REPUBLIC OF TURKEY

FIRAT UNIVERSITY

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

# SEQUENCE STRATIGRAPHY OF THE UPPER CRETACEOUS TANJERO FORMATION, EASTERN DARBANDIKHAN, NORTHERN IRAQ

MASTER THESIS

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Department: Geological Engineering
Program: General Geology (Sedimentology)
Supervisor: Assoc. Prof. Dr. Hasan ÇELİK

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Sincerely

**Aland Mahfoth Ahmed**

**Elazığ, 2019**

## ABSTRACT

With this sequence stratigraphy aimed study, spectacularly exhumed Campanian-Maastrichtian deep marine turbidities of Tanjero Formation near eastern part of Darbandikhan, to the northeastern part of Iraq was examined. A 1333 m thick sedimentary measured section was logged in detail for this study located near Iranian border at Sirwan valley nearby Sarshata village, to the east of the Darbandikhan town. The log starts from lower contact of the formation underling Campanian- Maastrichtian Shiranish Formation and finishes at the upper contact overlying Paleocene-Middle Eocene Kolosh Formation. From the shale intervals of the log 25 samples were collected and analyised containing deep marine microfossils. *Abathomphalus, Gansserina, Globotruncana, Globotruncanita, Heterohelix, Hedbergella, Pseudotextularia, Pseudoguembelina, Racemiguembelina, Rugoglobigerin* genera and 17 species of planctonic foraminifera along the logs were found. Late Maastrichtian *Abathomphalus mayaroensis* zone and bathyal environment have been identified by assemblage of the planktonic foraminifera, and *Krithe* sp. Ostracode genus has been identified in the uppermost level of the log which has been used for identifying infraneritic bathyal environment for the study area.

Palaeoflow data measured from flute marks and clast imbrications and analyised on a rose diagram show that the flow direction was toward the SW. This means the source area of the formation was located to the NE.

Sequence stratigraphy in term of parasequence and parasequence sets has been studied depending on the grain sizes and bed thickness changings along the measured log indicate that the formation includes third-order depositional systems. In the study area stratigraphic succession of the formation is separated into two (lower and upper sequences) depositional successions.

Around 15% thickness of the Tanjero Formation is deposited in the lower sequence which contains Highstand Systems Tract (HST) resulted in progradational to aggraditional parasequence. Approximately 85% thickness of the formation belongs to the upper sequence; the upper sequence is bounded by (sequence boundary 1) SB1 in the lower part and (sequence boundary 2) SB2 in the upper part. The upper sequence comprises Lowstand Systems Tract (LST), Transgressive Systems Tract (TST) and Highstand Systems Tract

(HST) resulted in progradational paracequence, Retrogradational parasequence and progradational to aggraditional parasequence respectively.

These parasequence data indicate that the sea level during the late Maastrichtian starts with high level (HTS), after that falls (LTS), then arises again with a transgression (TST), then keeps its level (HST) for a while for the study area.

**Keywords:** Sequence Stratigraphy, Late Cretaceous, Tanjero Formation, Darbandikhan, northeastern Iraq.

**ÖZET**

**Tanjero Formasyonu'nun (Üst Kretase) Sekans Stratigrafisi Darbendikhan Doğusu, Kuzeydoğu Irak**

Sekans stratigrafisi amaçlı bu çalışma ile kuzeydoğu Irak'ta Derbendikan ili doğusunda mükemmel yüzeylemelere sahip olan Kampaniyen-Maastrihtiyen yaşlı Tanjero Formasyonu'na ait derin deniz türbiditleri incelenmiştir. Bu kapsamda ran sınırına yakın Sirwan vadisindeki Sarshata köyü yakınında kalınlığı 1333 m olan detaylı bir sedimanter ölçülü kesit alınmıştır. Ölçülü kesit, Tanjero Formasyonu ile altındaki Shiranish Formasyonu'nun (Kampaniyen-Maastrihtiyen) kontağından başlar, üzerleyen birim olan Kolosh Formasyonu'nun (Paleosen-OEosen) dokunağına kadar devam eder. Ölçülü kesit boyunca şeyl seviyelerinden ortam ve yaş verileri elde etmek için alınan 25 örnekte tespit edilen *Abathomphalus, Gansserina, Globotruncana, Globotruncanita, Heterohelix, Hedbergella, Pseudotextularia, Pseudoguembelina, Racemiguembelina, Rugoglobigeri* cinsleri ile 17 ayrı planktonik foraminifer türü ve *Abathomphalus mayaroensis* zonu foraminifer topluluğu birimin bu bölgedeki ortamının batiyal ortam şartlarını ve Geç Maastrihtiyen zamanındaki bir depolanmayı temsil ettiğini ortaya koymuştur. Ayrıca birimin en üst seviyelerindeki şeyl örneklerinde tespit edilen *Krithe* sp. Ostracode cinsi, üstlere doğru ortamın infraneritik batiyal ortam şartlarına doğru nispeten sığlaştığını göstermiştir.

Eski akıntı yönünü tespit etmek için kaval yapıları ve kiremitlenmelerden elde edilen ölçümlerin gül diyagramı yardımıyla analiz edilmesi neticesinde eski akıntı yönünün güneydoğuya doğru olduğu ortaya çıkmıştır. Bu durumda inceleme alanında çökelen türbiditlerin kaynak alanının kuzeydoğuda yüzeyleme verdiği ortaya çıkmıştır.

Parasekans ve parasekans set bağlamında yapılan sekans stratigrafisi çalışmaları, ölçülü kesit üzerinde, tane boyu değişimi ve tabaka kalınlıklarında gözlenen değişim dikkate alınarak gerçekleştirilmiştir. Buna göre inceleme alanında formasyon için üçüncü derece depolanma sisteminin mevcut olduğu ortaya konmuş, alt ve üst olmak üzere iki ana sekans ardışımı belirlenmiştir. Bu kapsamda formasyonun yaklaşık % 15'lik alt bölümü Highstand System Tract (HTS) olarak ilerleyen – üst üste biriken parasekans şeklinde meydana gelmiştir. Formasyonun yaklaşık geri kalan % 85 kalınlığındaki kısmı ise üst bölümü oluşturmaktadır. Bu üst sekans bölümü, alttan (sekans sınırı 1) SS1 üstten ise (sekans sınırı 2) SS2 ile sınırlanmıştır. Üst sekans bölümü, Lowstand Systems Tract (LST), Transgressive Systems Tract (TST) ve Highstand Systems Tract (HST) olmak üzere üç sistem izi içermekte ve buna bağlı olarak; ilerleyen parasekans, gerileyen parasekans, ilerleyen-üst üste biriken parasekans örneklerini içermektedir.

Bu parasekans verileri inceleme alanında, deniz seviyesinin Geç Maastrihtiyen'de önce yüksek seviye ile başladığını (HTS), sonra düştüğünü (LST), tekrar bir deniz ilerlemesi ile yükselerek (TST) seviyesini koruduğunu (HST) ortaya koymaktadır.

**Anahtar Kelimeler:** Sekans Stratigrafisi, Geç Kretase, Tanjero Formasyonu, Derbendikan, kuzeydoğu Irak.

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## 1. INTRODUCTION

The “sequence” phrase was initially presented by Sloss et al. study in (1949) which was to entitle a stratigraphic unit bounded by subaerial unconformities. Subsequently, Sloss et al. (1949) insist the status of this type of sequence-bounding unconformities, and in this manner categorized the whole Phanerozoic succession of the interior craton of North America to six different main sequences.

The stratigraphic sequence system additionally gives the setting inside which to interpret the development of depositional frameworks through space and time. This analysis enhanced by the reconciliation of process sedimentology with a comprehension of the geometries and sizes of the segment depositional components (Bellen et al.,1959). Sequence stratigraphy ties change in stratal stacking patterns to the reactions to various accommodation and sediment supply during the time. Stratal stacking designs empower assurance of the request in which strata were set down and clarify the geometric connections and the construction of sedimentary strata (Zhu et al., 2013).

Sequence stratigraphic technique has become one of the unique methods which have used for creating exploration predictions, and quality of reservoir and seal has expected in both stratigraphic and structural traps by studying sequence stratigraphy (Dim, 2018; Oleson, 2018). Also, sequence stratigraphy plays a key role in sedimentary basin analysis, reservoir evaluation and hydrocarbon system. Hence, it might be taken in attention in the recent studies particularly in the region which is wealth in hydrocarbon and under the process of oil exploration (e.g. northern of Iraq) to understand petroleum system (Lawa, 2018). Sequence stratigraphy is a strategy that gives a structure for the components of any depositional setting, encouraging paleogeographic recreations and the expectation of facies and lithologies from control points (Amel et al., 2018).

It has stated in several studies that Tanjero Formation is a widely spread Upper Cretaceous (Campanian-Maastrichtian) unit in northeastern Iraq (Al-Rawi, 1980, Abdul-Kareem, 1986b, Jazza, 1991, Lawa et al., 1998, Al-Rawi andAl- Rawi, 2002, Karim, 2004. Karim, 2005, Karim and Surdashy, 2005a, Karim and Surdahy,2005b, Karim and Surdahy, 2005c). And it is studied and debated more than any other geological features this feature edits out inside the Imbricated and High Folded Zones in Northeastern Iraq (Buday, 1980; Buday and Jassim, 1987). The formation extends as restricted northwest-southeast belt and parallel to the Iranian border. The development of the upper part of the formation consists of a variation of clastic rock; sandstone, marl and calcareous shale with the occurrence of thick conglomerate and biogenic limestone (Bellen et al. 1959). The lateral equivalent of the Tanjero Formation isHartha, Shiranish, Aqra-Bekhme and Digma formations in the different part of Iraq. The lower boundary of the Tanjero Formation with Chia Gara and Barsarin or Naokelekan formations and it is unconformable contact. However, upper contact of the formation with a unit of limestone and dolomitic limestone which expected to be Aqra- Bekhma Formation is conformable and gradational, and the upper contact is noticeable by the finding of rudist reefs. The Tanjero Formation is one of important formation in the geology of Iraq because it conducted as a good oil reservoir (Bellen et al. 1959 and Jassim, 2006 after Hemin, 2017).

Firstly, stratigraphic succession of the Tanjero formation was studied in central and northern Iraq by Minas, (1997). It was determined that the Tanjero Formation has deeper depositional environment than Shiranish Formation, and it was thought that the formation deposited in a transgressive part of the cycle.

The stratigraphy and tectonics of the Tanjero formation were described and conversed in brief in the Chuwarta province (Al-Mehaidi, 1975). The author noticed that the Aqra iki paragraf üstte Aqra- Bekhma olarak yazılmış; birkaç paragraf altta ve burada ise sadece Aqra. Hangisi doğru? İkisi de doğru ise birini tercih edelim. Formation overlies the Tanjero formation.

Al-Rawi and Al-Rawi (2002) showed depositional environment of the Tanjero formation is a deep marine, but the limestone beds within the formation deposited in shallow water. The Tanjero Formation defined as turbidity model of flysch system extends north and northeast of Iraq.

Karim and Surdashy (2006) studied the stratigraphic succession of the upper Cretaceous Tanjero Formation in the Sulaimaniyah region, northeastern of Iraq, and they have divide it into two depositional (upper and lower) sequences.

Zhu et al. (2013) utilized a succession stratigraphic method for studying intra-cratonic basin, and it has produced some developments in the sequence stratigraphic model. This progress has a significant role in basin analysis and petroleum investigation and production.

Oleson (2018) used a stratigraphic sequence approach as more dependable tool integrates with well logs, biofacies and seismic data for understanding petroleum system and expecting oil sources, reservoirs, and caps or seal rocks. Additionally, the comprehensive depositional model has generated for demonstrating the relationship between successions and system tracks in sub-basin to assume depositional processes.

Lawa (2018) analyzed sequence stratigraphy framework of late Campanian–Maastrichtian in Kurdistan foreland basin, the northeastern part of Iraq. The author used detail fieldwork data and biostratigraphic data (several groups of fossils, e.g. larger foraminifera, planktonic foraminifera) for identifying various successions of stratigraphy including three formations; Shiranish, Tanjero and Aqra formations.

There are several studies, summarized in the succeeding former works part of the present thesis, about Tanjero Formation in the northern part of Iraq but the majority of them were studied depositional environment, sedimentology and petrology analysis, facies analysis, determining sedimentary structures on the clastic Tanjero Formation and carbonate rocks northern part of Iraq. In this thesis sequence stratigraphy of the clastic Tanjero formation in the eastern of Darbandikhan, Northeastern part of Iraq, was studied by using field logging, and palaeoflow direction to assess sequence stratigraphic systems tracks and find parasequences of the turbidite succession which play a significant role in demonstrating the sea level changes and identifying cyclic orders in the Tanjero Formation. Also, in the present study, potential reasons for the cyclic sedimentation, allogenic and/or autogenic controls on the cyclicity will be presented by finding hierarchy of orders in the Tanjero Formation. This new strategy has extensively enhanced our knowledge to comprehend how sedimentary basins accumulate and preserve sediments, and it has turn into a very effective investigation approach for exploring natural resources (oil and gas) hydrocarbons and understanding reservoir characteristics.

## 2. PREVIOUS WORK

Dunnington (1952) studied the Tanjero Formation, and it was primarily defined and labelled as a Tanjero Clastic Formation. The type locality of the formation selected in the near Halabja Town at 1 km from the south of Kani Karweshkan village in the Sirwan Valley, and age, fossil content, lithology, stratigraphy and distribution of the formation were described concisely by the author.

Bellen et al. (1959) stated that Tanjero Formation wide spreads in different sites through northeastern of Iraq, particularly in northwest-southeast belt close and parallel to the Iranian border. Also, it was studied that generally the Tanjero Formation has the essential features and it contains variations in lithology of clastic rocks of sandstone, calcareous shale and marl with the existence of an inclusive conglomerate and biogenic limestone (Bellen et al., 1959).

Kassab (1975) studied biostratigraphy of the Tanjero Formation, and numerous fossils (commonly planktonic fauna) found in the formation, based on those fossils the Tanjero Formation is Late Campanian –Maastrichtian age.

The sequence stratigraphy and tectonics of the Tanjero Formation were studied in the Chuwarta province (Al-Mehaidi, 1975). The author observed that the Aqra Formation overlies the upper part of Tanjero Formation.

However, in the current researches, the method of Vail et al. (1977) has been utilized for the dividing of the rock body of the Tanjero Formation into depositional sequences, this is as a result of the correlation of conformities and unconformities which can be used to identify in Sequence studies.

Geologically Tanjero Formation can be defined as an upper Cretaceous (Campanian-Maastrichtian) Unit, which exposed in Balambo-Tanjero zone (imbricated) and high folded zones in Northeastern Iraq as adjacent Iraqi-Iranian border (Buday, 1980).

Al-Rawi (1981) comprehensively studied Tanjero Formation in term of sedimentology and petrology. The author stated that lower part of the formation at Sulaimaniyah area deposited in the shallow depositional environment, and the direction of the paleoflow stands toward NW, which is parallel to the axis of the Tanjero Formation trough. He also studied lithology of the formation interim of clay mineralogy and sandstone, and the sandstones were classified and plotted them on triangles based on Pettijohn (1975).

Al-Mutwali (1983) used the biostratigraphic tool to study the nature contact between Cretaceous and Tertiary sediments.

Abdel-Kireem (1986a) studied the Tanjero Formation, which is a part of sequence stratigraphy of Upper Cretaceous and Lower Tertiary period in Sulaimaniyah- Dokan Area. He suggested that changing the name of formation by removing the “clastic” word to situate its lower part of formation belongs to the Shiranish Formation.

Stratigraphy and planktonic forams of Tanjero Formation were studied in Dokan area by Abdel-Kireem (1986b), and the age of Middle-Late Maastrichtian given to the formation due to this study.

Al- Shaibani *et al*. (1986) studied the K/T boundary at Dokan area by using a stratigraphic analysis technique, and the contact between the Tanjero and Kolosh Formations was determined by existence a one meter thick bed of conglomerate which is considered as indicate for occurrence the stratigraphic gap from M. Maastrichtian to M. Thanetian.

Saadallah and Hassan (1987) made a sedimentological analysis of the Tanjero Formation in two chosen sections in Sulaimaniyah and Dokan provinces. The palaeoflow direction determined toward west and southwest.

Posamentier et al. (1988) point out that Sequence consists of a series of fundamentally connected deposition systems (systems tracts) and is inferred to deposited between eustatic-fall inflection points.

Galloway (1989) stated that the study of repetitive hereditarily is associated with depositional units, which are limited in portion by exteriors of non-deposition or erosion. Oppositely, the technique of Galloway (1989) has been rejected in modern studies because there is a difficulty in using this method to study the Tanjero Formation.

It has been informed that Sequence stratigraphy is mainly about the study of inherently linked facies within a context of chronostratigraphically important surfaces (Van Wagoner et al., 1990).

Jaza (1992) analyzed the sedimentary facies of the Tanjero Formation in the selected area; Dokan and Sulaimaniyah. It was supposed that the depositional environment of the Tanjero Formation has the turbidity and submarine fan characteristic of the basin.

Minas (1997) studied sequence stratigraphy of the Tanjero Formation for the first time. Also, it was conducted that the Tanjero Formation has deeper depositional environment than Shiranish Formation, and it was considered that the Tanjero Formation deposited during the transgressive period.

Minas (1997) was the first researcher who was able to characterize the arrangement in perspective of sequence stratigraphy. Generally, his research relied upon the past works on the stratigraphic sequence. The researcher comprised both the lower parts and the middle parts as sediment of TST and HST correspondingly.

Lawa et al. (1998) studied the upper part of the Tanjero Formation which is carbonate layers in Chuarta-Mawat region, and he thought that those carbonate layers belong to the Aqra Formation which interfingered with Tanjero Formation.

Al-Rawi and Al-Rawi (2002) defined the Tanjero Formation as turbidity sample of flysch form in north and northeastern part of Iraq. It conducted that the Tanjero Formation was deposited deep marine whereas the limestone layers deposited in a shallow environment.

Karim (2004) thought that the Tanjero Formation comprises from three parts depends on main lithological distribution in Sulaimaniyah region. The sedimentary structure, lithology and depositional environment have been studied in detail by Author.

Karim (2004), Karim and Surdashy (2005a) used sedimentary structures and direction of channels to determine the palaeocurrent direction toward southern and southwestern.

Karim (2005c) identified the source of the ball and pillow-like sedimentary structures in Tanjero Formation in Sulaimaniyah province, Northeastern part of Iraq.

Karim (2004) and Karim and Surdashy (2005b and 2006) mentioned that northeastern part of Iraq was transformed from passive boundary to active Early Zagros Foreland Basin as a result of Iranian and Arabian Plates collision. Furthermore, it has stated that a number of formations such as Tanjero, Kolosh, and Shiranish deposited in the foreland basin. They conducted that Late Cretaceous sediments; Tanjero and Shiranish Formations was come from change accretionary prism to source orogenic belt due to the collision. This collision can be noted obviously at Mawat, Chuarta, and Qandil regions by being approximately 500m thick layer of gravel and boulder conglomerate. The unconformity found under the conglomerate bed, which is unique ascertained unconformity, and it belongs to the late Campanian and Early Maastrichtian (Karim, 2004 and Karim and Surdashy, 2006).

The stratigraphy succession of Tanjero Formation Upper Cretaceous age studied in Sulaimaniyah Region, Northeast of Iraq (Karim and Surdashy, 2006a). The formation has been divided into two main sequences of deposition, which are lower and upper sequences, and there correlated in eight sections.

Karim (2007) studied Tanjero Formation in term of tempestite. The author found several sedimentary structures in the upper and middle parts of the Tanjero Formation, which deposited in shallow depositional environments. The sedimentary structures exposed by changing of the sediments by storms throughout accumulation of Tanjero Formation and the reworked sediments were either deposited as turbidites (transportation of sediments to deep water by turbidity currents) or deposited as tempestite.

The unconformity age within Tanjero Formation studied in Chwarta section, NE of Iraq (Sharbazheri, 2007). The author estimated the depositional period of the thick sequence of Kato conglomerate, red claystone layers in the Tanjero Formation by 1.23 M.Y. It was conducted that the Kato conglomerate indicates an unconformity at the lower part of the Formation.

Karim and Taha (2009) studied the depositional history of Tanjero Formation, which is a part of the Cretaceous basin, and palaeotectonic evolution of the area has analyzed due to this study.

Sharbazheri (2010) studied biostratigraphy in term of planktonic foraminiferal of reddish to light brown transitional sequence at the Upper Cretaceous in Smaquli region, Northeast of Iraq. He estimated that the deposition period of the reddish to the pale brown sequence, which is a transition unit between Shiranish-Tanjero, and the deposition duration of the chosen section projected by 2.150 m.y. And more.

Aqrawi et al. (2010) demonstrated that upper part of the Tanjero Formation characterizes as a Maastrichtian reefal facies in various regions in northeastern of Iraq, and associations of those reefal facies defined as an inner ramp, middle ramp and outer ramp facies relations.

Karim et al. (2012) determined the relationship between stratigraphic units which deposited in shallow and deep water throughout the Cretaceous period in High Folded Zone, North and Northeastern part of Iraq. The humble graphical model of spatial and temporal relationships created between shallow and deep Cretaceous stratigraphic units, and the lateral equivalent of Shiranish- Tanjero Formations (deep facies) is Aqra Formation (shallow facies). On the model, the deep facies in the southeast are transited and changed to the shallow facies in the northwest.

Lawa (2013) studied stratigraphy succession of foreland basin of the northeastern part of Iraq, which formed due to a collision between the Arabian Plate under ophiolite–radiolarites obduction of the Iranian plate. Stratigraphy succession of late Campanian–Maastrichtian which including Aqra, Shiranish and Tanjero Formation has been identified and analyzed by using facies analysis and biostratigraphic data (large foraminifera and planktonic).

Al-Nakib and Dhannoun (2014) studied the Tanjero Formation in terms of geochemistry and mineralogy analysis for collected samples through a section Dokan province, north Iraq. Consequently, it has noticed that there are sharp changes in the environments of source rocks in lower and upper parts of the formation.

Karim et al. (2014) studied the origin of fossiliferous limestone layers which crop out in northwestern of Sulaimaniyah governorate, Northeast of Iraq, and those beds are cropped out within the upper part of Tanjero Formation. Also, it has been proven that the age of the fossiliferous limestone beds is late Maastrichtian, which indicated that the beds belong to the Aqra Formation based on determining their age and petrography.

Zubaidi et al. (2016) studied the Tanjero Formation in terms sedimentology at Dokan section in the north of Iraq. It has discussed that carbonate rock layers units belong to the Formation have been subdivided into four beds based on petrography analyzing, fossil contents and diagenetic processes by using a polarized microscope to analyze thinned sections.

Hemin (2017) analyzed turbidities sandstones in Tanjero Formation as a clastic reservoir characterisation in the Upper Cretaceous, the northwestern part of Sulaimaniyah, Northern Iraq. The author studied facies analysis, porosity and permeability, petrographic examination and associated provenance category of the sandstones.

Tavan (2017) studied the Tanjero Formation as a deep marine low-density turbidites unit which is aged late Cretaceous, and the formation has been investigated in terms sedimentary petrography to realize its provenance around Arbat town, northeast part of Iraq.

