REPUBLIC OF TURKEY

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LITHOFACIES DISTRIBUTION AND DEPOSITIONAL ENVIRONMENT OF TANJERO FORMATION (UPPER CRETACEOUS) EAST OF DARBANDIKHAN, NORTH EASTERN PART OF IRAQ

MASTER THESIS

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

JUNE-2019

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Sincerely

BAWAR AHMED
Elazığ, 2019

ABSTRACT

This thesis is aimed to examine the depositional environment of perfectly cropped out Campanian- Maastrichtian deep marine turbidities of Tanjero Formation near eastern part of Darbandikhan, to the northeastern part of Iraq. For this aim total 1333 m thick sedimentary measured section was logged in detail 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 lithofacies analysis of the Tanjero Formation in Sirwan Valley section, nine lithofacies (LF) and eight sub lithofacies (SLF) have been distinguished: LF-1: Conglomerate; SLF-1a: Pebbly to sandy matrix supported conglomerate; SLF-1b: Sandy matrix supported conglomerate; SLF-1c: Muddy matrix supported conglomerate; LF-2: Structureless sandstone beds; SLF-2a: Fine-coarse structureless sandstone; SLF-2b: Very coarse-pebbly structureless sandstone; SLF-2c: Amalgamated structureless sandstone; LF-3: Deformed sandstone beds; LF-4: Normal graded sandstone beds; SLF-4a: Pebbly to fine normal graded sandstone beds; SLF-4b: Coarse-medium to fine normal graded sandstone beds; LF-5: Reverse (inversely) graded sandstone beds-coarse to pebbly grained; LF-6: Laminated sandstone beds; LF-7: Siltstone beds; LF-8: Mudstone beds; LF-9: Chaotic-distorted lithofacies.

All facies are grouped into five facies associations based on standard models of deep-marine environment: FA-1: Slope; FA-2: Inner fan; FA-3: Middle fan; FA-4: Outer Fan; FA-5: Debrite deposits.

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.

In this study from the interpretation of these facies and facies associations, it is concluded that the turbidites of Tanjero Formation in Sirwan Valley deposited in a slope fan with NE-SW axis.

Keywords: Tanjero Formation, turbidite sandstones, facies analysis, deep marine slope fan, Sirwan valley, northeastern Iraq.

ÖZET

Tanjero Formasyonu'nun (Üst Kretase) Litofasiyes Dağılımı Ve Depolanma Ortamı Darbendikhan Doğusu , Kuzeydoğu Irak

Bu tezin amacı kuzeydoğu Irak'ta Derbendikan ilinin doğu kesiminde oldukça iyi yüzeylemeler veren Kampaniyen-Maastrihtiyen yaşlı Tanjero Formasyonu'na ait derin deniz türbiditlerinin depolanma ortamını ortaya çıkarmaktır. Bu amaçı gerçekleştirmek için yukarıda belirtilmiş olan lokasyondaki İran sınırına yakın Sirwan vadisindeki Sarshata köyü yakınlarında toplam kalınlığı 1333 m olan ayrıntılı bir ölçülü sedimanter stratigrafik kesit alınmıştır.

Alttan Kampaniyen-Maastrihtiyen yaşlı Shiranish Formasyonu, üstten ise Paleosen-orta Eosen yaşlı Kolosh Formasyonu ile sınırlanan birimden alınan bu ölçülü kesitte dokuz litofasiyes (LF) ve sekiz alt litofasiyes (ALF) tanımlanmıştır. Bunlar; LF-1: Konglomera; SLF-1a: Taneli-kumlu matriks destekli konglomera; SLF-1b: Kumlu matriks destekli konglomera; SLF-1c: Çamurlu martiks destekli konglomera; LF-2: Yapısız kumtaşı tabakaları; SLF-2a: İnce-kaba taneli yapısız kumtaşı; SLF-2b: Çok iri taneli-çakıllı yapısız kumtaşı; SLF-2c: Amalgam yapısız kumtaşı; LF-3: Deforme olmuş kumtaşı tabakaları; LF-4: Normal derecelenmiş kumtaşı tabakaları; SLF-4a: Çakıllı-ince taneli normal derecelenmiş kumtaşı tabakaları; SLF-4b: Kaba-orta-ince taneli normal derecelenmiş kumtaşı tabakaları; LF-5: Ters derecelenmiş kaba-çakıllı kumtaşı tabakaları; LF-6: Laminalı kumtaşı tabakaları; LF-7: Silttaşı tabakaları; LF-8: Çamurtaşı tabakaları; LF-9: Kaotik-bükülmüş litofasiyes.

Tüm bu fasiyesler, standart derin deniz ortamı modellerine göre beş ayrı fasiyes topluluğu (FT) altında gruplandırılmıştır. Bunlar; FT-1: Yamaç; FA-2: İç yelpaze; FA-3: Orta yelpaze; FA-4 Dış yelpaze; FA-5: Moloz depolanmaları.

Kaval yapıları ve kiremitlenmelerden alınan akıntı yönü verilerinin gül diyagramında yapılan analiz sonucu bu alanda beslenmenin KD'dan GB'ya doğru olduğunu, dolayısıyla kaynak alani KD'da bulunduğunu ortaya koymuştur.

Yapılan fasiyes analizleri sonucunda Tanjero Formasyonu'nun Sirwan vadisindeki kırıntılı sedimanter kayaçlarının KD-GB eksenli bir "yamaç yelpazesi" ortamında çökeldiği ortaya konmuştur.

Anahtar Kelimeler: Tanjero Formasyonu, türbidit kumtaşları, fasiyes analizi, derin deniz yamaç yelpazesi, Sirwan vadisi, kuzeydoğu Irak.

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1. INTRODUCTION

The term submarine fan is derived from fan-shaped bodies that are deposited by mass-flow, basically turbidity current, processes. It is varying in size from a couple of kilometers span to depositional systems covering over a million square kilometers and forming some of the largest geomorphological features on Earth. A submarine fan can be divided into a number of ‘architectural elements’, components of the depositional system that are the products of different processes and sub environments of deposition. Major portions of submarine-fan sequences are composed of turbidites that occur as channel-fill, lobes, and sheet sands. A turbidite bed represents a single depositional event from a turbidity flow. Turbidites are recognized routinely in both modern and ancient sediments by graded bedding and by a standard sequence of sedimentary structures known as the "Bouma sequence". Submarine fan channels form distinct elements on the fan surface and may have levees associated with them: these channels may incise into, or pass distally into, depositional lobes, which are broad, slightly convex bodies of sediment. Lobes are the most distal sedimentary deposits of siliciclastic turbidite systems. They can also be found in shallower environments along sedimentary ramps or in contourite systems (Mulder, 2010).

The geologic community's understanding of submarine fans/ lobes and turbidite systems has grown considerably during the past two decades. The geologic literature has proliferated with contributions addressing primarily the sedimentology and stratigraphy of ancient turbidites exposed in outcrops, and of modern submarine fans, as imaged with high-resolution, shallow-penetration seismic and side-looking imaging systems and piston cores (Gordon, 2015).

Major portions of submarine-fan sequences are composed of turbidites that occur as channel-fill, lobes, and sheet sands. Bouma (1962) proposed the most persuading connection between the turbidite facies display with five divisions, to be specific Ta, Tb, Tc, Td, and Te, and their areal distribution on a submarine fan. A turbidite bed represents a single depositional event from a turbidity flow. Depositional processes vary from mass movement (creep) at one end of the spectrum through cohesive flows (slumps, debris flows) and turbulent flow (turbidites) to laminar flow and settling from suspension (contourites, hemipelagites) on the other end of the spectrum (Middleton & Hampton, 1976). Fan sequence represents the deposition by gravity flows into a basin (Feeley, et al., 1985; Weimer and Buffler, 1985). Turbidites are recognized routinely in both modern and ancient sediments by graded bedding and by a standard sequence of sedimentary structures known as the "Bouma sequence". A submarine fan, called turbidite system by (Mutti and Normark, 1987, 1991). A stratigraphic succession of a number of turbidite systems is known as a submarine fan complex or turbidite complex (Mutti abd Normark, 1991).

Deep water depositional systems are commonly referred to as turbidite systems, these systems are composed of a sequence of sediment gravity flow deposits. According to Shanmugam (2016); A.H. Bouma mentioned that in the past few years, an additional type of turbidite bed has been recognized. Slurry beds are muddy turbidites that are intermediate between clean well-graded sandy turbidites and muddy debris flow beds, sometimes referred to as debrites.

Tanjero clastic Formation (late Campanian – Maastrichtian) was first determined and studied by Dunnington (1952). The type locality of Tanjero Formation is located Sirwan Valley, east of Darbandikhan town, southeast of Sulaymaniyah. It is belonging structurally to the Imbricated Zone. It is consisting of two parts according to Dunnington (1952), lower part consists of open sea globigerinal marlstone, rarely limestone and silty marly limestone. Upper part consists of silty marls, siltstone, sandstones and sandy or silty detrital limestones with intercalation of organic reef and shoal limestones.

There are several geological works on the formations in the distinct branches mainly in general geology by investigators in Northern Iraq, but very less in Sirwan Valley around Darbandikhan especially on the turbidites outcrop where is the subject of this study. This study will be in detail about Tanjero Formation in Sirwan Valley (Typical area), East of Darbandikhan. This project depends on facies and facies association.Karim and Surdashy(2006) studied on tectonic and depositional history and sequence stratigraphic features of the formation. Karim (2005, 2006a, 2007, 2010) worked on palaeoflow analysis, sedimentary structures and environment interpretations, comparison between the adjacent formations and the Tanjero Formation and origin of ball and pillow- like structures in the formation, basin analysis of the Tanjero Formation and tectonic evolution of the northern Iraq area especially including Sulaymaniyah. According to (Jaza, 1992): The outcrops of Tanjero Formation are characterized by a sequence of sandstone, marlstone, siltstone and conglomerate, in which the differential resistance to erosion formed the questa ridges and furrows. Biostratigraphy, stratigraphy and tectonic evolution have been accordingly studied by (Kassab, 1975; Al-Mehaidi, 1975). Also, sedimentology, petrology of Tanjero Formation described by (Al-Rawi, 1981). Sedimentary structures, palaeoflow direction and sequence stratigraphy of this formation examined by (Karim, 2004; Karim and Surdashy, 2005b; Karim, 2005c; Karim and Surdashy, 2006). In addition, (Karim, et al., 2012; Karim, et al., 2014) studied stratigraphy and the origin of fossiliferous limestone beds in the upper part of the Tanjero Formation.

Deep marine fan constitutes major hydrocarbon reservoirs throughout the world. Consequently, a clear understanding of their geometry, facies relationships, and reservoir quality is critical for exploring and exploiting these deposits effectively. In this regard, deep-marine fan have become one of the most thoroughly studied depositional systems in the rock record (Menard, 1960; Mutti and Ricci Lucchi, 1972; Middleton and Bouma, 1973; Stanley and Kelling, 1978; Bouma, 1983/1984; Nelson and Nilsen, 1984; Bouma, et al., 1985a; Mutti and Normark, 1987; Pickering, et al., 1989; Pickering, et al., 1995; Shanmugam, 1990, 2000a; Prélat, et al., 2009; Groenenberg, et al., 2010; Straub and Pyles, 2012; Marini et al., 2015) after (Shanmugam, 2016).

1.1 PREVIOUS WORKS

Bellen, et al. (1959) mentioned that Tanjero Formation is first defined and described under the name of Tanjero clastic Formation by Dunnington in 1952. Also, he chose the type section at Sirwan Valley near Halabja Town. In addition, he described briefly the distribution, age, lithology, fossil content, and stratigraphy of the Tanjero Formation at different localities in northeastern Iraq. Late Campanian-Maastrichtian was determined as an age of Tanjero Formation by (Kassab, 1975) while studying biostratigraphy of Tanjero Formation. Stratigraphy and tectonic of the formation were discussed in Chuarta area that observed present of the Aqra Formation in the upper part of Tanjero Formation as a lens (Al-Mehaidi, 1975).

Al-Rawi (1981) studied in detail about sedimentary, and petrology of the formation in two different locations (Sulaymaniyah, Dokan and Rawandoz sections). He mentioned that lower part at Sulaymaniyah has shallow environment of deposition and concluded that the palaeoflow is toward northwest and flow parallel to the axis of the Tanjero trough. Furthermore, he studied in detail the clay mineralogy and sandstone of the formation and classified the sandstones according to (Pettijohn, 1975) and plotted them on triangles.

Abdel-Kireem (1986a) studied the formation within stratigraphy of Upper Cretaceous and Lower Tertiary of Sulaymaniyah- Dokan Region. He suggested removing the word “clastic” from the name of the formation and to put the lower part with Shiranish Formation. Abdel-Kireem (1986b) investigated planktonic forams and stratigraphy of Tanjero Formation. He selected, for the formation, the age of middle-late Maastrichtian in Dokan area. Saadallah and Hassan (1987) analyzed sedimentology of the Tanjero Formation, they claimed that the type of sandstones graywackes and subgraywacke in Dokan and Sulaymaniyah areas. In addition, they mentioned that the palaeoflow is toward west and southwest. Jaza (1992) studied in detail the lithology facies through outcrops in Sulaymaniyah district. He noted the turbidite and submarine fan (as depositional feature of the basin) in the Tanjero Formation. He divided the rock body of the formation into sixteen lithofacies and suggested further detailed study of the formation to reconstruct depositional model for the whole basin and its relation to tectonics.

Minas (1997) investigated sequence stratigraphy of the formation and found that Tanjero Formation deposited in deeper environment than Shiranish Formation and plotted the formation as a transgressive part of the cycle. Lawa, et al. (1998) investigated carbonate layers in the upper part of the formation at Chuarta-Mawat area and conclude that these beds belong to Aqra Formation, which interfingered with Tanjero Formation.

Al-Rawi and Al-Rawi (2002) introduced Tanjero Formation as turbidite example of flysch type in northeast and north of Iraq, He mentioned that sandstone and shale beds deposited in deeper environment compared to limestone beds in Tanjero Formation. Karim and Surdashy (2005a, 2005b, 2006) studied on tectonic and depositional history and sequence stratigraphic features of the formation. Karim (2005, 2006a, 2006b, 2006c, 2007, 2010, 2015) worked on palaeoflow analysis, sedimentary structures and environment interpretations, comparison between the adjacent formations and Tanjero Formation and origin of ball and pillow- like structures in the formation, basin analysis of the Tanjero Formation and tectonic evolution of the northern Iraq area especially including Sulaymaniyah.

Zubaidi et al. (2016) quoted that sedimentological analysis showed that Tanjero Formation is deposited in marine environment. Clastic reservoir characterization has been investigated in the Tanjero Formation in the northern part of Sulaymaniyah by Hemn

(2017). In addition, Provenance of the Tanjero sediments has been studied via petrography in the south east of Sulaymaniyah city close to Arbat town by Tavan (2017).

1.2 AIM OF THE STUDY

The aim of this thesis is to study and establish depositional environment of Tanjero Formation (Campanian- Maastrichtian deposits) in Sirwan Valley close to the east of Darbandikhan by using lithofacies distributions and reconstruct a depositional model of the sediments outcropping in the study area. One log section was measured in typical area of the sediments known as Tanjero Formation in the region.

1.3 METHODS

1.3.1 Field work

From the field work, some areas were visited and some information collected. However, only one section investigated in detail, for example Sirwan valley section, eastern of Darnbandikhan. Recording surface outcrop in the Upper Cretaceous sediments of Tanjero Formation in typical area of Eastern Darbandikhan, Northern Iraq near Iran border was a big challenge due to the complexity of the roads to get the location and security issue due to geopolitics of the area. One log section was measured. The vertical and lateral analysis of the Tanjero Formation was done by measuring and describing a vertical stratigraphic section which Tanjero deposits exposers well. The log had the following main objectives: a) show facies analysis and facies associations of the studied deep marine systems; and b) record sedimentological information (e.g. interpretation of sedimentary processes).

During measuring vertical section studied and recorded bed to bed thickness, rock type, where the variety of lithology and grain sizes observed. Examine both vertical cuts and the topside and underside of bedding planes; all may have something to reveal. It was also useful, on larger outcrops, to walked back and examined them from a distance, even from a boat in the Sirwan river, as this was revealing large-scale lobe stacking, facies changes, and many other features of interest. Using GPS was useful to select the measured section location. The graphic log was drawn to show the sediment properties in a fashion as real as possible. A particularly high degree of detail has been put in the graphic log. The log was drawn in 1:50 scales to show, with relatively high-detail, textural and structural characteristics of predominantly conglomeratic sandstone deposits.

1.3.2 Office work

Office work consists of collecting and reviews the previous works to set up base information for the master degree thesis. Drawing vertical stratigraphic section (Log) by Adobe illustrator software (free trial version) then interpret and analyze the log, and using software for drawing and editing photos such as; Adobe photoshop and Corel draw. Plotting palaeoflow direction rose diagrams. Determine facies and made facies association by editing and crop pieces of stratigraphic section. Depositional environment was assigned by examining and interpreting sedimentary structures, rock type, size of sediments, textures, fossils, horizontal and vertical changes of the beds. The preceding data are used to reconstruct the depositional environmental of Tanjero Formation and determine lobe hierarchy in the studied area.

1.4 LOCATION

The location of the study area is shown in the (Figure 1.1). It is located northern Iraq close to Iranian border in the high folded zone, Eastern part of Darbandikhan Town near Sirwan river. The study area is located between latitudes 35 04’ 38” – 35 06’ 17” N and 45 53’ 50” – 45 54’ 35” E and longitudes 45 53’ 50” – 45 54’ 35” E.

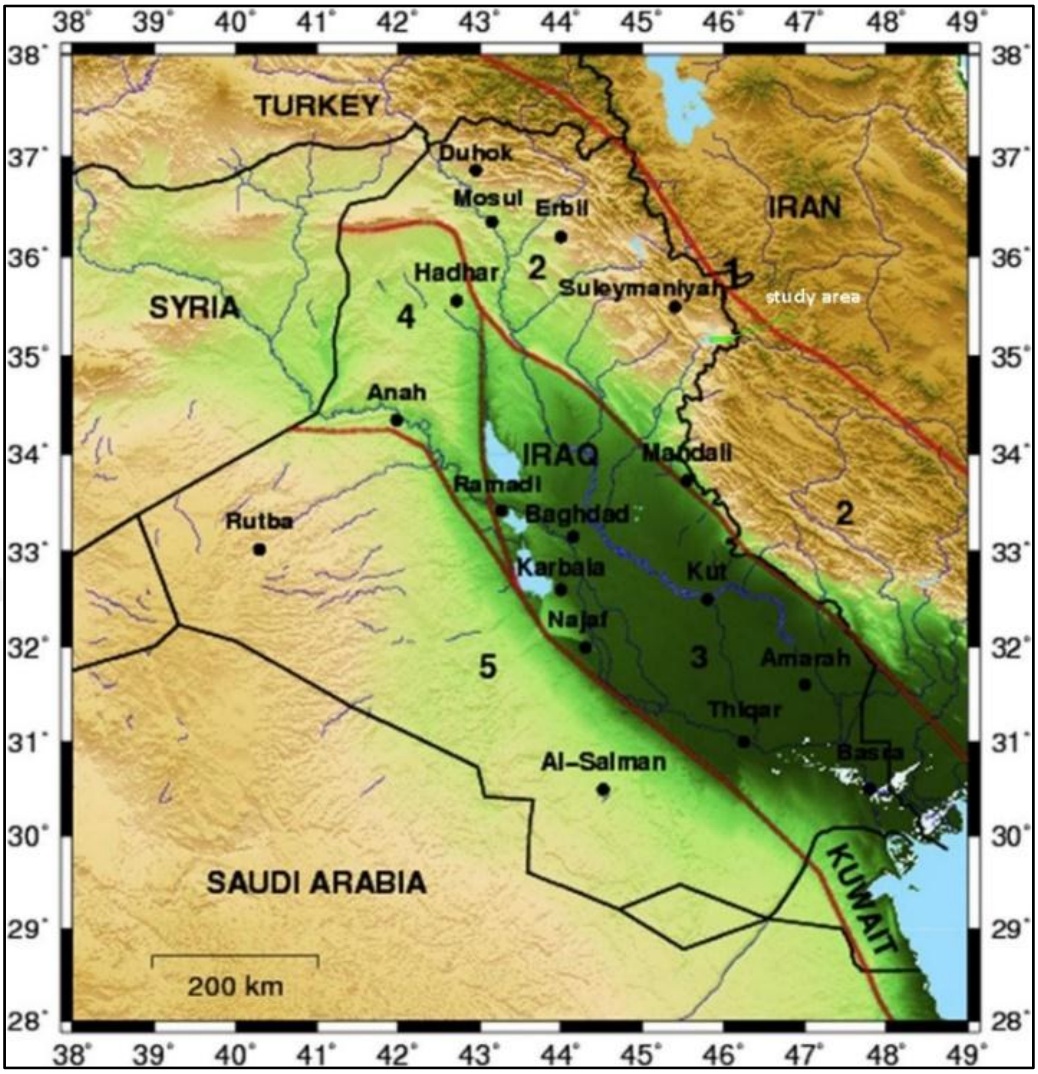

Figure 1. 1. Study area location on the Iraq map (modified after Jassim-and-Goeff-2006).

