped and the existed incised valley may begin to be filled with coarser braided stream sediments (coarse conglomerate in case of Tanjero Formation). The evidence, which proves that Kato conglomerate is deposited subaerially in the proximal area, is that red layers that overlie it. These layers represent deltaic deposits during TST. At Iranian section this conglomerate (13-150m thick) which is rested directly on Shiranish Formation. This condition reflects the most landward occurrence of the incised valleys deposits where the conglomerate terminated (on-lapped) against the steep slope of the source area.

The shape of the valleys and their sediment fills can be reconstructed from some outcrop sections exist in the studied area. One of these sections (Photo 2) can be seen at the northern part of Kato Mountain directly west of Suerala village. This section is scored by recent stream perpendicularly on the elongation of Kato conglomerate. The section shows thick beds of the conglomerate, which are tilted at about 35 degrees toward southwest. Tilt correction shows that the form of the paleo-valley has obtuse v-shaped form (Photo 2). This latter photo shows only part of the valley, which is not more than 1km wide. The obtuse shape of the valley is most possibly attributed to the fact that the incised valleys were scoured in soft sediments (partially lithified calcareous shale and marl of the HST deposits of lower sequence).

The thickest and thinnest part of the conglomerates exists at center and side of valley respectively. Although the original outlook of the conglomerate layers in the incised valleys are tilted and mostly eroded but the form and wideness of one valley is reconstructed as shown in the photo 2. In the field the bottom of the valleys (as shown by sediments fills) is convex downward and planner at the top (Photo 2.1).

The precise position of the Kato and Tagaran conglomerates is shown in sequence stratigraphic model. In the model, the system tracts are illustrated by the Wheeler diagram (time expanded section) and depth section. These sections are so drawn to pass through the incised valleys (Fig.6and 7).

According to Emery and Myers, (1996, p.140) [6] as a result of river rejuvenation; incised valley commonly contains the coarsest sediment available locally. They added (p. 137) if the new river course is steeper than equilibrium river profile, the river would firstly straighten coarse and then incise to form a valley. Furthermore, they mentioned that these valleys are important because they represent unequivocal evidence of a sequence boundary and they can form stratigraphic traps for hydrocarbon.

Possible incised canyon

According to Bate and Jackson (1980)[16] a canyon is defined as erosional geomorphologic features, which are long, deep, relatively narrow steep-sided valley confined between high and nearly vertical walls in mountainous area, often with a stream at the bottom. According to Emery and Myers (1996, p.140) [6] the thickness of incised valley fill cannot exceed 100m but submarine canyon can exceed this thickness. In the Bangal Gulf, Kottke et al (2003) [17] has found submarine canyon which occurred as conduit for discharge fluvial sediments that by pass the shelf and reach deep sea fan.

In the studied area, there are many places (at proximal area); the thickness of the Kato conglomerate reaches 500m. But the sides of the valleys are not steep. These suppose that these locations (Kato Mountain and south and west of Mawat town) are position of Upper Cretaceous canyons that developed by subaerial and possibly by submarine erosion. These canyons are most possibly located on the previous lower shelf and upper slope.
Field studies showed that the floor of the canyons (base of Kato conglomerate) is resting sharply on the alternation of calcareous shale and sandstone of HST of the previous shelf and upper slope. The scouring of the deep canyon is attributed to the softness of the lithology on which the regression (sea level fall) occurred on the previous HST. This softness (not lithified) is resulted from the lapse of short time between previous HST and the new LST that caused rejuvenation of the stream and canyon formation.

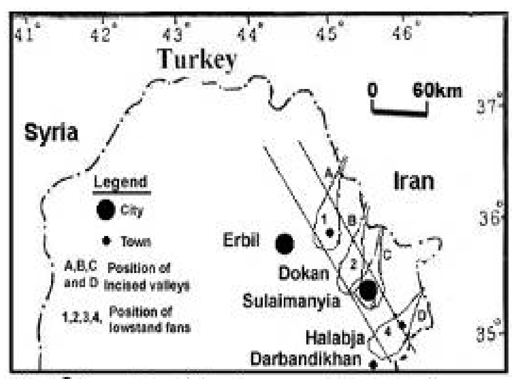


Fig. (3) Location of the discovered incised valleys and associated submarine and alluvial lowstand fans

C. Channels and their sediment fill

In the definition of canyons, it was mentioned that there is a stream on the bottom. This is also true for the incised valleys. Lots of evidence has been observed in the field, which show channels on the floor of the incised valley at southeastern side of Kato mountain very clear channel is exposed under the Kato Conglomerate. It is filled with about 20m wide coarse conglomerates and located inside the calcareous shale of sediment of HST of the lower sequence (Photo 2). The layers of the conglomerate pinch out rapidly against the channel wall and in some cases change to sandstone on the paleo flood plain. The pinching out give the conglomerate lensoidal form.

The channel shows at least two stages of incision at different levels. The lower level is narrower than the upper one (Photo 2.1 shows channel below the valley). They represent the depth reached by the stream during consecutive and falling by coarse sediment in late lowstand system tract when the sea level gradually rises .The streams were, most possibly, of braided type by which the thick pile of Kato conglomerate is laid down during late LST.

Sediment fill of the incised valleys during TST

At southwestern side of Kato Mountain there are abnormal occurrence of 50m of red layers (red beds), which are composed of red claystones and sandstone with intercalation of some thin bed of conglomerate (Photo5.5). These layers are called "Kato Red Layers". These layers