Çelik and Salih T. (2018) stated that the Tanjero Formation was fed not only fed by Qulqula Radiolarian Formation which is consisting of only deep marine radiaolaria rich unit but also by shallow marine formations exhumed in the northeastern source area.

There are lacks in studying the turbidites of Tanjero Formation (Upper Cretaceous) in terms of petrography, depositional environment, reservoir characterisation and sequence stratigraphy in the Eastern Darbandikhan province, northeastern part of Iraq. This research will provide an opportunity to know the sequence stratigraphic characteristics of the unit for the several other geologists and other scientists who will work for oil firms in Iraq.

## 3. AIM OF THE STUDY

However, there is a limited work about sequence stratigraphy on Tanjero Formation around the Sulaimaniyah area, this will be the first sequence stratigraphy study on the turbidites exposure around Darbandikan area. The goal of this study is to examine sequence stratigraphy of Campanian- Maastrichtian clastic turbidities deposits close eastern part of Darbandikhan, northeastern part of Iraq. Also, this research will present possible reasons of the cyclic sedimentation, allogenic and/or autogenic controls on the cyclicity by finding cyclic orders in the turbidities, based on to find parasequences of the turbidite succession by field logging.

## 4. METHODOLOGY

### 4.1. Field Work

The following extensive fieldwork has conducted for achieving the aims and objectives of the present study**:**

Firstly, an exploration survey has been carried out in the selected area, which situated near the Iraqi-Iranian border in the Balambo-Tanjero and high folded zones. A study of general geology and stratigraphy relations of the upper Cretaceous formation involved in order to select an appropriate outcrop section for the present study. Then, suitable traverse has selected in the outcrop section for measuring and sampling and description in details, this is consists of description type of logging lithology, lateral and vertical changes, distinguishing and identifying sedimentary structures and stratigraphic relation of the formation with surrounding formations in terms outlining and determining the attitude of the lower and upper boundaries.The collecting samples taken along the traverse line through measuring process concerning the lithological changes through the Tanjero Formation and samples have been carefully collected from the fresh surface with recording field note in details, in order to acquire accurate and useful information for the present study. Moreover, the palaeoflow or palaeocurrent direction (PFD), flute marks, imbrication, groove marks and tool marks are measured and analyzed by using a compass.

### 4.2. Lab Work

It includes the following steps;

The collected samples crushed into grain size or friable sediments by using machine mill. Then, the friable sediments soaked in water, and two spoonfuls of hydrogen peroxide ($H_2O_2$) with 15% concentration added to the water mixture, the mixture was left soaking for a night. After the soaking stage overnight, the spoonful of sodium bicarbonate (Na2HCO3) was added for the mixture and the cooking procedure on the hot plate for at least five hours have conducted. Next, the cooked samples washed with water remove clay, and clean remains sediments dehydrated in the oven in order be prepared for sieving process. Then, in the sieving process six sieves (of the mesh 10, 20, 40, 60, 80, 100) were utilized for separating the sediments into dissimilar fractions, then all sieved samples were placed in the oven for 10 to 15 minutes under temperature 60 to 80 C to be prepared for study under the reflector light microscope. In the final stage, the different species of microfossils practically foraminifera were picked out and selected fossilis studies and determined the species and origin of fossilis on the lab under micriscipe.

### 4.3. Office Work

This section is related to the computer programs which can be utilized for measuring and calculating the necessary parts of the report, which are almost impossible to be done by hand. Finally, with the help of the mentioned program, the calculated number of the samples can label on the log successfully. Additionally, the parasequence and parasequence sets have identified and marked on the logs for determining sequence stratigraphy of the formation.

## 5. LOCATION

The study area of the present thesis is located in about 20 km eastern of Darbandikhan district, around 70 km to the southeast of Sulaymaniyah city centre, in the northeastern part of Iraq near boundary of Iran (Figure 5.1 and 5.2). The geographic coordinate of the study area extends from latitude 35° 04' 38"- 35° 06’ 17" N, and longitude 45° 53' 50" - 45° 54' 35" E. The formation outcrop sited near Darbandikhan Dam Reservoir, near Sarshata village.

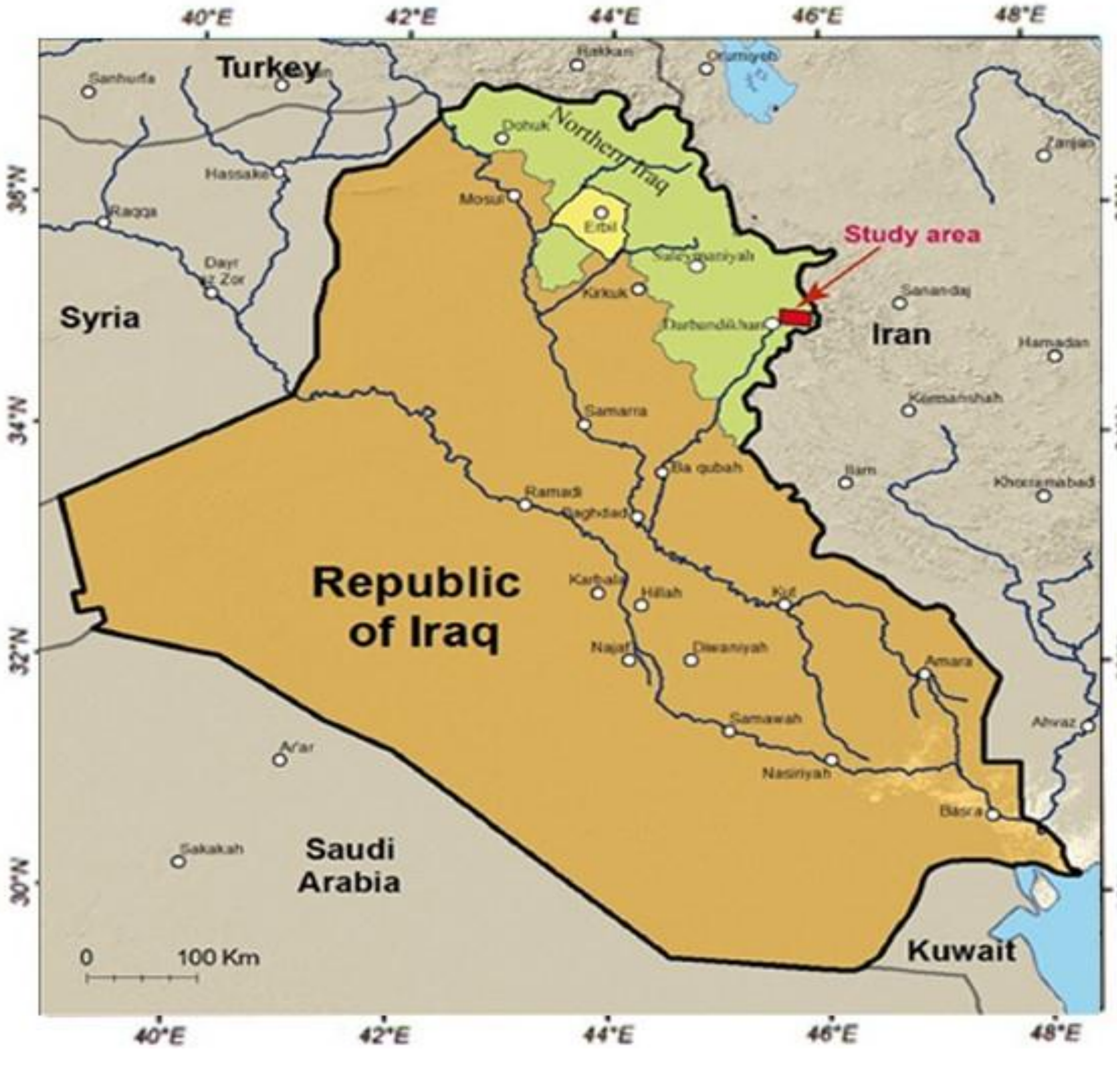



**Figure 5.1.** Location map of Darbandikhan (URL-1). Boxed area represents the location of the study area for this work.

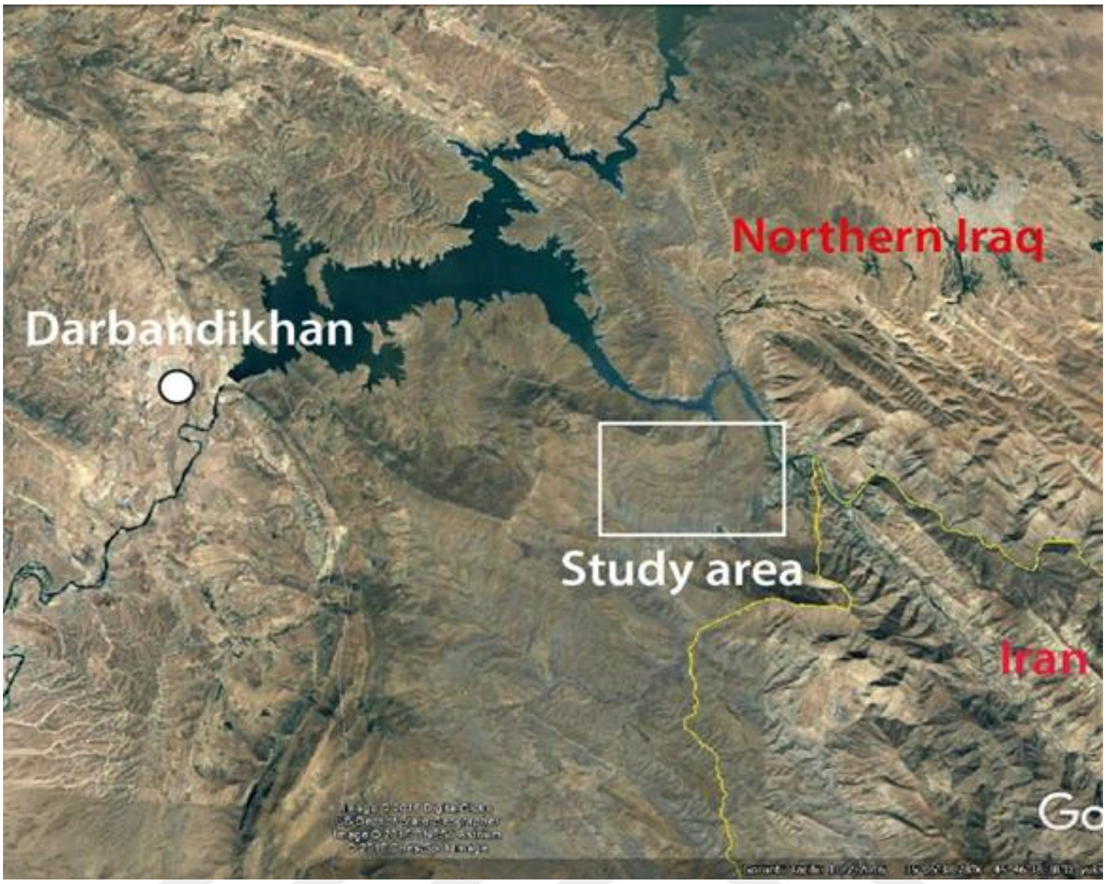



**Figure 5.2.** Close up view of the study area located to about 20 km east of Darbandikhan (Google Earth image).

# 6. GEOLOGICAL SETTING

Tectonically northern part of Iraq comprising the study area belongs to the northwestern extension of the Zagros Mountain series (the Zagros Fold and Thrust belt) and the northeastern part of the stable Arabian Platform (Buday and Jassim, 1987). Zagros folds and thrust belt formed due to the convergence between Arabian and Iranian plates, and it also formed the result of the closing of the southern part of the Neo-Tethys's Ocean (Ahmed, 2013) (Figure 6.1).

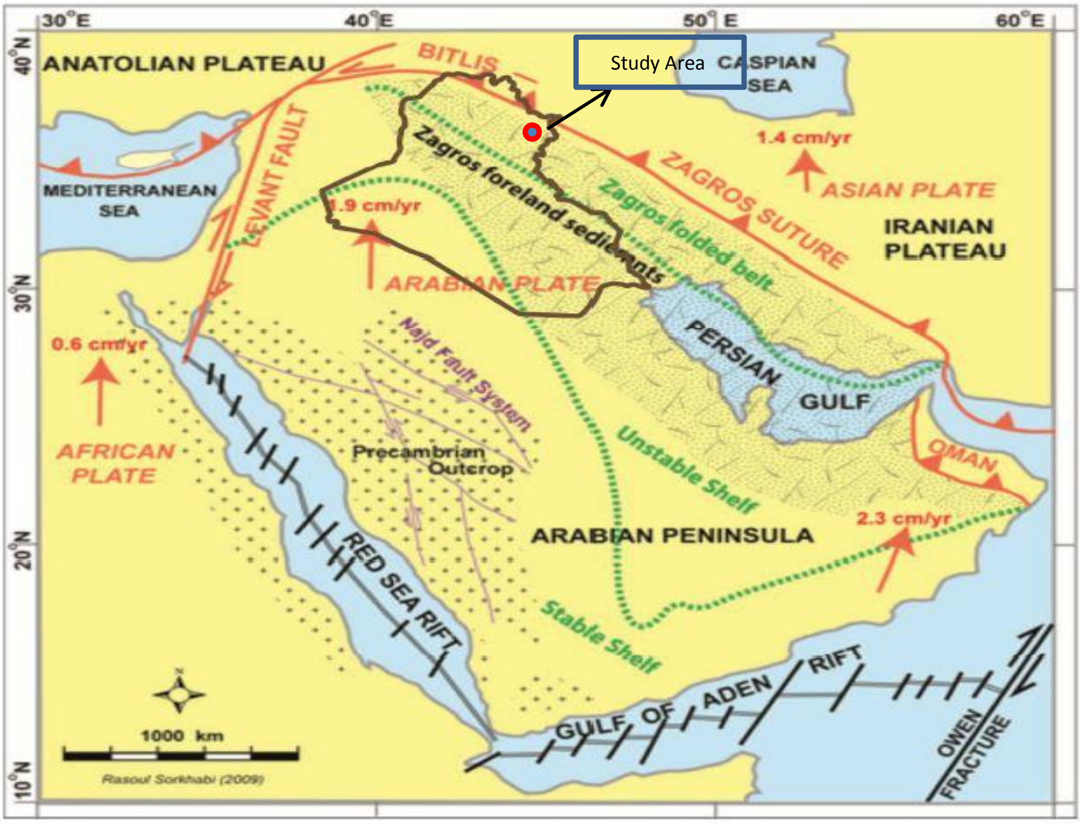



**Figure 6.1.** Main tectonic sub-divisions of the Arabian plate and location of Iraq (Ahmed, 2013).

Moreover, first tectonically Iraq has been divided into four zones; Mesopotamian, Foothill, High Folded and Geosynclinal Zones, which are going to an unstable shelf (Fouad, 2010). Then the tectonic division has been developed to those zones; low folded, high folded, imbricated zone, suture (thrust) zones which belong to the stable and unstable shelf (Jassim and Goff, 2006; Aqrawi et al., 2010) (Figure 6.2). Structurally the study region is situated in High Folded Zone and Balambo-Tanjero zone which is represented by a number of topographically high anticlines and deep synclines such as Bammo anticline, Shmee-ran anticline and Balambo anticline, etc. (Fouad, 2014).

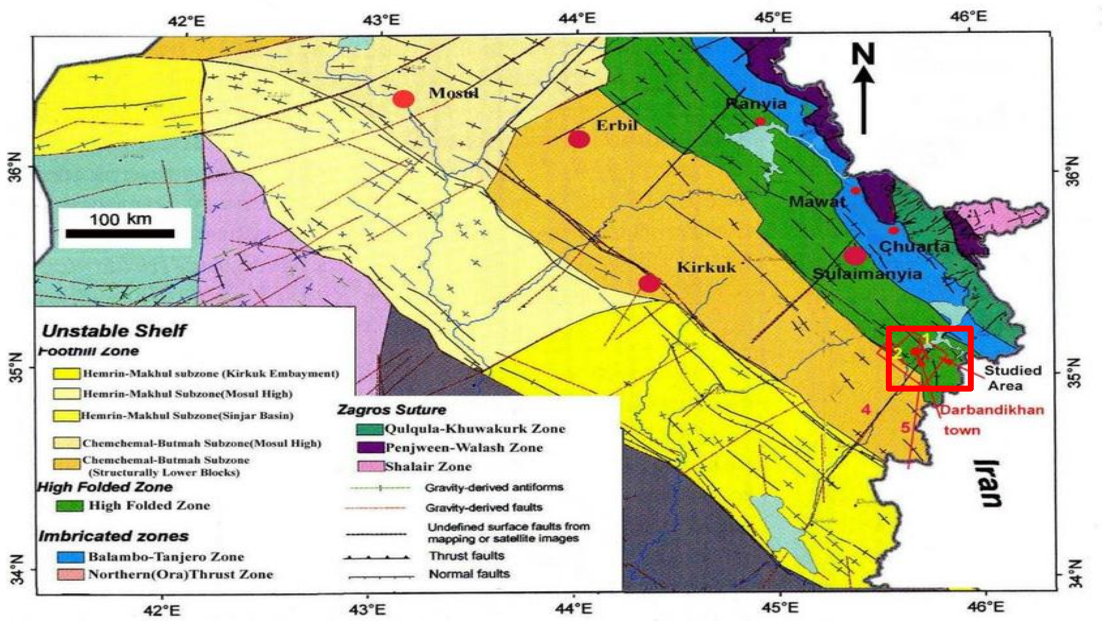



**Figure 6.2.** Tectonic subdivision map of northern Iraq (after Jassim and Goff, 2006)

General geology of Darbandikhan region offers to earth scientists' remarkable structural elements, particularly fold progress and thrusts in a well outcropped accretionary wedge alongside the border of Iran. Also, there are several carbonate formations in the study site, which are good reservoirs for oil and gas or hydrocarbons. Therefore, numerous general geological studies have undertaken by geologists in the folded zone of northern Iraq.

There are numerous geological studies have been done on the Tanjero Formation in the different aspects, principally in general geology works by researchers in northern part of Iraq while there are lack studies in the selected area around Darbandikhan district especially on sequence stratigraphy of the turbidites clastic exposure which is the theme of the present study. The present study will be the first work about sequence stratigraphy in the selected area. Several previous works have mentioned in the previous work chapter (Karim 2004 and Karim and Surdashy, 2006).

A spectacular sheet-like turbidite which belongs to the Tanjero Formation was deposited in the north east limb of Shmee-ran anticline from deep marine fan turbidites in the eastern of Darbandikhan district. Furthermore, as result of elevated thrust sheets, flysch facies of the Tanjero Formation formed and developed as turbidites in the Balambo-Tanjero Zone at late Campanian- early Maastrichtian (Jassim and Goff, 2006) (Figure 6.3).

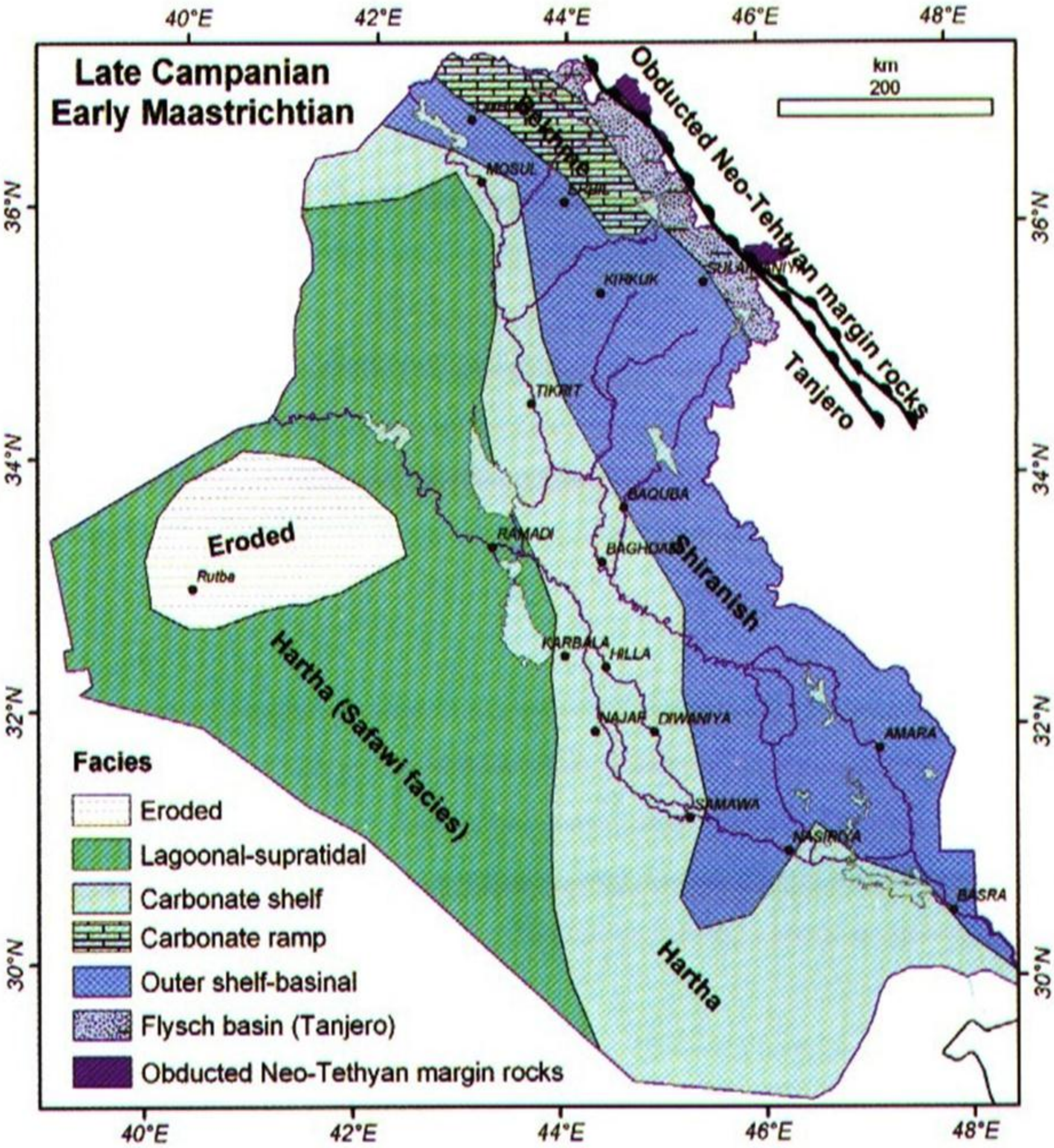



**Figure 6.3.** Late Campanian- Early Maastrichtian paleogeography map (after Jassim and Goff, 2006).

A comprehensive geological map of the northern part of Iraq was created by Sissakian (2005) (Figure 6.4). It can be seen that tectonically Darbandikhan area is situated in the high folded zone and adjacent to the imbricated zone in the northeastern part of Iraq along to the border of Iran.