1.5 GEOLOGICAL SETTING

Iraq lies in the border between the two main Phanerozoic units of the Middle East; Arabian part of the African (Nubio- Arabian) platform and the Asian branches of the Alpine Geosyncline according to Budday (1980) and Buday and Jassim (1984). Agard et al. (2005) classified the Zagros orogenic belt to four tectonically related parallel zones, which is extend from south-west to north-east: Low folded Thrust Zone (LFTZ), High Folded Thrust Zone (HFTZ), Imbricated Zone (IZ) and Zagros Suture Zone (ZSZ), (Fig. 1.2). The main structural trend is north-west–south-east (NW–SE, in Sulaymaniyah and Arbil area) and changes to Taurus (E–W trend, in Duhok area) with less complexity towards Arabian platform.

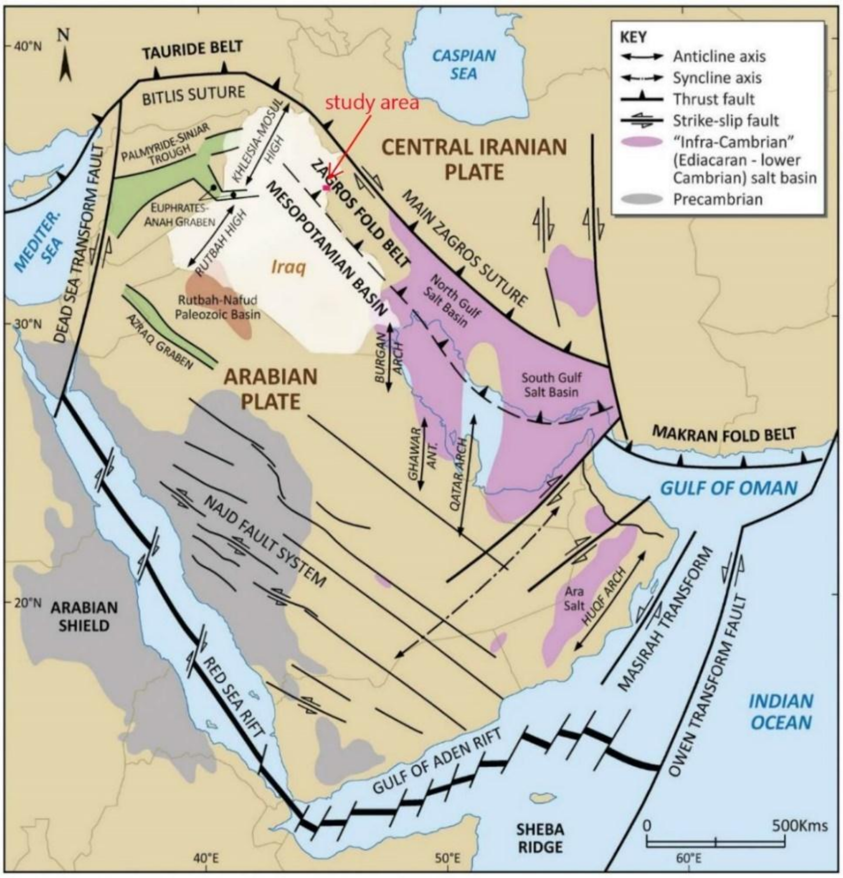

Figure 1. 2. Main tectonic sub-divisions of the Arabian plate and location of Iraq include study area modified after (English, et al., 2015).

Iraq tectonically divided for 5 tectonic zones according to tectonic activity and topography from north east to south west to: Thrust zone, Imbricate zone, High Folded Zone, Low Folded Zone, Mesopotamian Zone and Stable Shelf Zone (Fig. 1.3).

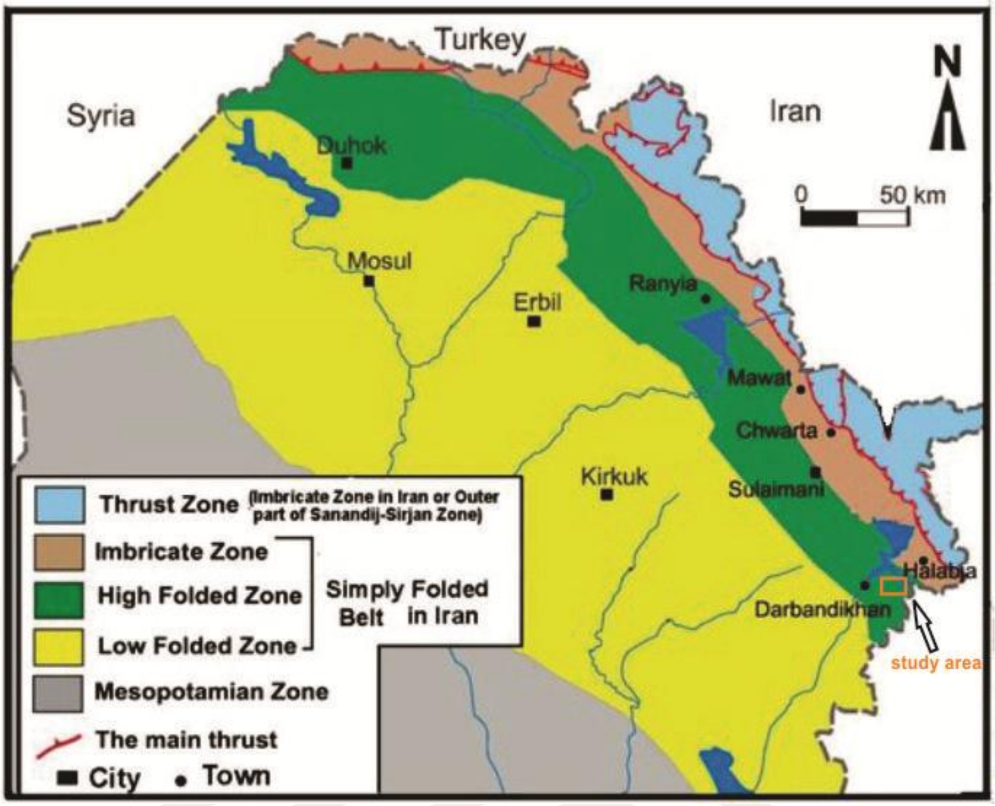

Figure 1.3. Tectonic map of northern Iraq, selected study area on it (Jassim and Goff,2006).

The studied area located the lower part of Zagros thrust belt through Imbricated zone and High folded zone between Halabja and Darbandikhan towns in Sirwan valley, which is developed from the Neo-Tethys sea basin fill and collision of Iranian and Arabian plates.

The late Cretaceous successions of Iraq- foreland basin is very important for hydrocarbon potentiality, and hence the lithostratigraphic units have been studied from different geological viewpoints by several researchers (Al-Mehaidi, 1975; Kassab, 1975; Al-Rawi, 1981; Abdul Kireem, 1986; Jaza, 1992; Lawa, et al., 1998; Aziz et al. 2000; Karim, 2004). The late Campanian late Maastrichtian supersequences are manifested by the Shiranish, Tanjero and Aqra formations in Kurdistan foreland basin. The late Cretaceous system outcrops in the imbricated and high folded thrust zones.

The study area is in the type section of Tanjero Formation which is located at Sirwan Valley near Halabja town (Fig. 1.4). Tanjero Formation is contacted with Shiranish Formation in the lower part which is gradational. Tanjero Formation is contacted with Kolosh Formation in the upper boundary which is unconformity.

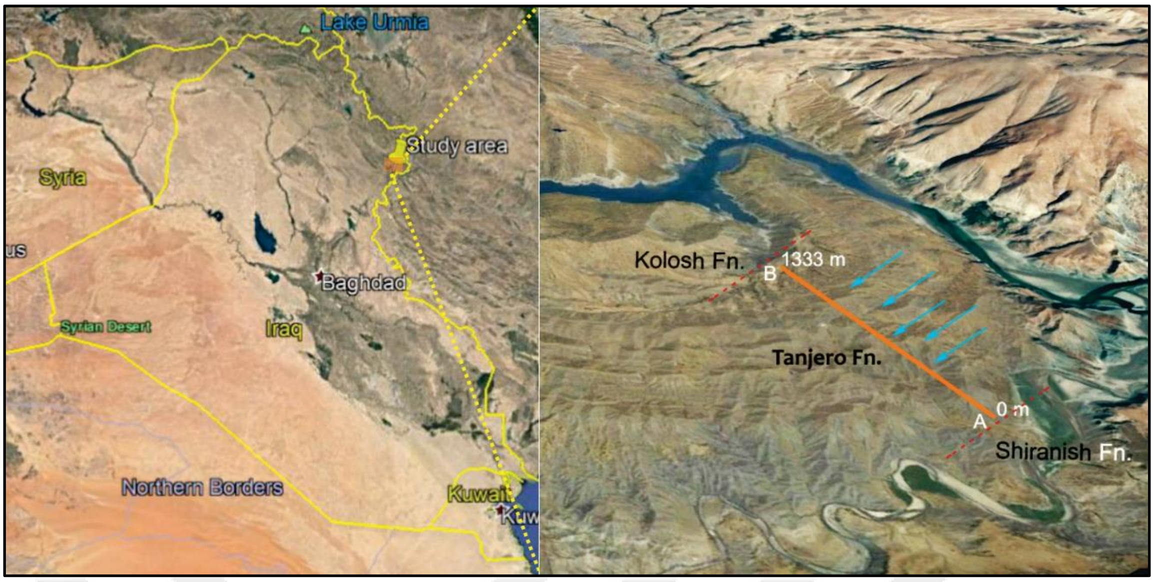

Figure 1.4. Google earth picture of the study area located 20 km East of Darbandikhan in Sirwan-North Iraq), blue arrows show palaeoflow direction, the orange color line shows measured section.

1.6 TANJERO FORMATION

1.6.1 Definition

The Tanjero Formation has been first described by H.V. Dunnington in 1952 ((Bellen, et al., 1959). It is characterized as flysch series by Dunnington (1958). In addition, the age of the formation was determined by Dunnington (1952) as late cretaceous (late Campanian – Maastrichtian).

1.6.2 Stratigraphy

The Tanjero Formation is distributed through Imbricated zone and high folded zone in the north and northeastern part of Iraq (Buday, 1980). According to (Al-Rawi, 1981), This formation exposed along a belt which is extending NW-SE from the type locality through Sulaimanyah, Surdash, Dokan, Rawandoz, Megasoor to Argosh (Fig. 1.5). The deposits of this unit indicate flysch facies within the foreland basin and recorded the type section from Sirwan Valley about 87 km south-east of Sulaymaniyah city, by Dunnington (1952) in Lawa (2018) after Bellen et al. (1959). The study area is located in Sirwan valley, east of Darbandikhan town, the formation consists of deep marine turbidite (Fig. 1.6). Tanjero Formation's lower boundary is contacted gradationally with the Shiranish Formation (Bellen, et al., 1959; Buday, 1980; Karim, 2004; Jassim and Goff, 2006). It is upper boundary is contacted with Kolosh Formation is disconformity (Bellen, et al., 1959; Buday, 1980; Jassim and Goff, 2006), (Fig. 1.7).

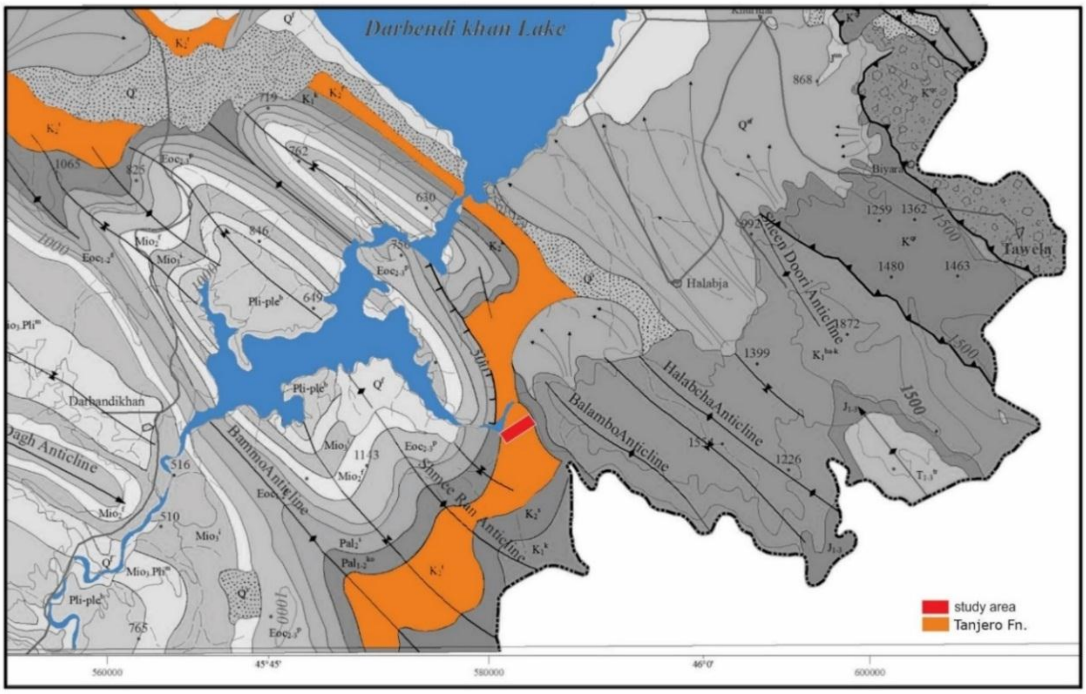

Figure 1. 5. Derbandikhan lake area current map showed the distribution of the Tanjero Formation and study area in North Iraq modified from (Sissakian, 2006).

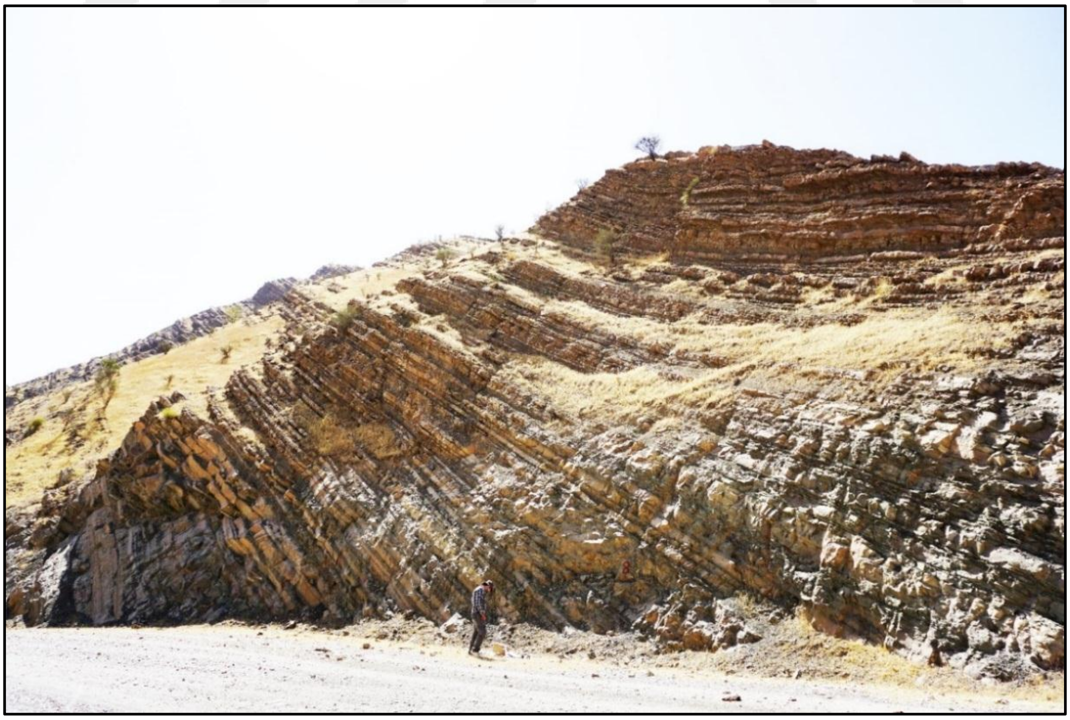

Figure 1. 6. Interbedded sandstone beds with calcareous mudstone of Tanjero Formation in the studied area. Sirwan valley- E. Derbandikhan.

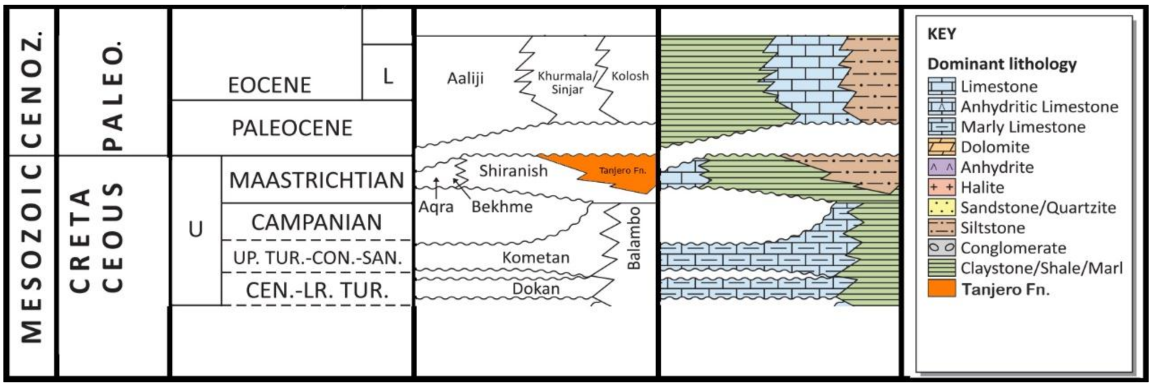

Figure 1. 7. Chronostratigraphic column section in the Kurdistan region of Iraq (modified after English et al., 2015)

1.6.3 Lithology

Tanjero Formation was first defined and described under the name of Tanjero clastic Formation by Dunnington (1952) from the Sirwan Valley, southeast of Sulaymaniyah, 2 km to the south of Kani Karweshkan village, near Halabja. The type section of the formation in the Sirwan Valley (SE of Sulaymaniyah comprises two divisions. Bellen, et al. (1959) observed that the lower division comprises pelagic marl, and occasional beds of argillaceous limestone with siltstone beds in the upper part and the upper division comprises silty marl, sandstone conglomerates, and sandy or silty organic detrital limestones; it interfingers with the Aqra Limestone Formation. The sandstones are composed predominantly of grains of chert and green igneous and metamorphic rocks.