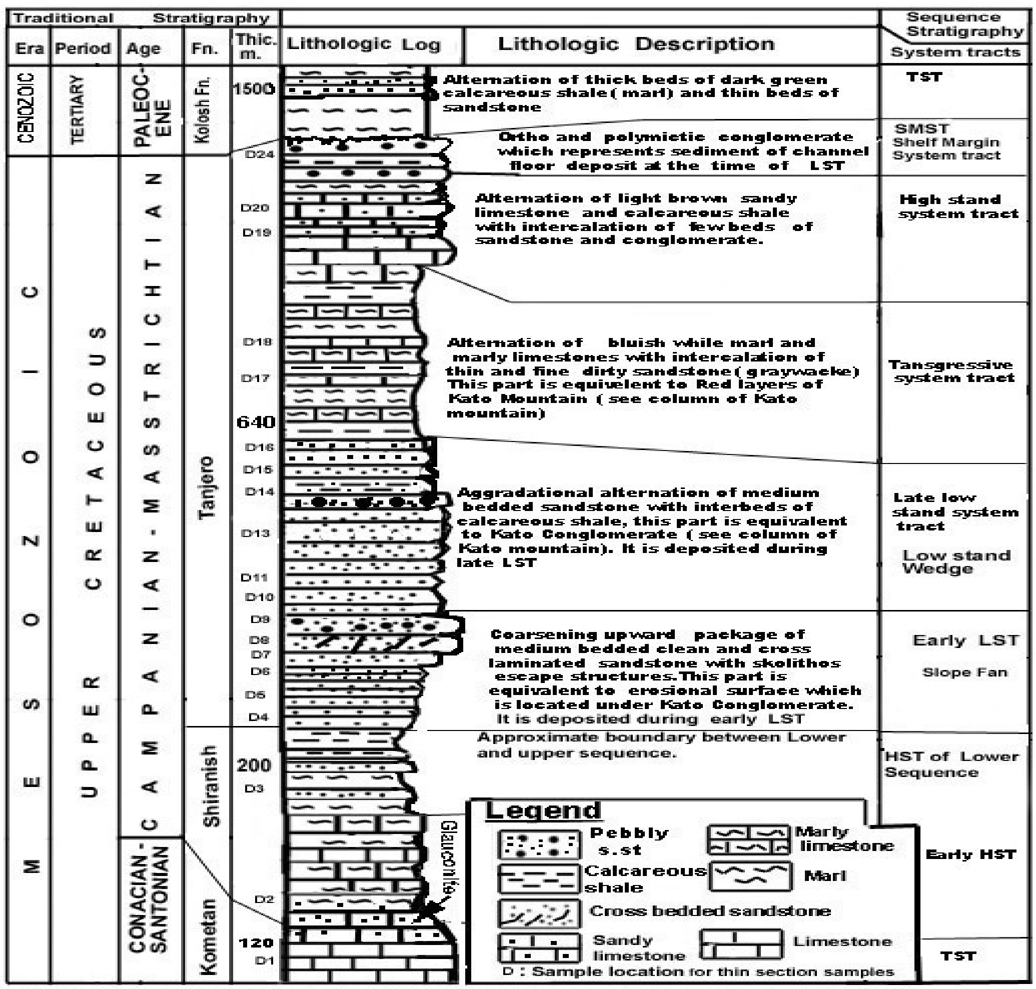


Fig. (4) Stratigraphic column of Dokan area showing traditional and sequence stratigraphy subdivision. (Not to scale, the thickness is shown on each parts) are underlain and overlain by Kato conglomerate and Kato mixed carbonate-siliciclastic succession respectively. This succession consists of alternation of more than 10 beds of rudist-bearing limestone and shale (Photo 5.4). The thickness reaches, in some place, more than 150m.

These red layers are also present at the area south of Mawat town near Qashan Bridge and directly east of Yalanqoz village (N: 35^{o} 51^{-} $24^{=}$, E: 45^{o} 24^{-} $29.3^{=}$), which reach only 20 m in thickness. These exist in the proximal area (near source area) while they are not observed in the distal area. Their equivalent lithology in the latter area is marl on the slope and calcareous shale one shelf area. The red layers and their equivalent represent the sediment of transgressive system tract (TST), which is deposited during the valleys flooding. They closely resemble Red Bed Series but can be differentiated by their stratigraphic position, which is located between lower and upper parts of the formation between Kato conglomerate and Kato mixed carbonate-siliciclastic succession.

These red layers have great importance in the study of Tanjero Formation because one can decide that the Kato Conglomerate represents continental or coastal area deposits and not deep deposits. This is because these layers contain lenses of conglomerate and the cooked samples yield no planktonic forams.

During the time of late LST the Kato Conglomerate is deposited. After the Kato conglomerate the red layers are deposited during rapid flooding of early TST when the deposition of the conglomerate sequestered.

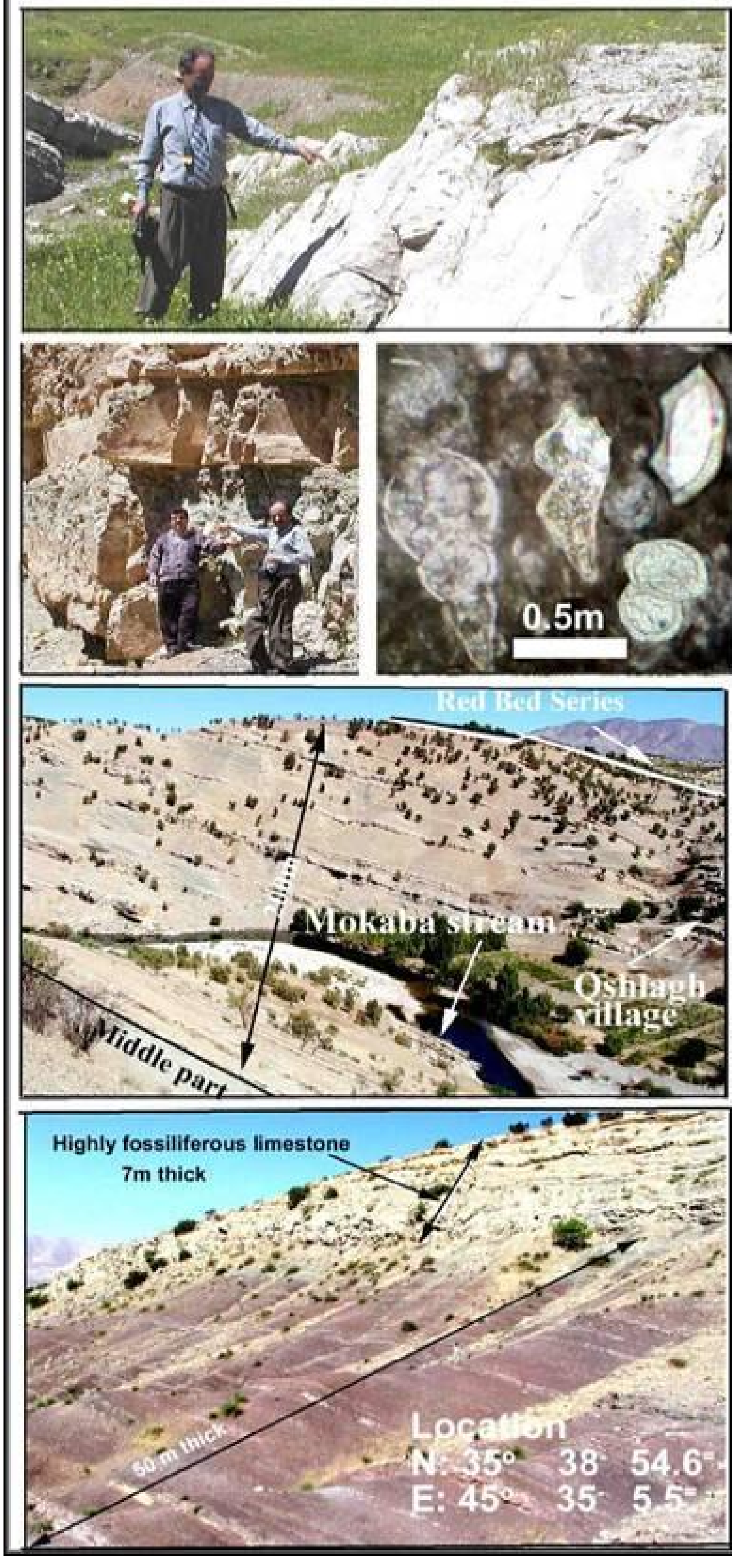
Transgressive system tract of Tanjero Formation

The deposit of the transgressive system tract is very clear which is overlying directly the low stand system tract (lowstand sandstone wedge and Kato conglomerate) of the formation. This deposit consists of bluish marl in the Sulaimaniya, Sharazoor and Piramagroon areas, whereas in Chuarta and Mawat area it consists of thick succession of dark green calcareous shale with some marls which change to red layers at south of Yallanqoz village and southern side of Kato mountain inside incised valleys. At Sirwan valley the lithology of HST is nearly the same as Chuarta with some sandstone layers and rare conglomerate intercalation, while in Dokan area it is relatively thin (no more than 130 meters). During deposition of this system, Tanjero environment has suffered sudden deepening demonstrated in the field by sudden vertical change of sandstone of LST to hemipelagic marls, while at Kato Mountain, the conglomerate; it changes with the same manner to Red claystone.