The weathering resistive outcropping formations around Darbandikhan district are changeable from Cretaceous to Pliocene (Figure 6.4) which are followings from oldest to youngest; Balambo Formation (Valanginian-Turonian), Qamchuqa Formation (Hauterivian-Albian), Kometan Formation (Turonian-Santonian), Shiranish Formation (Late Campanian-Early Maastrichtian), Tanjero Formation (Late Campanian-Maastrichtian) and Aqra Formation (Maastrichtian) and those formations cover core of anticlines in the area. Lithology and stratigraphic positions of the formations can be seen in Figure 6.4 and 6.5 (Bellen et al., 1959).

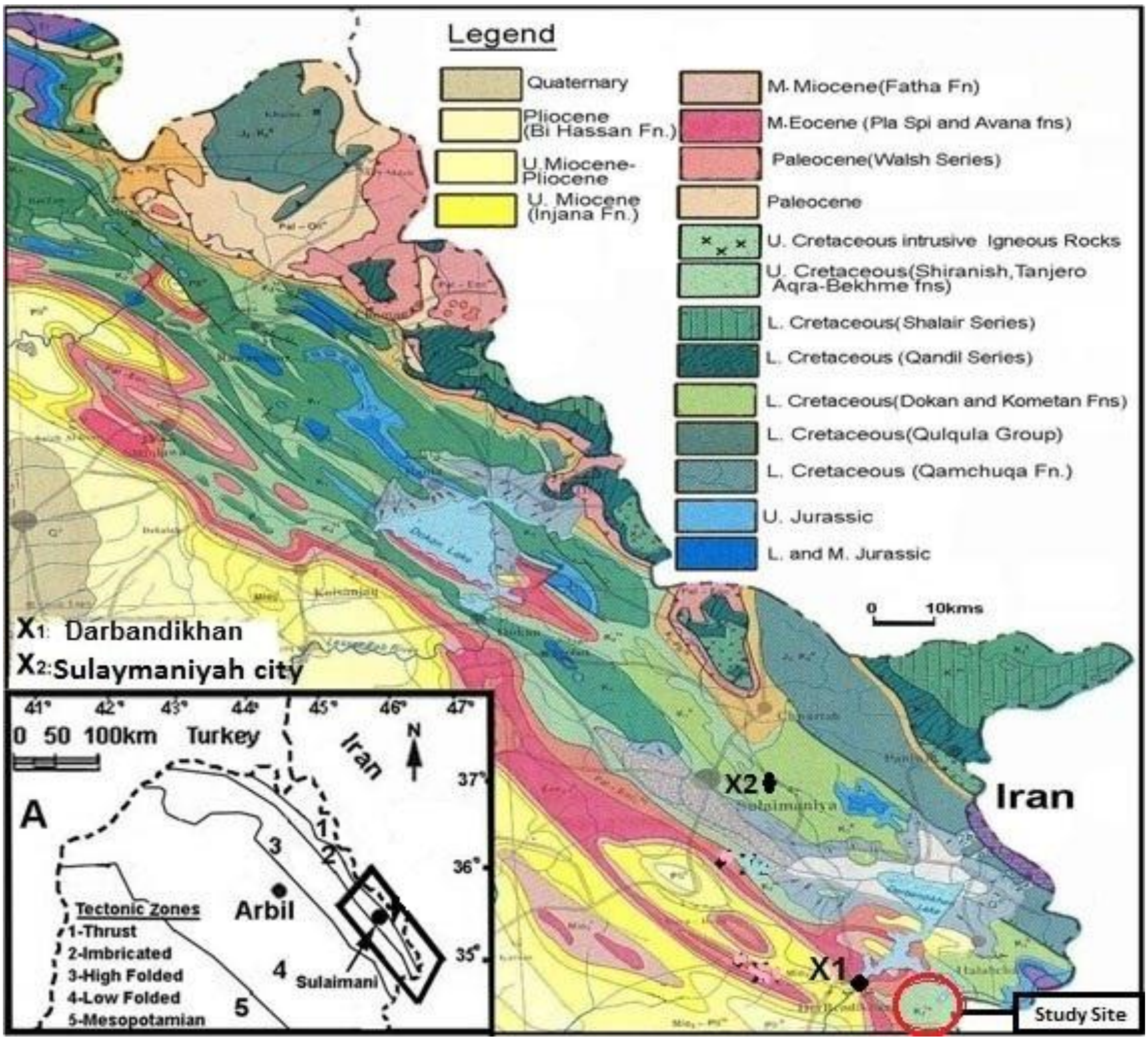



**Figure 6.4**. Geological map of the Sulaimaniyah area (Sissakian, 2005). The red circle on the geological map shows the location of this work.

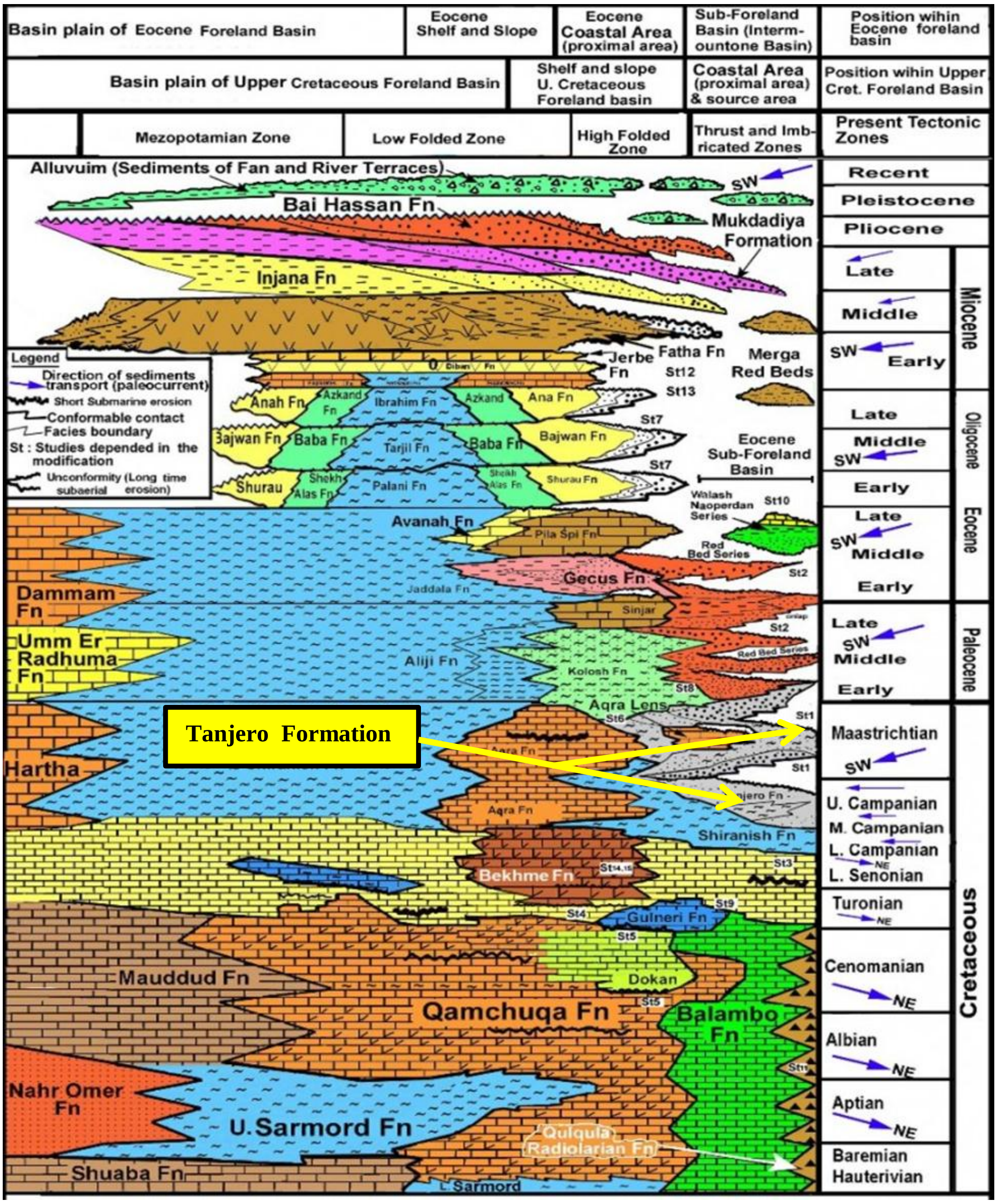



**Figure 6.5.** Chronostratigraphic columnar section of northern Iraq during the Cretaceous and Tertiary (Karim, 2010).

Several formations outcrop around the Darbandikhan area and which described below:

Balambo Formation composed from two parts; the lower part consists of bedded ammonitiferous limestones with intercalation of clastics; marls and shale while the upper part contains thin bedded globigerina limestone transient down to radiolarian limestone (Ahmed, 2013).

Qamchuqa Formation campsites of thin-bedded limestone. Mostly vulgarly crystalline, rhombic, granular, and mosaic dolomites substituting neritic, organic limestones with molluscan detritus (Qadir, 2008).

Kometan Formation consists of marly and limestone. Also, there are alterations in facies between purely globigerional limestone with secondary oligostegial inter-beds and commonly oligosteginal facies (Al-Khafaf, 2005).

The shiranish formation comprises pelagic marls, dolomitic limestone, and marly limestone beds, which are rich in micro-fauna (Buday, 1980).

Tanjero Formation is composed of an alternation of clastic rocks between sand and calcareous shale and thick beds of the conglomerate in the field (Bellen et al., 1959) (Figure 6.6). Tanjero Formation will be studied in this study in terms of sequence stratigraphy.

Aqra Formation composed from massive and thick bedded of limestone and dolomitic limestone, and depositional environments of the formation are a reef, back reef and fore reef (Buday, 1980 and Zebari, 2010). There are various types of fossils in the Aqra Formation; the rudists is the most common type. Also, foraminifera and other microfossils can be seen frequently in the formation.

**Figure 6.6.** Deep marine turbidites of Tanjero Formation. 20 km East of Darbandikhan, Northern Iraq. View to the West. (Aland Mahfoth as a scale for the photo representing cyclic turbidites in the area. The dark level where Aland put his hand on is a debris flow deposite.

# 7. TANJERO FORMATION

## 7.1. Definition

The unit of bedded clastic rocks was initially termed the Tanjero Formation by Dunnington in 1952 (Jassim and Goff, 2006). In the previous work chapter of the present thesis, all authors studied the Tanjero Formation in various aspects after the first definition, and it was generally accepted the formation name it is. Because of the Tanjero Formation is one of the most important formations in the area as a reservoir rock.

## 7.2. Outcrop Distribution and Stratigraphic Contacts

The Tanjero Formation is widespread in the high folded zone (Balambo-Tanjero zone) and imbricated zone in the northeast part of Iraq and south-west of great Zab river (Dunnington, 1952). The selected section exposed in Sirwan gorge, around Darbandikhan town, southeastern of Sulaimaniyah governorate, northeast of Iraq. The outcrop of the Tanjero Formation exposes from northern lime of Shmee-ran Anticline near Iranian boundary (Figure 6.4.) (Bellen et al., 1959). The Tanjero Formation is underlain by the Shiranish Formation as a gradational contact, and the lower contact can be identified by initial presence of the grey sandstone or siltstone beds on the Shiranish Formation (Figure 6.5). The Tanjero Formation starts with a greenish olive lithology (Karim, 2004) (Figure7.1 and 7.2). Also, the Kolosh Formation overlies the Tanjero Formation in the High Folded Zone which is upper contact of the Tanjero Formation, and it was defined as unconformable contact (Figure 6.5) (Jassim and Goff, 2006). However, in the recent researches, the upper contact was found as a conformable contact by studying the foraminifera bio-zonation (Sharbazheri et al., 2009). Wide view of the Tanjero Formation can be seen in Figure 6.5, and also sandstone beds within the formation in the study area shown in Figure 6.6. which are exposed in the lower part of the Tanjero Formation.

**Figure 7.1.** Panoramic view of the Tanjero Formation in the selected section, near Darbandikhan town.

**Figure 7.2.** Sandstone beds in the lower part of Tanjero Formation in the selected section.

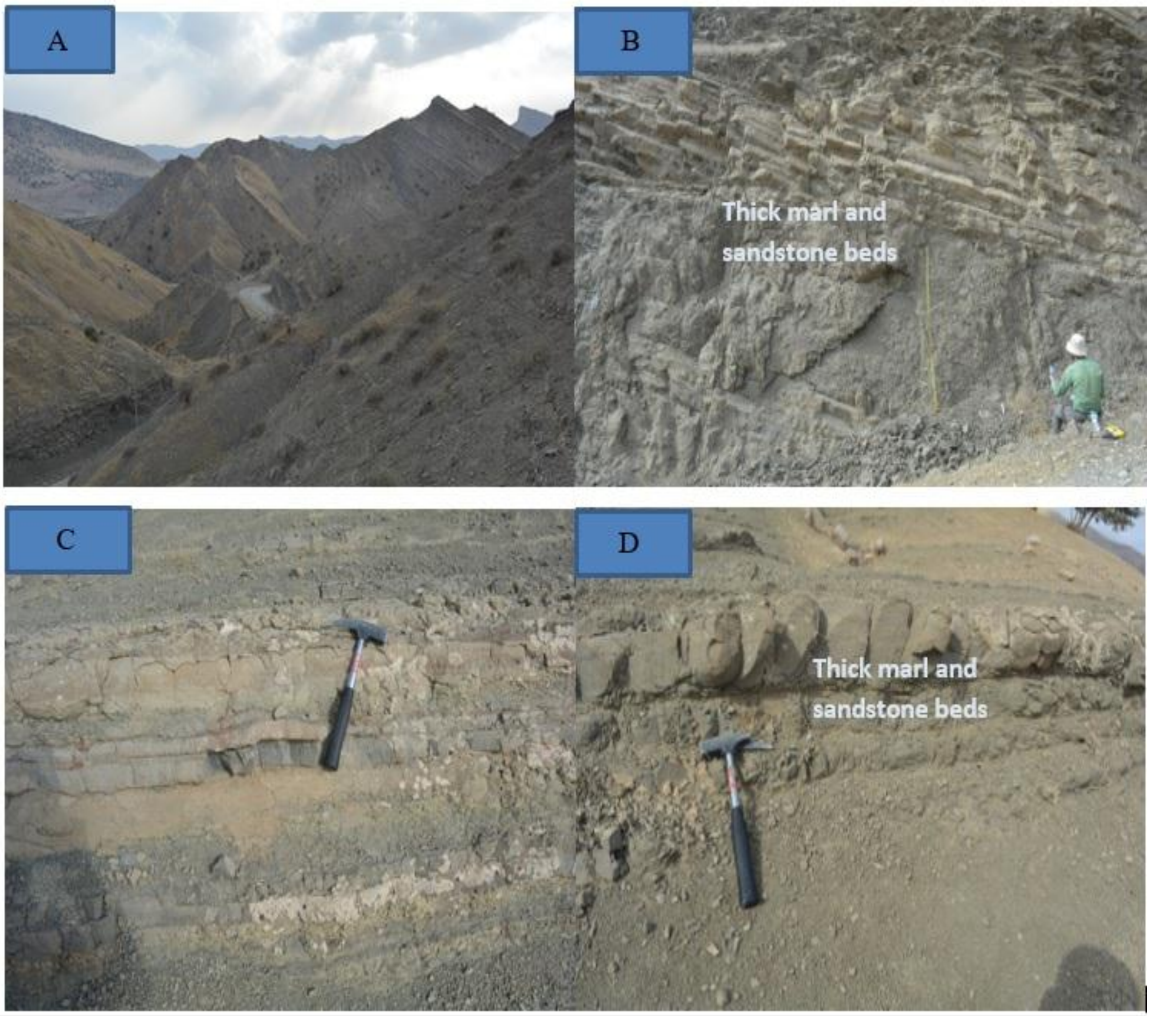
### 7.3. Lithology

It has been described in the most previous studies that the Tanjero Formation mostly comprises of alternation clastics rocks; shale, marl, siltstone, sandstone and conglomerate, and according to this alternation the formation has divided into three parts (Abdel-Kireem,1986; Stevanovitic et al. 2003, Karim, 2004) (Figure 7.3.A). The lower part of the formation in the nominated type section which is contacted with the Shiranish formation starts with light grey to dark grey or greenish grey (olive) colour of thick marl and shale beds with thin beds of siltstone and thin sandstone beds, and this part is about 250 m to 300 m. This lithology also has been reverted to the lower unit of the Tanjero Formation by

Karim and Surdashy (2005) (Figure 7.3.B, C and D). The middle part is the thicker unit of the formation which is around 900 m to 950m thick and starts from 250-300 m to 1150-1200 m, it is mainly composed sandstone beds and siltstone, and the thickness, grain size and occurrence of sandstone beds increase from lower part until the end of the middle part. There are a number of thick turbidite beds in the middle unit, which is composed of siltstone and sandstone and pebble of conglomerate (Figure 7.3.E and F). The upper part composes the thick bed of conglomerate, and thin beds of sandstone and thick beds of shale and this unit are almost 180m to 200m which starts from 1150-1200m to upper contact with Kolosh formation, and Karim and Surdashy (2006) resumed this kind of lithology to the upper unit of the formation. Moreover, the numbers of sedimentary structures have been seen in all part of the formation, and they have been mentioned in the paleocurrent directions section (Figure 7.3.G and H).

The selected type section of the Tanjero Formation for this study has been separated into three parts. The total thickness of the formation is around 1333 m from lower to upper contacts.

There is an agreement between this study and previous studies that the Tanjero Formation has been divided into three units into various areas in north Iraq. Karim (2006) separated the formation into three units in several different areas in the imbricated and high folded zone, for example, in Chwarta, Qandil Mountain, Mawat and Dokan type sections, but there are dissimilar in terms of lithology and thickness of units in each type section. On the other hand, some previous studies divided the Tanjero Formation into two parts into several regions in the north of Iraq. Sharbazheri (2007) considered that the formation consists of two parts in Chwarta region. Furthermore, Al- Zubaidi et al. (2016) studied the Formation in the Dokan region and mentioned that the Tanjero Formation is composed of three parts. However, Hemin (2017) divided the Tanjero Formation into two units of alternation siltstone, sandstone and conglomerate with silty, sandy and marly organic limestone and in the northern of Sulaymaniyah governorate. Generally, the Tanjero Formation is composed of the alternation of clastic rocks in the north of Iraq either it is divided into two or three parts.


A
B
Thick marl and
sandstone beds
C
D
Thick marl and
sandstone beds

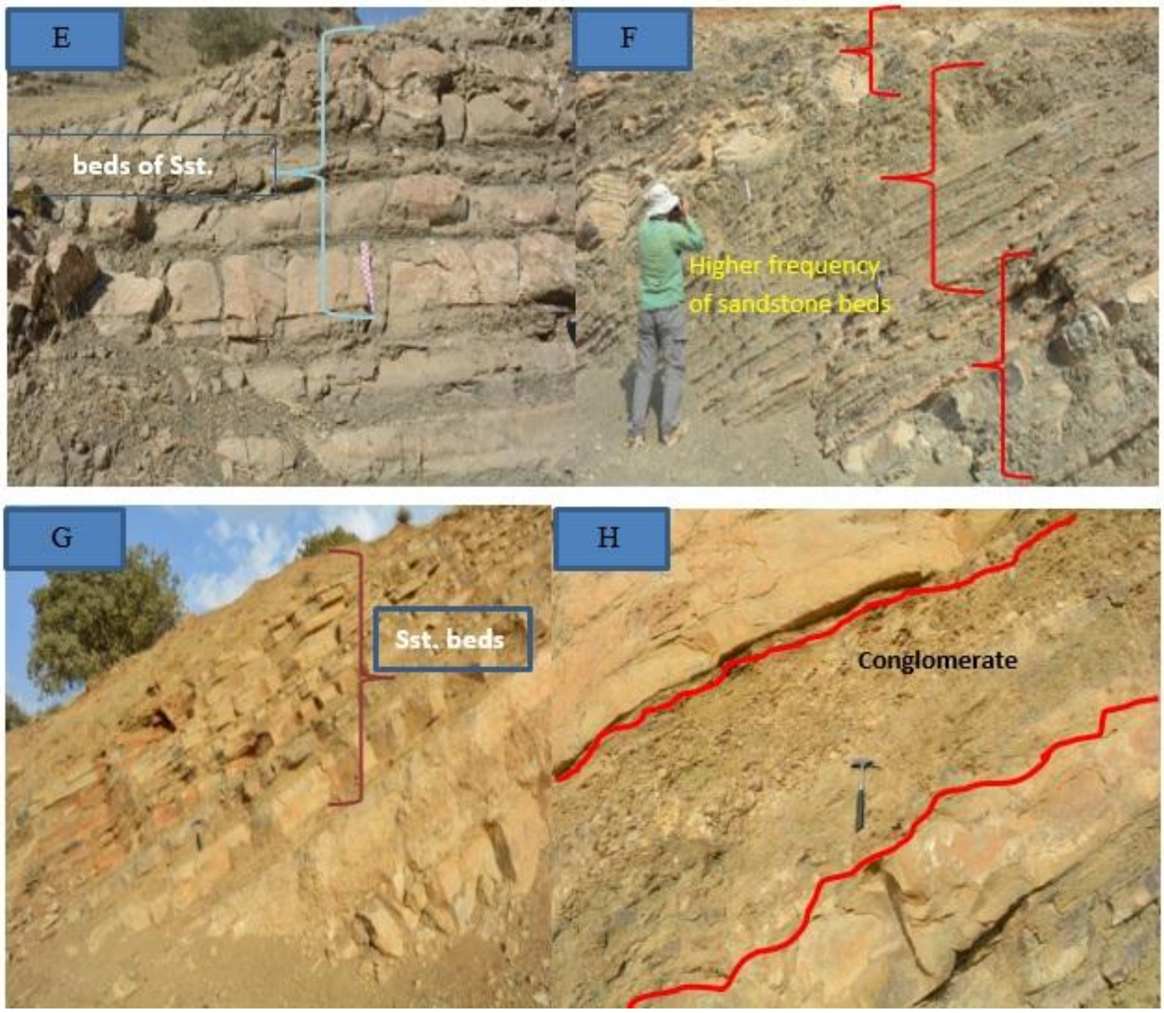



**Figure 7.3.** A: Outcrop exposure of the formation B: Lower part (shale and sandstone) C: Lower part (shale and sandstone) D: Lower part (shale and sandstone) E: Middle part (sandstone and thin shale) F: Middle part higher Sst. Repetition G: Upper part (sandstone) H: Upper part (sandstone and thick conglomerate)

## 7.4. Measured Section

One measured section was taken in detail near the Iranian border at Sirwan gorge around Sarshata village, Darbandikhan town. The thickness of the section is approximately 1333 meters (Figure 7.4 and the logs starting on the page number 27).