The conglomerates contain pebbles of Mesozoic limestones, dolomites, recrystallized limestones, and radiolarian chert. The thickness of the formation is varied. The maximum thickness of the formation is about 2000 m between Rowanduz and Chuwarta. The Tanjero Formation decreases the thickness of the beds and the grain sizes towards the SW (Jassim & Goff, 2006), also he mentioned that this formation was deposited as flysch in a rapidly subsiding foredeep basin immediately in front of the thrust sheets of the abducted margin of the Southern Neo- Tethys. The onset of flysch deposition occurred when these thrust sheets were elevated above sea level and rapidly eroded. Fossils (mostly planktonic fauna) are abundant in the Tanjero Formation and they are indicative of late Campanian Maastrichtian age.

The Germav Formation in southeast Turkey is Tanjore Formation’s equivalent (Altinli, 1966). The sediments of this unit indicate flysch facies within the foreland basin and observed typical section from Sirwan valley about 87 km south-east of Sulaymaniyah city, by Dunnington,1952 in Lawa (2018) after Bellen et al. (1959). This deposit consists of rhythmic alternation of olive-green sandstone, marl, calcareous shale and sandstone or siltstone, about 2018 m thick in the type section. This unit is recorded only from the imbricated and high folded thrust zone and disappears towards the low folded thrust zone. There are different sedimentary structures in the erosive beds of the turbidites deposits like flute cast, graded bedding, ball and pillow, cross-lamination, parallel laminations and large trace fossils and plant remains. The lower part is recognized by a thick marl bed interbedding with a lensoidal bed of conglomerates, and a bioturbated sandstone bed shows progressive increase in marl and shale beds and disappearance of the conglomerate in the middle part, the marl prone parts are rich in planktonic foraminifera. The upper part exhibits the interbedding of a pebbly sandstone bed and thick sandstone with marl and carbonates.

In the studied area the Tanjero Formation is composed of alternation of sandstone and calcareous mudstone (Fig. 1.8). In general, in the lower part observed thin bedded sandstone with thick calcareous mudstone. The grain size and thickness of sandstone beds increased upward. In the middle part and upper part observed conglomerate beds and pebbly sandstone beds. The thickness of sandstone varies from thin bed to thick bed as well as grain size changed from fine to pebbly. The color of sandstone beds was variable from grey, yellowish brown to greenish grey. The color of calcareous mudstone is mostly dark grey to greenish grey.

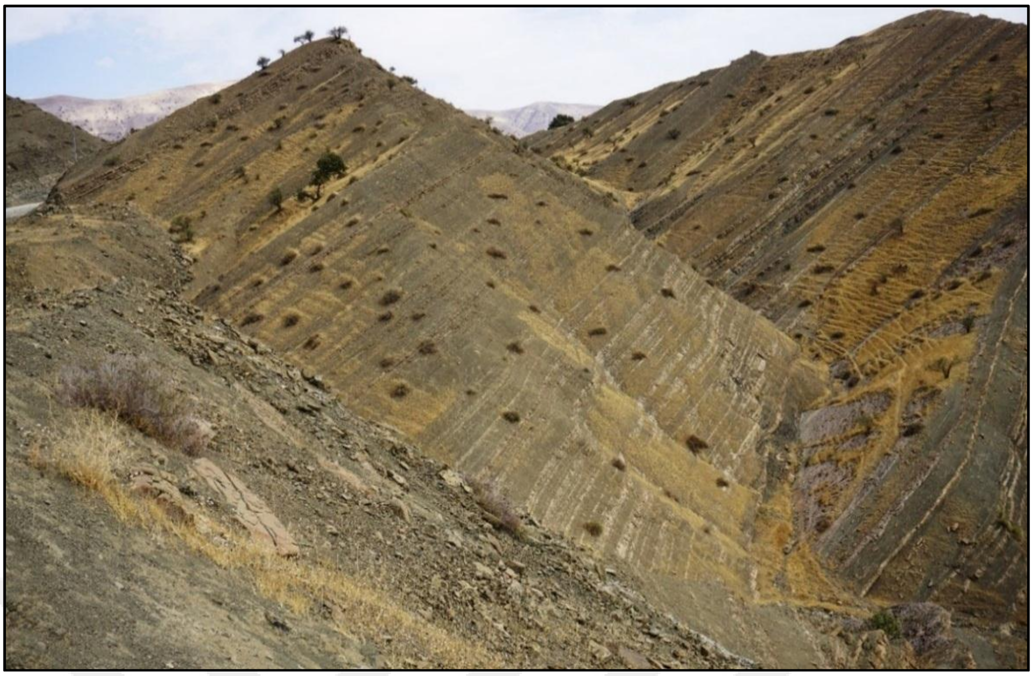

Figure 1.8. Photo of Tanjero Formation showing different type of beds in the studied area. Sirwan valley- E. Derbandikhan.

1.7 Current Studied Section

The measured section was taken from Sirwan Valley about 87 km south-east of Sulaimaniya near Darbandikhan area. The measured section started from the lower boundary of the Tanjero Formation with Shiranish Formation to the upper boundary of the Tanjero Formation with Kolosh formation (Fig. 1.9). The length of the measured section is 1333 m (Fig. 1.10).

Figure 1.9. Google Earth image covering the study area Sirwan valley- East of Darbandikhan town. Orange rectangle represents the location of the measured log from right to the left.

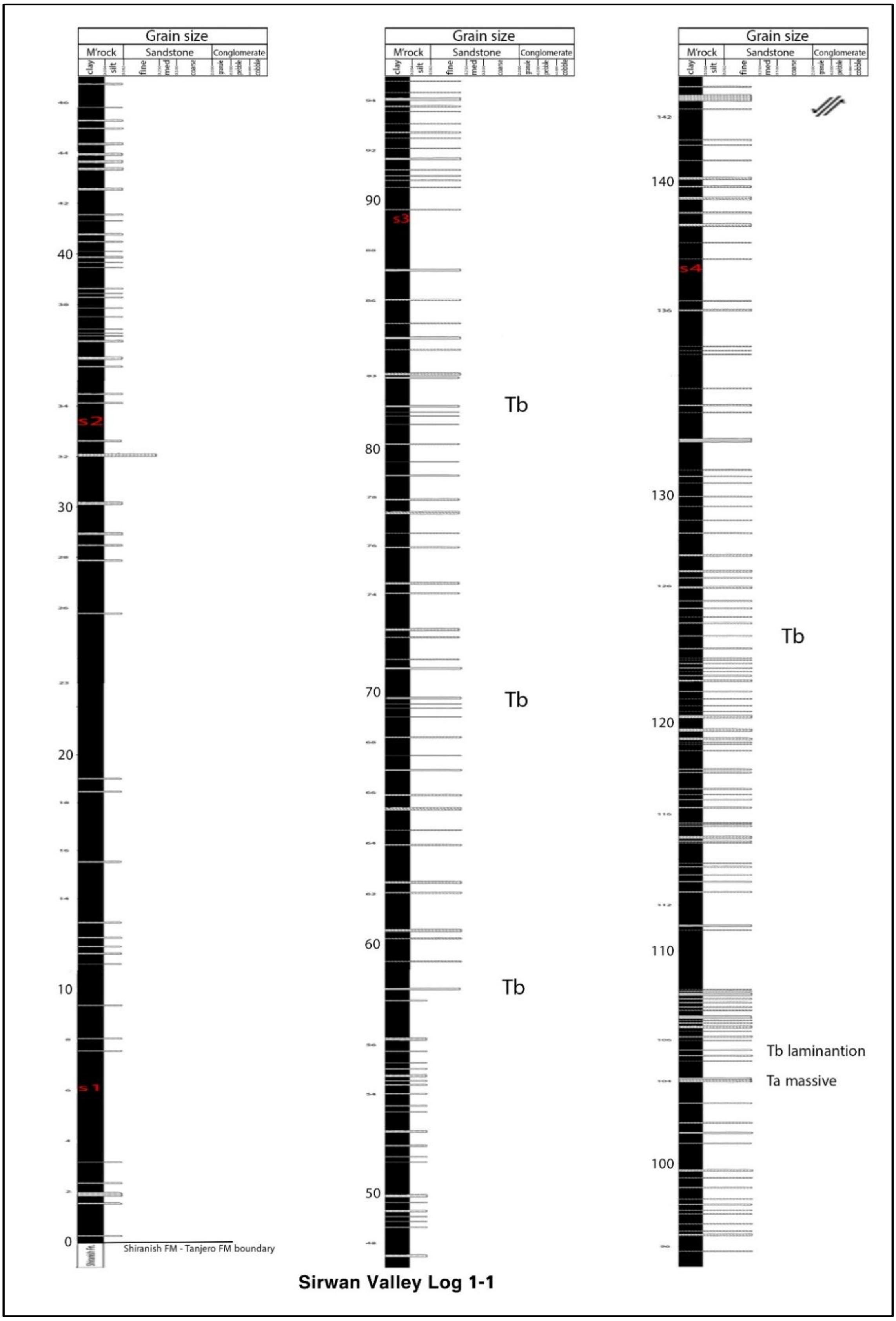

Figure 1.10. Measured section in study area (Sirwan Valley, East of Derbendikhan).

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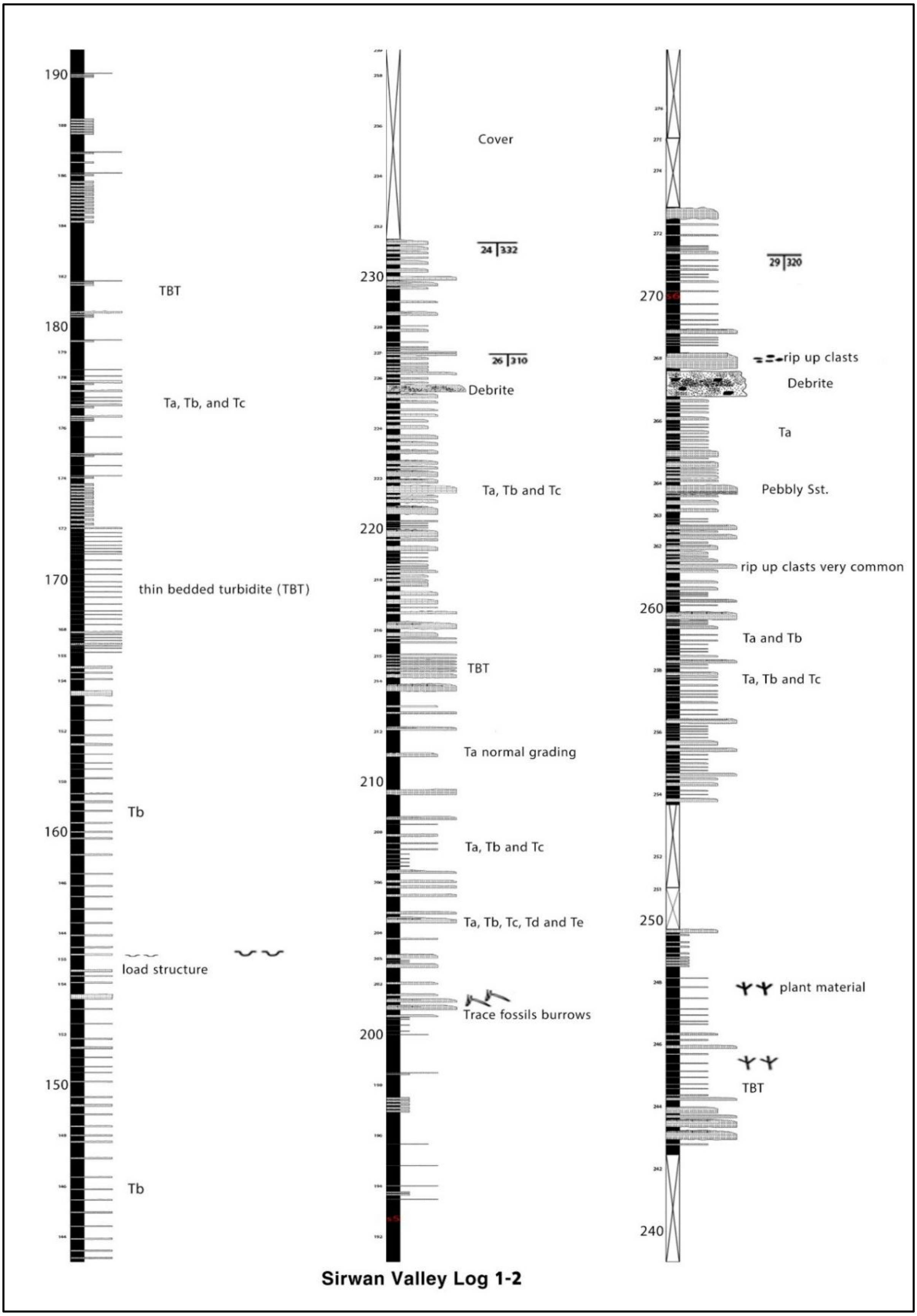
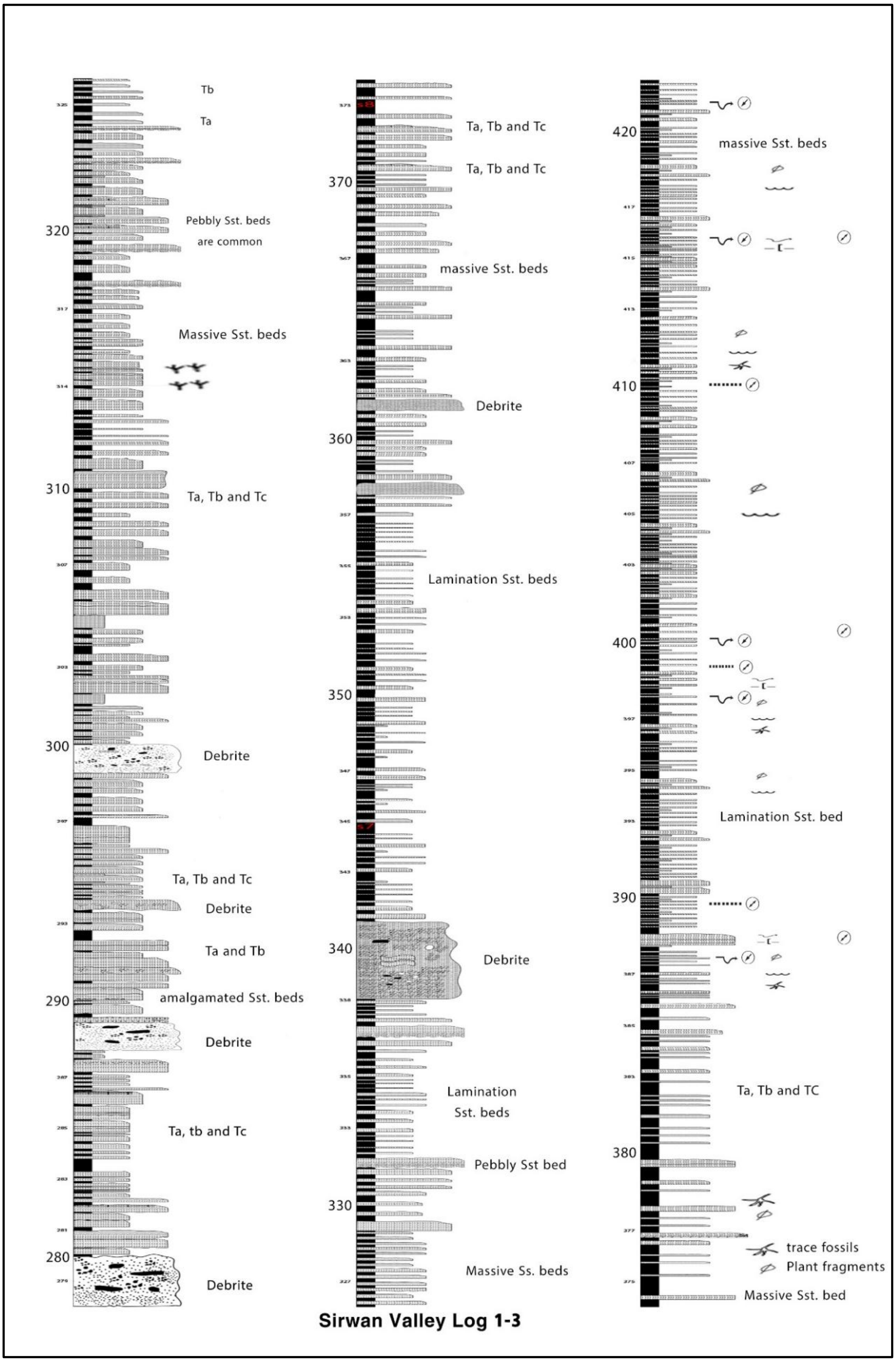


Figure 1.10. Continued



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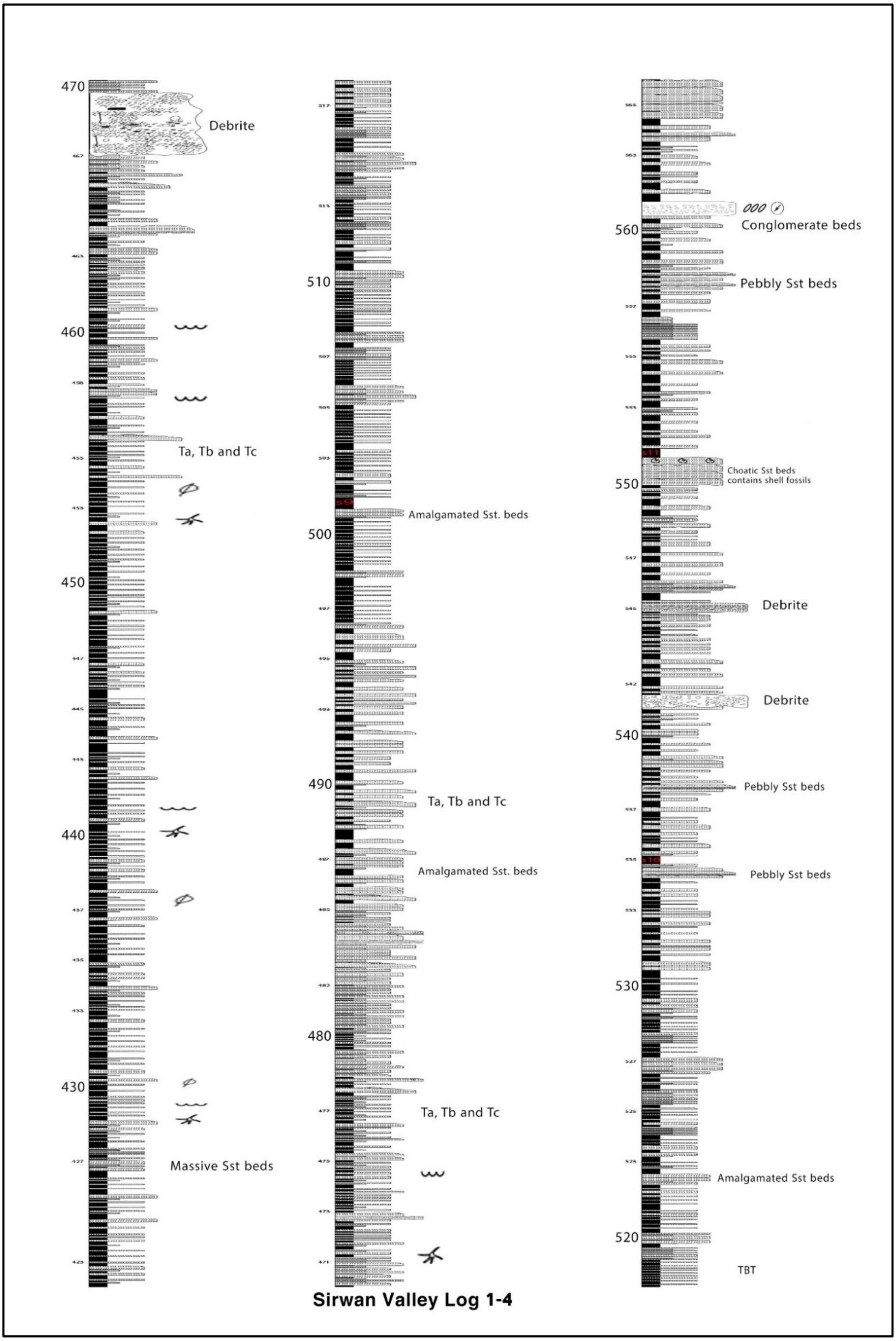