Because of deepening, this system tract has no sedimentary structures and fossils found in the lower LST and upper HST. They contain only Upper Cretaceous planktonic forams and shows retrogradational parasequences.

Photo (4) Sharp and clear transgressive surface at the top of the thick lowstand sandstone wedge, directly at the west of Kurdsat satalite center about 1.5km north to Sulaimanyia City.

Photo 5



(1) This 1.5 m thick white and fine grain limestone is most well developed condensed-like section in the middle part of Tanjero Formation. It is expoed on the left bank of Ballakian stream between Diana and Mergasur at N; 36° 47' 56.2", E: 44° 22' 55.1"

(2) The same bed (most possibly) the western end of Naudasht valley inside Razhwan village. At this locality it changes to marly limestone about 3.5m thick This bed and the above one are representing the deposits of maxium flooding of the sea at the end of TST when the clastic influx is stopped.

(3)Different genus of planktonic forams found in the above limestone. S.No. 95

(4) This alternation of carbonate and clastic (calcareous shale) is called Kato mixed carbonate-siliciclastic succession which exposed along right bank of Mokaba stream at 2km east of Mokaba village. The succession is deposited during HST directly below Red Bed Series. The limestone beds contain different assemblages of Large fossils (rudist, large forams, pelecypods, echinoderm and gastropods. previosly called Aqra lense.

(5) These succession of red layers (similar to Red Bed Series lithologically) but stratigraphically located between the Aqra lense (Mokaba succession) and Kato conglomerate. The Ihighly fossiliferous limestone at 5he top(8m) Thick is represent more or less condensed- like section or equvelent to condensed section. This layer are called Kato Red Layers which represent the TST sediment of incised valley fills overlying sediment late LST of Kato onglomerate

This is also confirmed by Smith and Jacobi (2001, p.21) [18] during study of stratigraphy and sea level change of Upper Devonian Canadaway Group in New York State.

Highstand-system tract

In Tanjero Formation, this system tract consists of mixed siliciclastic-carbonate succession. In this study, it called Kato mixed siliciclastic-carbonate succession). This succession is more than 150m thick in some places and consisting of alternation of thick beds of biogenic limestone and calcareous shale on the shelf (Chuarta area). Lawa et al (1998) [19] called this succession "interfingering of Aqra with Tanjero Formation". The biogenic limestone laterally changes, in most cases, to sandy limestone or calcarenite (detrital limestone). Fossils of rudists, belemnites, and gastropods (or their bioclast) are densely concentrated in some beds of biogenic limestone (Photo5.4 and 5.5). Other beds contain pelecypods, large forams (Discocyclina, *Loftusia, Amphalocyclus*), echinoderm and pelecypods or (their bioclast)Lawa et al(1998) [19]. In many places the calcarenite beds are cross-bedded and burrowed by *Planolite* and Cruziana trace fossils.

The repetition of these beds suggests aggradation parasequence. Above the mixed carbonate-siliciclastic parasequence come another parasequence, which consist of alternation of calcareous shale, sandstone and conglomerate (of Tagaran type). This pure clastic parasequence grades vertically into lithology of Red Bed Series. This parasequence does not exist in all places such as near Mokaba village where the biogenic limestone grade in to Red Bed Series). So the contact of the Red Bed Series and Tanjero Formation (including Aqra Lens) is gradational in some place and unconformable in others. The unconformable contact is very clear near Zarda Bee village and at Barda Qal and Siramerg valleys.

The explanation of Haq (1991, p.22) [15], can be accepted for alternation of biogenic carbonate and calcareous shale in Tanjero basin. He mentioned that during lowstand, siliciclastic is deposited while in highstand carbonate is deposited. This is true when each thick couplet of carbonate –shale is regarded as minor forth or fifth order cycles which suffered from the high and low stand. The field evidence in Chuarta agreed with that mentioned by Haq (op.cit) that in such successions limestones are mostly deposited in the early high stand when the accommodation on the shelf is plentiful, while during the late high stand, in Chuarta area, shale, sand and conglomerate are deposited when accommodation decreases and shore line prograde basinward as can be seen near Zarda Bee village.

Condensed section

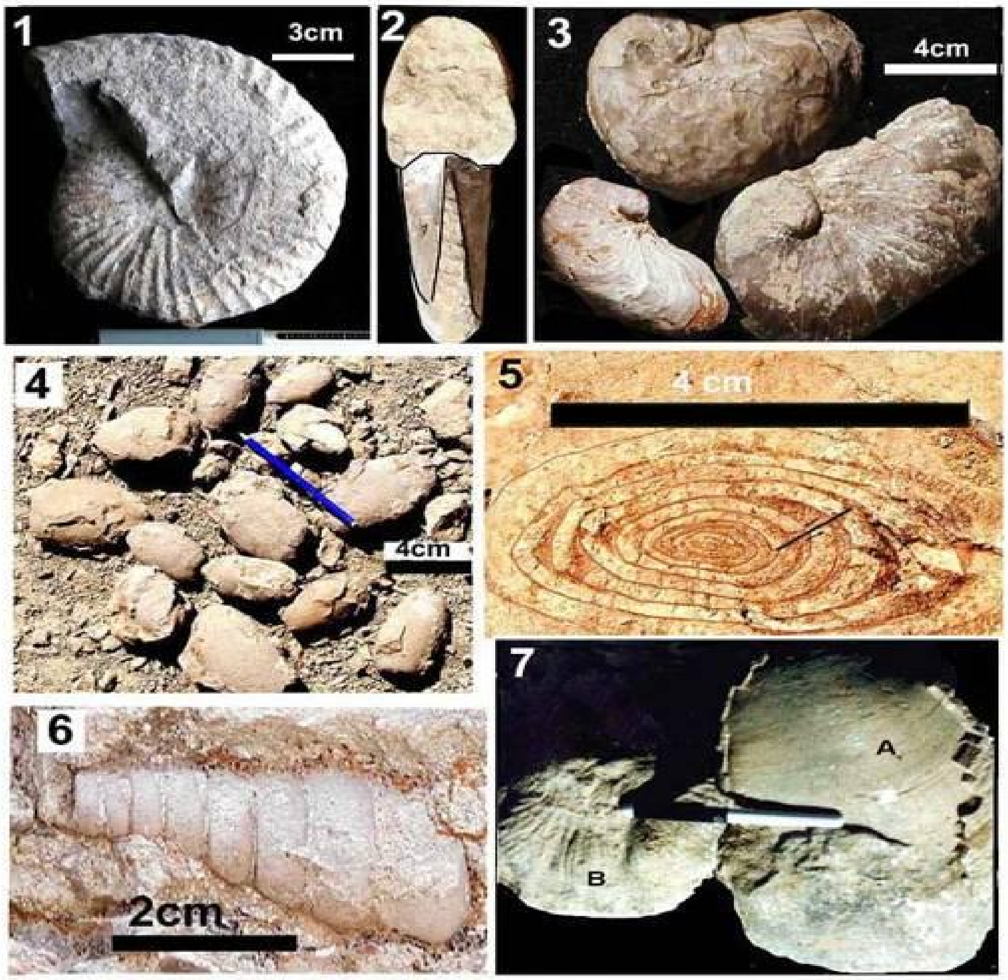
Condensed sections as thin marine stratigraphic horizons are composed of pelagic and hemipelagic sediments characterized by very slow sedimentation rate (Loutit *et al.* 1988) [20]. Within depositional sequence, the condensed section occurs partly at the top of transgressive system tract and partly within high stand system tract. They represent the maximum landward extent of marine condition. Marine condensed sections are created by sediment starvation and thus characterized by apparent hiatus, thin zones of burrowed and somewhat lithified beds (Haq 1991) [15].