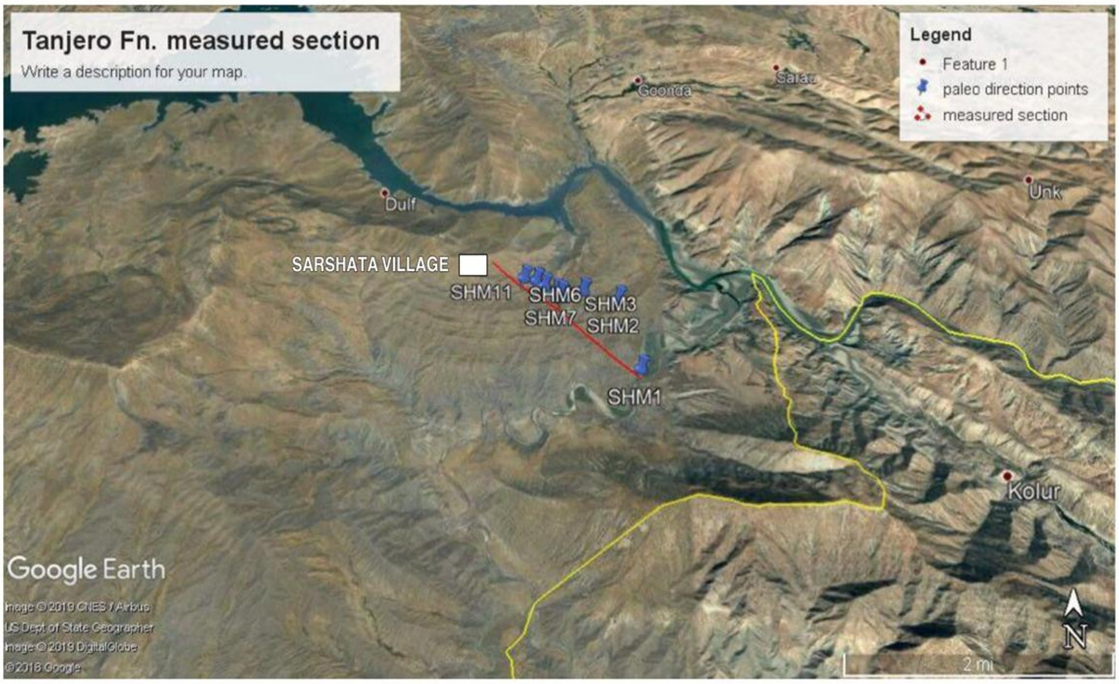
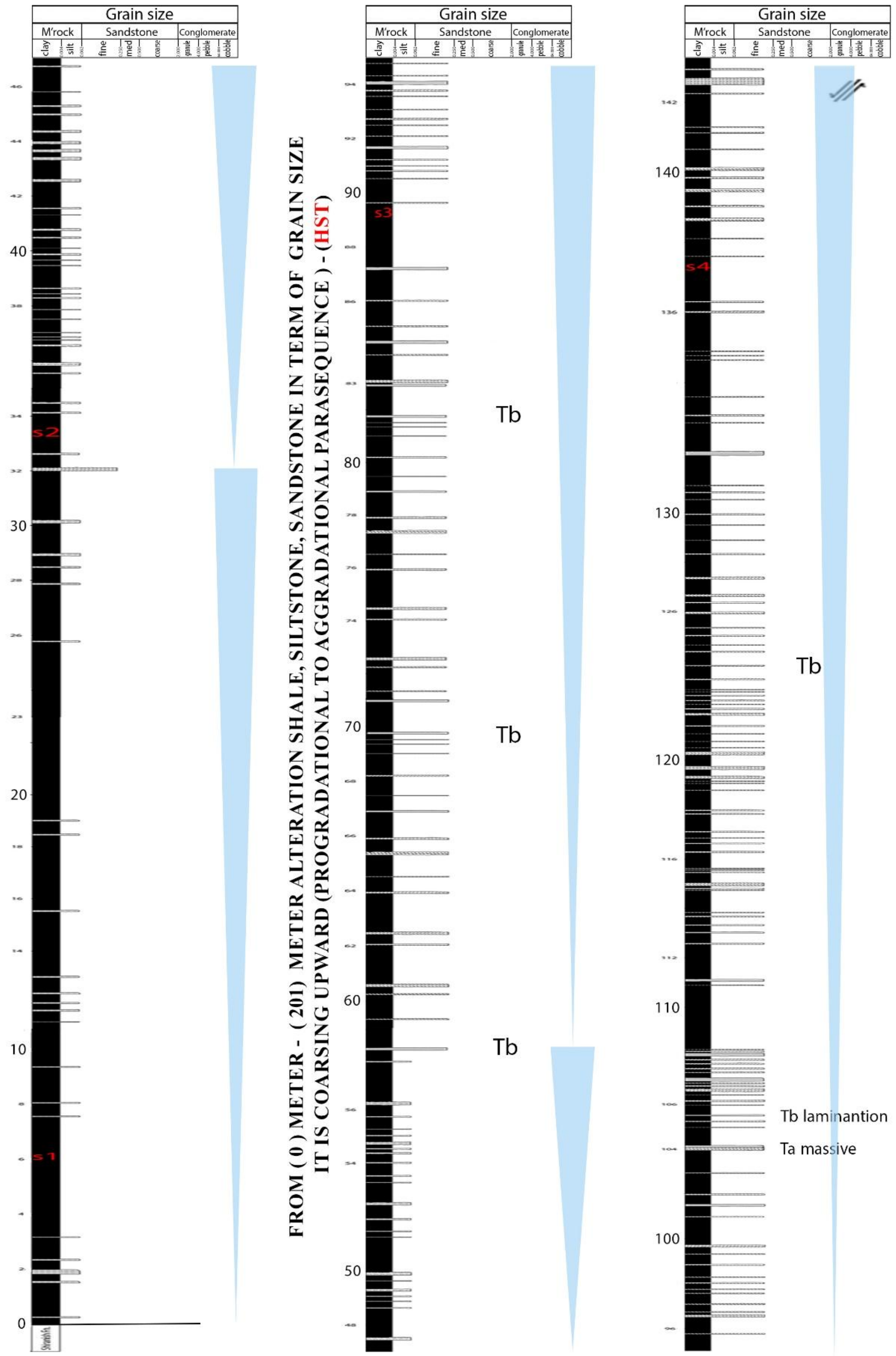
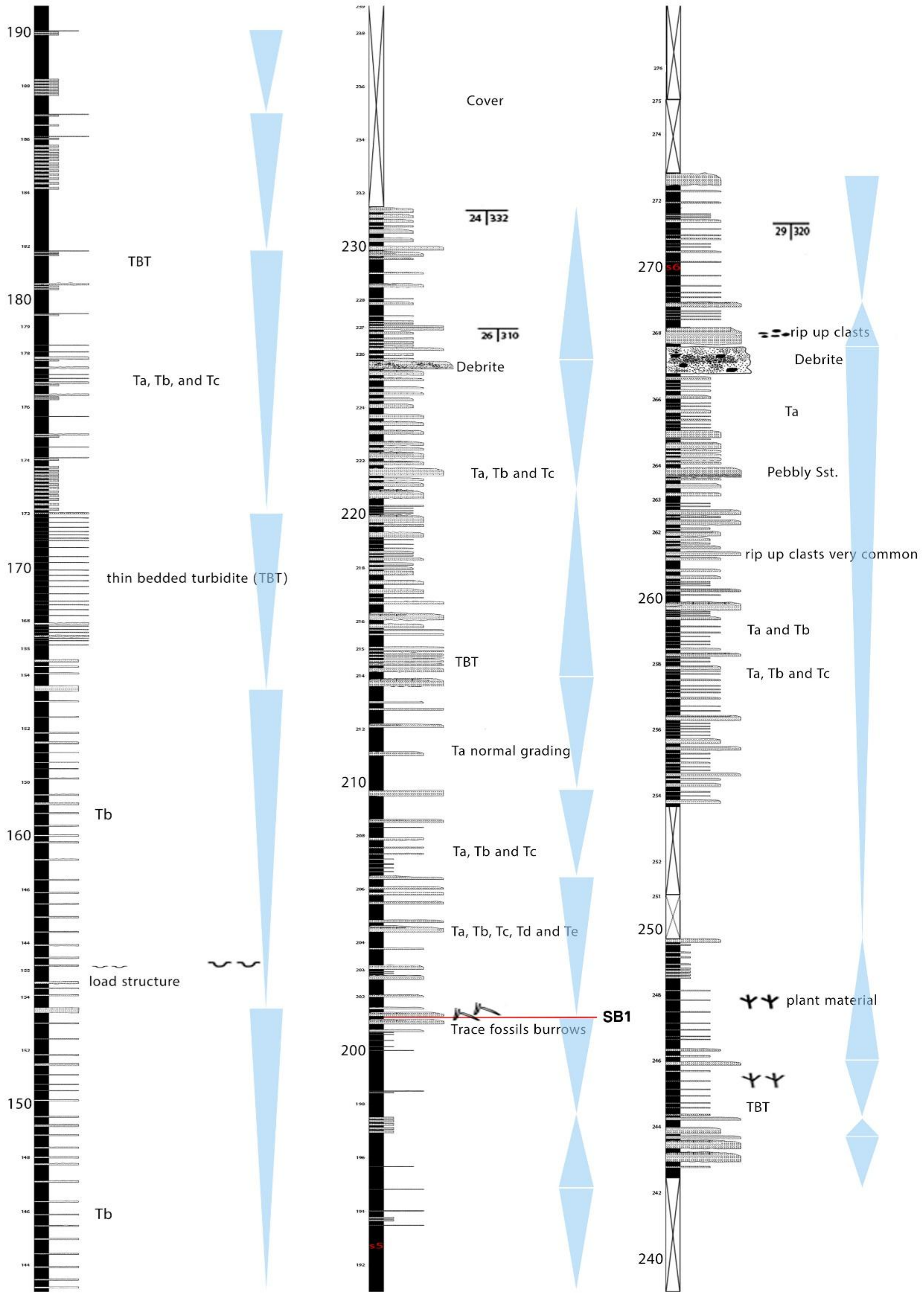


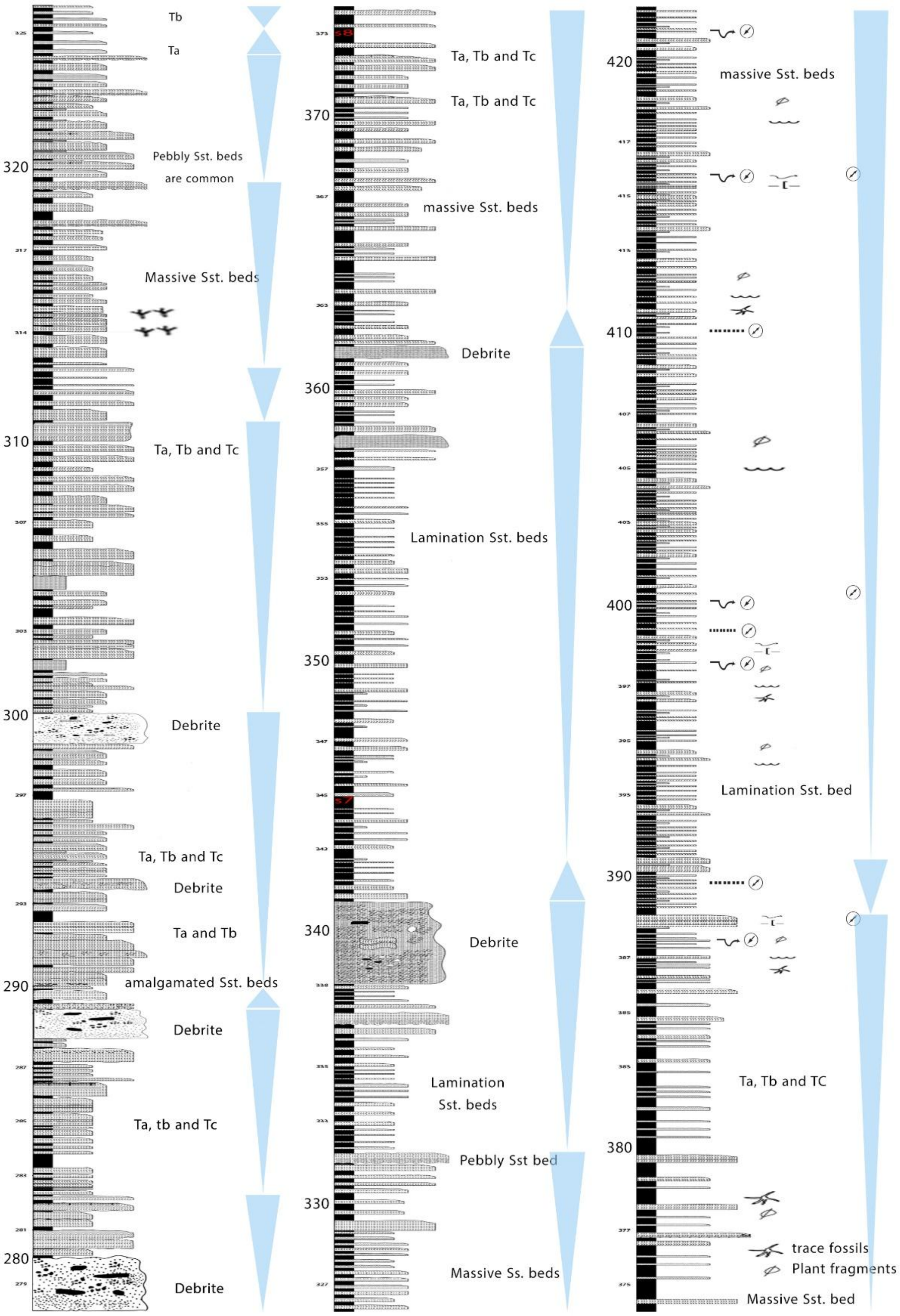

**Figure 7.4.** Google Earth image shows the study area around the Sarshata village. Redline is representing the logline.