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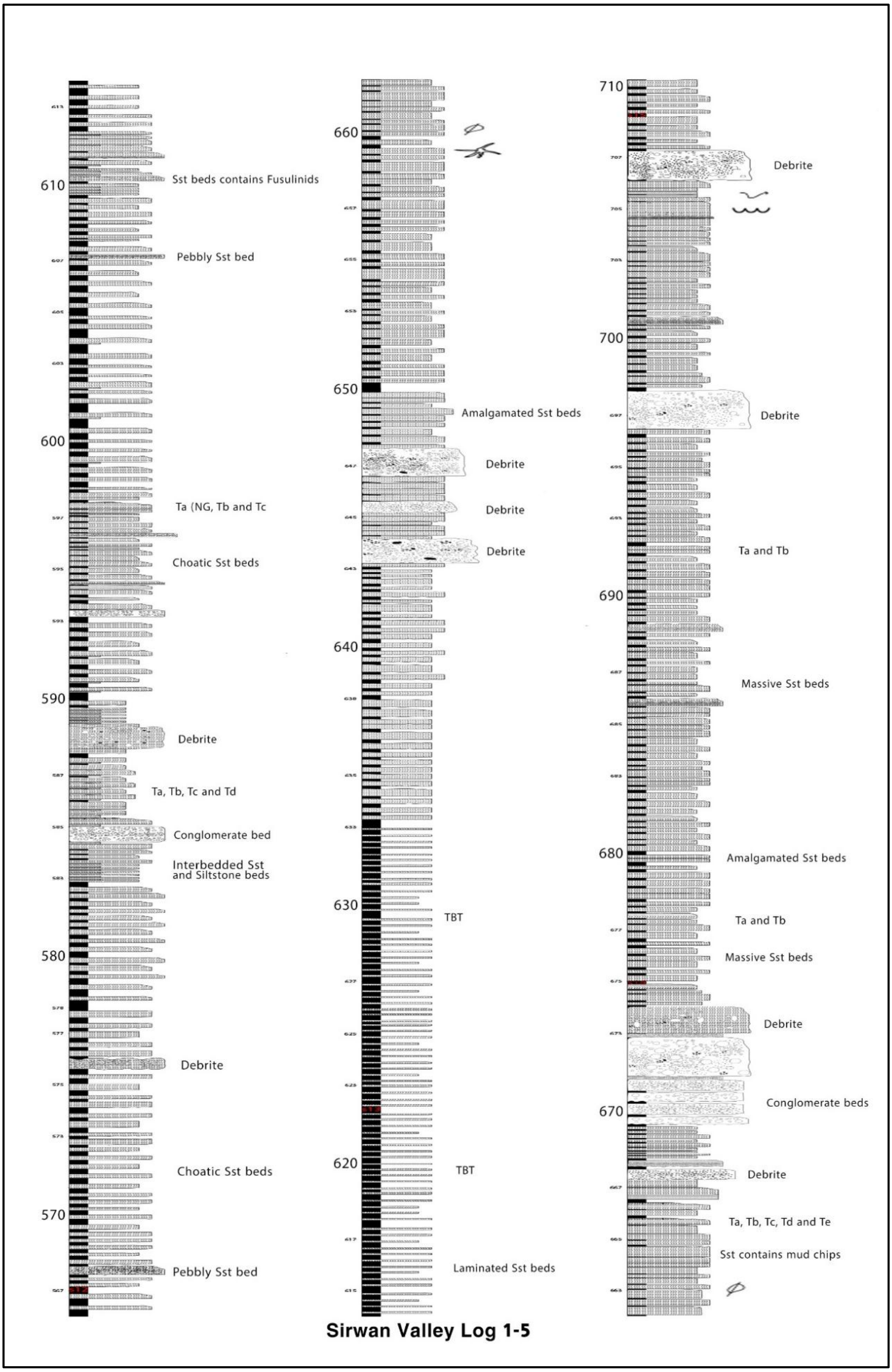

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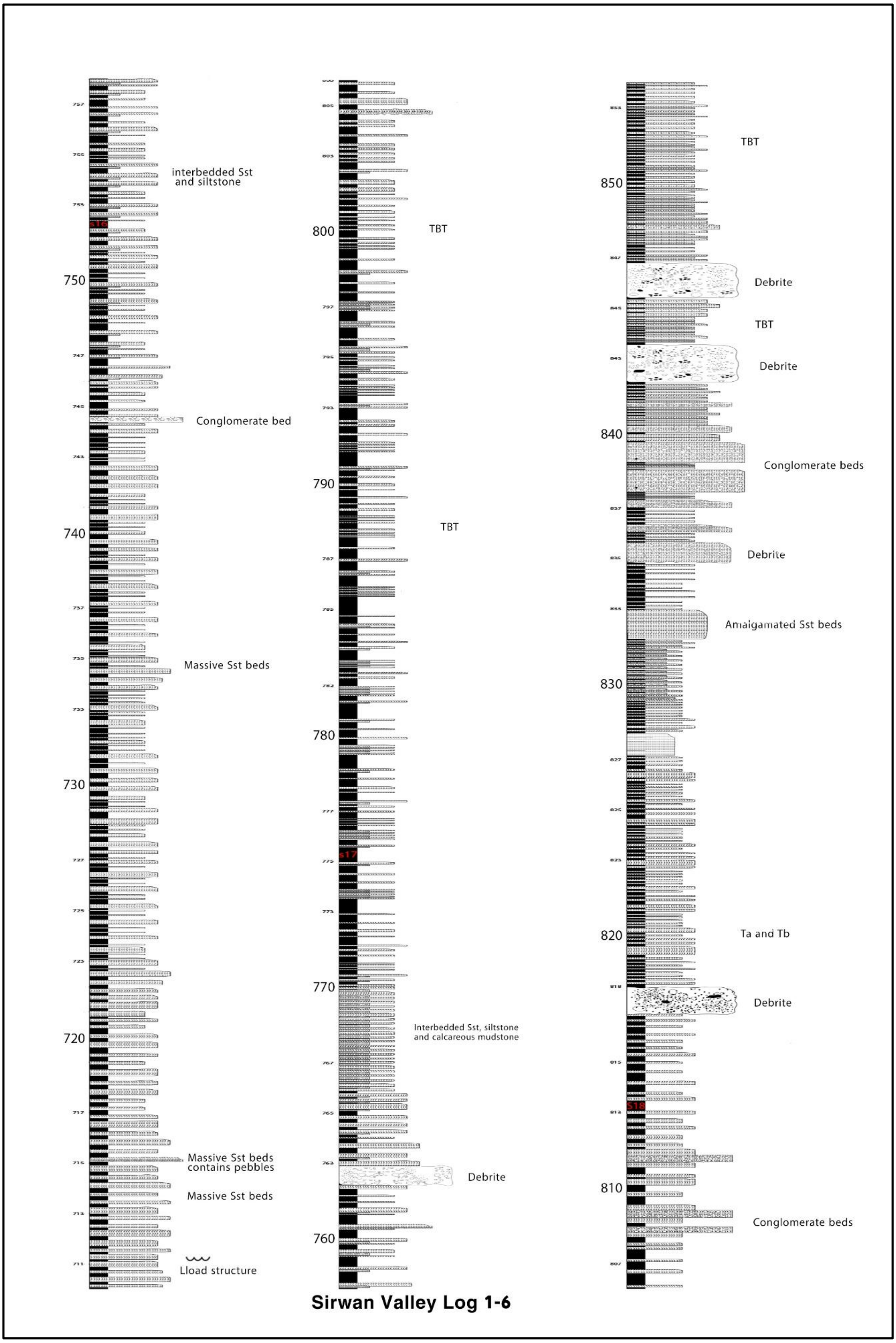

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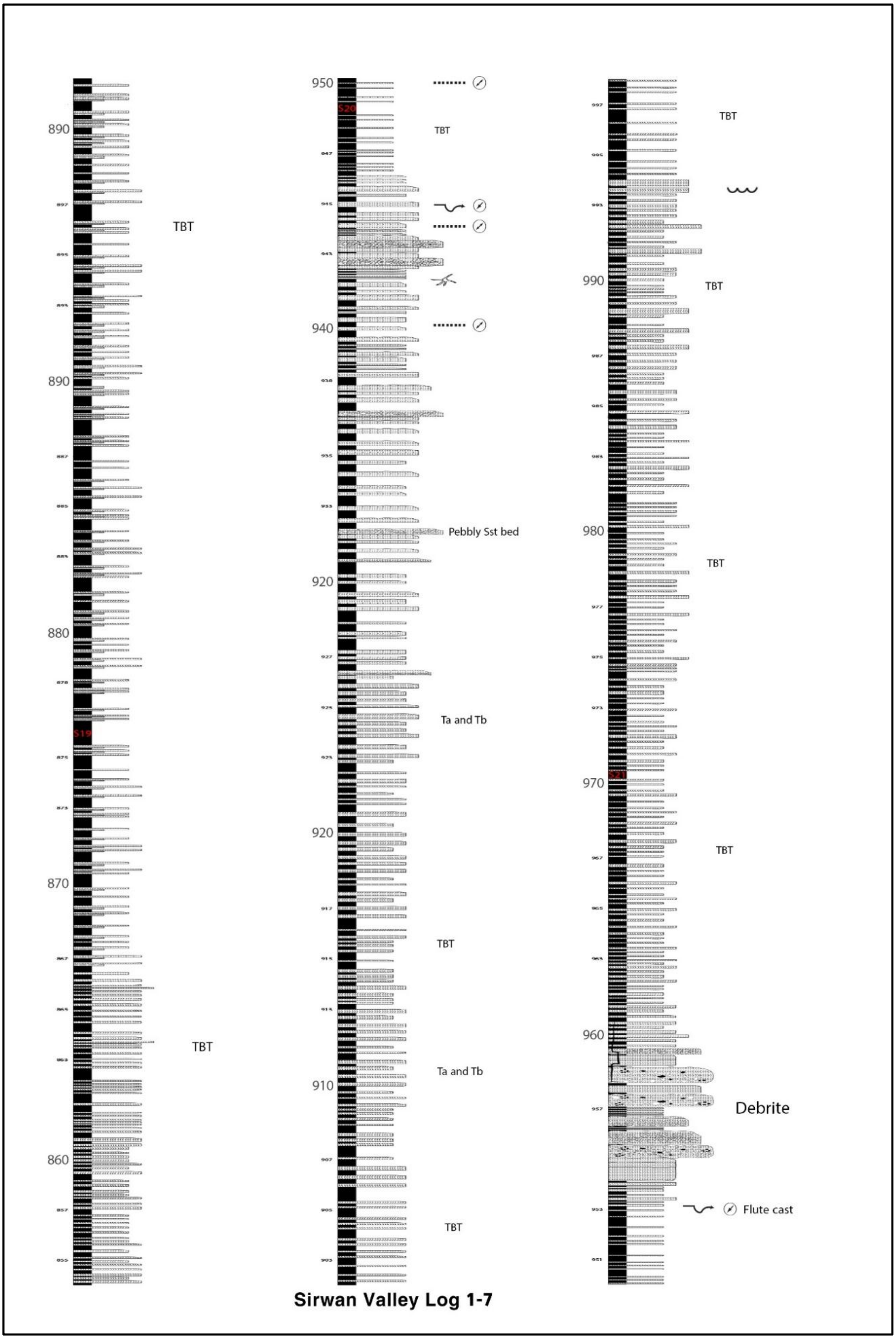

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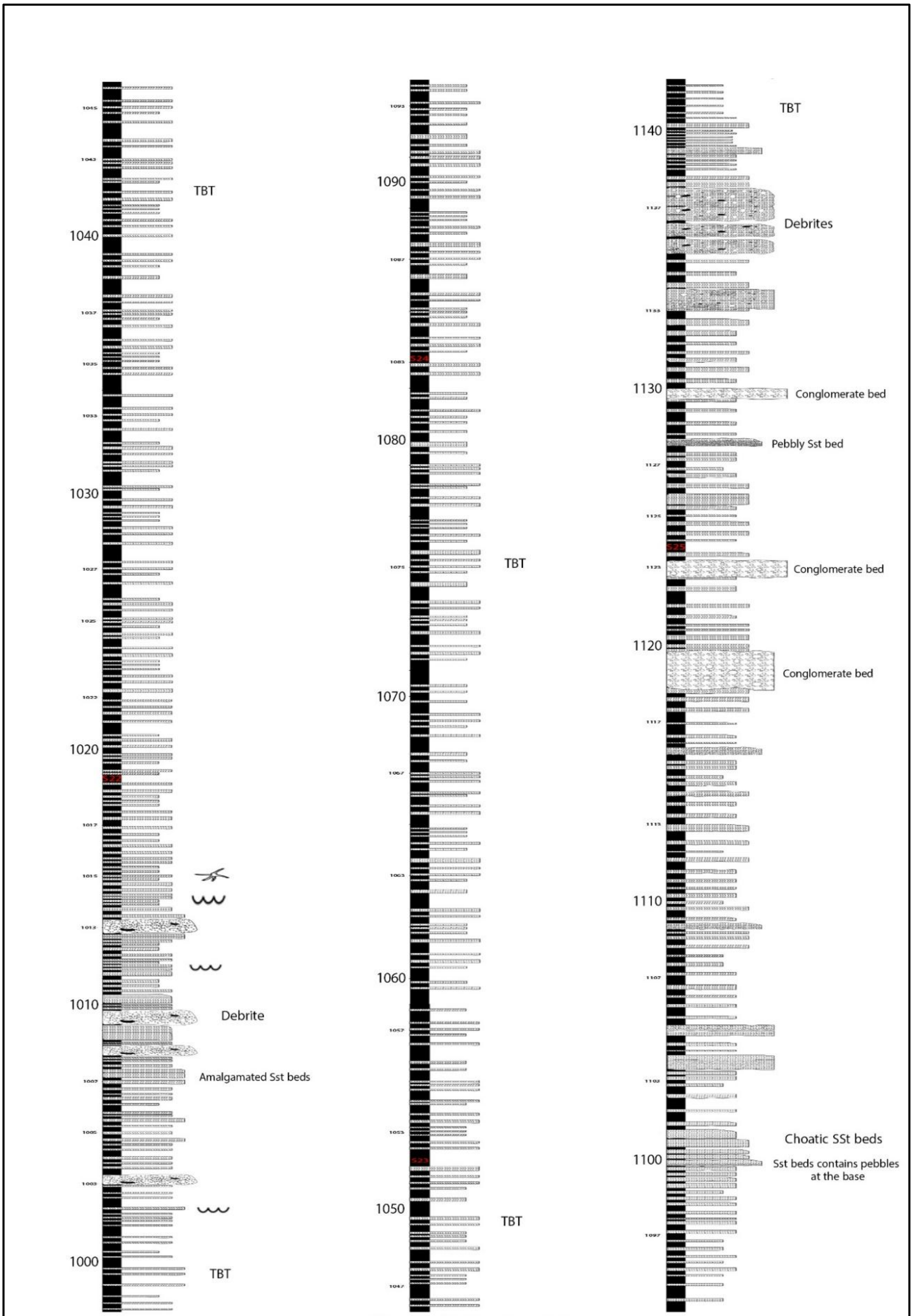

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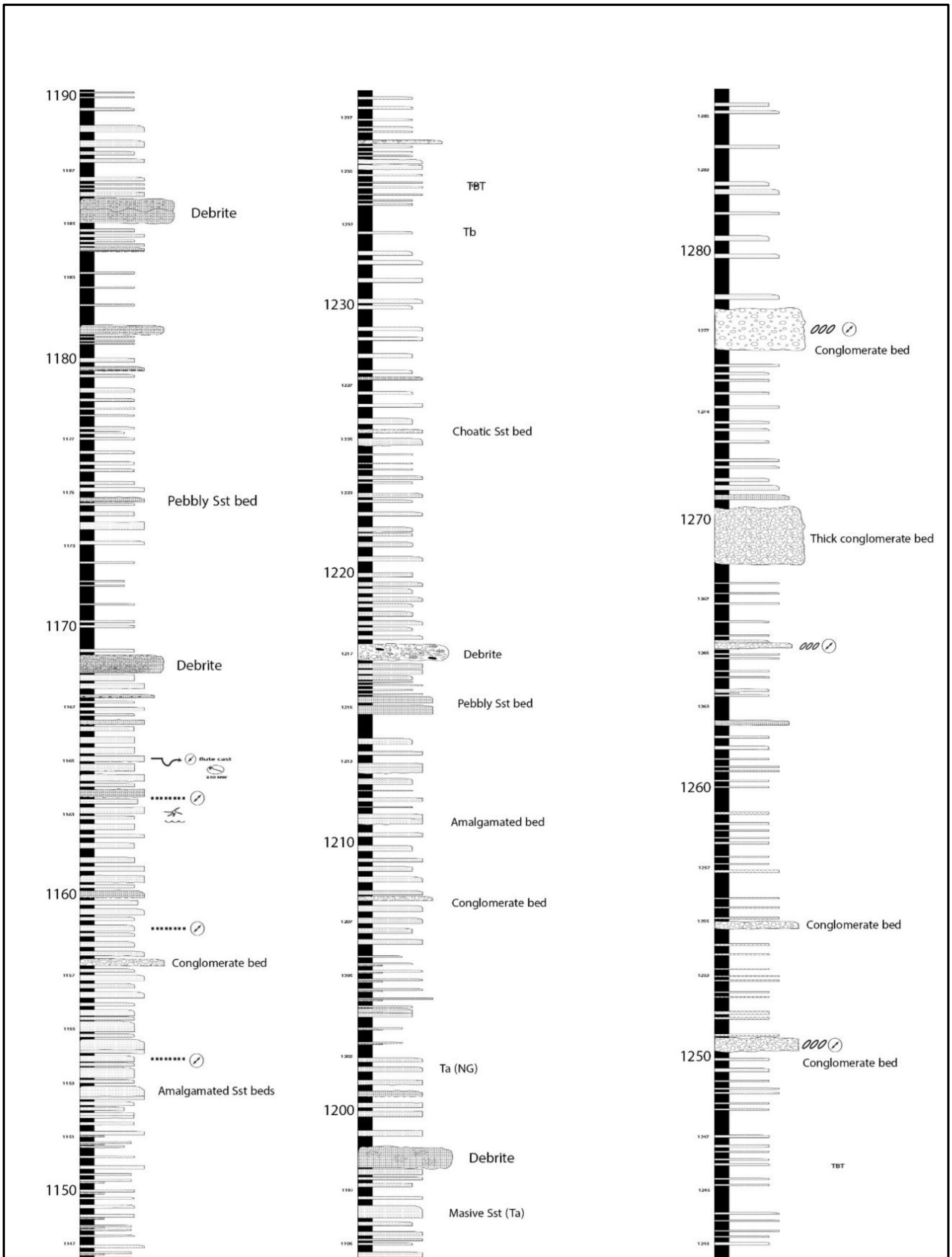