Only few of these characteristics fit some beds within Tanjero Formation, so no typical condensed sections are found.

This may be returned to high sedimentation rate of formation in the relatively active foreland basin and to shallower water than Shiranish Formation. This latter formation contains at least one typical condensed section, which is located at the top (in Dokan area) of the formation in the middle of the formation (in Chuarta area). But, in the Tanjero Formation, the beds resembling or related to condensed section are as following:

In the proximal area (coastal area during LST) there is a biogenic limestone bed about 7m thick (Photo 5.4 and 5.4). These limestones are located

Photo 6



Different fossils genera in upper part (mixed carbonate- siliciclastic succession) of Tanjero Formation. Only the photo No. 7 is belong to middle part. 1) Large Ammonite, upper part, Barda Qal Valley, Chuarta. 2) The front view of the same Ammonite. 3) Oysters (*Exogyrea*). 4) Gasropod (*Actenonella*) with its cross section(5) southwestern side of Kato Mountain
6) Gastropod (*Turritella*) at same locality of sample (4).
7) Large rudist body fossil, the main shell (A) is about 30cm high 15 wide while the cap (B) is smaller, Southwestern side Kato mountain .

directly above Kato Red Layers. The position of this bed is directly above TST can be confidently regarded as a kind of condensed section or proximal equivalent deposit of a condensed section. It is deposited during maximum flooding of the sea (maximum landward extent of marine condition of Tanjero Formation) when the basin starved as concerned to terrigenous clastic influx from source area. This bed consists of several horizons of limestones rich in Upper Cretaceous fossils (Photo 5.5) with or without their bioclasts.

On the shelf (toe of northeastern limb of Azmir, Goizha anticlines) very thick TST calcareous shale is capped by biogenic limestone (0.3 – 2m). The fossils content shows densely populated by diverse organisms such as rudist (Photo 6.7) and gastropod (photo 6.2) this assemblage laterally changes to other ones such as: pelecypods (*Gryphaea*) (Photo 6.3) large forams, and echinoderm, large ammonite (Photo 6.) in other places changes to bioclast of these organisms. These types of bed are not unique but repeat several times upward in the HST.

C. The most well developed condensed section-like bed is a fine grain gray (white weathering) limestone occur nearly at the middle of the formation at west of Diana town on the left bank of Balakian stream (GPS reading: N: 36^{o} 47^{-} 56.2 $^{=}$, E: 44^{o} 22^{-} $55.1^{=}$) . This bed is 1.5 m thick and lithologically very similar to Kometan Formation both in color and lithology as it contains Upper Cretaceous planktonic forams (Photo 5.3).

In the Piramagroon and Sharazoor plain in addition to Dokan area, there are many thin beds and lamina of marly limestone in the middle part (TST). These may be regarded as relatively a kind of condensed section that represents time of non-deposition.

Shelf margin system tract (SMST) and type two-sequence boundary (SB2)

As mentioned above an alternation of dark color conglomerate (Tagaran type) and shale (with or without sandstone) exist, in some places, at the top of Kato mixed carbonate –siliciclastic succession. The thickness of this succession is about 50m near Tagaran and Zarda Bee villages. In the other area (with same tectonic setting) such as area around Mokaba, Homarakh, Konamassi and Harmin villages these conglomerates are not present. But the succession goes more or less gradationally to Red Bed Series. This type of contact and lithologic change is evidence of shelf margin system tract at the end of basin fill of Tanjero Formation and the underlying surface is type two-sequence boundary. This SB2 may be changed to SB1 in other areas such as toe of Qandil Mountain at the north of Kometan village (Photo 3). This lateral change of sequence boundary may be returned to high tectonic of the source area and part of the basin.

Emery and Myers (1996) [6] mentioned that SB2 and overly shelf margin system tract might be very difficult to recognize in outcrops. They added that could be differentiated from underlying HST by subtle (minor) unconformity.

Finally it seems that all system tracts of Tanjero formation belonged and deposited during third order eustatic sea level change. In literature Cunningham and Collins (2001) [21] studied the similar system tract in Morocco during Miocene and concluded that they belonged to third order sea level change cycles.