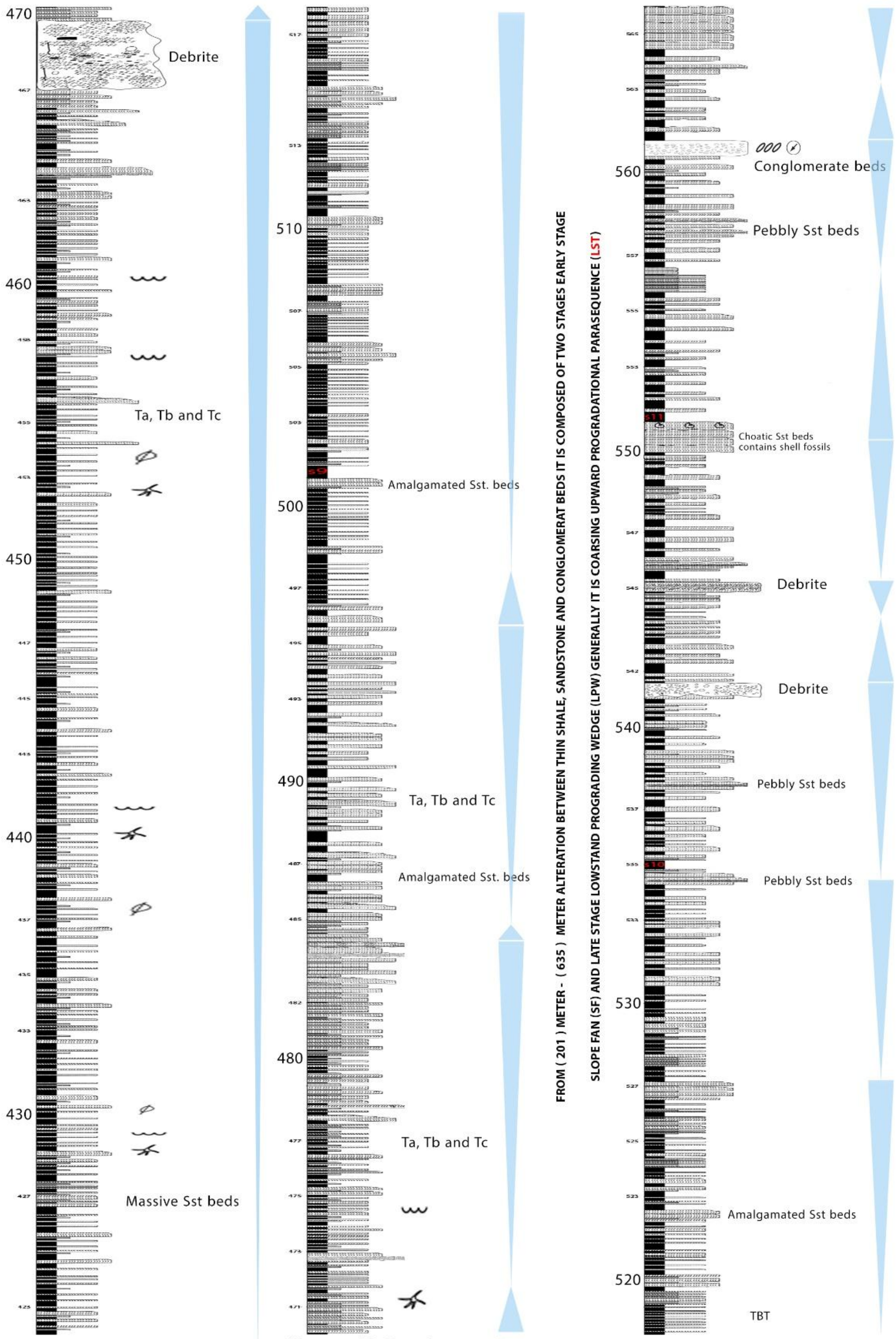

Sirwan Valley Log 1-1



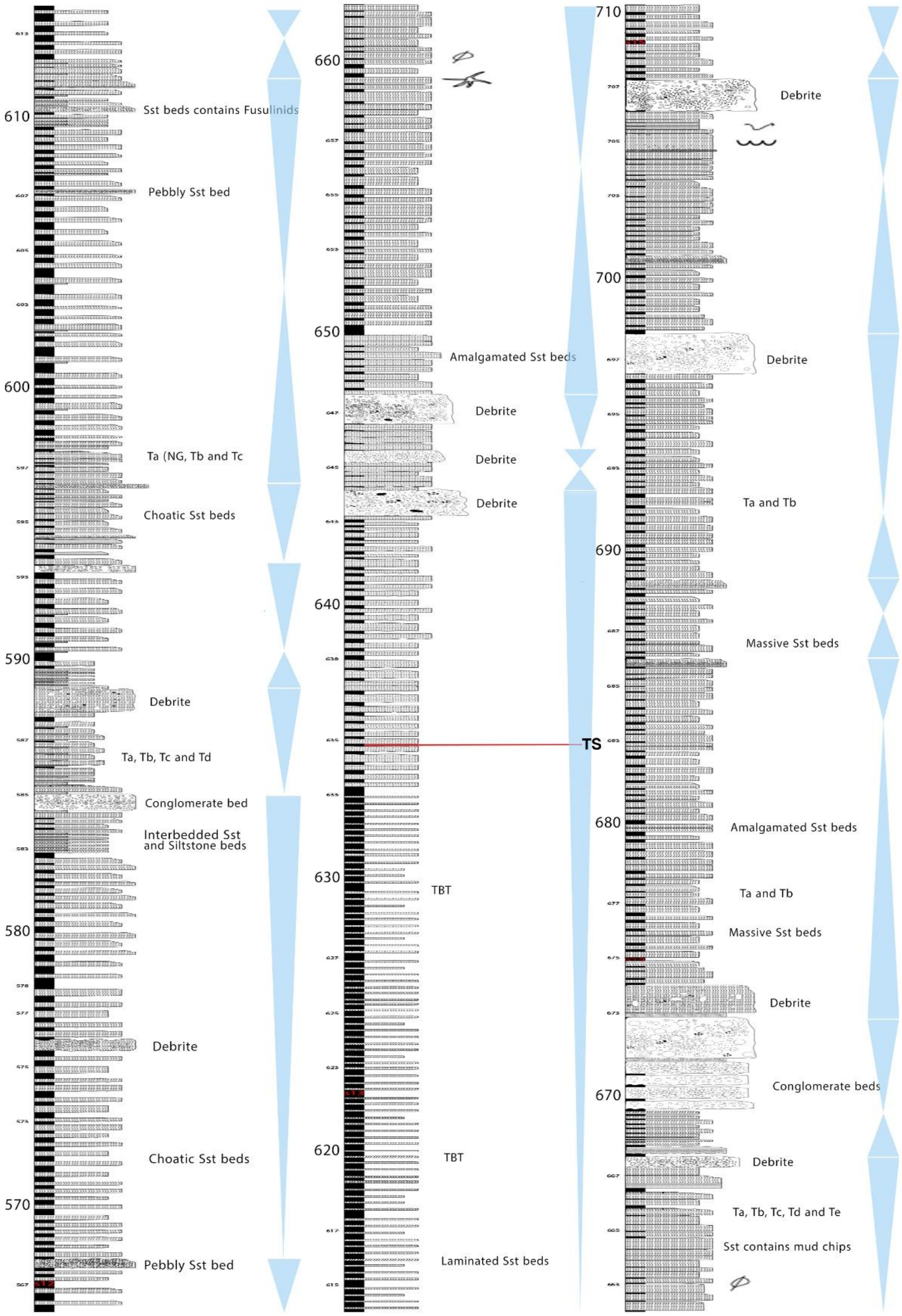

Sirwan Valley Log 1-2



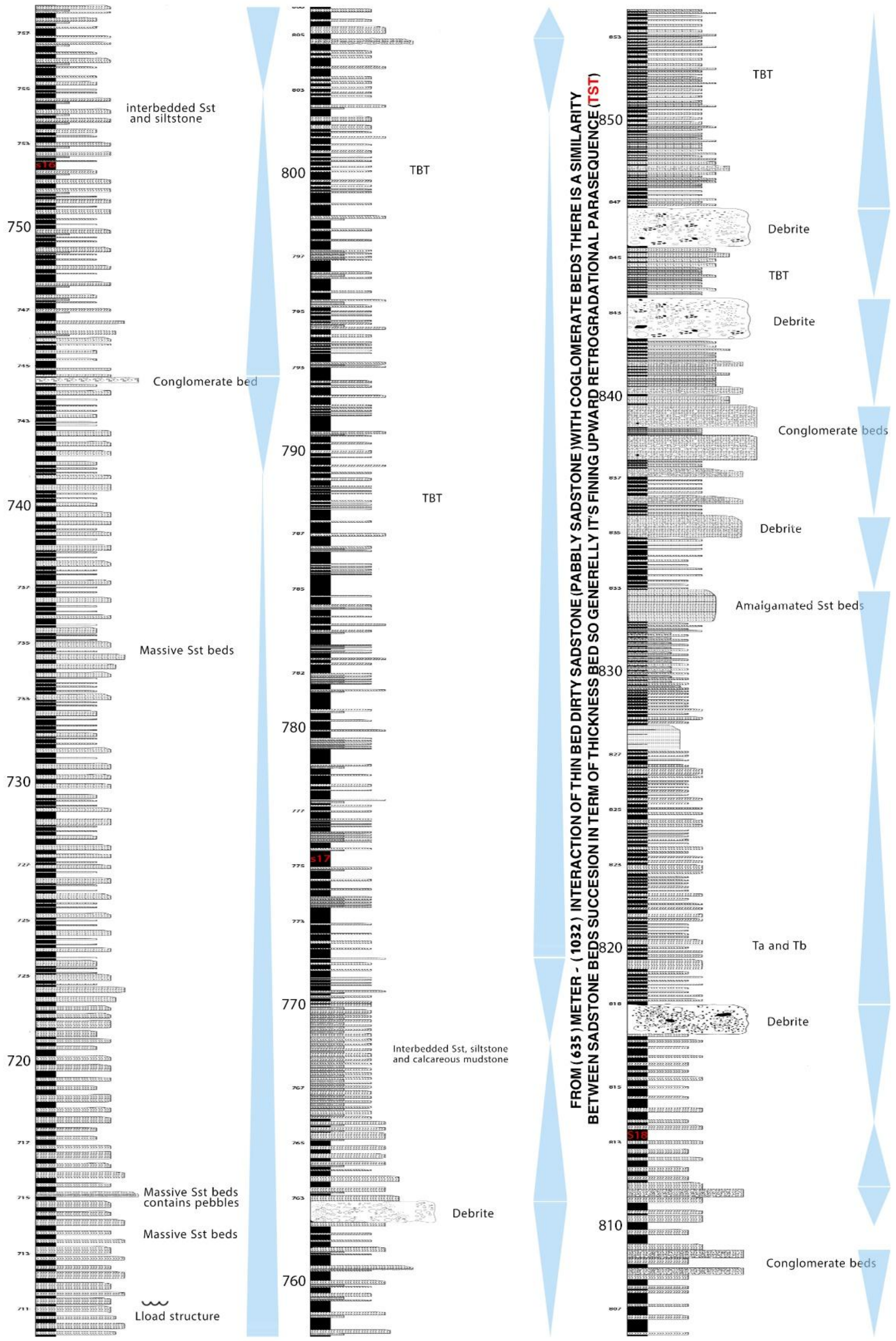

Sirwan Valley Log 1-3



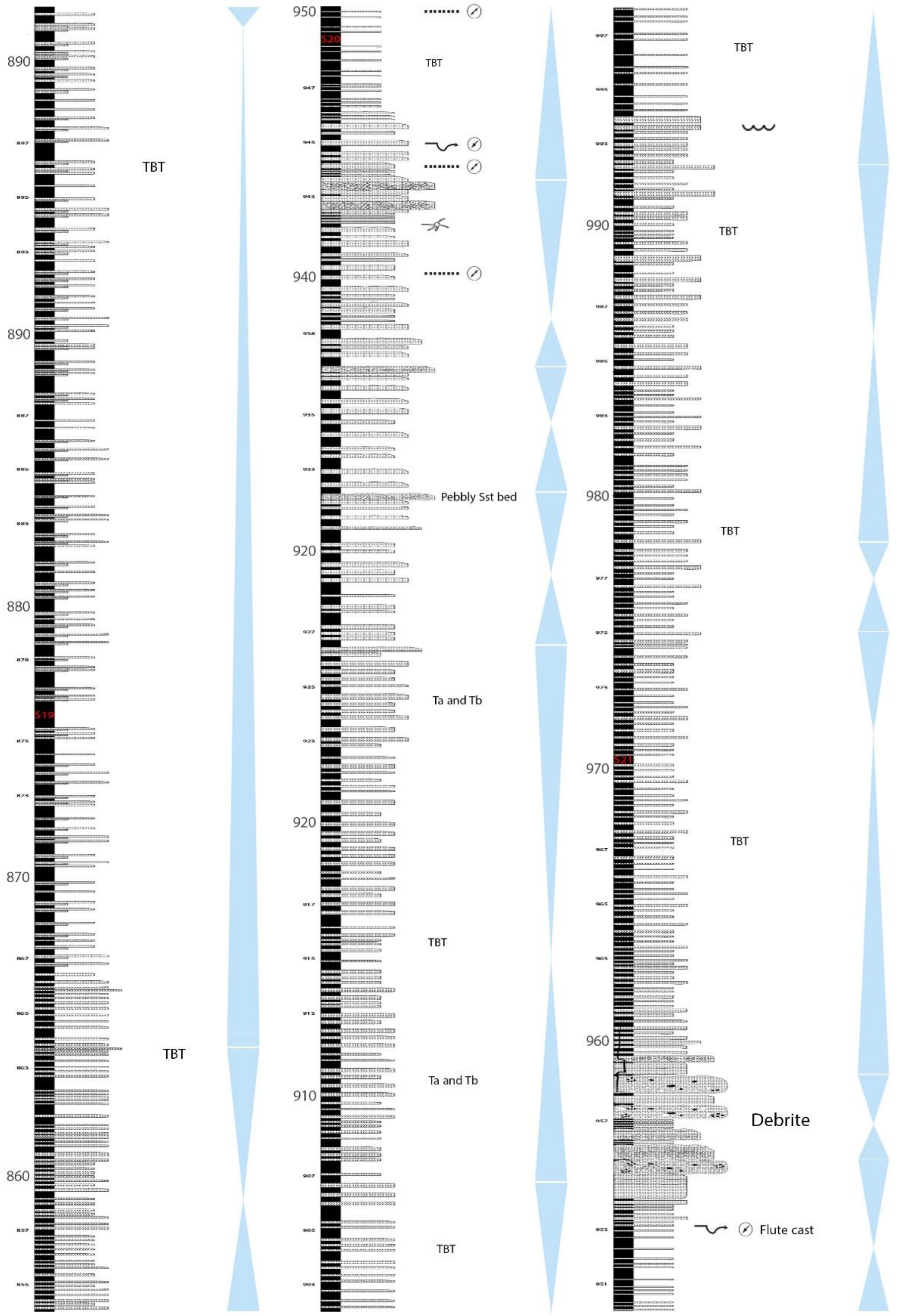

**Sirwan Valley Log 1-4**



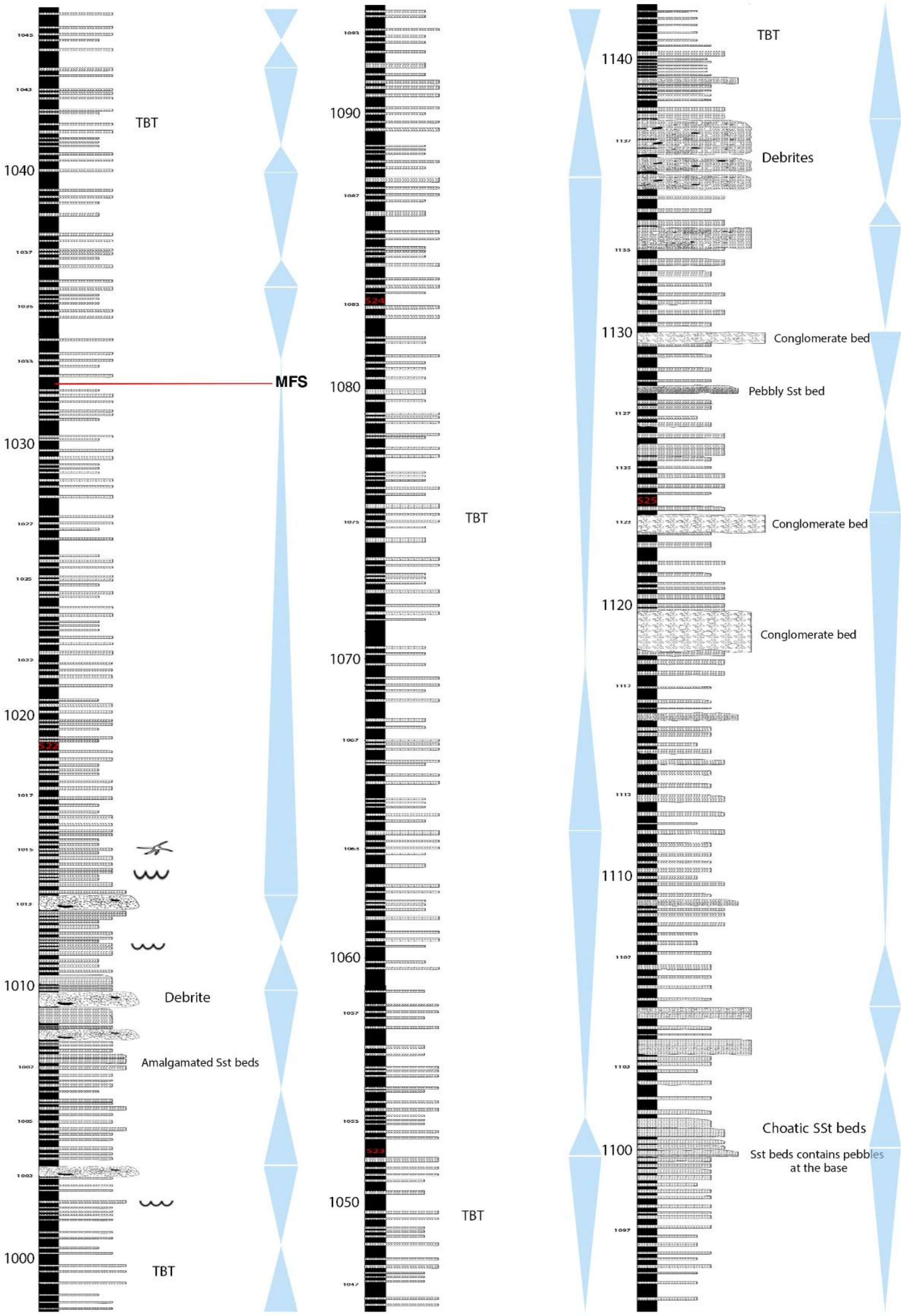

**Sirwan Valley Log 1-5**



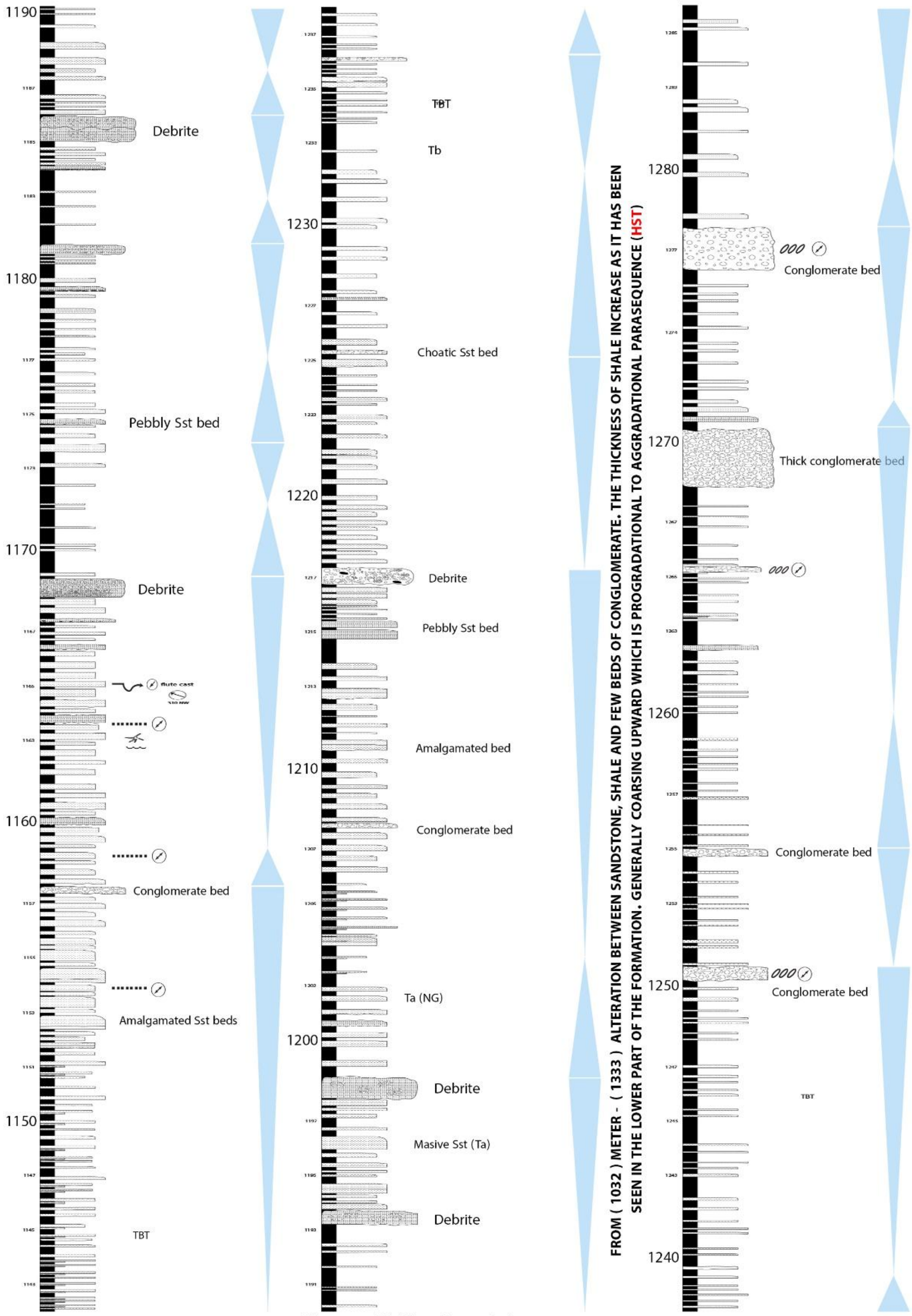

**Sirwan Valley Log 1-6**



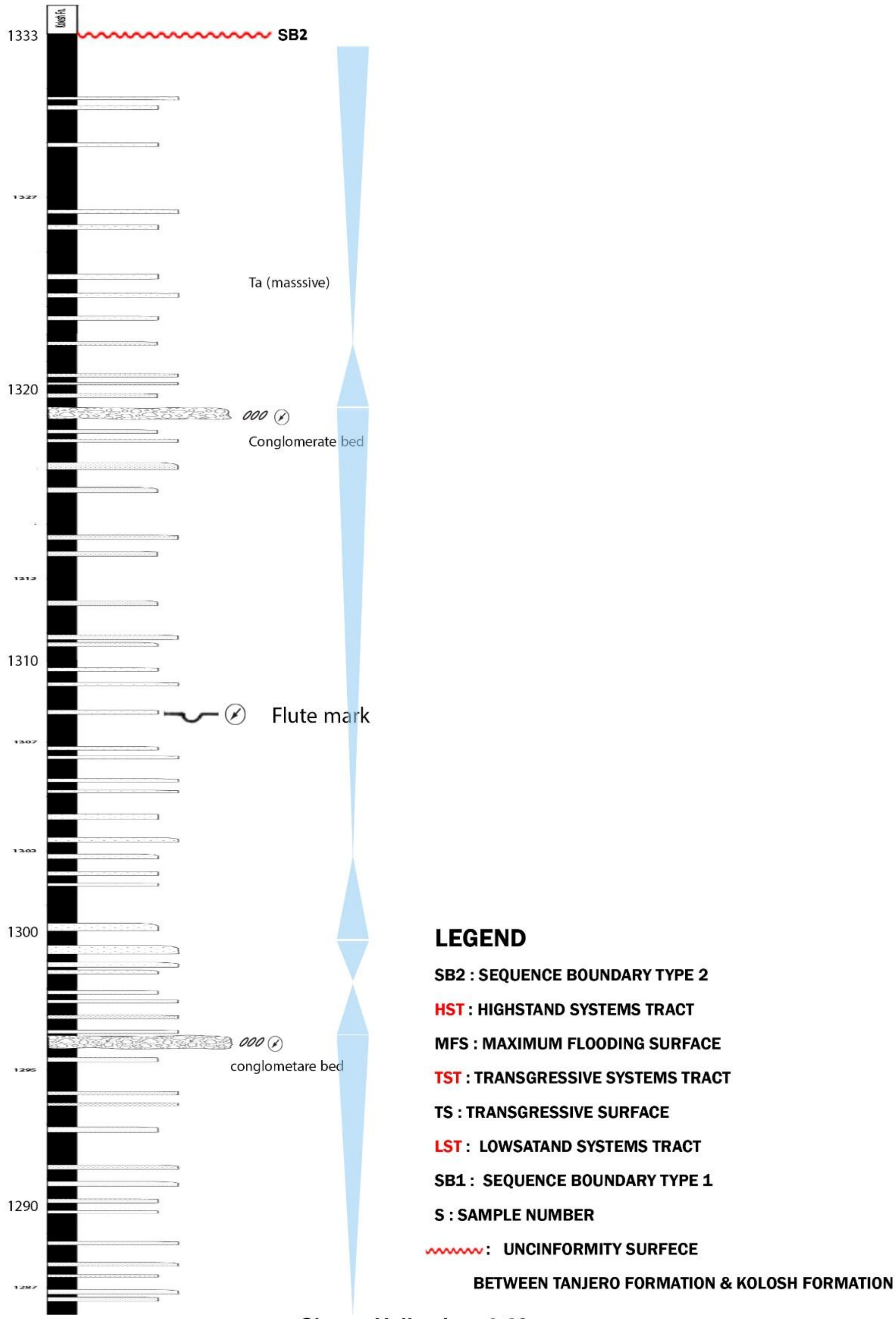

**Sirwan Valley Log 1-7**




Sirwan Valley Log 1-8




**Sirwan Valley Log 1-9**




Sirwan Valley Log 1-10

### 7.5. Palaeontology

Total 10 genus (*Abathomphalus, Gansserina, Globotruncana, Globotruncanita, Heterohelix, Hedbergella, Pseudotextularia, Pseudoguembelina, Racemiguembelina, Rugoglobigerina* ) and 17 species of planctonic foraminifera (Plate 1 and Plate 2) from the shale samples along the log were identified by palaontologist Dr. Deniz İbilioğlu, Dumlupınar University, Department of Geological Engineering in Turkey.

Identified planctonic foraminifera assemblage represent late Maastrichtian *Abathomphalus mayaroensis* zone and indicate bathyal environment. In the uppermost level of the log (in the sample S-23) *Krithe* sp. Ostracode genus representing infraneritic bathyal environment was identified. The fossil content from base to the top of the log shows the depositional environment is slope for the turbidites in this study.

**S1**

*Abathomphalus mayaroensis* (Bolli)

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncanita stuarti* (de Lapparent)

*Heterohelix navarroensis* Loeblich

*Pseudotextularia elegans* (Rzehak)

*Pseudoguembelina excolata* (Cushman)

**S2**

*Gansserina gansseri* (Bolli)

*Globotruncanita stuarti* (de Lapparent)

*Heterohelix striata* (Ehrenberg)

*Pseudotextularia elegans* (Rzehak)

*Pseudoguembelina palpebra* Brönnimann and Brown

*Pseudoguembelina costula* (Cushman)

**S3**

No fossil

**S4**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncanita conica* (White)

*Globotruncanita stuarti* (de Lapparent)

*Hedbergella* aff. *holmdelensis* Olsson

*Heterohelix navarroensis* Loeblich

*Pseudotextularia elegans* (Rzehak)

*Pseudoguembelina excolata* (Cushman)

*Pseudoguembelina costula* (Cushman)

**S5**

*Abathomphalus mayaroensis* (Bolli)

*Gansserina gansseri* (Bolli)

*Heterohelix* sp.

*Pseudoguembelina palpebra* Brönnimann and Brown

*Rugoglobigerina macrocephala* Bronnimann

**S6**

*Globotruncana aegyptica* Nakkady

*Globotruncanita conica* (White)

*Heterohelix striata* (Ehrenberg)

*Pseudoguembelina palpebra* Brönnimann and Brown

*Rugoglobigerina scotti* (Brönnimann)

**S7**

*Globotruncanita conica* (White)

*Globotruncanita stuarti* (de Lapparent)

*Globotruncana* sp.

**S8**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncanita conica* (White)

*Globotruncanita stuarti* (de Lapparent)

*Pseudoguembelina costula* (Cushman)

*Pseudotextularia elegans* (Rzehak)

*Racemiguembelina powelli* (Smith and Pessagno)

**S9**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncanita conica* (White)

*Globotruncanita stuarti* (de Lapparent)

**S10**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

**S11**

*Gansserina gansseri* (Bolli)

*Pseudoguembelina excolata* (Cushman)

*Pseudoguembelina palpebra* Brönnimann and Brown

*Pseudotextularia elegans*(Rzehak)

*Rugoglobigerina macrocephala* Bronniman

**S12**

*Abathomphalus intermedius* (Bolli)

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncana arca* (Cushman)

*Globotruncanita conica* (White)

*Heterohelix navarroensis* Loeblich

*Pseudotextularia elegans* (Rzehak)

**S13**

*Globotruncana aegyptica* Nakkady

**S14**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

**S15**

*Globotruncana* sp.

**S16**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

**S17**

No fossil

**S18**

*Gansserina gansseri* (Bolli)

**S19**

*Gansserina gansseri* (Bolli)

*Globotruncana arca* (Cushman)

**S20**

*Globotruncana arca* (Cushman)

**S21**

No fossil

**S22**

*Gansserina gansseri* (Bolli)

*Heterohelix striata* (Ehrenberg)

**S23**

*Gansserina gansseri* (Bolli)

*Globotruncana aegyptica* Nakkady

*Globotruncanita conica* (White)

**S24**

*Globotruncana aegyptica* Nakkady

*Globotruncana arca* (Cushman)

*Globotruncanita stuarti* (de Lapparent)

*Globotruncanita* sp.