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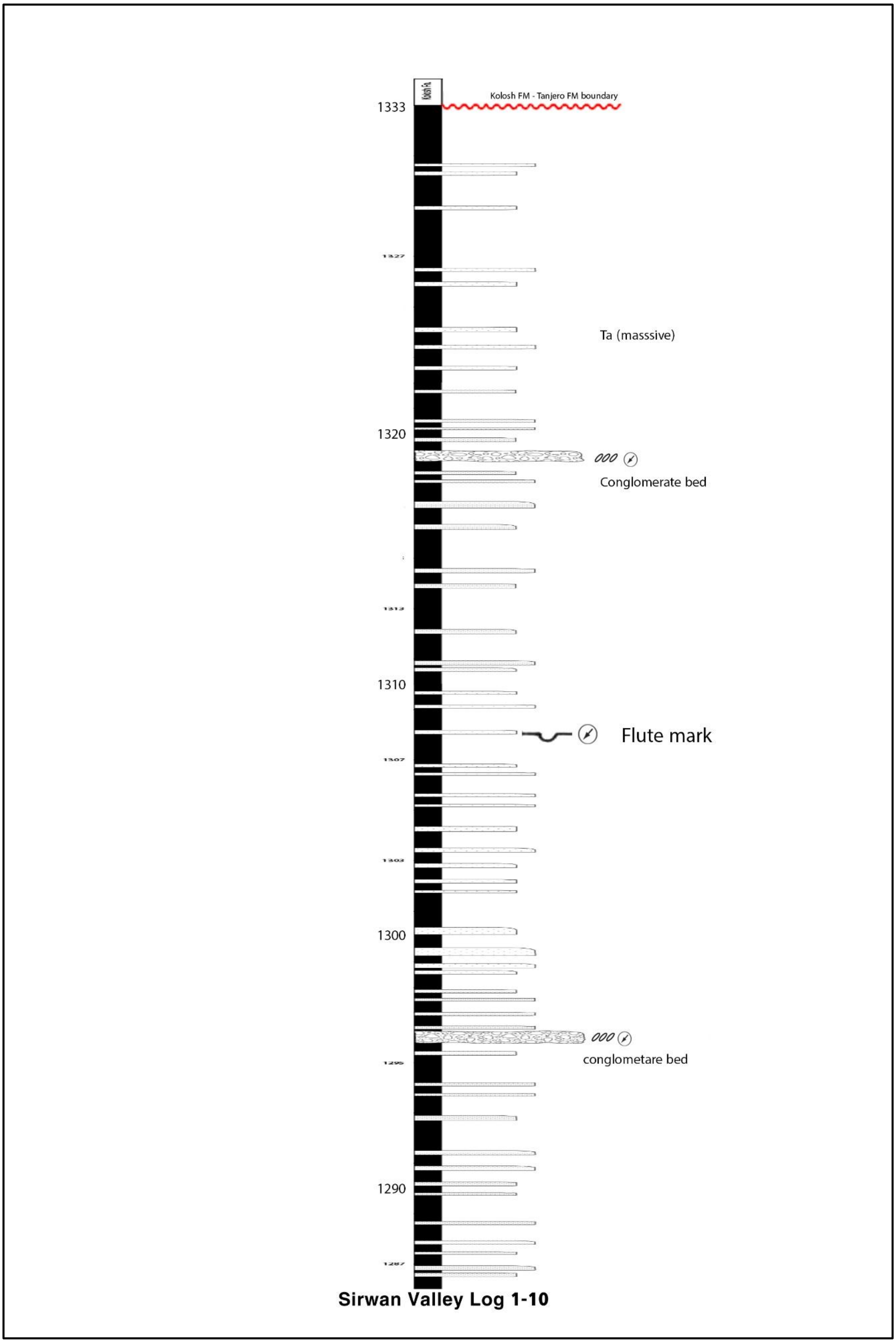


Figure 1.10. continued

2. SEDIMENTARY LITHOFACIES AND FACIES ASSOCIATION

2.1 SEDIMENTARY LITHOFACIES

Gressly (1883) coined the name "facies" for units of rock which were characterized by similar lithological and paleontological criteria, the rock unit which recognized and determined physical as well as chemical specifications. Such specifications are the consequences of physical, chemical and biological natural process during and after the emplacement of sediments (Gary, 1999). In particular, it ceased to be used to define rocks purely by lithology and paleontology. Facies is a term used previously to describe grain size and sedimentary structures for rocks and sediments (Moore, 1949; Teichert, 1958). Moreover, facies describe and introduce the principal "building blocks" for sedimentary units, and they ought to be separated by their specification such as bedding geometry sedimentary structures and fossils (Harms et al., 1975). Nowadays sedimentologists use the term facies by mean a certain volume of rock that can be characterized by a set of features such as grain size, geometry and sedimentary structure, that distinguish it from other rock units. The idea of turbidite facies was first presented by Mutti and Ricci Lucchi (1972), The concept of turbidite facies was first introduced by Mutti and Ricci Lucchi (1972), who used the term facies to indicate a group of strata with well-defined sedimentary features.

The term "turbidite" give a genetic connotation to the term, describing its interpreted depositional process. More recently still the term "facies" has been applied to describe the character of seismic data. Terms like "mounded, wavy, eroded and contorted" are applied to seismic character, and used to interpret the depositional environment (Mitchum, et al., 1977).

This text uses facies as a descriptive term as stated by Moore (1949): "Sedimentary facies is defined an any really restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of other parts of the unit." A further refinement of this definition is that facies has five defining parameters: geometry, lithology, paleontology, sedimentary structures, and palaeoflow pattern (Selley, 1970, p. 1). Sedimentary facies are highly variable laterally and vertically. They might be composed of an individual bed or a succession of beds, and they could form also under a certain depositional process or multiple conditions (Middleton, 1973).

Following previous principles, siliciclastic sediments of the current research (Tanjero Formation) are studied thoroughly in the field. In the field, detailed observations have been collected by a sedimentological measuring logging at a cm-scale. These observations are recorded and interpreted, including identification and description of the main grain, matrix types and geometry of the beds. On the basis of that, nine lithofacies have been recognized; some of which are subdivided into two or more sublithofacies. These lithofacies and sublithofacies are described and interpreted in the succeeding sections, and they are also mentioned in the (table 2.1). The main matrix types, framework grains, sedimentary structures and other characteristics are discussed in this chapter.

LITHOFACIES AND SUBLITHOFACIES

LF-1: Conglomerates:

SLF-1a: Pebbly to sandy matrix supported conglomerate:

Pebbly to Sandy matrix supported Conglomerates are present in the middle and upper parts of Tanjero Formation. This conglomeratic bodies separated by white to yellowish gray pebbles and sediments (Fig. 2.1). Moreover, they are laterally interfingering with pebbly thick bedded sandstones (SLF-2b) and cut amalgamated thick bedded sandstones (Fig. 2.1 and Fig. 2.2). the conglomerate body are lenticular, channel-like, 1-2.5m thick, and where shifted laterally, it exposes around tenth of meters with changing the thickness of the body due to the channel-like shape. In addition, the contacts of pebbly to sandy matrix supported conglomerate bodies are wavy, irregular and erosional in nature. The lower part of these conglomerates (SLF-1a) are mostly typified by clast-supported well to moderately sorted angular and rounded and elongate shaped clasts, while the upper parts are represented by sandy matrix-supported with decreasing the pebble sizes which is well sorted rounded and sub-rounded shaped features. The latter are usually capped by amalgamated thick beds of fine-coarse grained sandstones (Fig. 2.1).

This conglomeratic bodies are interbedded with thick bedded sandstone or calcareous mudstone. The matrix is made of medium to course yellow to gray in color sands. Clasts are up to cobbles in grain size and they are of variant shapes and origins, comprising cherts, igneous, and metamorphic clasts. Furthermore, they are randomly to sub-parallelly distributed relative to bedding, with imbrications in the clast-supported intervals.

Markedly, long-axis (a-axis) of the majority of blade and rod-shaped clasts have a preferred orientation transverse to the flow direction (Fig. 2.3). Fossils, trace fossils and plant fragments are absent.

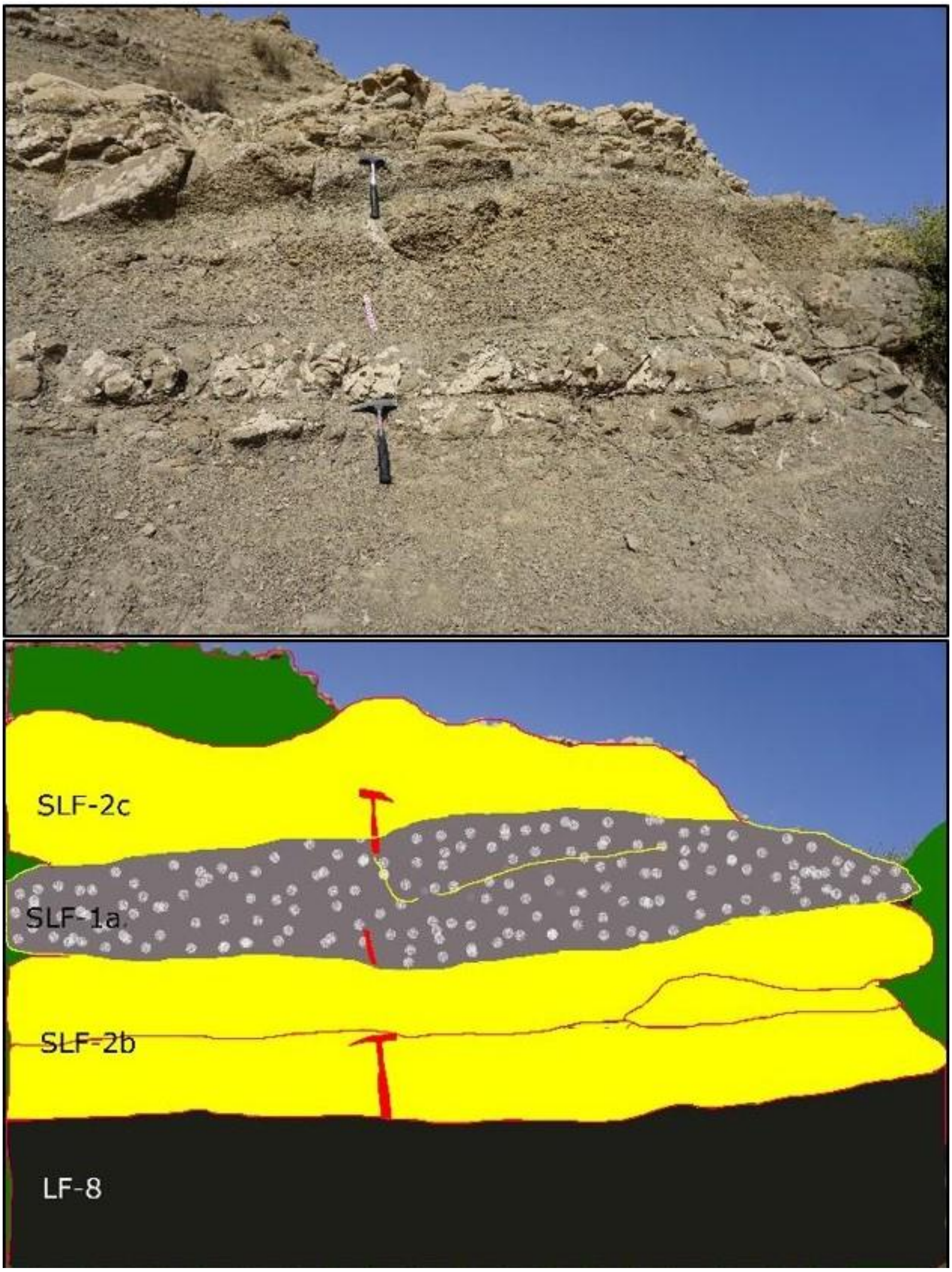


Figure 2.1. Lenticular shape of pebbly- sandy matrix supported conglomerate (SLF-1a) interbedded with very coarse-pebbly structureless sandstone (SLF-2b) and amalgamated structureless sandstone (SLF-2c); calcareous mudstone bed (SLF-8), illustrated in the lower photo.

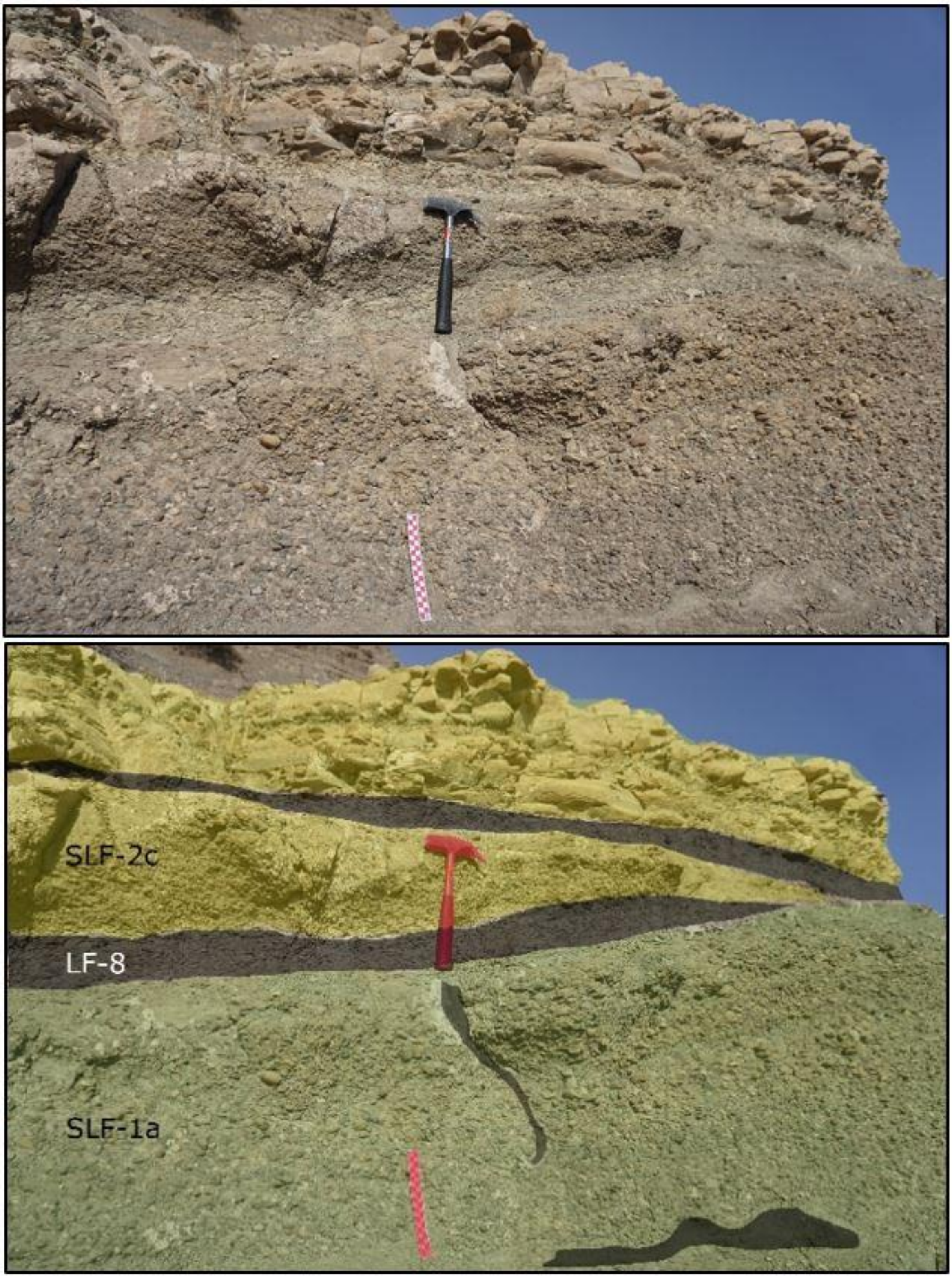


Figure 2.2. pebbly- sandy matrix supported conglomerate (SLF-1a) contains mud clasts interbedded with calcareous mudstone bed (LF-8); and amalgamated structureless sandstone (SLF-2c), illustrated in the lower photo.


Figure 2.3. Close view of pebbly-sandy matrix supported conglomerate (SLF-1a).

Depositional process: Conglomerates are common in a range of depositional sites, from subaerial to deep-marine settings. Distinction of conglomerates in these areas is difficult as many of the depositional features could be formed in different depositional environments; for example, channeling, stratification, and grading (Walker, 1978). However, other criteria and especially those that are taken from the field might be decisive. Normal orientation and imbrications of long axis (a-axes) of the clasts to flow direction, which indicates bed-load rolling of clasts along their long-axes, is very common in the fluvial settings (Walker, 1984; Posamentier and Walker, 2006).

Nemec and Steel (1984) discussed about subaqueous conglomerates as the following paragraph; In a succession of gravelly mass-flow deposits, their subaqueous emplacement can often be inferred directly from such features as: (1) association with turbidites (2) presence of wave-generated structures in the sandy interlayers; or at least (3) common presence of mud/silt interbeds or partings. Association with pebbly mudstones and/or slump-contorted muddy units. Otherwise, as in the absence of such self-evident features, the subaqueous emplacement of conglomeratic deposits may not be obvious or easy to infer. Fining-upward of stratified conglomerates with sandstone bed capping might be due to sediment-laden stream flow that followed debris flow or its main surge (Nemec and Steel, 1984). Additionally, they figure out that thick conglomeratic unit with crude to "distinct internal layering" or with discontinuous sandstone beds are the result of rapidly surging flows, which is frequent in the more waterier flow depositional systems. To sum up, it can be concluded that the conglomerates of the present study (SLF-1a) are mostly deposited under the subaqueous conditions.

SLF-1b: Sandy matrix supported conglomerate:

Sandy matrix-supported conglomerates (SLF-1b) are observed from both middle and upper parts of the Tanjero Formation (Fig. 1.10). In these areas, conglomerates are present as isolated channel-like bodies and wavy base lenticular shape range in thickness from 50 cm to 2 m (Fig. 2.4 - 2.7). Moreover, where observable in the field, these sandy matrix-supported conglomerates (SLF-1b) could be traced laterally over 200 m. Conglomerates have wavy, erosional and deeply scoured contacts with calcareous mudstone beds (SLF-8) and Amalgamated Sandstone beds (SLF-2c) (Fig. 2.5).

Generally, the conglomerates are lacking internal clastic organizations without clast-imbrications and they are matrix-supported by various grain size of greenish to bluish gray sands and sandy muds (Fig. 2.6 and 2.8). Clasts range from small granule to big deformed blocks of sandstone and mud clasts, are poorly sorted, and subangular to sub-rounded (Fig. 2.8). Observably, the pebbles are of different shapes, and most importantly the long-axis (a-axis) of blade and rod-shaped clasts are parallel to flow direction. According to previous workers origins of pebbles and clasts in the Tanjero Formation are consist of; sedimentary, igneous and metamorphic rock types.