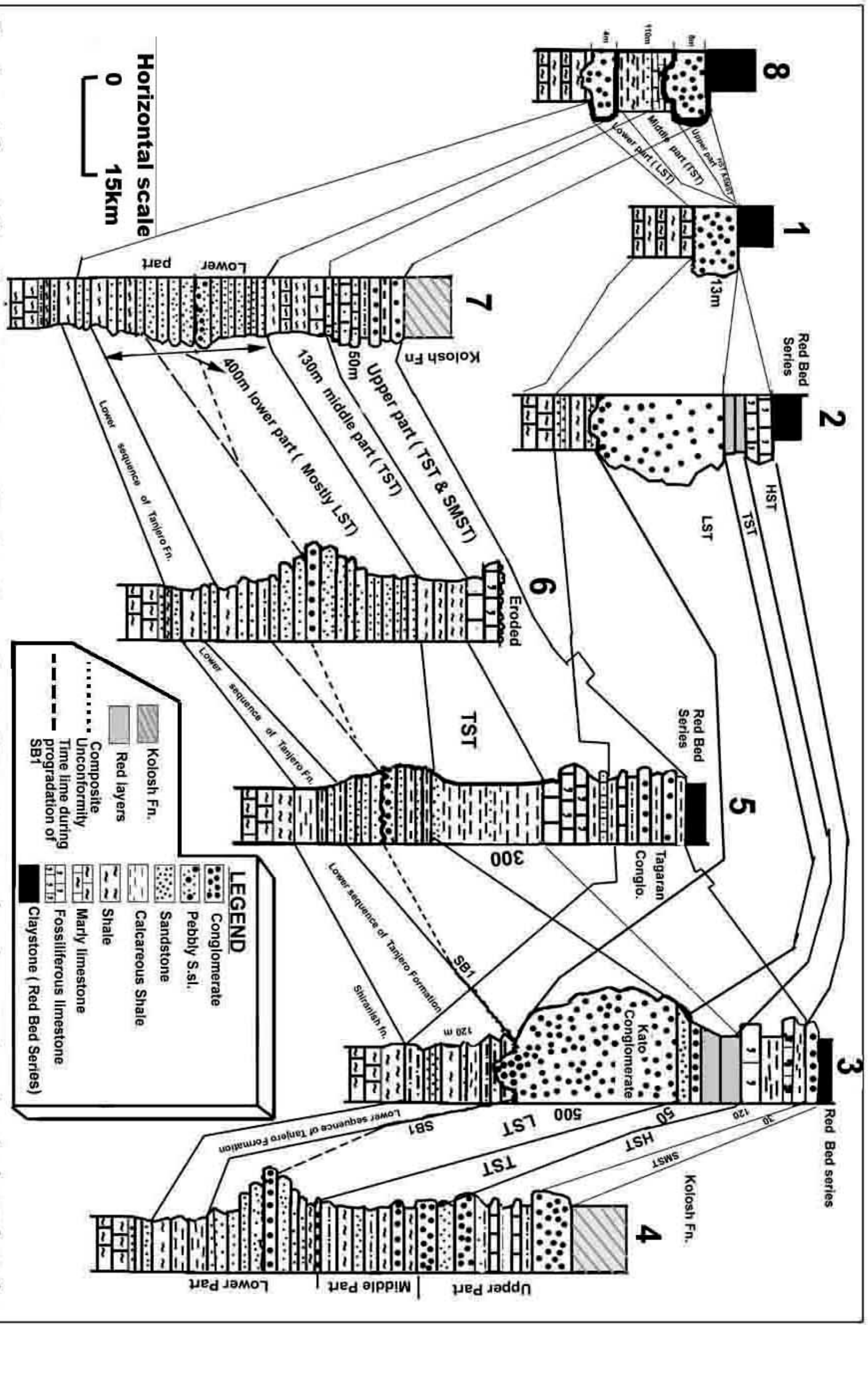


Fig. (5) Correlation between sections of Tanjero Formation at different areas showing system tracts based on the Kato conglomerate postion and their equivalents. 1) Iran section, 2) Qashan section, 3) Kato section, 4) Sirwan section, 5) Tagaran section, 6) Malkandi section, 7) Dokan section, 8) Kometan village section(Qandil Mountain toe)

Wheeler diagram logging for available outcrops

X1: Iran section
X2: Base of conglomerate at Kato mountain
X3: Middle of Kato Congl. at Kato mountain and Qashan bridge
X4: Lower sequence at Kato mountain
X5: sandstone low stand wedge at Chaqchaq and Sirwan valleys
X6: calcarous shale at Azmira Bechkolla valley
X7: Bluish marl at Chaqchaq valley, Piramagroon and Sharazoor Plains
X8: Red layers at Kato Mt. and Qashan brige
X9: Middle part of mixed carbonate-siliciclastic Succe.
X10: condesed like limestone at Balakian valley and other places.
X11: Shiranish Fn. at he base of Tanjero Fn. everywhere in the basin
X12: Base of Tagaran congl, at Tagaran village
X13: Calcarous shale at base of Kolosh Fn. at Dokan area
X14 : SB1 at Malkandi Hill and west of Arbat Town.

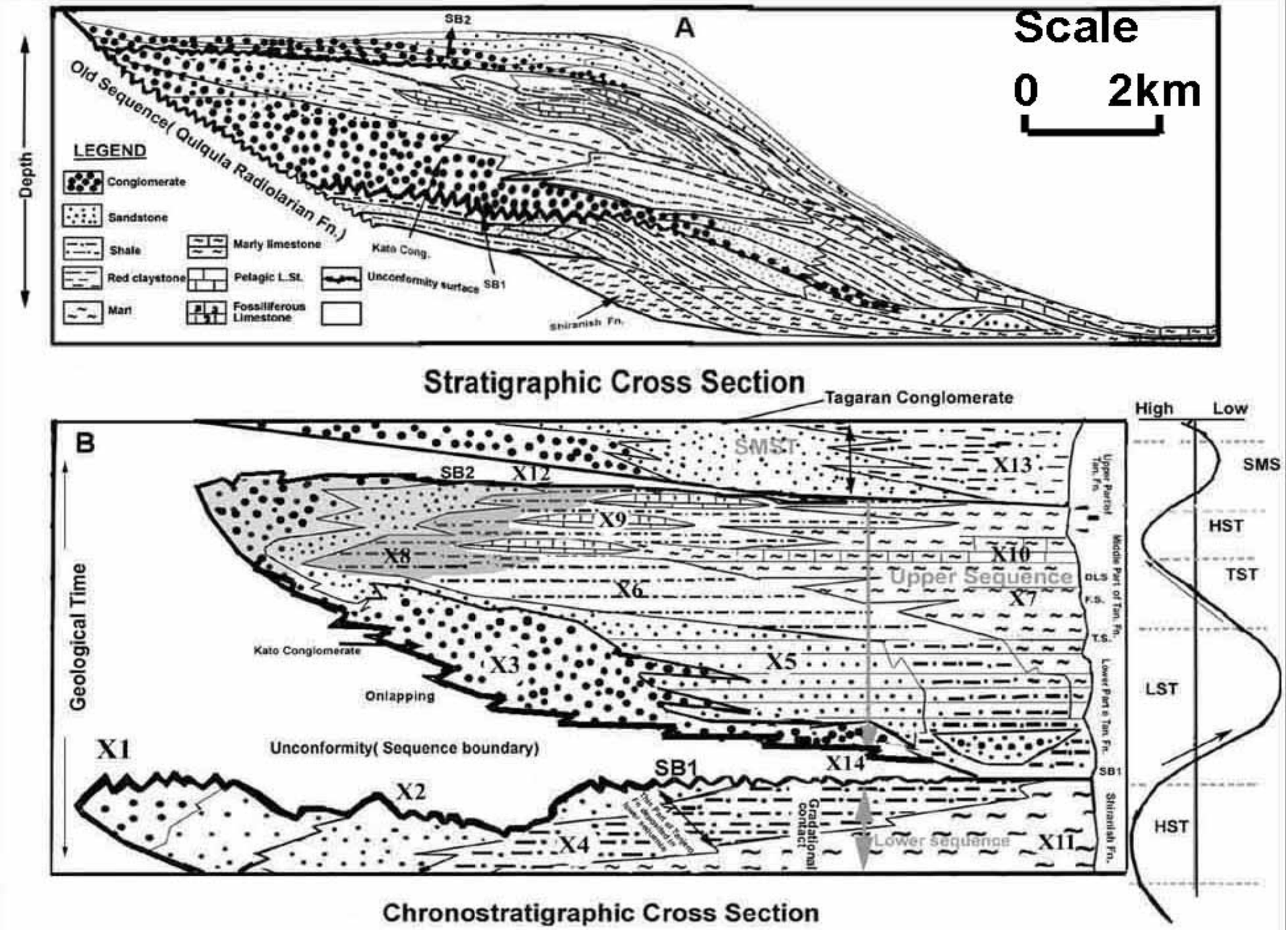


Fig. (6) Sequence stratigraphic depositional model showing depostional system tracts (in depth (A) and geologic time (B) Both models are drawn according to accurate field works and applicable for the areas of incised valleys with the associated fans The model is mainly fit the active foreland basin with tectonic uplift. The Chronostratigraphic (B) is called wheeler diagram. The column at the right is showing the survey of the representation points of geographic location inside diagram (B).