**S25**

*Abathomphalus mayaroensis* (Bolli)

*Abathomphalus intermediuus* (Bolli)

*Globotruncana arca* (Cushman)

*Globotruncanita conica* (White)

## PLATE 1

**Figure 1.** *Globotruncana aegyptica* NAKKADY, umbilical view, sample no. S-23, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 2.** *Gansserina gansseri* (BOLLI), umbilical view, sample no. S-23, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 3.** *Gansserina gansseri* (BOLLI), umbilical view, sample no. S-19, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 4.** *Gansserina gansseri* (BOLLI), spiral view, sample no. S-18, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 5.** *Abathomphalus mayaroensis* (BOLLI), umbilical view, sample no. S-25, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 6.** *Abathomphalus mayaroensis* (BOLLI), spiral view, sample no. S-25, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 7.** *Abathomphalus intermedius* (BOLLI), umbilical view, sample no. S-12, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 8**. *Gansserina gansseri* (BOLLI), umbilical view, sample no. S-1, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 9.** *Globotruncanita conica* (WHITE), side view, sample no. S-12, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 10.** *Globotruncanita conica* (WHITE), umbilical view, sample no. S-4, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

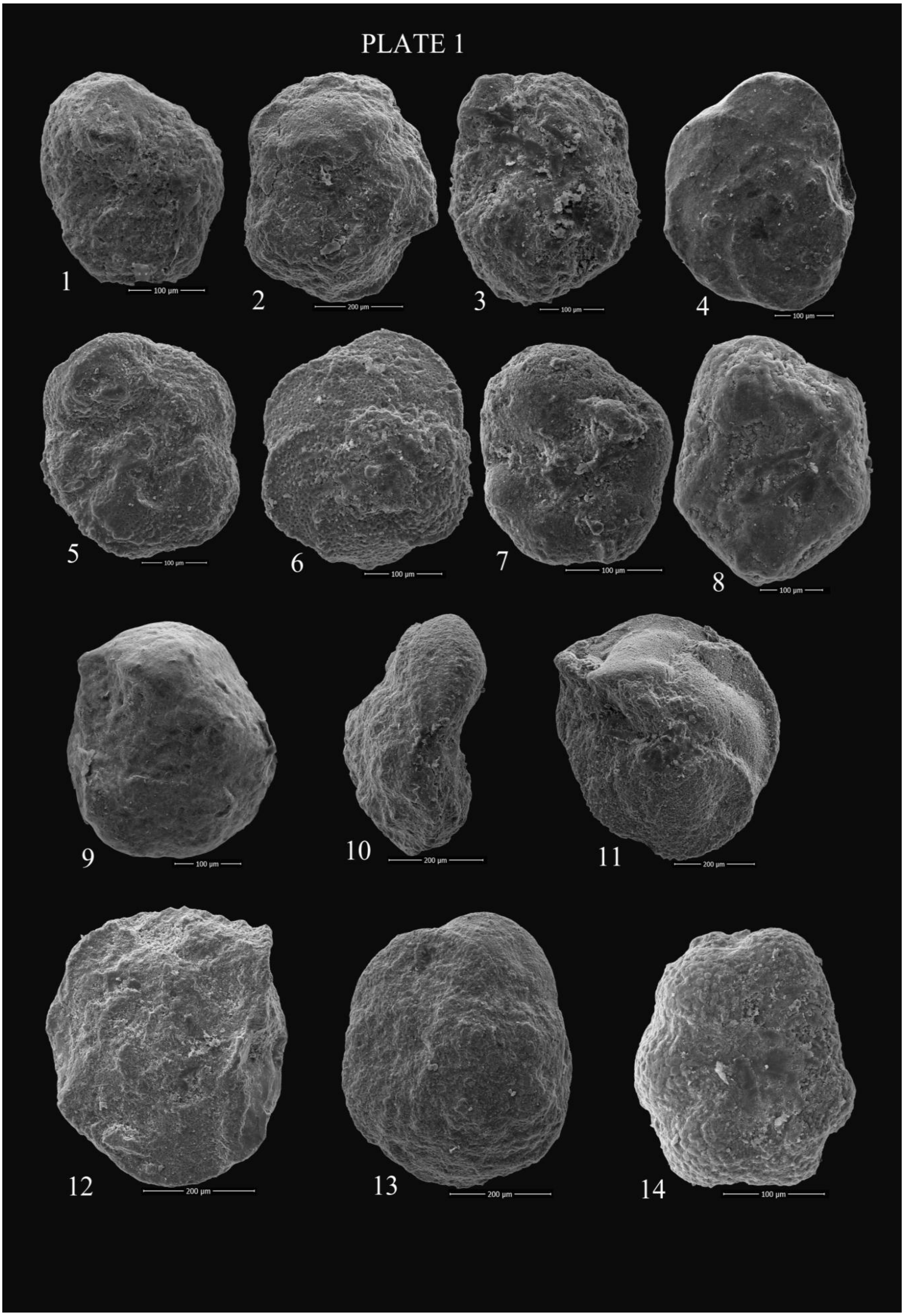
**Figure 11.** *Globotruncanita* sp.,umbilical view, sample no. S-24, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 12.** *Globotruncanita stuarti* (DE LAPPARENT), umbilical view, sample no. S-7, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 13**. *Globotruncanita stuarti* (DE LAPPARENT), spiral view, sample no. S-8, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 14.** *Hedbergella* aff. *holmdelensis* OLSSON, umbilical view, sample no. S-4, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

PLATE 1


1
100 µm
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14
100 µm

## PLATE 2

**Figure 1.** *Heteorehelix* sp., side view, sample no. S-5, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 2.** *Pseudoguembelina costula* (CUSHMAN), side view, sample no. S-4, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 3.** *Heterohelix navarroensis* LOEBLICH, side view, sample no. S-4, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 4.** *Pseudotextularia elegans* (RZEHAK), side view, sample no. S-4, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 5.** *Pseudoguembelina costula* (CUSHMAN), side view, sample no. S-8, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

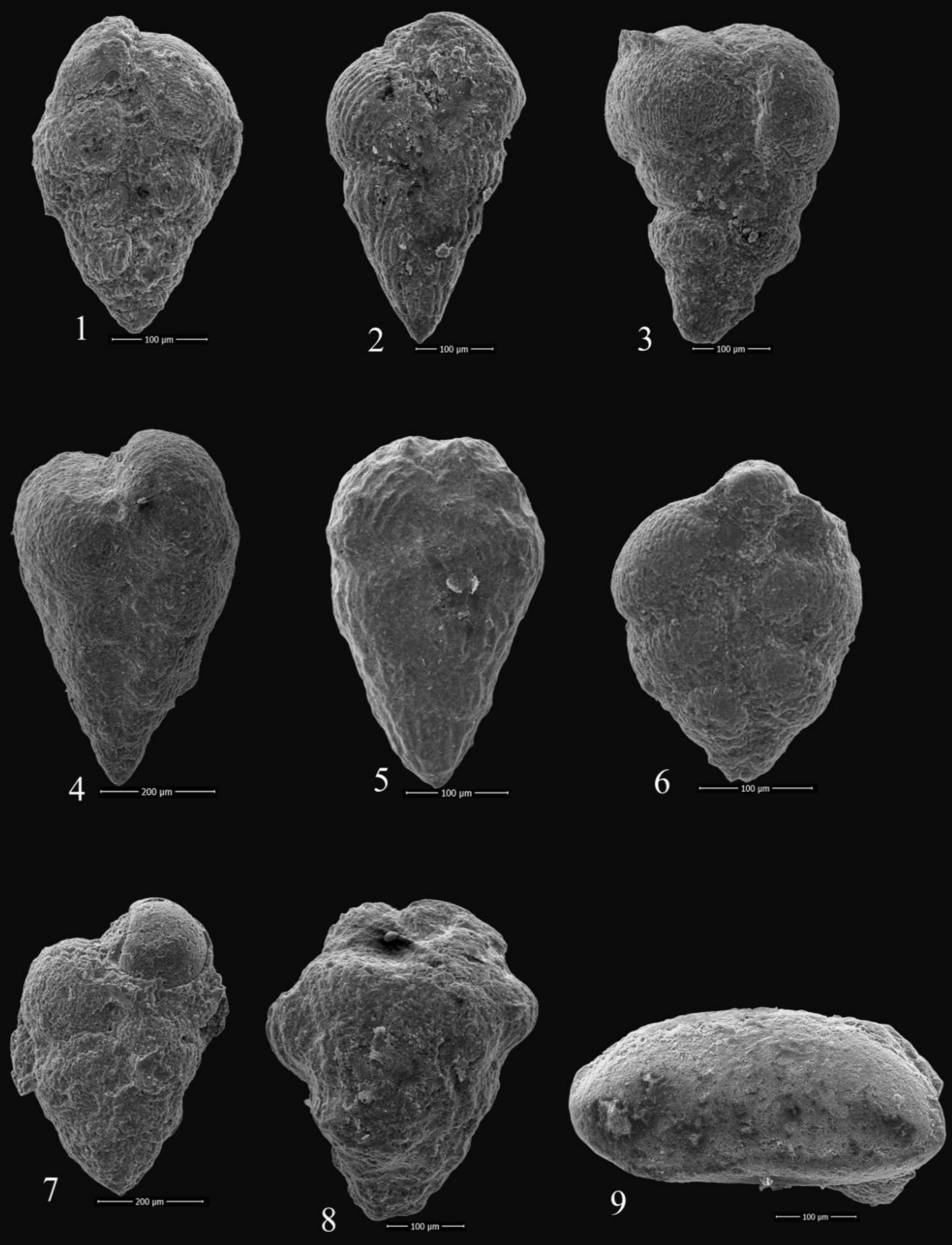
**Figure 6.** *Pseudoguembelina palpebra* BRONNIMANN and BROWN, side view, sample no. S-6, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 7.** *Heterohelix striata* (EHRENBERG), side view, sample no. S-6, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 8.** *Racemiguembelina powelli* (SMITH and PESSAGNO), sample no. S-8, *Abathomphalus mayaroensis* Zone, Late Maastrichtian.

**Figure 9.** *Krithe* sp. left side view, sample no. S-23.

PLATE 2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### 7.6. Palaeoflow Analysis

The paleoflow direction (PFD) of Tanjero Formation has studied by a number of studies, and several sedimentary structures were utilized for determining the paleoflow direction of the formation in various locations in the north part of Iraq (Al-Rawi, 1980, Karim, 2004 and Karim and Surdashy, 2005 and Hemin, 2017).

Al-Rawi (1981) utilized these sedimentary structures (cross-bedding, groove casts, flute casts and ripple marks) for analyzing the paleoflow direction of the Formation in various areas. The results of his study were that the paleoflow direction in Sulaimaniyah zone and Rawandoz region was toward N45W in Dokan was toward N45W and N85W.

Karim and Surdashy (2005) analyzed the paleoflow direction of the formation in the imbricated and high folded zone in Sulaimaniyah region, by using several sedimentary structures such as; sole marks, ripple marks, cross-bedding, imbricated pebbles, valleys and channels, plant debris, and elongate fossil skeleton. Generally, it has been evidenced that the direction of sedimentary structures is to south and southwest.

Hemin (2017) studied several unidirectional and bidirectional sedimentary structures within Tanjero Formation for determining the paleoflow direction of the formation in Sulaimaniyah area, and it has been proved that paleoflow direction of unidirectional structures generally toward South 45 East.

In this study paleoflow direction of Tanjero Formation has been studied by using several unidirectional and bidirectional sedimentary structures:

#### 7.6.1. Unidirectional sedimentary structures

Those sedimentary structures which have one current direction are known unidirectional sedimentary structures, and their value ranges from 0 to 360 degrees (Karim and Surdashy, 2005a). Pebble imbrication, flute marks and cross bedding have been used as unidirectional sedimentary structures (Table 7.1) to indicate the paleoflow direction in Tanjero Formation which is frequently toward S65W as can be seen in (Figure 7.5).

**Table 7.1**. Summary of unidirectional sedimentary structures

| No. | Sedimentary structures | Type of sedimentary structure | PFD | No. | Sedimentary structures | Type of sedimentary structure | PFD |
|---|---|---|---|---|---|---|---|
| **1** | Flute mark | Unidirectional | 311 | **29** | Imbrication | Unidirectional | 212 |
| **2** | Flute mark | Unidirectional | 310 | **30** | Imbrication | Unidirectional | 212 |
| **3** | Flute mark | Unidirectional | 160 | **31** | Imbrication | Unidirectional | 212 |
| **4** | Imbrication | Unidirectional | 180 | **32** | Imbrication | Unidirectional | 220 |
| **5** | Imbrication | Unidirectional | 190 | **33** | Imbrication | Unidirectional | 219 |
| **6** | Flute mark | Unidirectional | 310 | **34** | Imbrication | Unidirectional | 218 |
| **7** | Flute mark | Unidirectional | 306 | **35** | Imbrication | Unidirectional | 219 |
| **8** | Imbrication | Unidirectional | 307 | **36** | Imbrication | Unidirectional | 225 |
| **9** | Imbrication | Unidirectional | 140 | **37** | Imbrication | Unidirectional | 225 |
| **10** | Imbrication | Unidirectional | 144 | **38** | Imbrication | Unidirectional | 223 |
| **11** | Imbrication | Unidirectional | 148 | **39** | Imbrication | Unidirectional | 223 |
| **12** | Imbrication | Unidirectional | 160 | **40** | Imbrication | Unidirectional | 220 |
| **13** | Imbrication | Unidirectional | 175 | **41** | Imbrication | Unidirectional | 220 |
| **14** | Imbrication | Unidirectional | 190 | **42** | Imbrication | Unidirectional | 242 |
| **15** | Imbrication | Unidirectional | 200 | **43** | Imbrication | Unidirectional | 240 |
| **16** | Imbrication | Unidirectional | 230 | **44** | Imbrication | Unidirectional | 245 |
| **17** | Imbrication | Unidirectional | 230 | **45** | Imbrication | Unidirectional | 245 |
| **18** | Imbrication | Unidirectional | 240 | **46** | Imbrication | Unidirectional | 244 |
| **19** | Imbrication | Unidirectional | 240 | **47** | Imbrication | Unidirectional | 239 |
| **20** | Imbrication | Unidirectional | 245 | **48** | Imbrication | Unidirectional | 243 |
| **21** | Imbrication | Unidirectional | 190 | **49** | Imbrication | Unidirectional | 244 |
| **22** | Imbrication | Unidirectional | 190 | **50** | Imbrication | Unidirectional | 245 |
| **23** | Imbrication | Unidirectional | 200 | **51** | Imbrication | Unidirectional | 247 |
| **24** | Imbrication | Unidirectional | 200 | **52** | Imbrication | Unidirectional | 245 |
| **25** | Imbrication | Unidirectional | 220 | **53** | Imbrication | Unidirectional | 239 |
| **26** | Flute mark | Unidirectional | 300 | **54** | Imbrication | Unidirectional | 240 |
| **27** | Flute mark | Unidirectional | 300 | **55** | Imbrication | Unidirectional | 245 |
| **28** | Flute mark | Unidirectional | 300 | | | | |

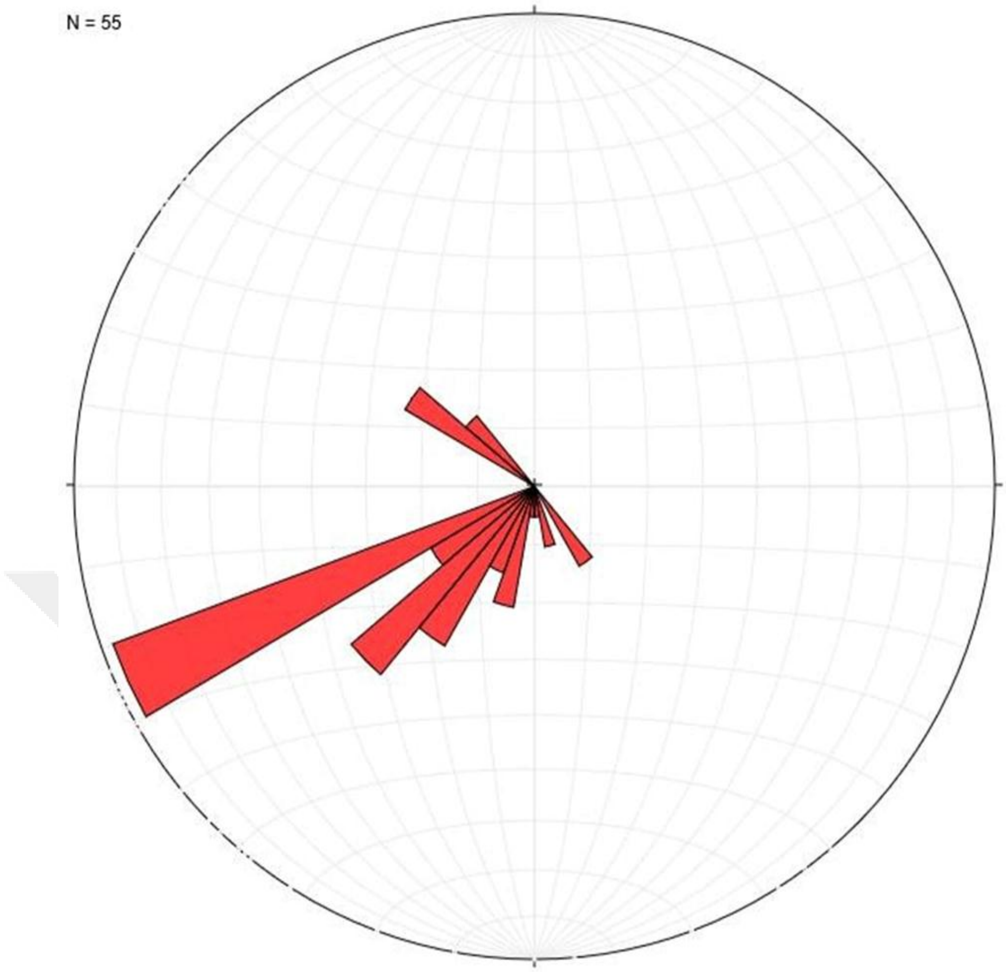


**Figure 7.5.** Rose diagram of unidirectional paleoflow of Tanjero Formation, which is toward the south-west in Sirwan gorge, around Darbandikhan town northeastern of Iraq.

### 7.6.2. Bedding Attitudes

The bedding planes of the sandstone beds (Table 7.2) also have been plotted on the Steronet, which are toward North-East and South-West, and it can be seen in Figure 7.6.

**Table 7.2.** Summary about bedding planes

| No. | Bedding plane | Dip Angle | No. | Bedding plane | Dip Angle |
|---|---|---|---|---|---|
| **1** | 240 | 36 | **34** | 232 | 30 |
| **2** | 252 | 29 | **35** | 230 | 26 |
| **3** | 240 | 30 | **36** | 230 | 26 |
| **4** | 224 | 28 | **37** | 280 | 25 |
| **5** | 247 | 29 | **38** | 280 | 25 |
| **6** | 246 | 27 | **39** | 280 | 26 |
| **7** | 230 | 32 | **40** | 252 | 25 |
| **8** | 242 | 24 | **41** | 252 | 30 |
| **9** | 220 | 26 | **42** | 252 | 30 |
| **10** | 350 | 28 | **43** | 250 | 30 |
| **11** | 350 | 28 | **44** | 248 | 28 |
| **12** | 350 | 30 | **45** | 248 | 28 |
| **13** | 216 | 33 | **46** | 215 | 28 |
| **14** | 216 | 33 | **47** | 215 | 29 |
| **15** | 260 | 33 | **48** | 210 | 30 |
| **16** | 260 | 32 | **49** | 210 | 30 |
| **17** | 260 | 32 | **50** | 210 | 32 |
| **18** | 260 | 33 | **51** | 210 | 32 |
| **19** | 252 | 30 | **52** | 240 | 35 |
| **20** | 250 | 30 | **53** | 240 | 35 |
| **21** | 250 | 30 | **54** | 250 | 35 |
| **22** | 252 | 26 | **55** | 248 | 35 |
| **23** | 246 | 26 | **56** | 250 | 35 |
| **24** | 246 | 34 | **57** | 255 | 33 |
| **25** | 258 | 35 | **58** | 256 | 33 |
| **26** | 258 | 34 | **59** | 255 | 34 |
| **27** | 250 | 35 | **60** | 260 | 34 |
| **28** | 248 | 33 | **61** | 256 | 33 |
| **29** | 248 | 34 | **62** | 260 | 33 |
| **30** | 252 | 34 | **63** | 262 | 32 |
| **31** | 254 | 36 | **64** | 262 | 34 |
| **32** | 255 | 36 | **65** | 260 | 34 |
| **33** | 232 | 30 | | 260 | 30 |

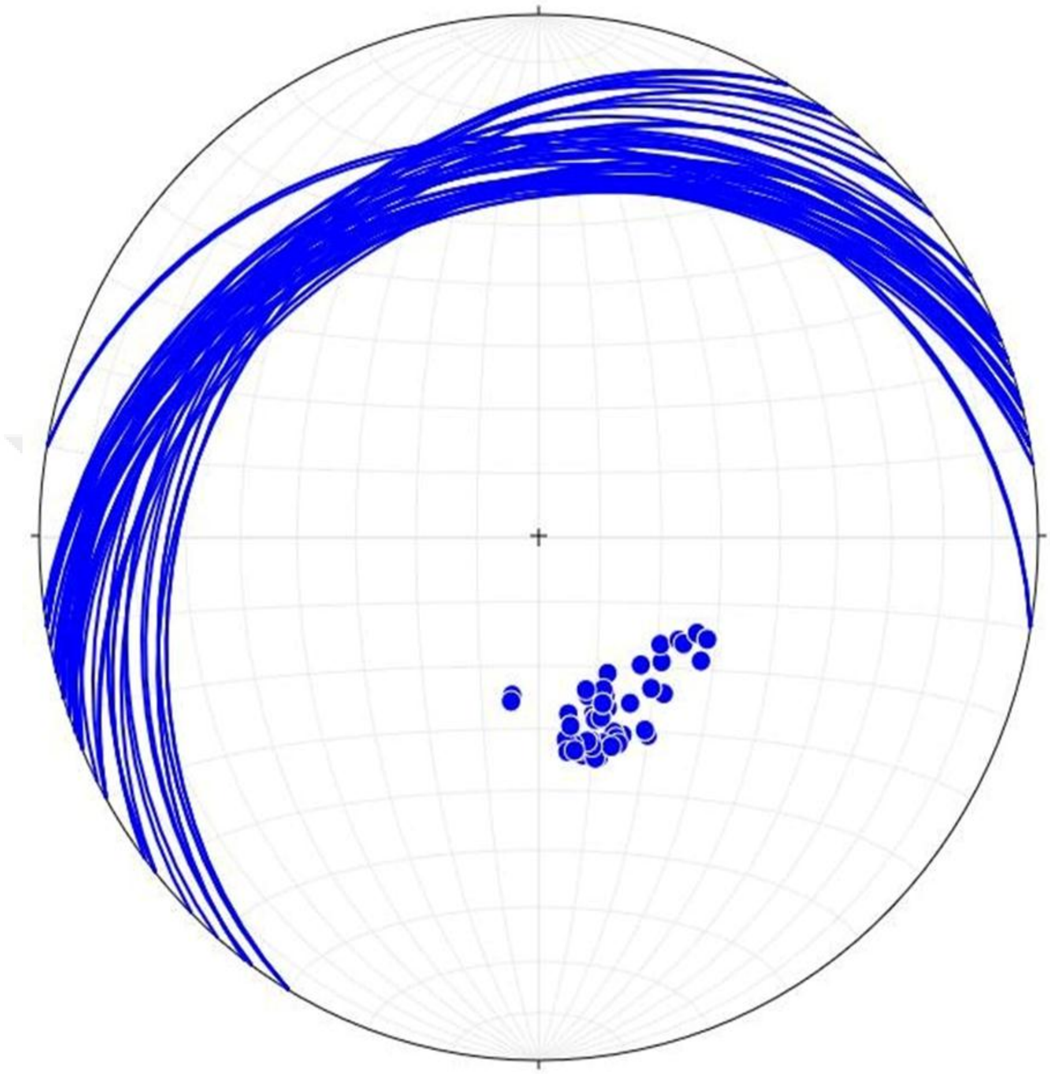

**Figure 7.6.** Bedding planes of sandstone beds in the studied site on stereonet by using GeoRose software.

# 8. SEQUENCE STRATIGRAPHY

## 8.1. Introduction to Sequence Stratigraphy

Sloss et al. (1949) initially defined the term sequence, and subaerial unconformities were used for describing stratigraphic unit bounded to initiate the sequence stratigraphy.

Unconformities and their correlative conformities used for determining genetic packages of strata of upper and lower boundaries in term comparatively conformable sequence (Vail et al., 1977).

It is clear that studying sequence stratigraphy is essential for understanding properties and behaviour of the formation in petroleum system, especially as reservoir rocks or source rocks (Van Wagoner et al., 1988). Therefore, in this section, the sequence stratigraphy of Tanjero Formation will be discussed.