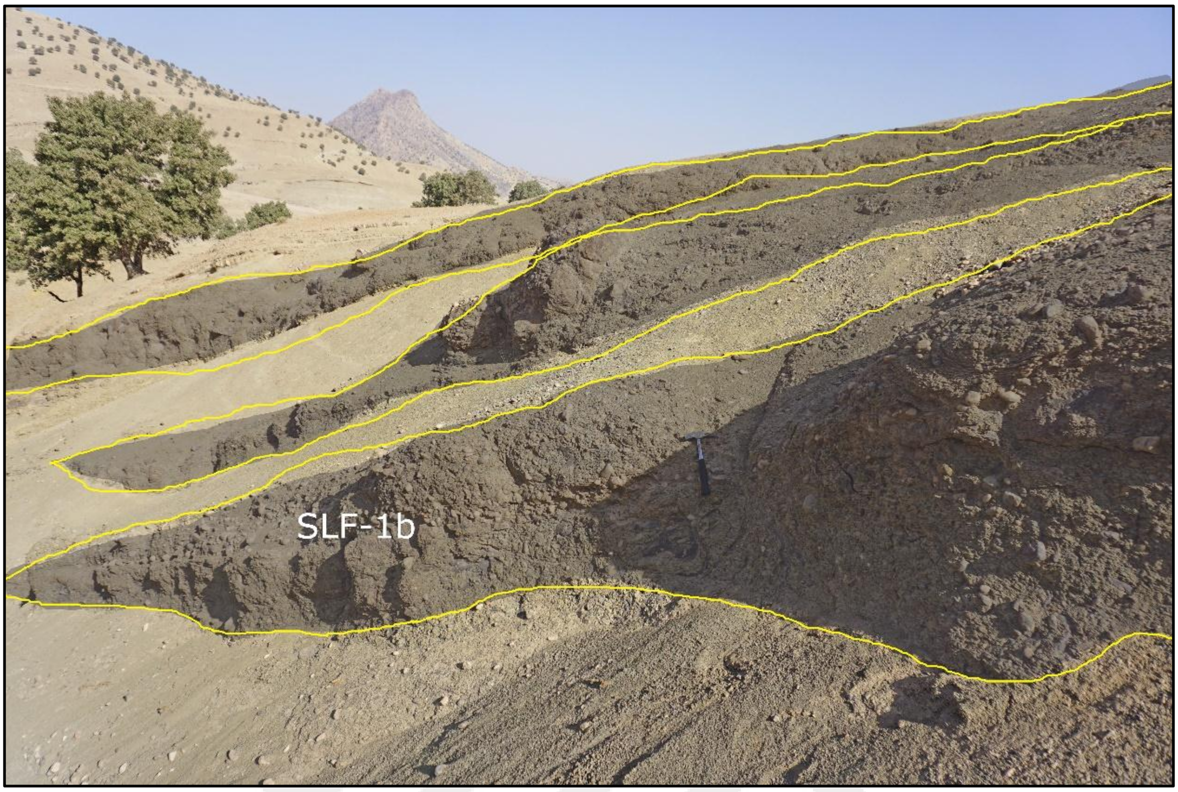


Figure 2.4. Channel fill bodies with sandy matrix supported conglomerate (SLF-1b)

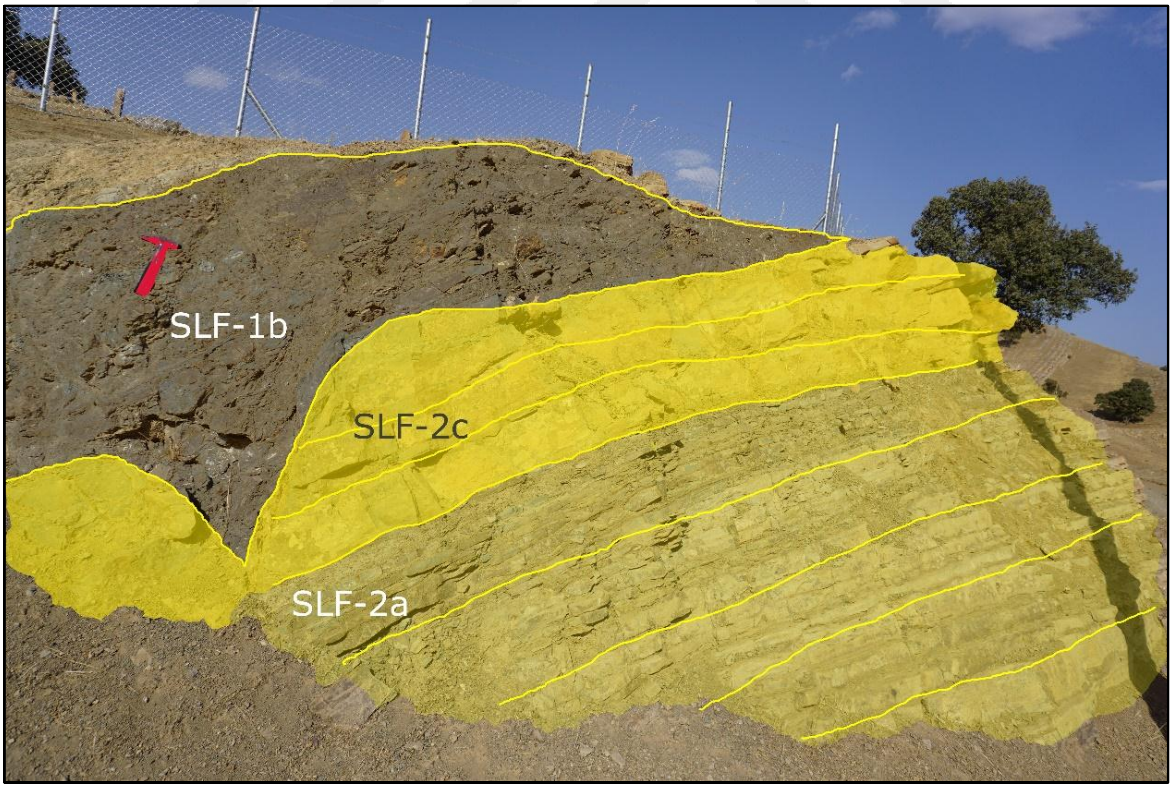


Figure 2.5. Sandy matrix supported conglomerate bed (SLF-1b) cut amalgamated structureless sandstone bed (SLF-2c), fine-coarse structureless sandstone (SLF-2c).

Figure 2.6. Close view of sandy matrix supported conglomerate (SLF-1b).

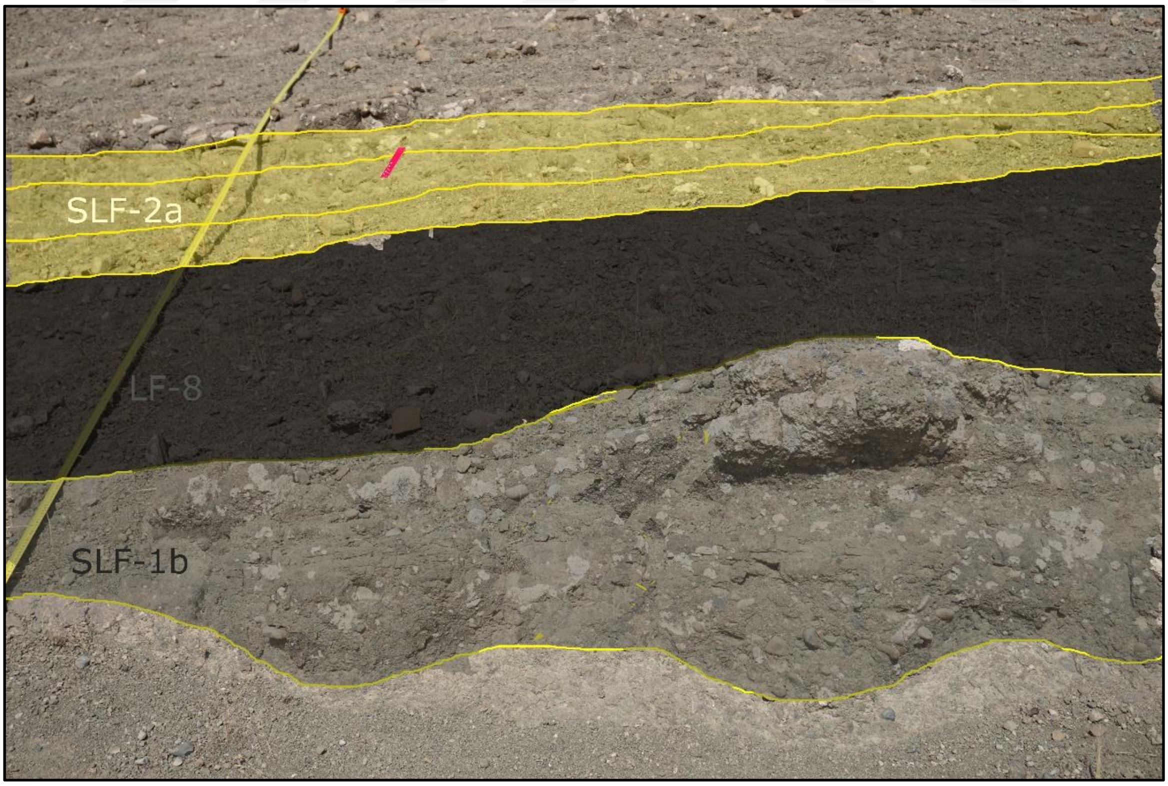


Figure 2.7. Wavy boundary of sandy matrix supported conglomerate (SLF-1b) interbedded with calcareous mudstone (LF-8); fine-coarse structureless sandstone (SLF-2a)

Figure 2.8. Close view of sandy matrix supported conglomerates (SLF-1b) shows pebbles and mud clasts.

Depositional process: In the Tanjero Formation, the presence of conglomerates interbedded with coarse-grained amalgamated and pebbly sandstone beds rich in fossils like foraminifera of both shallow and deep marine environments, as well as gastropod and plant fragments within the sandy matrix and the parallel-orientation of long axes of clasts to flow direction indicate that these conglomerates are subaqueous mass flow deposits (Walker, 1975; Nemec and Steel, 1984; Einsele, 2000; Posamentier and Walker, 2006). The latter situation supports the fact that these conglomerates, in spite of rareness of skeletal grains among their matrix, are also deposited by mass flow processes under subaqueous conditions.

In general, characters such as structureless, poorly sorted and fossiliferous high ratio mud/silt-sand matrix suggests that these represent cohesive debris flows (Lowe, 1982). Debris flows occur when the supported mechanisms of the clasts are controlled by a cohesive strength of the matrix that are 25 complemented by the buoyancy (Stow, et al., 1996). In such flows, sandy matrix is the supporting mechanism for clasts, preventing frictional locking through buoyant lift, reducing the effective weight of clasts and grain lubrication (Rodine & Johnson, 1976). Because debris flows are rheologically plastic and whenever their internal shear strength overcomes shear stresses, they freeze leaving behind poorly sorted texture with little or no internal organization of the clasts (Stow, et al., 1996). Existence of bioclasts, foraminifera, within the matrix of conglomerates (SLF-1b) interprets these debris flows were originally sourced from shallow marine shelves downslope via submarine channels.

SLF-1c: Muddy matrix supported conglomerate:

Muddy matrix-supported conglomerates (LF-1c) are documented from both lower and middle parts of the Tanjero Formation (measured section-1). In the study area, conglomerates are present as isolated channel-like bodies or tabular and range in thickness from 50cm to 3m (Fig. 2.9).

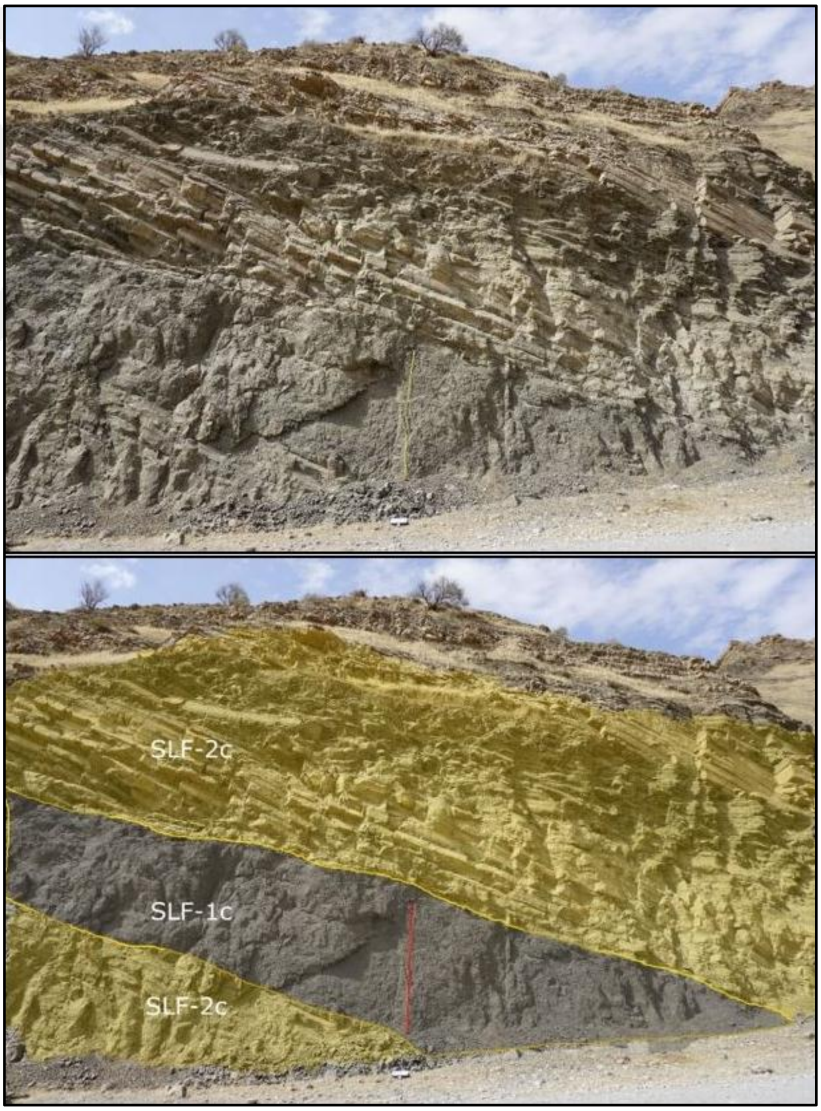


Figure 2.9. Muddy matrix supported conglomerate (SLF-1c) interbedded with amalgamated structureless sandstone (SLF-2c) on the top and bottom, illustrated in the lower photo.

Moreover, where observable in the field, these muddy matrix-supported conglomerates (LF-1c) could be traced laterally over hundreds of meters in Tanjero Formation. Conglomerates have wavy, erosional and scoured contacts with structureless sandstone beds (LF-2) (Fig. 2.9 and Fig. 2.10). Generally, the mud matrix covered more than 80% and the rest are deformed sand blocks (slumped) and pebbles. conglomerates are lacking internal clastic organizations, and they are matrix-supported by greenish to dark gray calcareous mudstone. Clasts range from small granule to cobbles grade size, are poorly sorted, and rounded to sub-rounded (Fig. 2.11).

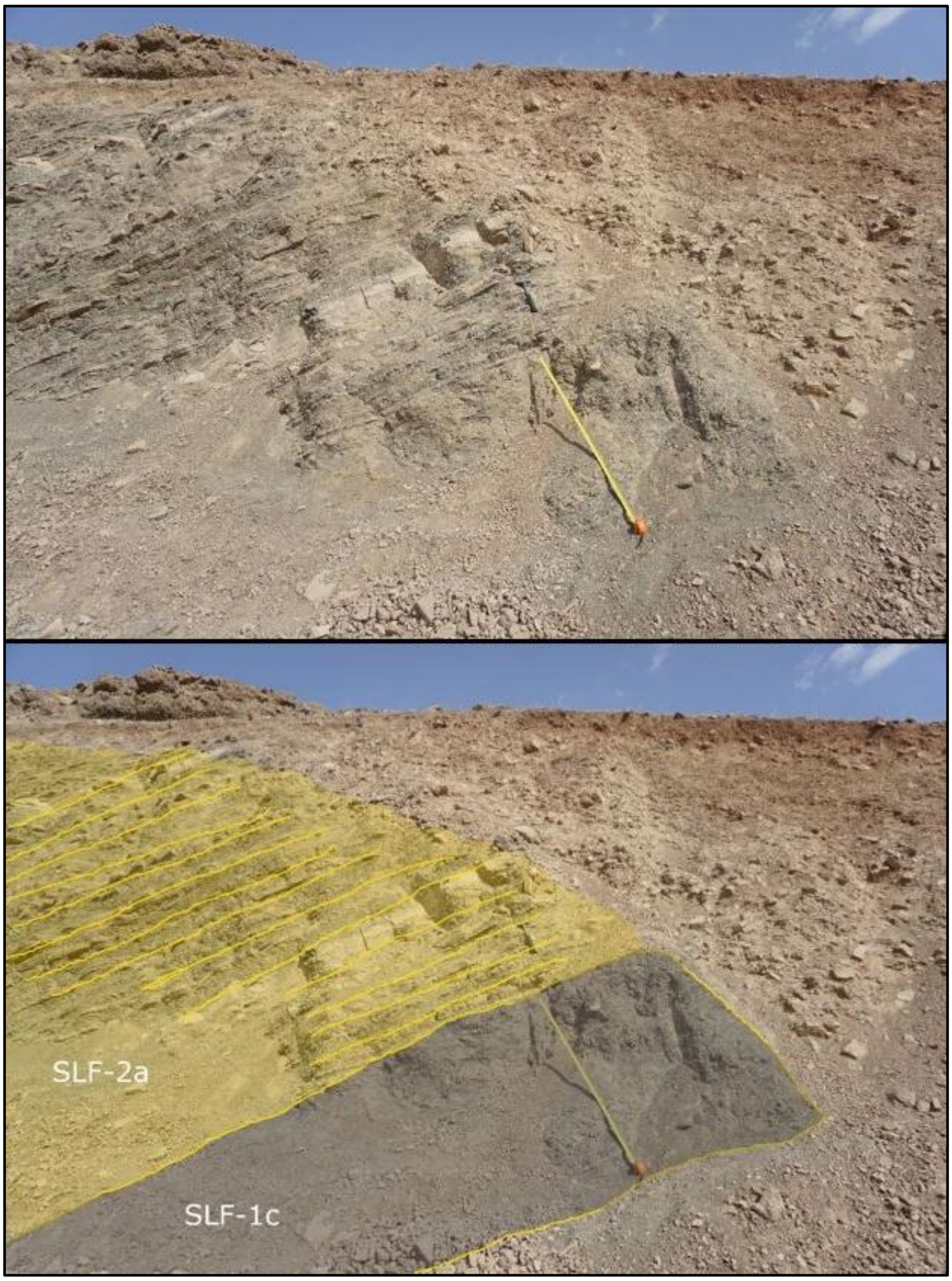


Figure 2.10. Muddy matrix supported conglomerate (SLF-1c) interbedded with fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

Figure 2.11. Close view of muddy matrix supported conglomerate (SLF-1c) shows pebbles and chaotic mixture of mud and fine-grained sandstone.

Depositional process: The source of the course clastic is from a nigh bordering high lands, the pebbles color is mostly greenish to brown with little red pebbles. These clastics are transported by high concentration turbidity currents or debris flows, then deposited by rapid sedimentation of all grains by frictional freezing (Pickering, et al., 1986). Slumps and deformed sandstone blocks represent rotational shear-surface movements. Slumps are capable of transporting gravel and coarse-grained sand because of their inherent strength. This type of facies is recorded by (Walker, 1978), he suggested that such disorganized gravel is generally more proximal than graded stratified beds. Additionally, Facies-1c may occur even closer to source on steeper slopes, within the submarine canyon or feeder channel (Harms, et al., 1975).