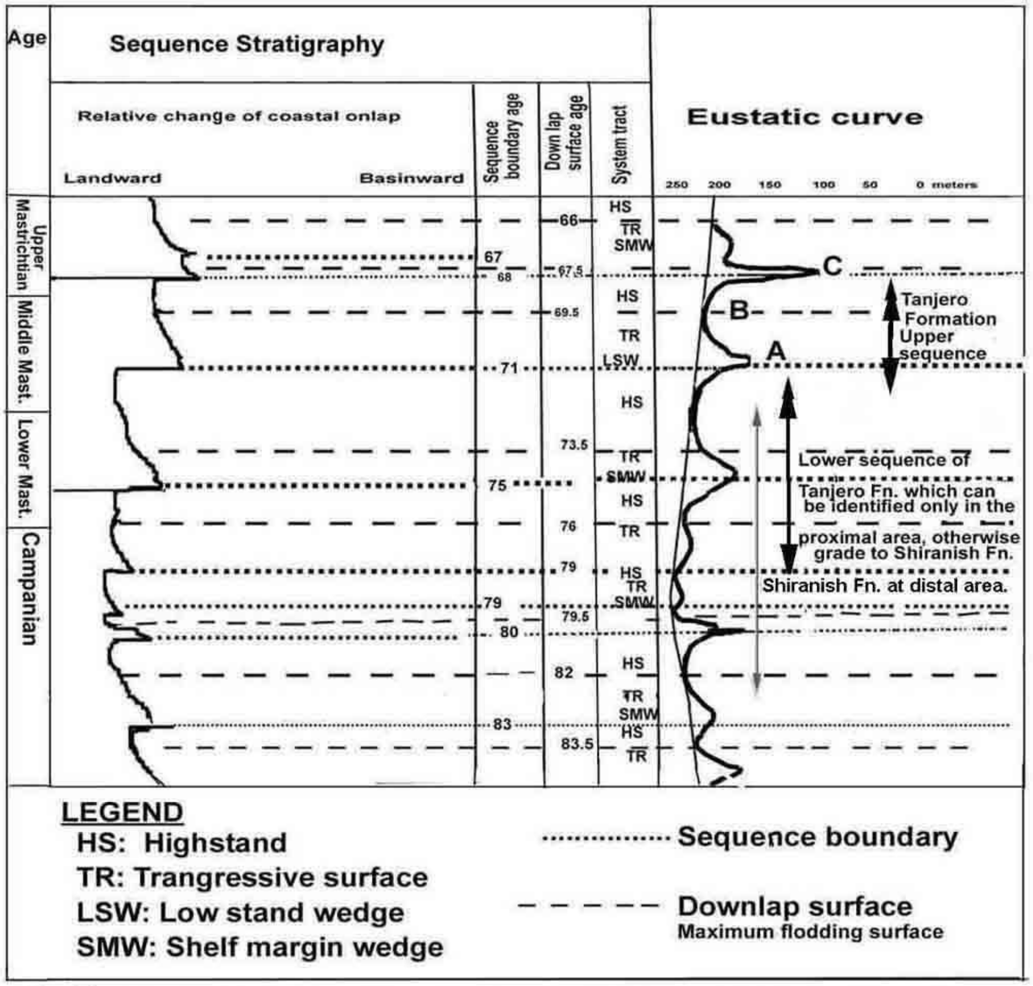
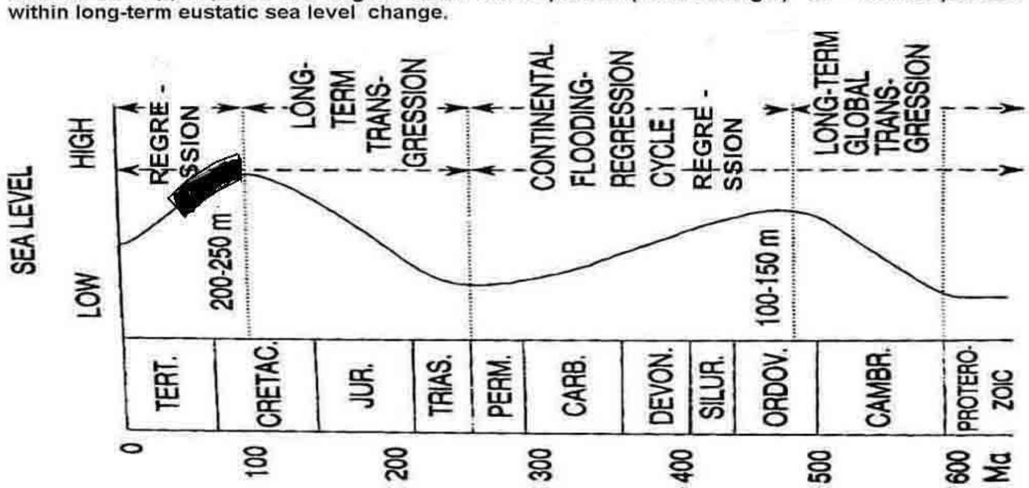


Fig. (**7**) Eustaic sea level and coastal onlap changes of Upper Cretaceous (modified from Haq *et al.* (1987b)(22) If the age of Tanjero Fn. is Midlle and Upper Maastrichtian(Abdul-Kareem 1986)[23] position of the system tract can be A, B, and C, for low, transgressive and high stand system tracts respectively. These system tracts are deposited during upper sequence which some of them enhanced by tectonics uplift and subsidence. These system tract are coinciding with lower , middle and upper parts. The diagram below shows postion (black traingle) of both sequences within long-term eustatic sea level change.