Moreover, Posamentier et al. (1988) claimed that the sequence of genetic relationship of systems tracts which is taken to be deposited as an inflection point between eustatic-fall base level, it is known sequence.

Sequence stratigraphy is used to analyses associations of sedimentary rocks within a repetitive time of stratigraphic system, genetic relationships units bounded by the surface of non-deposition or erosion, or their correlative conformities (Van Wagoner et al., 1988; Galloway, 1989). Also, sequence stratigraphy can be used to studies cycle of sedimentation patterns which are in the framework of stratigraphic series, and it is developed from the variations in accommodation space (space obtainable for sediment accumulation) and sediment supply (Posamentier and Allen, 1999). Furthermore, the concepts of sequence stratigraphy meaningfully used for studying regional and local exploration, seismic evaluation, and evaluating reservoir rocks of hydrocarbon (oil and gas) companies (Embry, 2001).

Sequence stratigraphy is one of the most current techniques of stratigraphic analysis for more understanding how sedimentary basins formed in terms sediment accumulation and preservation by geologists, and this method has played a key role in an aspect of natural resources exploration by collecting data and analyzing stratigraphic succession (Catuneanu, 2002).

Deposits defined as a basis of delineation any sequence stratigraphic surface and units which is formed by particular stratal stacking patterns, in this order from sequence to systems tract and parasequence. Position and timing of systems tract margins or stratigraphic succession surface can be marked by changes in stratal stacking patterns (Catuneanu et al., 2011).

Relative base level variations and time are integrated by sequence stratigraphy to track the relocation of facies. It mentioned that the root and basis of the sequence stratigraphy is an analysis of the seismic stratigraphic sequence (Obaje, 2013).

Potential combination traps and the open window of deep exploration, unexpanded sub-fault reservoirs and traps are conducted by sequence stratigraphy, and it is functionally used by explorationist to evaluate and identify a suitable site in term a cost-effective mode for sub-basin in the petroleum system framework (Obaje, 2013). Therefore, sequence stratigraphy is used as a powerful tool for identifying three order depositional successions and determining systems tracts which are related to the potentiality of a petroleum system in a sedimentary basin; source rocks, reservoirs rocks and cap rocks or seals (Obaje, 2013).

The main purpose of this section is analyzing sequence stratigraphy of Tanjero Formation to identify their role in hydrocarbon system in the area as a reservoirs rock.

## 8.2. Concepts of Sequence Stratigraphy

### 8.2.1. Base Level / Sea Level

Several definitions have been given to base level by previous researches;

"Base level is the highest level to which a sedimentary succession can be built" (Twenhofe, 1939).

The imaginary surface of active equilibrium between sedimentation and erosion, which is known base level, which particle of sediment cannot come to rest and below those depositional and erosional surfaces (Sloss, 1962).

Base level and sea level is frequently approached to each other, but in actuality, based on erosional action of waves and currents of sea seal level is regularly above base level (Jervey, 1988; Schum, 1993).

The relations between processes for generating and eliminating accumulate sediment (accommodation space) and surficial processes for bringing or removing sediment from the space (Cross and Lessenger, (1998) (Figure 8.1).

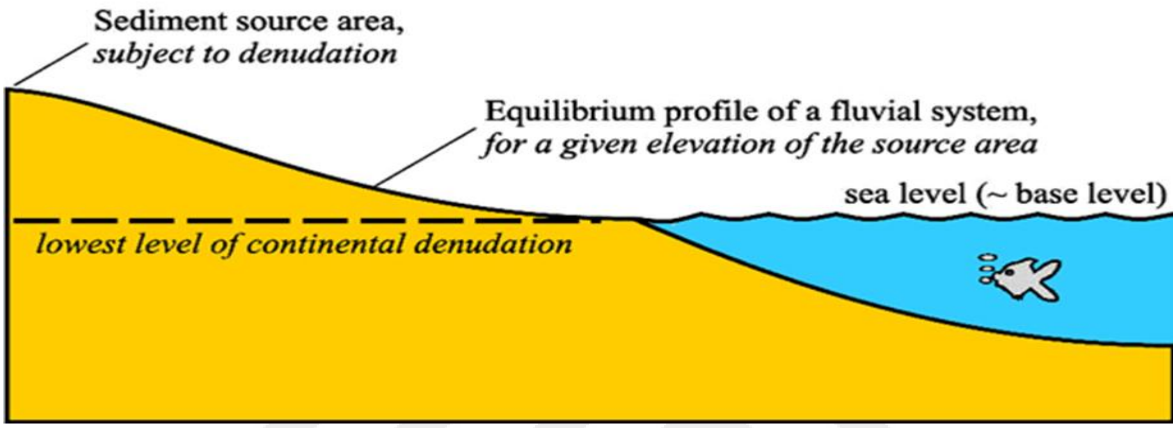


**Figure 8.1.** The concept of base level, defined as the lowest level of continental denudation (Plummer & McGeary, 1996)

### 8.2.1.1. Types of Sea Level Change

Two main mechanisms cause the rising sea level. Ice melting in some place particularly in mountain glaciers and polar ice is first causing for rising sea level due to discharging water into the oceans and changing the total mass of the sea this is called Eustatic sea level. Rising water temperatures of the ocean are the second reason of sea level rise due to the expansion of the warmer water with respects of a reference point of lands it is known Relative sea level (Cazenave and Llovel, 2010).

### 8.2.1.2. Marine Transgression

The transgressions are happened due to rising sea level towards land and shoreline covers land, and ocean basins become deeper due to filling with water. In this case, shale and limestone as deeper sea sediments deposit over the sand as continent sediment and fining upward (Van Wagoner et al., 1988).

#### 8.2.1.3. Marine Regression

Falling sea level caused sea regression and shoreline moves towards the back into the sea, and sea being shallower than before. In this occasion, deposition sand as continent sediment over shale and limestone as sea sediments it means coarsening upward (Posamentier et al., 1988).

#### 8.2.1.4. Rise and Fall in Sea Level

The vertical movement of a plane in term of rising and falling base (sea) level with regards to the basin floor (Figure 8.2) (Van Wagoner et al., 1988).

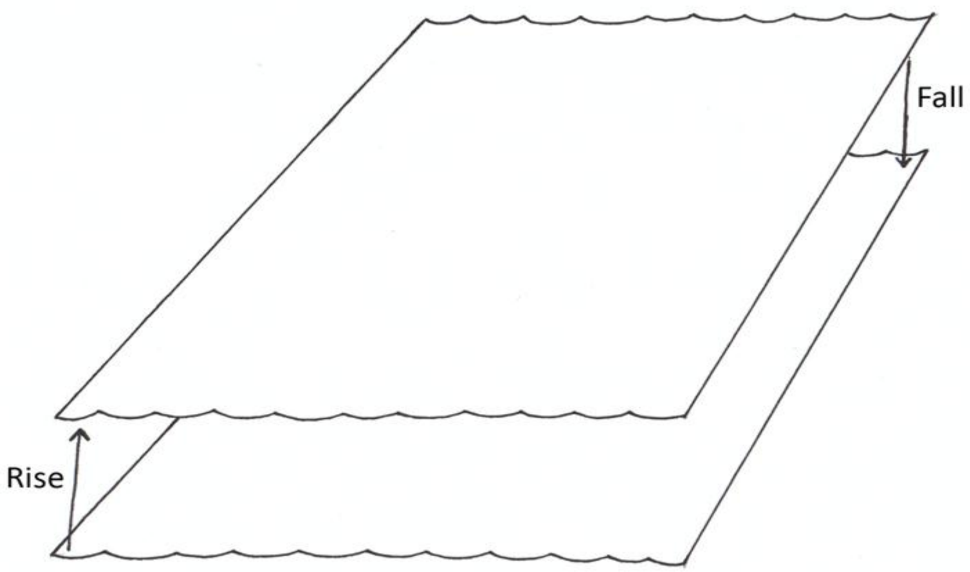


**Figure 8.2.** The Rise and fall of sea level (Van Wagoner et al., 1988).

#### 8.2.1.5. Sediment Supply

Sediment supply represents the volume of erosional material from the uplift area as a source region, and it transported to a basin floor over time. Rate of sediment supply changes (decrease and increase) based on amounts of the uplift of the source area (Posamentier and Allen, 1999).

#### 8.2.1.6. Accommodation Space

Accommodation space is an available space for accumulating sediments over a period of time (Holland, 2008), and base level can control it and either it is filled by water or by sediments (Obaje, 2013).

### 8. 2.2. Hierarchy of Sequence Stratigraphy Cycle Orders

#### 8.2.2.1. Definitions of Cycle Order

The concept of hierarchy comes from the classification of successions depends on their stratigraphic importance and comparative scale. The most significant sequence within hierarchy system is known as each order sequence can be subdivided into two or more next order sequence, especially occurrence of low frequency in the stratigraphic record within higher-order (Catuneanu, 2002). The cycle's duration is a base for defining a hierarchy of sequences due to the processes of forming sequence which have natural periodicities (Miall, 2010).

#### 8.2.2.2. Duration of Cycle Order

The duration of cycles is based approach for identifying cycle hierarchies. The experiential solution has been provided by this method for the problem, which is inapplicable and unacceptable commonly approaches to define the cycle hierarchy (Catuneanu et al., 2011) (Table 8.1).

**Table 8.1.** Terminology of cycle hierarchies and orders of cyclicity (Kerans & Tinker, n.d.) (Modified from Glodhammer et al.,1991).

| Tectono-Eustatic/Eustatic Cycle Order | Sequence Stratigraphic Unit | Duration (my) | Relative Sea Level Amplitude (m) | Relative Sea Level Rise/Fall Rate (cm/1000 yr.) |
|---|---|---|---|---|
| **First** | | **> 100** | | **<1** |
| **Second** | **Supersequence** | **10-100** | **50-100** | **1-3** |
| **Third** | **Depositional Sequence Composite Sequence** | **1-10** | **50-100** | **1--10** |
| **Fourth** | **High Energy Sequence, Parasequence and Cycle Set** | **0.1-1** | **1-150** | **40-500** |
| **Fifth** | **Parasequence, High-Frequency Cycle** | **0.01-0.1** | **1-150** | **60-700** |

### 8.2.3. System Tracts

**Definition**

A systems tract is subdivisions of successions that consist of distinct depositional systems which vary from other systems tracts in term geometry and facies connections that have different boundaries (Brown and Fisher 1977). Spatiotemporal scales have an independent role in defining a systems tract. A comparatively conformable sequence of related genetic units bounded by the surface of unconformable or conformable stratigraphy sequence and stratal stacking patterns are used for comprising a systems tract (Van Wagoner et al. 1987). It stated that the concept of systems tracts involved from the definition of a sequence which given in Mitchum's research, and it is more appropriate for identifying systems tracts because internal unconformities can comprise a sequence. These types of unconformities commonly located at the boundary between two systems tracts (Catuneanu et al., 2009). There are several types of systems tracts, and for this research, some of them will be covered followings (Figure 8.3).

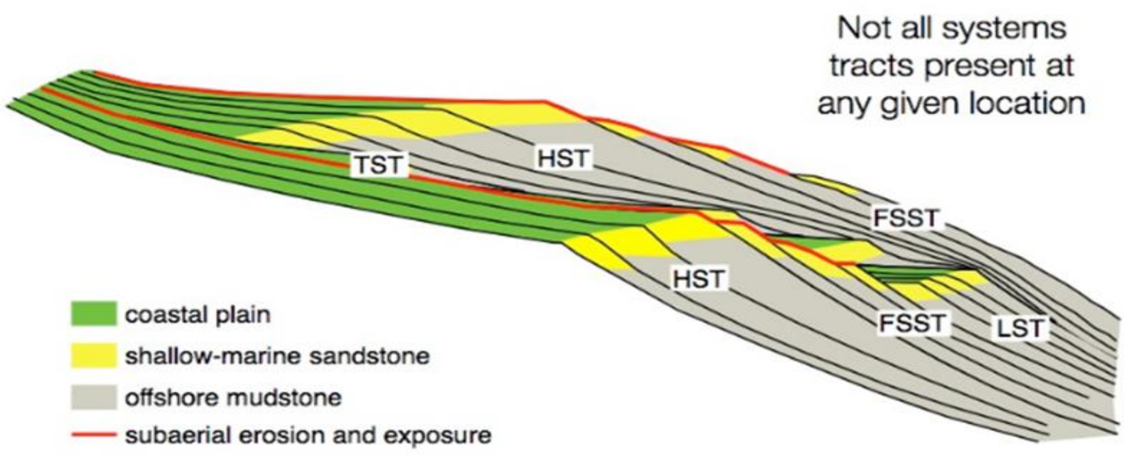


**Figure 8.3.** The four systems tract model (Posamentier, et al., 1988).

**Types of Systems Tract**

#### 8.2.3.1. Lowstand Systems Tract (LST)

Due to rising relative base-level, the sediment accumulates, and it forms lowstand systems tracts LST, and at the top is bounded by forced regressive surface while at the base is bounded by its sea correlative conformity and subaerial unconformity (Figure 8.4) (Catuneanu, 2002).

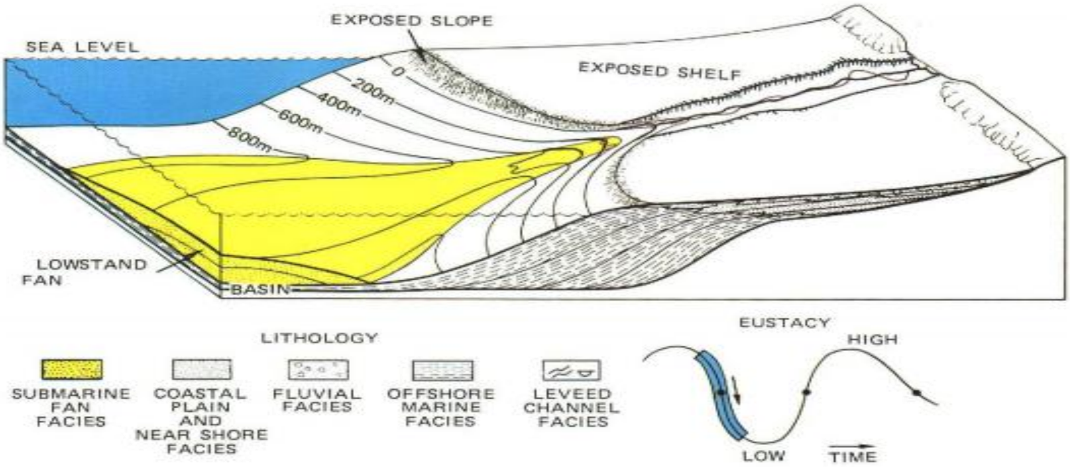


**Figure 8.4.** Lowstand Systems Tract (LST) – lowstand fan (Posamentier, et al., 1988).

### 8.2.3.2. Transgressive Systems Tract (TST)

The sediments accumulation due to rapidly rising in sea level until maximum transgression of the shoreline just preceding to new regression formed TST. At the top maximum flooding, surface overlies TST boundary and the maximum regressive surface bounds the base of TST (Figure 8.5) (Catuneanu, 2002). The highest rates of non-marine aggradation recorded in TST, and as of result of transgression, there is the fastest accommodation. In consequent, the marine environment supplied by the lowest rates of siliciclastic sediment (Morad et al. 2012).

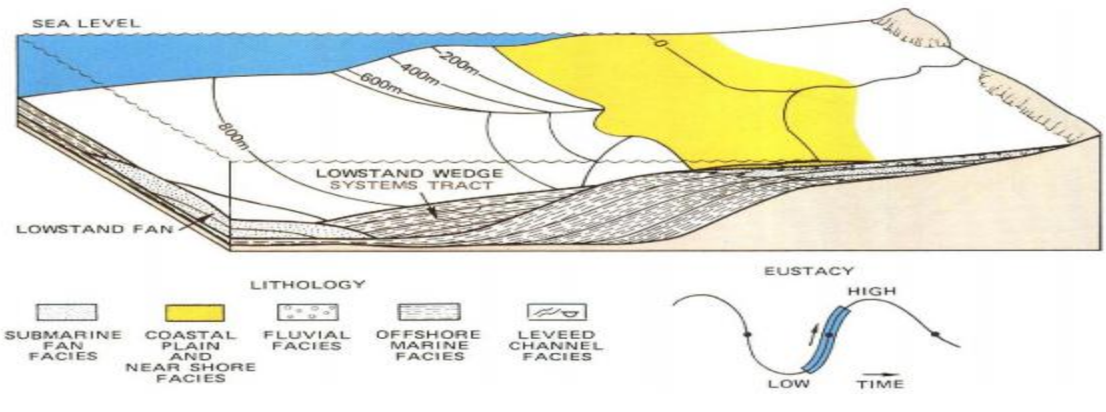


**Figure 8.5.** Transgressive Systems Tract (TST) (Posamentier, et al., 1988).

#### 8.2.3.3. Highstand Systems Tract (HST)

During the late phases of rising relative base-level, the rates of accumulation exceed the highest rate in accommodation space formed progradational deposits, which are involved HST (Posamentier and Allen 1999). The HST overlay by the maximum regressive surface and the subaerial unconformity at the top, and at the base, the maximum flooding surface bounded HST. Therefore, the continental sediments are a top set for typical HST and marine sediments are a bottom set of HST (Morad et al. 2012) (Figure 8.6).

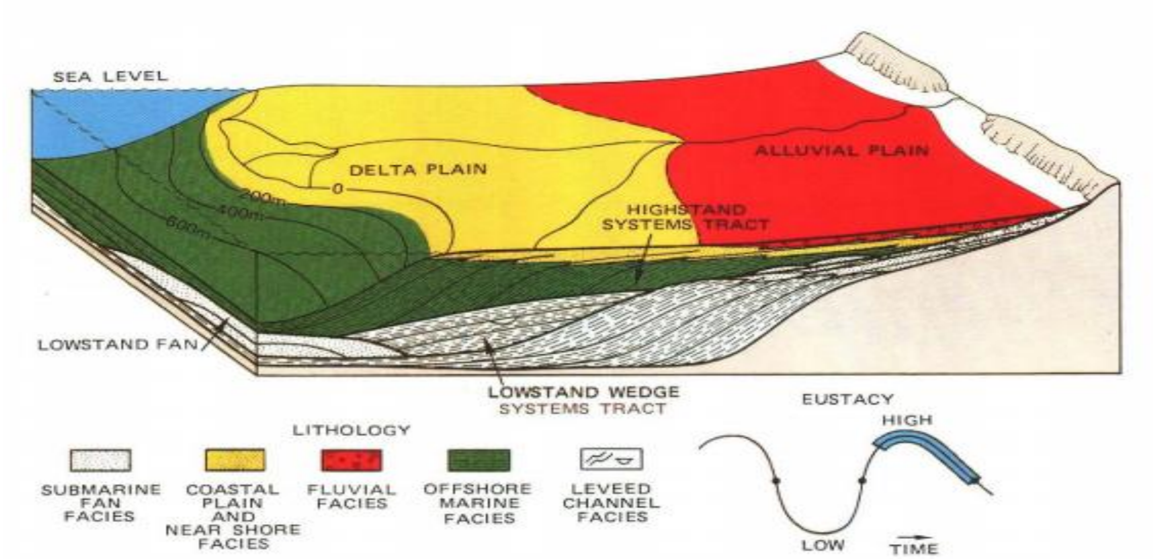


**Figure 8.6.** Highstand Systems Tract (HST) (Posamentier, et al., 1988).

### 8.2.4. Types of Surface

#### 8.2.4.1. Sequence Boundary (SB)

The erosional surface used for separating various deposition cycles. Forms sequence boundary, and frequently it is represented by subaerial unconformity plays the role because there is the most significant break in sedimentation due to the surface as up-dip, and in rare cases surface of correlative conformity represents sequence boundary as down-dip, and rapid basin-ward shit in facies indicates a sequence boundary due to forced regression (Catuneanu, 2002). The boundary between HST and TST or FSST can demark by sequence boundary (Catuneanu et al., 2011). Falling in relative base level generates sequence boundaries this is the result of variations in the rate of tectonic subsidence, and there is a net loss of accommodation space due to this variation (obaje, 2013). It mentioned that sequence boundaries had been divided into two groups, the sequence boundaries are defined as a comparative to sea level curve by the first group while the second group defines the sequence boundaries as relative to genetic transgression and regression curvature (Catuneanu, 2017) (Figure 8.7).

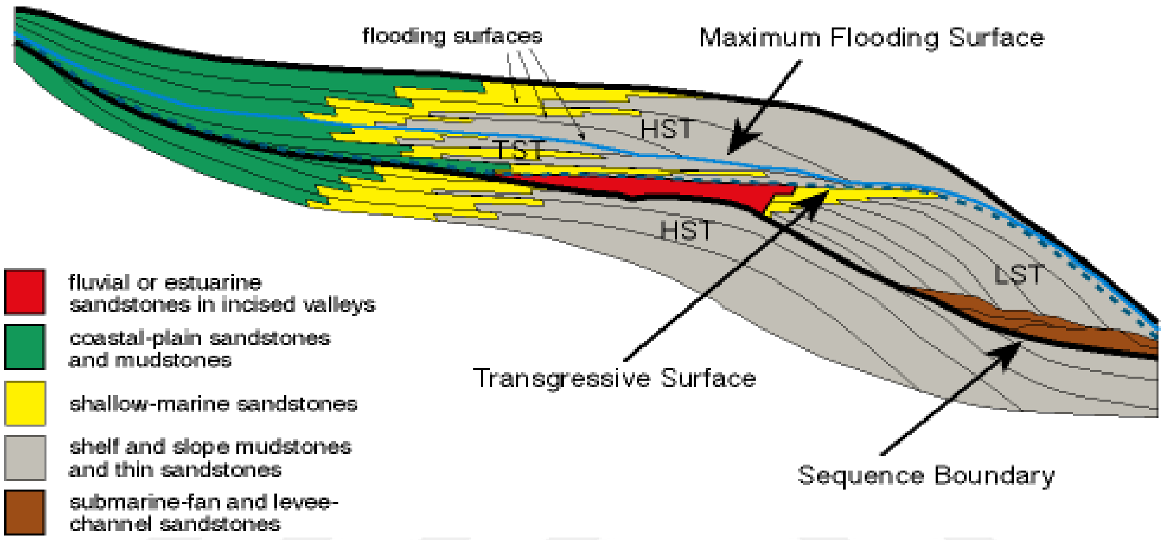


**Figure 8.7.** Sequence boundary& Transgressive surface (SB) (Van Wagoner, et al., 1990).

### 8.2.4.2. Transgressive Surface (TS)

The first main flooding surface to monitor the sequence boundary is represented by the transgressive surface and is commonly separate from a relative slight flooding surface to survey the sequence boundary that different parasequences in the LST. A protuberant flooding surface frequently covers the lowstand systems tract is known as the transgressive surface (Nigerian Geological Survey Aagency, 2013).

### 8.2.4.3. Maximum Flooding Surface (MFS)

The variation in stratal stacking patterns from retrogradational (transgression) to progradation or (highstand normal regression) is marked as a stratigraphic surface which is called the maximum flooding surface (Van Wagoner et al., 1988). Moreover, the sequence boundaries or systems tract, which is located on stratal stacking patterns are defined as maximum flooding surface. The relationship between rising sea level at coastline and rates of sedimentation based on their relative timing and changes in subsidence and sedimentation rates far away from coastal is not affect the relationship (Catuneanu et al., 1998) (Figure 8.8).