LF-2 Structureless sandstone beds

SLF-2a: Fine-coarse structureless sandstone:

Fine to medium grained structureless sandstones (SLF-2a) occur throughout the studied section (lower, middle and upper parts of Tanjero Formation). The variant thickness of the structureless sandstones bed-set of these sediments (SLF-2a) is from 4 cm to 10 cm thick.

Lower boundary of these structureless sandstones is interbedded with Calcareous mudstone beds (LF-8), Siltstone (LF-7), Amalgamated structureless sandstone beds (SLF-2c) and rarely conglomerates (LF-1) (Fig. 2.12); on the other hand, upper boundary of SLF-2a sediments is interbedded with calcareous mudstone beds (LF-8), siltstone (LF-7), and amalgamated structureless sandstone beds (SLF-2c) (measured section-1). Beds generally have flat, sharp and wavy bases (Fig. 2.13), but erosional, irregular, loaded base have been registered, too. The nature of the upper surface is either sharp or wavy. The geometries of the beds are various; tabular, sheet-like, wavy, parallel and continuous. Noticeably, thin bedded sandstones (SLF-2a) are evenly-spaced and intervened with thin to medium bedded grey and yellowish siltstone (LF-7) and calcareous mudstones (LF-8) lithofacies (Fig. 2.12 and Fig. 2.13). Additionally, the beds are also rich in plant materials. Fine-Coarse structureless sandstones (SLF-2a) are dark gray, brownish gray, yellowish gray in color. The main sedimentary structures that have been documented are load structure, whilst the grading is very rare.

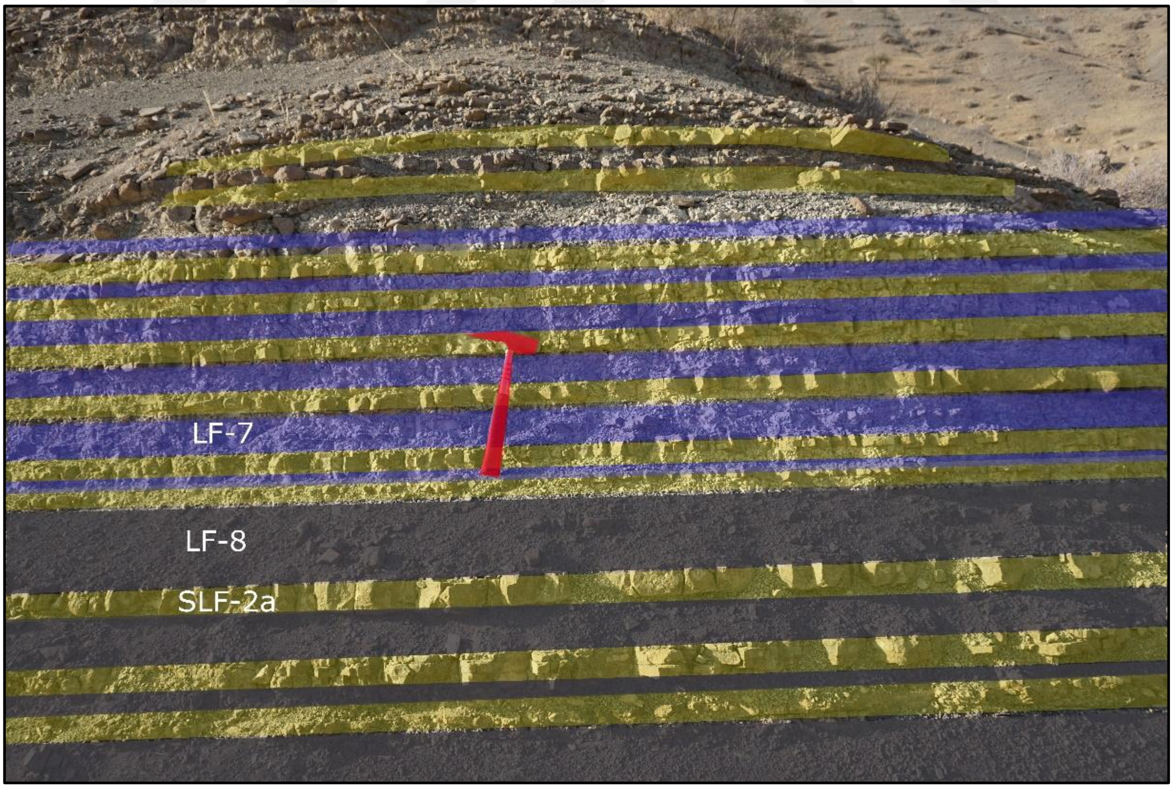


Figure 2.12. Fine-coarse structureless sandstone (SLF-2a) interbedded with calcareous mudstone (LF-8), siltstone beds (LF-7).

Figure 2.13. Fine-coarse structureless sandstone (SLF-2a) interbedded with siltstone beds (LF-7)

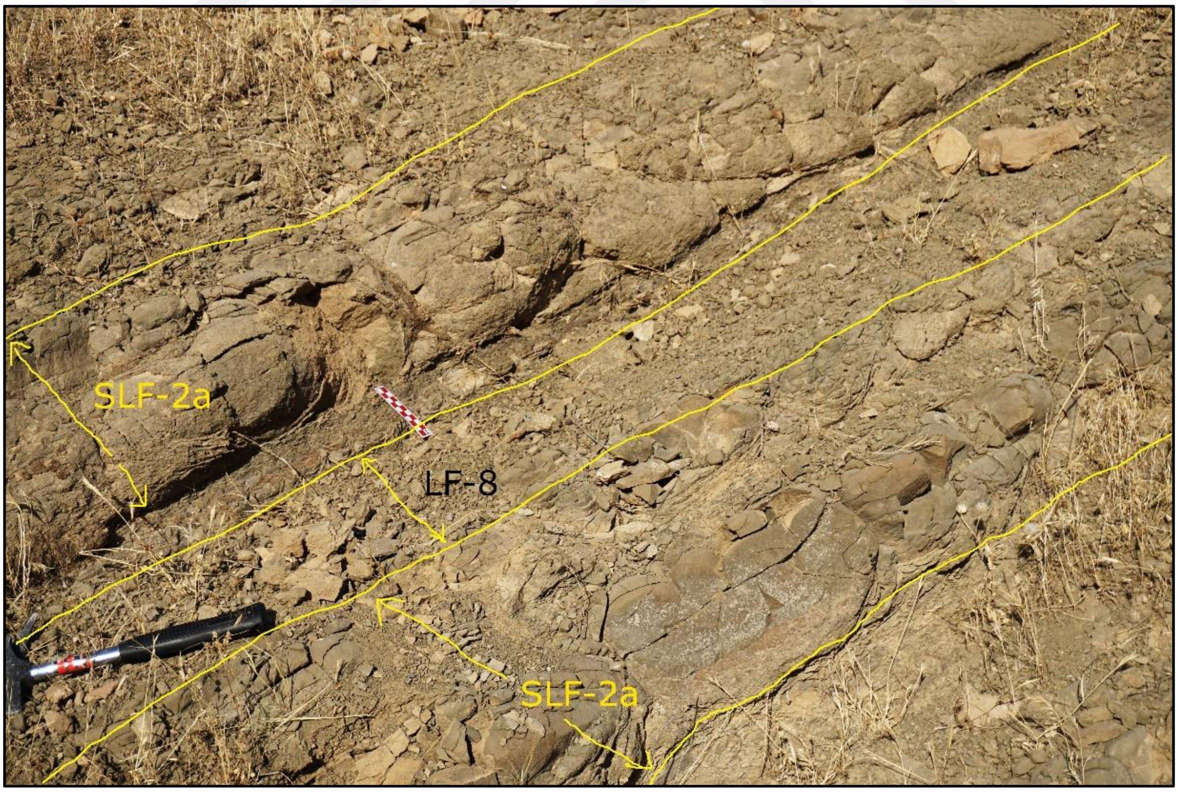


Figure 2.14. Fine-coarse structureless sandstone (SLF-2a) interbedded with calcareous mudstone (LF-8).

Depositional process: Association of fine-coarse grained and structureless sandstone lithofacies (SLF-2a) gradationally with the other lithofacies and specifically siltstones (SLF-7) and mudstones (LF-8) indicates that the sediments are deposited from suspension load of low-density turbidity currents. Similarly, covering gradationally with thin-bedded mudstone (LF-8) could also support the idea that sediments came to existence via low-density turbidity current (*sensu* Ta division of (Bouma, 1962). Such association between thin bedded turbidites and mudstone is very common and implying deposition of structureless sandstones (thin bedded) from turbidity currents (Posamentier and Walker, 2006). Kneller and Branney (1995) exemplified that the structureless fine to medium grained sandstones that are lacking erosional bases characters could be deposited from the waning and strongly depositional flows. The reason for the latter is that the beds show no visible signs for change in grain size below and above the clast zone, indicating that they are deposited through the steady flows. Summing up, there is no grading, these facies is transported and deposited by bed-load transport beneath turbidity currents or strong bottom currents. Transport may be short and the major process may be winnowing out of finer grain sizes and deposited by grain-by-grain deposition of bed load (Pickering et al., 1989).

SLF-2b: Very coarse-pebbly structureless sandstone:

Coarse to pebbly grained structureless sandstones (SLF-2b) have been observed in the middle part and upper part of the Tanjero Formation (Fig. 1.10). Their thickness is highly variable, for example, it is from 10 cm to 80 cm thick. Where they are intervening with thin to thick bedded mudstones (SLF-8) (5-50 cm thick), the total thickness of the succession could reach to more than 60m. The geometries of the beds are wavy, lenticular shape, sometimes amalgamated and thin and pinch-out laterally. However, sheet-like, tabular, wavy and continuous geometries have also been seen; wherever observable in the field, they could be traced laterally for more than 100 m. Lower surfaces of these coarsely to pebbly grained sandstones (SLF-2b) are erosionally, wavy and irregularly with fine to medium-grained structureless sandstones (SLF-2a), siltstones (SLF-7) and calcareous mudstones (LF-8) (Fig. 2.15).

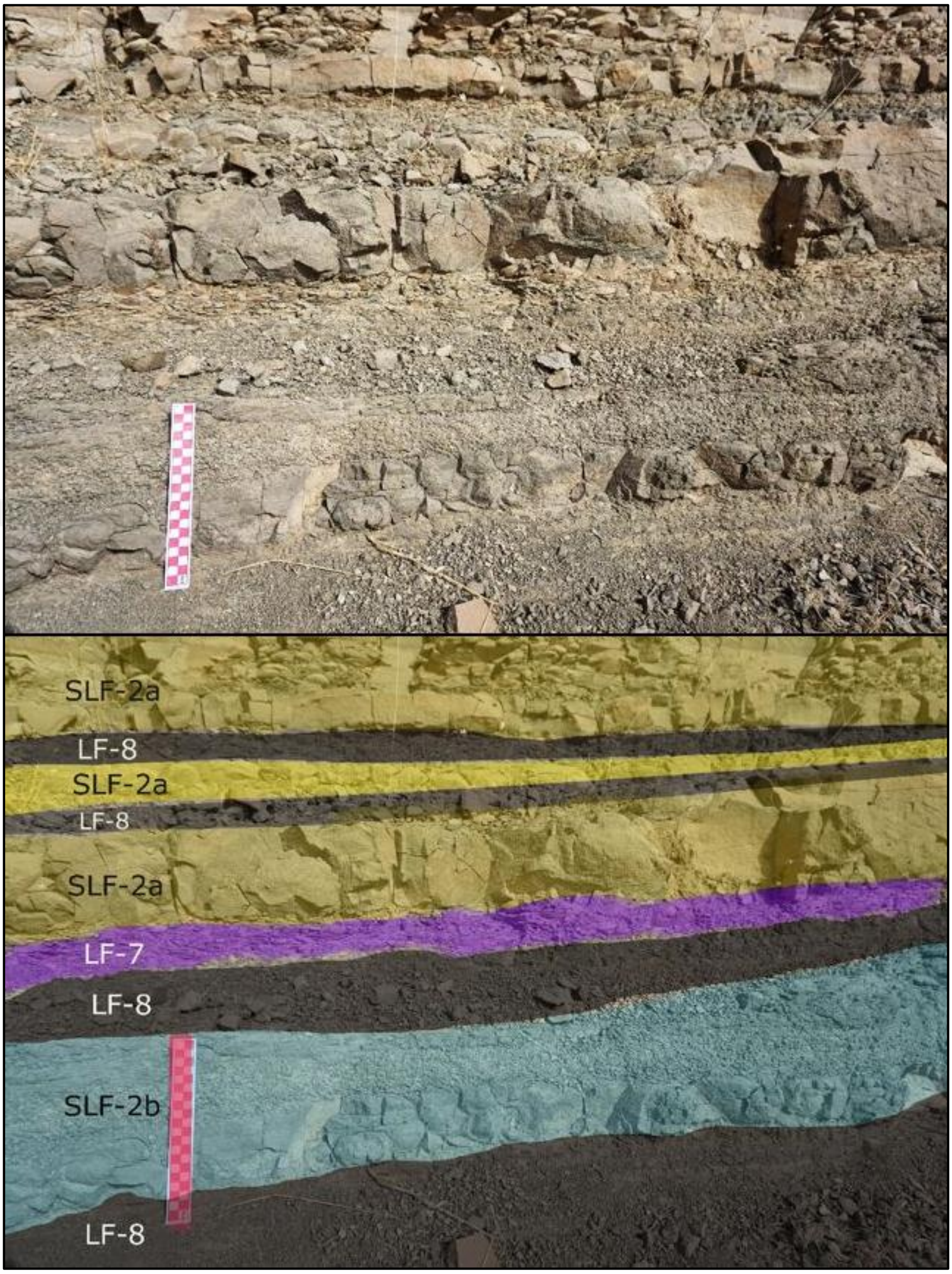


Figure 2.15. Pebbly sandstone beds (SLF-2b) interbedded with calcareous mudstone (LF-8), siltstone beds (LF-7); Fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

At the same time, their upper surfaces have sharp and flat nature with fine to medium structureless sandstones, Siltstones and Calcareous mudstones (SLF-2a, LF-7 and LF-8). Clasts in the pebbly grade intervals are various, angular, sub-rounded to rounded, and they are sedimentary, igneous and metamorphic in origin, floating in a sandy matrix and calcite cement, (Fig. 2.16 and 2.17).

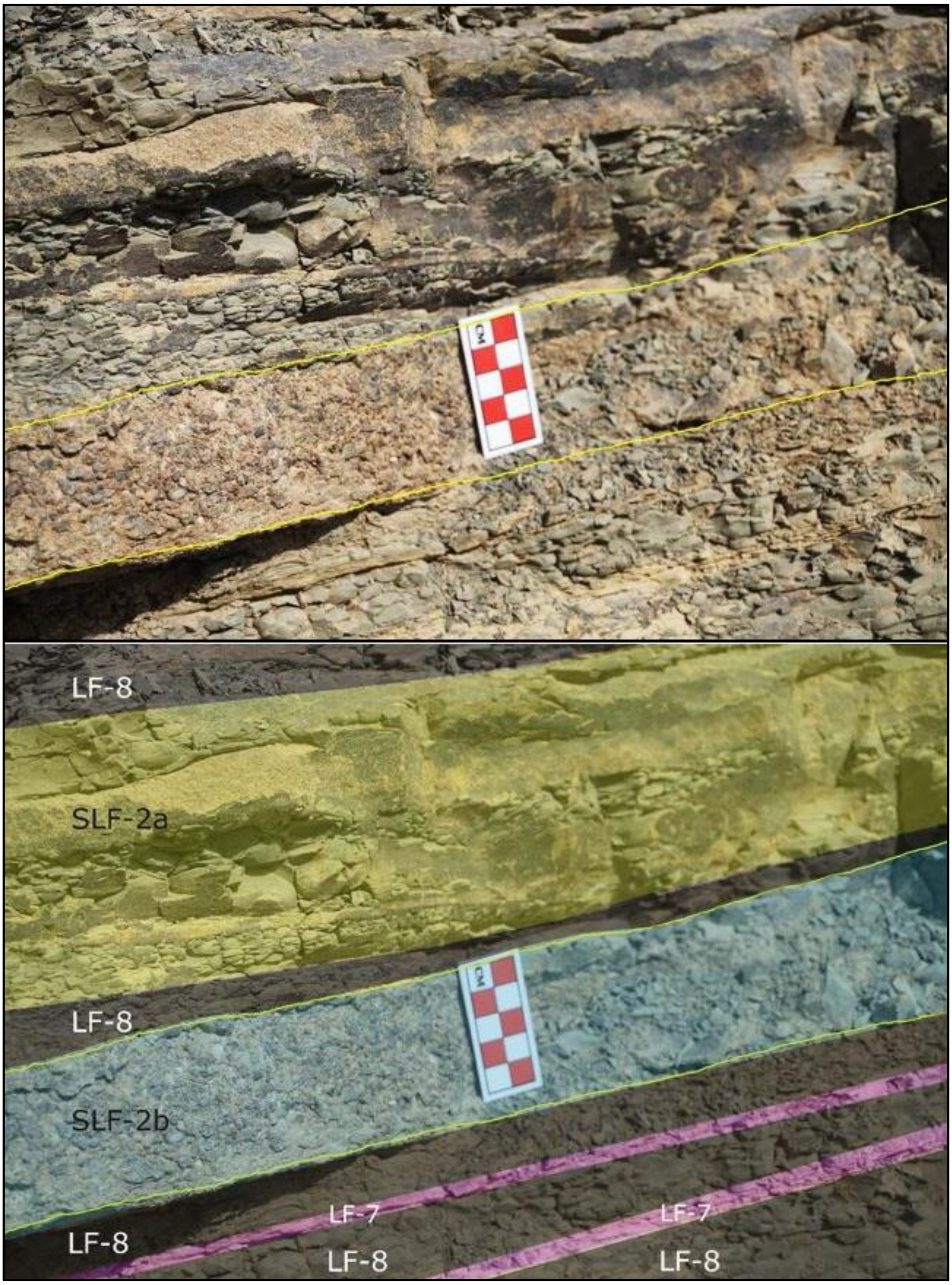


Figure 2.16. Close view of pebbly sandstone beds (SLF-2b) interbedded with calcareous mudstone (LF-8). Fine-coarse structureless sandstone (SLF-2a); Siltstone beds (LF-7), illustrated in the lower photo.

Figure 2.17. Close view of pebbly sandstone beds (SLF-2b) shows the pebble size.

Transported fossils like Fusulinida and Gastropoda bioclasts of the shallow marine organisms have been identified, including Fusulinida, larger benthic foraminifera and corals as demonstrated in the middle part of Tanjero Formation section (Fig. 2.18). The beds are gray, light brownish in color. Sedimentary structures are tool and scour marks on the bed bases, mud clasts and the sediments are ungraded and lacking internal structures with rare fluid-escape dewatering features. Planolite trace fossils present in this facies. (Fig. 2.18 and 2.19)

Figure 2.18. Fusulinids and broken shells of fossils.

Figure 2.19. Planolite trace fossils.