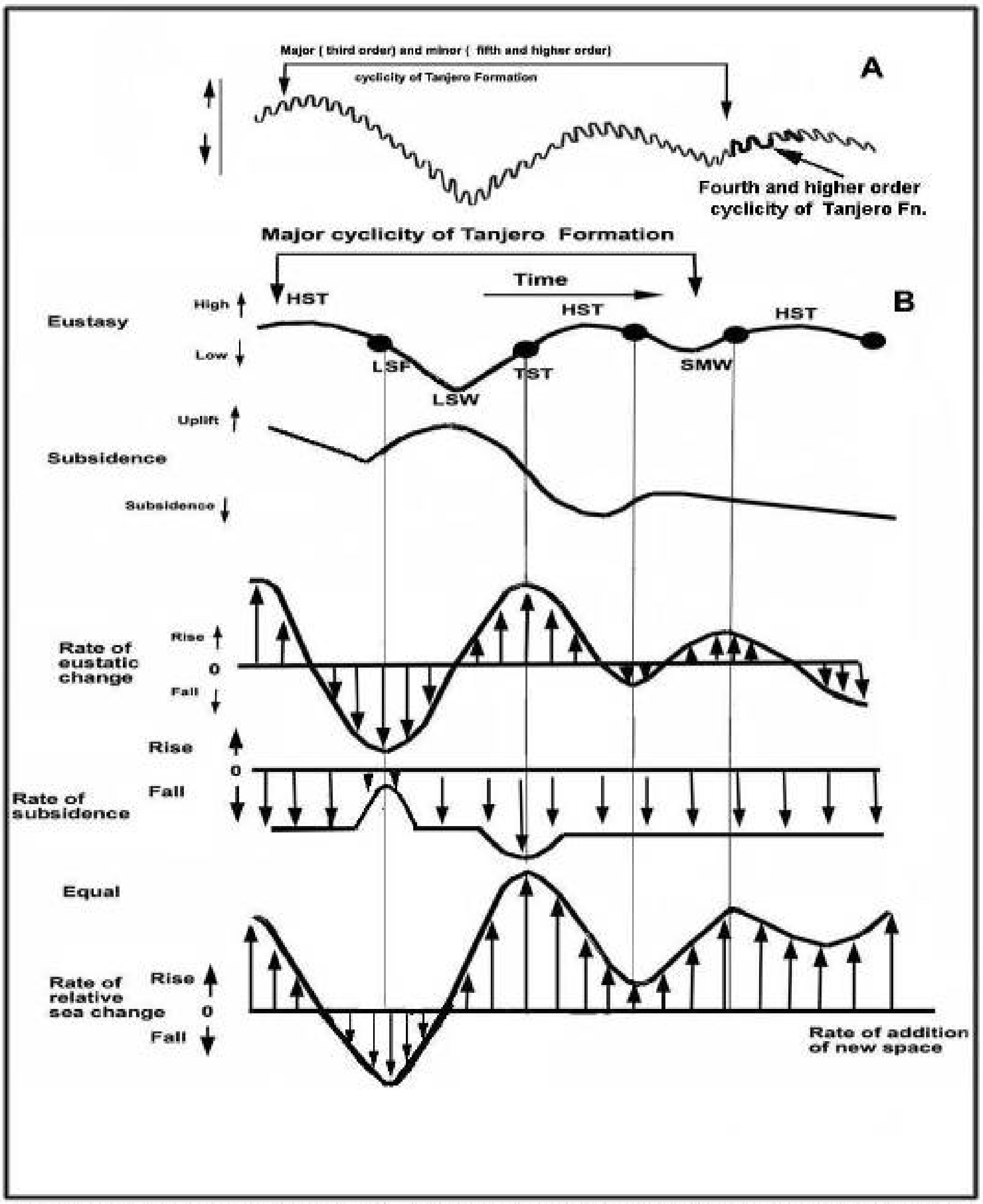


Fig.(٥)Relative sea level change as function of eustatic change and tectonic subsidence.
The curves are deduced from the stacking pattern(system tracts) of Tanjero Formation.
The curve(A) represent fourth and higher orders while the (B) stand for third order.

Conclusion

The study revealed the following results:

1-The whole rock body of the formation is divided into two main depostional sequences and correlated in eight sections, which are named lower and upper sequences. About 80% of the formation is deposited in the upper sequence while the rest is deposited in the lower sequence.

2. In the upper sequence, the LST, TST and HST are identified with a SMST at the top of the formation.

3. The lower sequence can be identified at the Chuarta, Mawat, Qandil area (proximal area) while at Sharazoor-

Piramagroon plain, Dokan area it grade with Shiranish Formation and can not be identified.

4. A type one and two sequence boundary (SB1 and SB2) is identified; they located at lower and middle part of the formation respectively. Above each 500m and 30m of conglomerate are deposited respectively.

5. The (500m) conglomerate has aggradational stacking pattern, which deposited inside more than four the incised valleys during sea level fall. This conglomerate changes to thick low stand wedge of sandstone at the distal area.

6. The transgressive surface and condensed sections are identified.

7. All the system tracts in the studied area are as following:

Qamchuqa Formation… LST
Kometan Formation… TST
Shiranish …. Formation…. early HST
Tanjero Fn…..late HST, LST, TST and HST

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چینە لە دوایی یەکی پێکهاتووی تا نجەرۆ (کریتاسی سەروو) لە ناوچەی سێلمانی، سەرووی رۆژهەلاتی عیراق

کمال حاجی کریم/بەشی جیۆلۆجی-زانکۆی سلێمانی – هەرێمی کوردستانی عیراق
علی محمود سورداشی / زانکۆی کۆیە / کۆلیجی ئەندازیاری نەوت و کانزا

لە سەربنچینەی زانستی چینە لە دوایی یەك (سکوێنس) ، هەموو چینەکانی کریتا سی سەروو دابەش کرا بە دوو چینە لەدوای یەکی بەردی نیشتوو . وە ئەم دوو لە دووای یەکە ناو نران لەدوا ییەکی خواروو وە سەروو . نزیکەی (80٪) ی سیکوێنسی پێکهاتوی تا نجەرۆ نیشتوە لە سکوێنس ی سەروو کە لە خوارەوەو سەرەوە دەورە دراوە بە(SB1) وە (SB2) . بەشەکەی تری (20٪) ی پێکهاتوە کە لە سکوێنس خوارەوە نیشتوە. (SB1) بریتی‌یە لە سەرەکی ترین رووی داخوران وئەنکۆنفۆرمبتی کە درێژ دەبێتەوە لە دەریا کەدا لەناوچەی چوارتاوە بۆ دەشتی شارەزوورو پیرە مەگروون لەکاتی ماستەریختیانی خوارووداا . پوازکی ئەستوری کونگلومێریت و بەردی لمی لەسەر ئەم رووە نیشتوە لەکاتی گە ڕانەوەی دەریای بەزۆر . ئەم گەڕانەوە یە رووی داوە بە هۆی دابەزیینی ئاستی ئاوی جیهانییەوە کە یارمەتی دراو بەتەکتۆنی 0 لە سەرووی (SB2) نیشتنی (SMST) رووی داوە کاتی ماستریختانی سەروو کە بریتیە لە ئەستوورییە کی لە کۆنگلومێریت لە هەندێ شوێن وە بەکۆنفۆرمیتی شوێنی تر . (SMST) نیشتوە بە هۆی پڕبوونی دەریاوە بە نیشتوو وە بەهۆی گەڕانەوەی ئاسایی دەریاوە (لەم باسەدا وا دا نراوە) . لە بەر ئەوە من ئەتوان نین بلێین کە دەریای فۆرلاندی سەرەتای کەریتاسی سەروو بەش بووە بەهۆی دوو ئەنکۆنفۆرمیتی لەتەمەنی پێکهاتوی تە نجەرۆدا کەلەناوقولایدا دەبێت بە کۆنفۆرمینی . لە لە نێوان دوو رووەکەدا وە لە سکوینسی سەرروودا توانرا (SMST, HST,TST, LS) بناسرێتەوە لەگەڵ ڕووەکانیاندا وە لیسۆلوجی ئەم سیستەم تراکانە هەمان شتەکە لە بەشی خوارەوە و ناوەڕاست و سەرەوەدا لە پێشەوە ناو براون . سیستەم تراکی سکوێنسی خوارەوە نا توانرێت بناسرێتەوە چونکە تەنها بەردی دەریای قوڵی ئەو سکوێنسە بەدیار کەوتوە کە هەموو سیستەم تراکەکانی تێکەڵبوون .