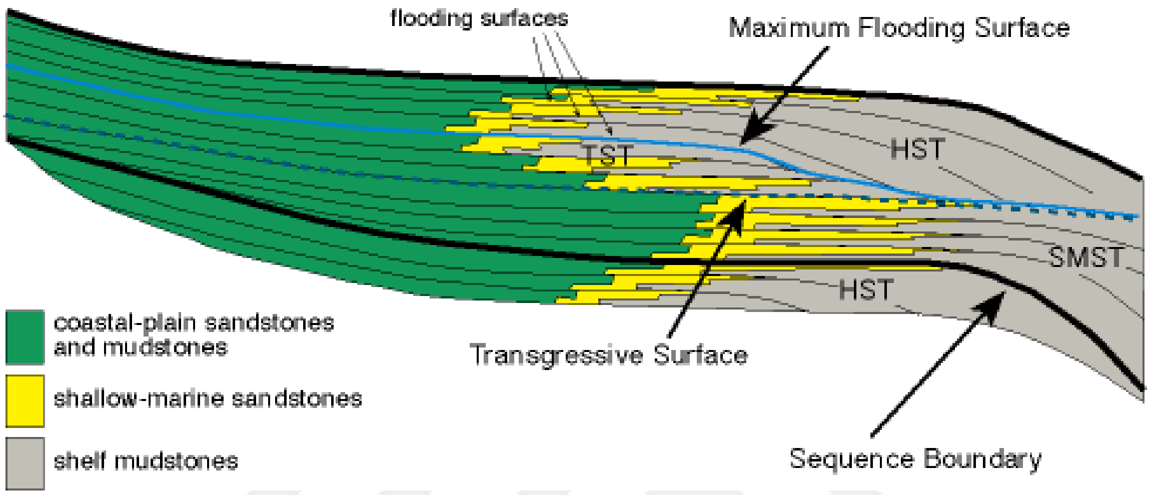


**Figure 8.8.** Maximum flooding surface (MFS) & Flooding surfaces (FS) (Van Wagoner, et al., 1990).

### 8.2.4.4. Subaerial Unconformity (SU)

There are several processes; fluvial erosion or passing wind degradation, pedogenesis, karstification and dissolution that form unconformity which under subaerial conditions is called the subaerial unconformity (Schlager 1992). When fluvial or shoreline erosion takes place, the subaerial unconformities formed due to forced regression (Leckie 1994).

### 8.2.4.5. Correlative Conformities (CC)

The surface formed at the last falling of sea level at the coastline within the marine environment is called the correlative conformity (Hunt and Tucker, 1992).

## 8.2.5. Parasequences

### Definition

Van Wagoner et al., (1988) firstly defined the parasequence as a small- scale unit of stratigraphic succession, and boundary surfaces are used meaningfully of the definition; "a relatively conformable succession of beds or bed sets bound by marine-flooding surfaces" (Embry, 2009, p.55). Moreover, old and young units across are separated by a marine flooding surface depends on immediate deepening water depth (Embry, 2009). The types of parasequences are below;

### 8.2.5.1. Aggradation

A sedimentary succession builds up vertically. Commonly follows when the relative base level rise due to subsidence or/and rising in eustatic base level, and when the surface of deposition at the base level and rate of sediment influx are same (Van Wagoner et al., 1988; Galloway, 1989) (Figure 8.9). Composition of facies in each parasequence successions that above each other are similar to each other, it is used for identifying parasequence set of aggradation in an outcrop, and there is not noticeable lateral changes or no net vertical trend in marine depth, therefore, each parasequence deposits approximately the same lateral location to prior parasequence in an aggradational parasequence set (Posamentier and Allen, 1999) (Figure 8.10).

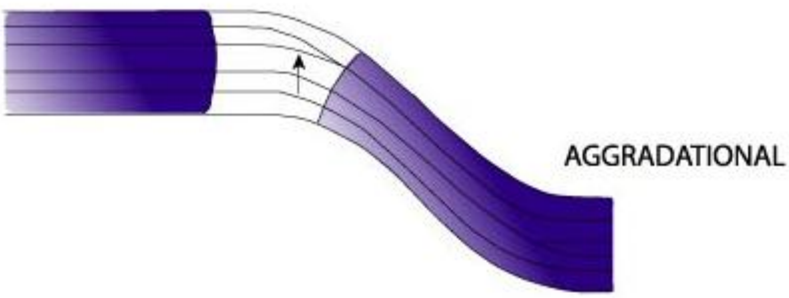


**Figure 8.9.** Aggradation Parasequence (Galloway, 1989).

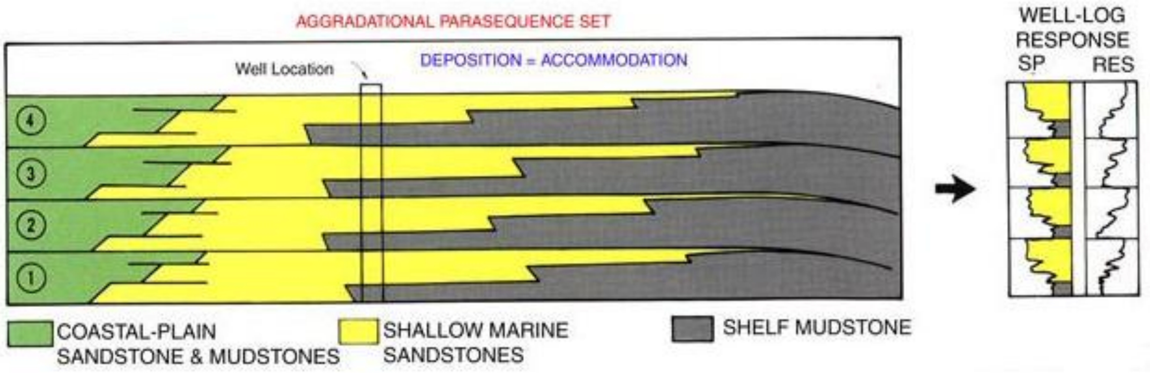


**Figure 8.10.** Aggradational Parasequence Set (Van Wagoner, et al., 1988).

### 8.2.5.2. Progradation

Progradation is defined as a construction onward in the direction of the sea of a coastline or oceanfront, which is the beach, delta, or fan. Also, it is the typical depositional tendency of regressions, the waves (currents) or long coast drifting moves and thrown upstream tolerated sediments or constant buildup of beach material to near seaboard deposition (Bates and Jackson, 1987; Van Wagoner et al., 1988). Progradation occurs due to rising sea level attended with the regression or with high sediment fluctuation and happens through the late phases of the improvement of HST or and FSST. The pattern of facies in each parasequence, progression extra proximal is at the top of each other (Posamentier and Allen, 1999) (Figures 8.11 and 8.12).

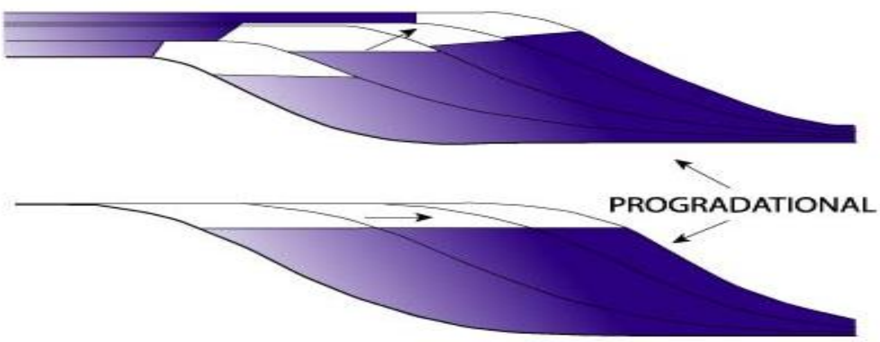


**Figure 8.11.** Progradational Parasequence (Galloway, 1989).

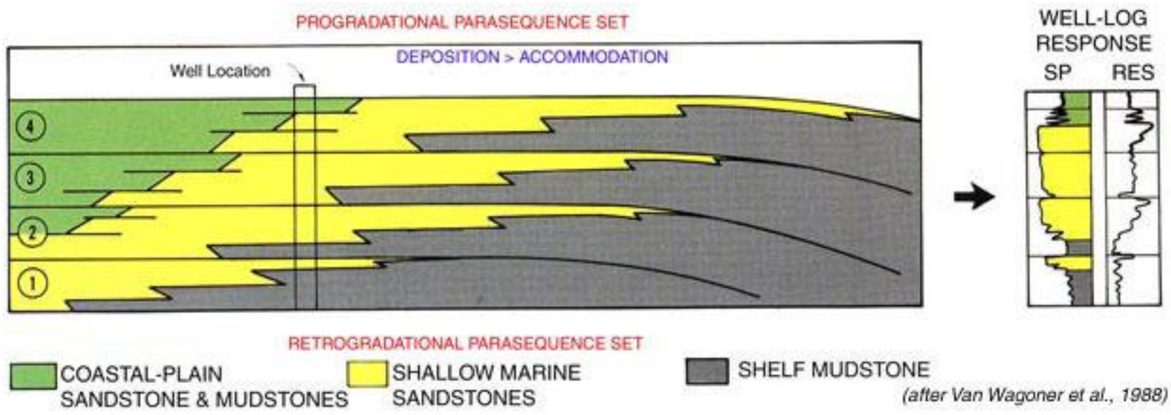


**Figure 8.12.** Progradational Parasequence Sets (Van Wagoner, et al., 1988).

### 8.2.5.3. Retrogradation

Retrogradation appears when shoreline moves toward land or continental as a result of transgression. Retrogradation occurs due to rising sea-level by low sediment fluctuation. Facies patterns in each parasequence are progressive extra distal once outlined upward vertically is represented retrogradational stacking patterns (Posamentier et al., 1988) (Figure 8.13). Younger parasequences sequence deposit more toward land in a back treading pattern, in this case, generally rate of accommodation is more than the rate of the deposition (Van Wagoner et al., 1988) (Figure 8.14).

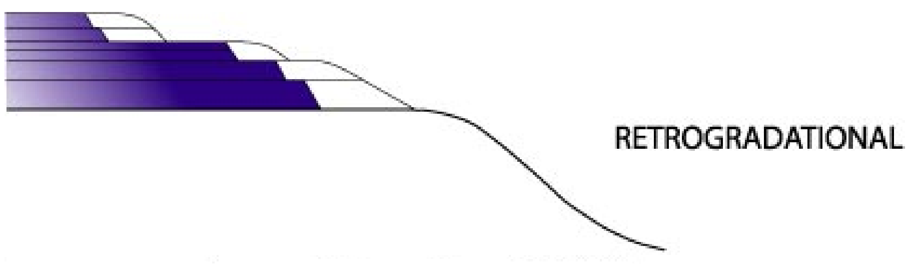


**Figure 8.13.** Retrogradational Parasequence (Galloway, 1989).

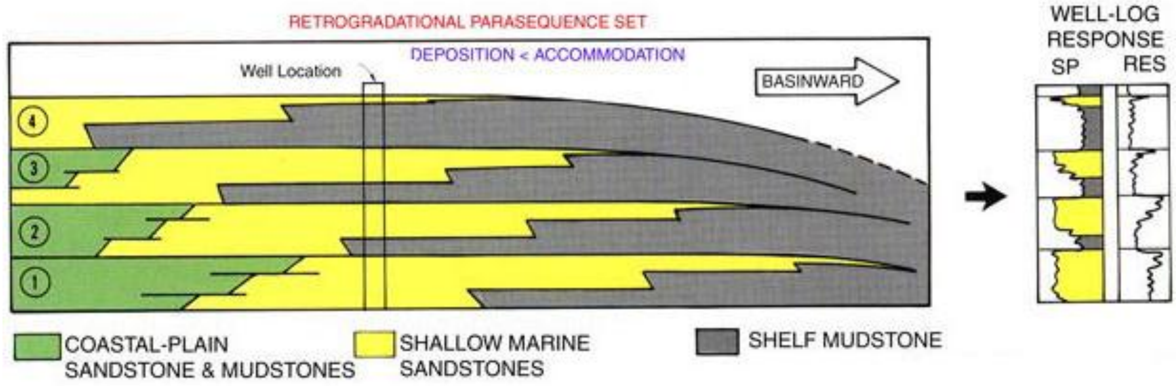


**Figure 8.14.** Retrogradational Parasequence Sets (Van Wagoner et al., 1988).

## 8.3. Result of Sequence Stratigraphy in Tanjero Formation

Sequence stratigraphy defined by numbers of the researcher in the dissimilar definitions due to their point of view and types of the formation that has studied. Therefore, different approaches have previously used for investigating sequence stratigraphy. The rock unit of the Tanjero Formation has divided into depositional successions or genetic packages based on the method that was initially used by Vail et al. (1977) study's, because of depositional sequence can be recognized by correlative conformities and unconformities in the sequences investigation. Although, studying sequence stratigraphy of Tanjero Formation is difficult by using the method of Galloway (1989). In this study, the Upper Cretaceous (Late Campanian- Late Maastrichtian) Tanjero Formation is divided into two third-order sequences (first and second third order sequences) (around 74.0 m.y. to 66.0 m.y..) which covers about 8.0 m. y time snap (Jassim and Goff, 2006) (Figure 8.15). In general, the successions have been divided into system tracts depending on distribution of parasequense sets and thire postion within successions, grain sizes, thickness of beds, types of bounding surface (Posamentier et al., 2009).

The two depositional sequences (lower deositional sequence and upper depositional sequence) have been identified within Tanjero Formation in the selected section. The lower depositional sequence of the Tanjero Formation is about 15% and intregate with upper part of the Shiranish formation belongs first-third order sequence which is composited Highstand Systems Tract (HST) rates of exceed rising of the accomendation compare to the sea level, and it is bounded by SB1.The accomendation space is less than sediment supply. The lower depostional sequence of the formation was deposited due to progradational to aggraditional parasequence when sea level rise and it is generally coarsing upward from log 1-1 to log 1-2 in 0 m to 201m (Figure 8.15).

SB1 is the main boundary is located within Tanjero Formation and it is base of the upper depositional sequence of the formation and the base of the relative sea level stand and start of the second-third order sequence. Upper depositional sequence composites around 85% of the Tanjero Formation. Above SB1 Lowstand Systems Tract (LST) is deposited resalt of progradational parasequence when rising sea level stand as a contiouse of pervious rise which consists of two parts; slope fun (SF) at the base of LST and lowstand progading wedge (LPW) at the top of LST. Sediment supply is grater than accomendation space. Therfore, it is also coarsing upward in general from log1-2 to log1-5 in 201m to 635m (Figure 8.15).

Trangrassive Surface (TS) is located over LST. From the TS the sea level start to fall and it is the base of deposting the Transgrassive Systems Tract (TST) this is due to retrogradational parasequence, and it contniouse until maximum flooding surface (MFS) boundary. The TST is generally fining upward due to falling of the sea level start from log1-5 to log1-8 in 635m to 1032m, therefore, accomendation space is grater than sediment supply rate (Figure 8.15).

The maximum flooding surface indicates of starting rising sea level and base of HST due to progradational to aggraditional parasequence. HST is coursing upward in general from log1-8 to log1-10 in 1032m to 1333m, and sediment supply is greater than accomendation Space in HST. Then SB2 covers the HST and end of the second-third order sequence. Also the SB2 is contact between Tanjero and Kolosh formations, and SB2 is upper boundary of upper depositional sequence. Characterization of type SB2 of sequence boundary indicates the sea level fell in the Early Maastrichtian, and the second and third-order of the depositional system presented from turbidites flysch facies of the Tanjero Formation (Lawa,

2018). In general, the lower depositional sequence from 0 m to 201 m consists HST and first- third order sequence. Moreover, upper depositional sequence from 201 m to 1333 m composites LST, TST and HST (Figure 8.15).

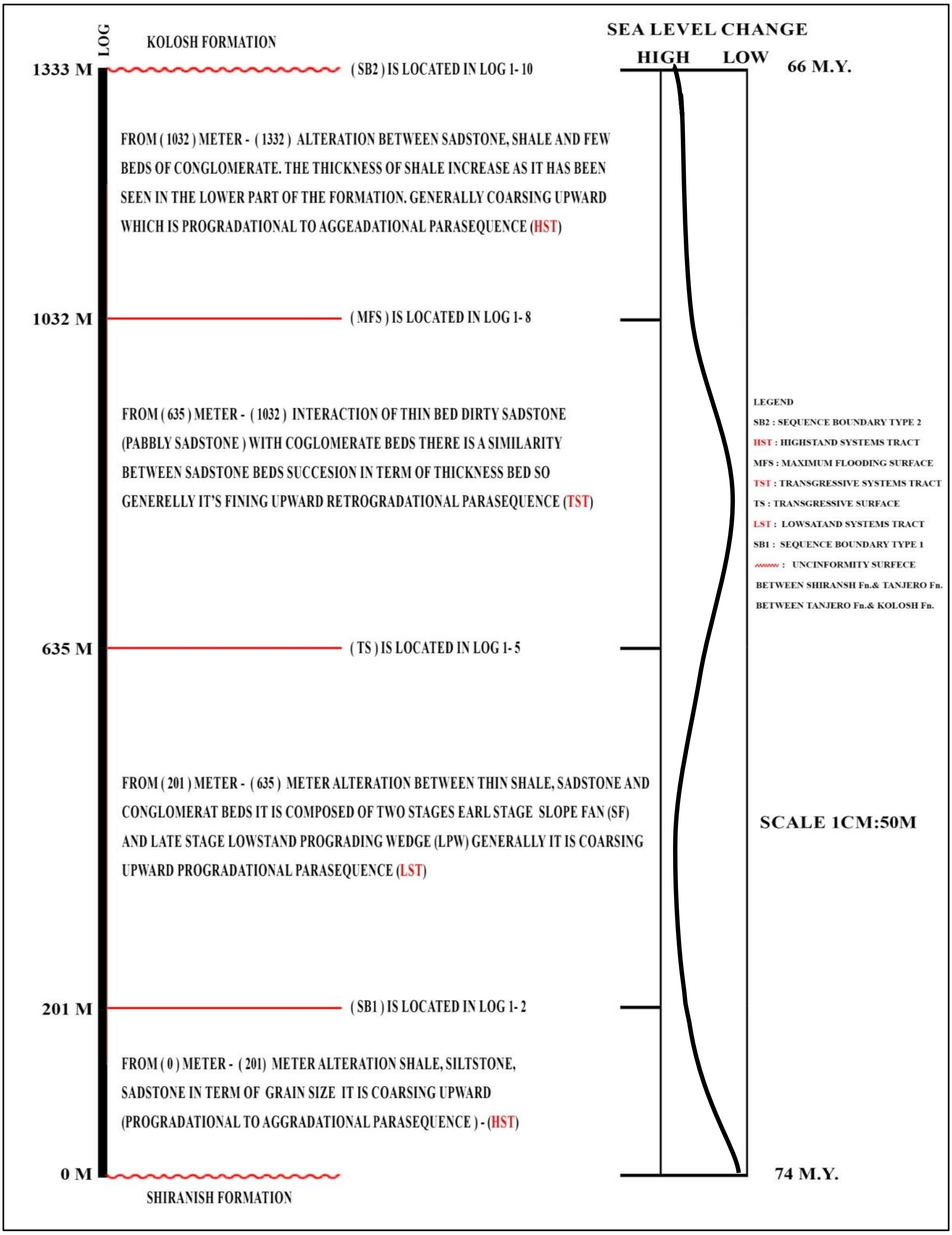


**Figure 8.15.** Sequence Stratigraphy Result including parasequence, system tracts and sea level change during Tanjero Formation age (Jassim and Goff, 2006)

## 9. CONCLUSION

This work was carried out Eastern part of Darbandikhan town, Northeastern part of Iraq, near the Sarshata villages on the Upper Cretaceous (Late Campanian-Late Maastrichtian) Tanjero Formation to study the sequance stratigraphy of the deep marine turbidite formation.

The present research contains parasequences, system tracts, fossil content, paleoflow analysis and related sequence startigraphy information and detail fieldwork of the Tanjero Formation. Paleoflow direction of sedimentary structures in the formation towards to southwest. In this study has been identified that the Tanjero Formation belongs to first and second- third order sequence.

In Palaeontology study, it has been approved that the formation was aged Late Maastrichtian due to indentification of planctonic foraminifera assemblage, and *Abathomphalus mayaroensis* zone and *Krithe* sp. Ostracode genus indicate bathyal environment and infraneritic bathyal environment respectively. Also it was shown that slope fan is a depositioanl environment of the turbidite Tanjero Formation based on the fossil content and pretty much of debris flow deposits from base to top of the formation.

The turbidite Tanjero Formation is separated into two depositional succesions (lower and upper depositional sequences) in the selected section, and the formation is subdivided into three part in term lithology alterations.

The lower depostional sequence is approximatly 15% of the Tanjero Formation which is equivalent to the lower part of the formation in term lithology and composites HST system tract. Whereas, the upper depositional sequence composites almost of the formation which corresponding to two other remaine parts of lithology and its about 85% of the formation. LST , TST and HST have been identified in the upper depositional sequence in this study. The two sequence bounderies are identified within the Tanjero Formation which are SB1 and SB2. SB1 is located over first-third order sequence (late HST) which is base of second-third order sequence below LST, and second-third order is covered by SB2 which is above HST and the end of the formation. Moreove, TS and MSF are identified in the middle of the formation.

In this study following system tracts are identified, Late HST, LST, TST and HST.

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**CV**

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- 3 years experience working as a geologist with Company drilling artesian wells
- Two years experience working as a geologist in the field of measuring groundwater (Static water level and Dynamic water level).
- Member of Kurdistan geological syndicate.
- TOEFL ITP total score in 31/1/2011 :- 380
- TOEFL ITP total score in 10/1/2012 :- 400
- Certification of demonstrated basic computer hardware, software and internet skills through the successful completion of the examinations comprising ic3 and the result 85%.

## Key Skills and abilities:

- Ability to work under pressure and hard times.
- Ability to work well with others and highly respective to new environment.
- Ability to lead work efficiently and harmoniously in an international and multicultural environment and good interpersonal skills with sensitively and respect for diversity.
- Computer literate in Internet and Microsoft Office.
- Language (Kurdish native, English, Arabic, little Turkish language) .

## Work Experience and skills

Key Roles:

Water management activities (ground water and surface water)

- Field work geologist
- Well site geologist (sampling and litho description of water wells)
- Supervising geological quarries

## *Attending courses*

* Project management training course in USAID /2007.
* A training course for testing construction material in the directorate of construction material laboratories /akre branch /2007.
* Permit man with seismic survey company / Terraseis company / Dinarta 2D program crew 207

## Education:

*BSc of science in General Geology*, University of Salahaddin, college of science, Erbil/ Iraq -2006

## Personal Details:

* *Date of Birth :_* 22/06/1983
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Note

- From all above I would like to say that I was Master's student at the University of Puna Indian but I did not finish it because of the economic conditions, I have certificates are available upon request.