داخوران و دوو بارە نیشتن بۆ ناو ژینگەی قوڵ ڕوویداوە بەهۆی جۆگەو دۆڵ و خندە قی دابڕاوەوە لە کاتی دەرکەوتنی هەوایی شێلف و سلوپی سەرەوەی ژینگەی پێکهاتووی تا نجرۆە بەهۆی دابەزینی ئاستی ئاوەوەو گەڕانەوەی بەزۆر لەکاتی (LST) . زیاتر لە چوار دۆڵی دابڕاوی سەرەکی دۆزرایەوە لەناو نیشتوی (HST) پێشو (شێلفی سکوێنی پێشوو) نیشتووی دۆڵە دابراوە کە بریتییە لە پوازکی بەردی لم و کۆ نگلۆمیریت و بەردی گلی سووری نیشتوو لەکاتی (High stand)) دا . لە ناوچەی دووکان ودۆڵی چەقچەق و دەشتی شارزور و پیرەمە گروون رووی بەروو پێشرەو ئەتوانرێ بە روونی ببینرێ کەبریتی‌یە لە گۆڕانی‌خێرای بەردی لم بۆ بەردی مارڵ لەگەڵ هەندێ ناواخنی بەردی کلسی مارڵی . ئەم رووە بریتیە لە خالی سەرەتایی نیشتنی بەستەیەکی سیستەم تراکی بەروپێش رەوو کەلەلایەن لیسۆلۆجی یەوە زۆر لە پێکهاتووی شیرانش دەچێت لە ناوچەی دوورە سەرچاوە لە دەریای قوڵدا نیشتووە رووی بەرزترین لافاو وە برگەی چر گفتوگۆی لە سەرکراوە.

بەشی سەرەوە بریتیە لە نیشتووی تێکەلاوی کلس -سلیسیکالاستیك کە دەگەڕێتەوە بۆ ژینگە ی تەنکی شە پۆدار. لەم ژینگەیەدا بەردی کلسی گیانداری (هەڵگری رۆدیست و ئامۆنایت و گاسترۆپۆدو پلیدسی) نیشتووە سکۆێنسی سەروو سەری گیراوە بەهۆی سیستەم تراکی شلێف مارجینەکە ئەستووری تارادەیەك کەمە.

ألطباقية التتابعية لتكوين تانجيرو (الطباشري الأعلى) في منطقة السليمانية ، شمال شرق العراق

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قسم الجسم الصخري الكلي للطباشيري الأعلى على أساس ألطباقية التتابعية إلى التتابعين الرسوبيين حيث سميتا تتابع السفلي والعلوي . ترسب 80% من سمك التكوين ضمن التتابع العلوي والمحصورة بين SB1 و SB2 من الأعلى والأسفل على التوالي . الباقي التكوين 20% ترسب ضمن التتابع السفلي . يعتبر (SB1) اهم سطح للتعرية وعدم التوافق الموجودة داخل التكوين حيث يمتد من منطقة جوارتا و ماوت إلى سهلي شارةزور و بيرةمكرون خلال عصر ماسترختيان اسفل . و قد ترسب سمك كبير من حجر الرملي والمدملكات بشكل وتد على هذا السطح بواسطة التراجع الإجباري . هذا التراجع نتجت من انخفاض مستوى السطح العالمي المعزز بحركات التكتونية . فوق SB2 ترسبت سمك قليل من رسوبيات (SMST) خلال ماسترختيان أعلى و المتمثلة بوجود المدملكات (عدم التوافق) و الحجر الرملي بعض أماكن وعدم وجوده (توافق) في أماكن أخرى . ترسيب (SMST) نتيجة لملء حوض التكوين مع نزول بسيط لمستوى البحر حيث اعتبر هذا الملء في هذا الدراسة كتراجع اعتيادي وليس إجباري . يمكن القول إن رسوبيات حوض مقدمة القارة الزاحفة والتابعة لكريتاسي الأعلى قد قسمت إلى القسمين خلال عمر تكوين تانجرو بواسطة سطحي عدم التوافق و يتغير كلاهما إلى التوافق الرسوبي داخل الحوض العميق . بين سطحين و ضمن تتابع الأعلى تم التعرف على نظم المسارات التالية (LST, TST, HST , SMST) بالإضافة إلى أسطح التابعة لهم . أن الرسوبيات هذه المسارات عبارة عن نفس ما يحتوي ألاجزاء الثلاثة المذكورة الأعلاه . نظم المسارات التتابع السفلي لا يمكن تميزها بسبب وجود مكاشف البحر العميق (المناطق البعيدة عن المصدر) فقط و اندماجهم معا.تعرية (بواسطة الأنهار) الرف والمنحدر العلوي العائد للتتابع السفلي كونت القنوات والوديان و الخنادق المقتحمة . و تم خلال هذه الأشكال نقل الترسبات و إعادة ترسيبها في بيئة عميقة . هذا كله حدث أثناء تراجع الماء من الرف نتيجة لهبوط مستوى المياه و تراجع الإجباري أثناء ترسيب **(LST)** . وجدت أربعة وديان مقتحمة داخل الرسوبيات **(HST)**السابق (رف التتابع السابق) حيث امتلأ هذا الوديان من بوتد من المدملكات الركود الواطئ **(Low stand wedge)** والحجر الطيني الحمراء التابع لنظام المسار التقدمي. **(TST)**

فوق وتد الحجر الرملي وفي منطقة دوكان و وادي جقجق و سهلي شارةزوور و بيرةمكروون يمكن مشاهدة سطح التقدم البحري بشكل تغير سريع للحجر الرملي إلى المارل مع تداخلات من طبقات الرقيقة من حجر الجير المارلي . هذا السطح عبارة من نقطة البداية لترسيب السميك من رسوبيات **(TST)** فوق الرف . رسوبية هذه المسار يشبة كثيرا تكوين شيرانش في المناطق البعيدة من الساحل (على المنحدر و في البحر العميق) ولكن يتغير إلى الحجر الطيني الحمراء داخل الوديان . سطح لتقدم بحري و مقاطع مركزة نقشت الذي تقع بين الجزء الوسطي والعلوي . الجزء العلوي عبارة عن نظام لمسار الركود العالي الذي يتكون من تتابع من الطبقات المختلطة من الصخور الكاربوناتية و السليسيكلاستيكة **(Mixed carbonate - siliciclastic succession)** الذي ساد أثناء ترسيبه بيئة ضحلة علي الرف ذو جو و عاصف و ترسب فيها الحجر الجيري الحياتي و متكون من أصداف من رودست و امونايت و بطنية الأقدام و راسية الأقدام و الفورامنفرا الكبيرة. هذا المسار تم تغطيته بسمك قليل من نظام مسار حافة الرف (**SMST**).

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