Depositional process: The structureless and very coarse to pebbly grained sandstones are lacking dewatering features, reflecting grain collision with less effective of pore water escape and causing structureless nature of the lithologic unit (Walker, 1978). This lithofacies also determined that they are the result of freezing of dense cohesionless suspension load from swift deposition of high-concentration turbidity currents. This process is very common in steep slopes (Pickering et al., 1986) and proximal regions in connection with the sediment source (Einsele, 2000). It should be kept in mind that erosive bases of structureless and very coarse sand to pebble grade size sediments are more likely they are found solely, very coarse and pebbly structureless sandstones possibly the deposits of cohesive debris flows (Stow et al., 1996). Besides all of these, abundance of Gastropods bioclasts is good indicators that the turbidity current or debris flows is sourced from shallow marine realm, and it may be triggered by storm actions.

SLF-2c: Amalgamated structureless sandstone:

This facies consists of structureless massive amalgamated sandstones (Fig. 2.20). The individual beds thickness varies from 20 cm to 80 cm, with amalgamated units up to more than 10 m thick. Beds normally have sharp bases, (commonly erosive) cutting underlying laminae, or are continuous but squashed, loaded and straight top boundary. The beds are generally non-graded, although faint top normal grading occurs with occasional thin intervals convolute lamination. The beds geometry is tabular, Amalgamated sandstone beds are interbedded with fine -coarse structureless sandstones (SLF-2a), Siltstone (LF-7) and Mudstone (LF-8). The overall grain-size distribution is uniform with generally course to medium and occasional granular/ pebble grain sizes (Fig. 2.21). mud clasts may occur at the base, often marking surfaces of amalgamation. Also, tool marks and flute mark present. Deformation structures due to water escape are occur.

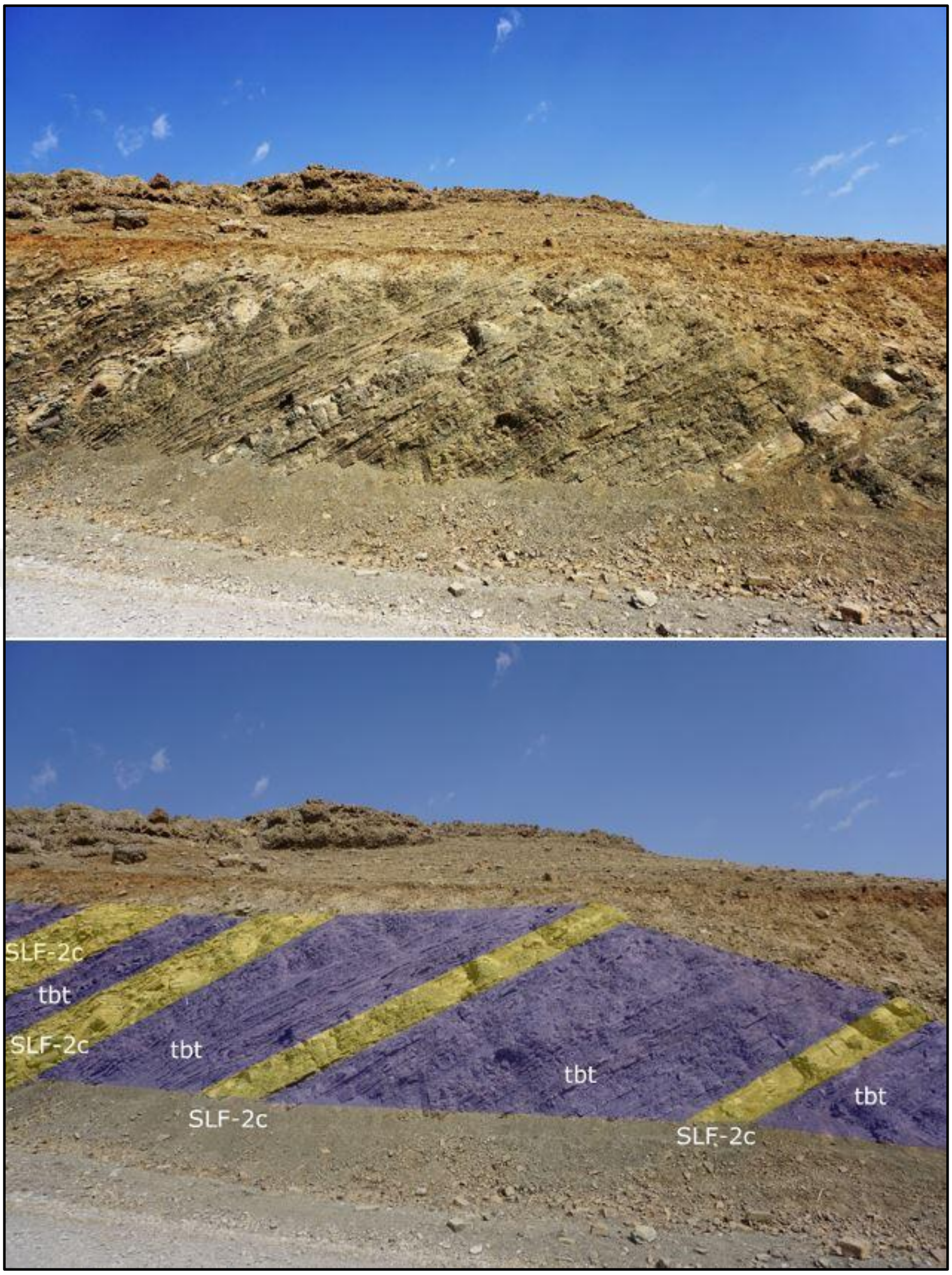


Figure 2.20. Amalgamated sandstone beds (SLF-2c) interbedded with thin bedded turbidite (tbt), illustrated in the lower photo.

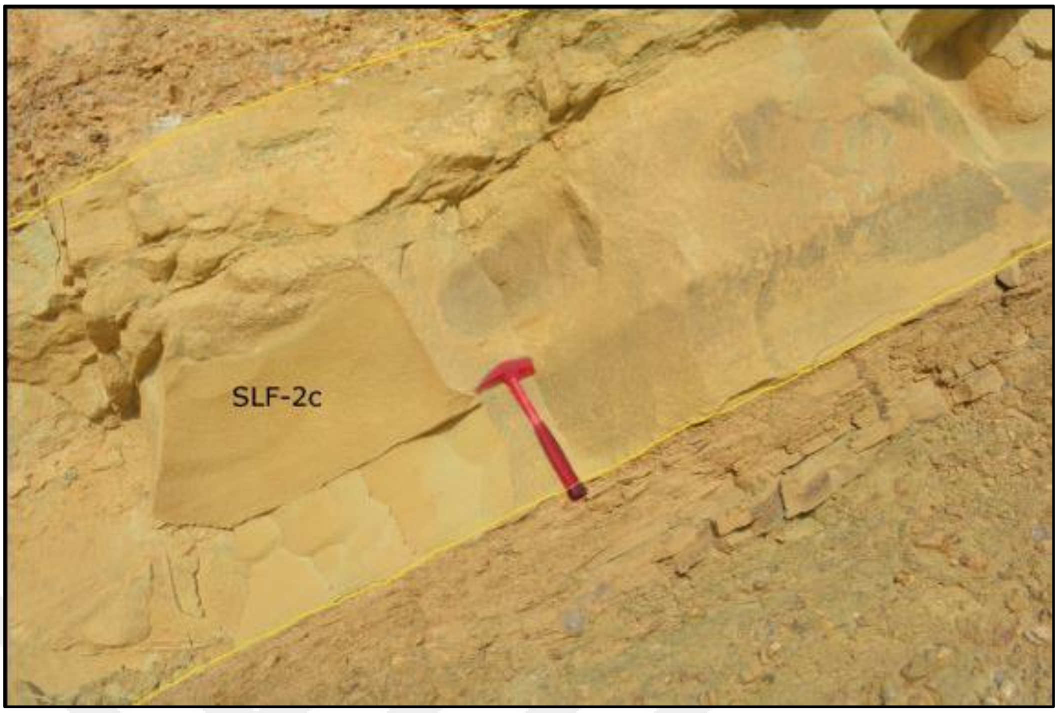


Figure 2.21. Close view of amalgamated sandstone beds (SLF-2c).

Depositional Process: The degree of amalgamation is normally a result of the time between emplacements of successive beds, or is caused by the erosive nature of the sandstone bases related to local scouring of the flows. The undulating and squashed character implies loading of the newly deposited sediments onto the underlying water-rich sediment. Due to the faint grading, erosive character, coarse grain-size, matrix-poor nature and associated water escape structures, the facies is interpreted as having been deposited by a high-density turbidity current according to the Lowe (1982). Rapid deposition forming thick sandstone beds probably reflects the beginning of lateral expansion of flows from a channelized setting, or filling of pre-existing channels by large sandy flows. Besides all of these, abundance of Gastropods bioclasts is good indicators that the turbidity current or debris flows is sourced from shallow marine realm, and it may be triggered by storm actions.

LF-3: Deformed sandstone beds:

This facies is present in the middle part of the Tanjero Formation, this facies is composed of (20-50 cm) thick beds, coarse sand, irregular folded and contorted beds (Fig. 2.22). Also folded laminated on the upper part of the bed have been recorded (Fig. 2.23). On the upper surface of the contorted strata, small ripple marks are observed, in addition at the base on the bed load structure has been observed. The beds shape is tabular and irregular shape. The upper and lower boundary of the beds are irregular, erosional and wavy. These beds are interbedded with conglomerate (LF-1), amalgamated sandstone (LF-2c) and mudstone (LF-8).

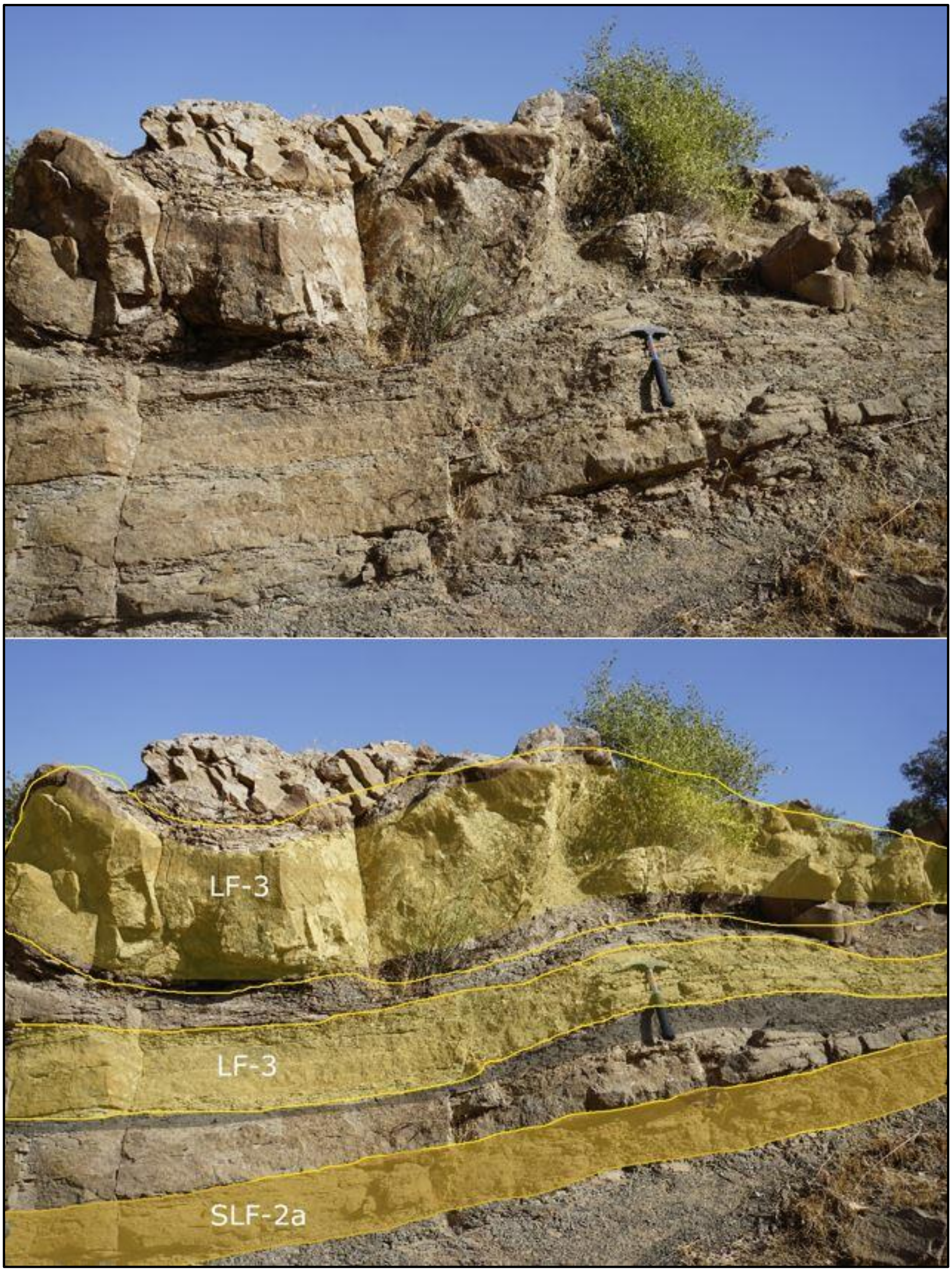


Figure 2.22. Close view of deformed sandstone beds (LF-3) interbedded with calcareous mudstone. Fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.


Figure 2.23. Thin bedded folded sandstone bed.

Depositional process: The deformed sandstone beds and contorted sediment layers are very clear in these facies. This facies is mainly deposited by gravity-induced sediment. Facies F of the (Mutti and Ricci Lucchi, 1972) scheme would be interpreted as deposits of slumps and facies F2 of (Pickering et al., 1989) would be interpreted as deposits of slides and rotational slumps. It is a good evidence for syn-sedimentary deformation in slump sheets (Woodcock, 1976).

LF-4: Normal Graded Sandstone Beds:

SLF-4a: Pebbly to fine Normal Graded Sandstones:

Pebbly to fine grained normal graded sandstones (SLF-4a) are present in many areas like middle part and the upper part of the Tanjero Formation (Fig. 1.10). Some beds have laminated layers of sandstone at the upper part of the bed. The thickness of individual bed is 10 cm to 60 cm (medium to thick bedded), and when it is combined with a discontinuous very thin beds of calcareous mudstone (SLF-8), it could be as thick as 10 m thick. This normally graded lithofacies is interbedded with many of the lithological units described here. The lower contact is with sandy matrix-supported conglomerates (SLF-1b), medium and coarse to pebbly-grained structureless sandstones (SLF-2a and SLF-2b), laminated sandstones (SLF-4), and finally with bluish gray calcareous mudstones (LF-8) (Fig. 2.24).

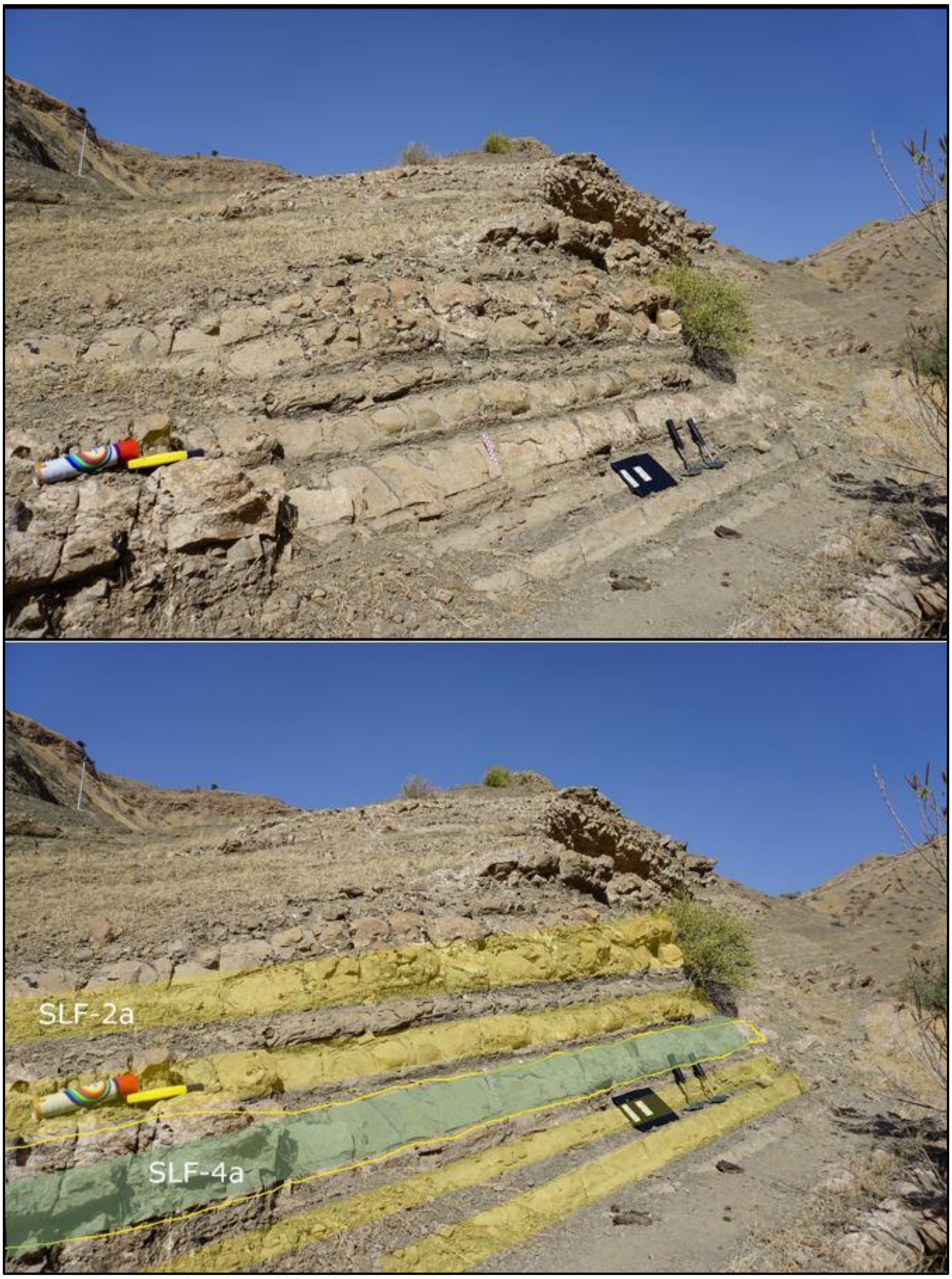


Figure 2.24. Pebbly to fine normal graded sandstone beds (SLF-4a) interbedded with thin bedded of calcareous mudstone (LF-8), fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

While the upper contact is with medium and coarse to pebbly-grained structureless sandstones (SLF-2a and SLF-2b), laminated sandstones (LF-6), siltstones (SLF-7) and mudstones (SLF-8). Frequently, lower surface has scoured, irregular, and erosional bases (Fig. 2. 25); meanwhile, the upper surface is either erosive and irregular, or gradational. The latter is very common in the places which it is underlying coarse to medium-grained structureless sandstone (SLF-2a), demonstrating normal graded bedding. About the geometry; beds of the pebbly to fine normal grade sandstones (SLF-4a) are mostly amalgamated, lenticular and channel-like. Obviously, the clasts in the pebbly parts of the beds are usually characterized by blade and rod shapes, subangular to sub rounded, moderately to well sorted. The original of the pebbles are markedly sedimentary, igneous and metamorphic in origins. In addition to normal grading, other sedimentary structures that have been encountered in these sediments are erosional sole mark structures**.**

Figure 2.25. Close view of normal graded sandstone beds shows normal graded (Ta of Bouma division) and lamination (Tb of Bouma division) and convolute bedding (Tc of Bouma division).

Depositional Process: Lowe (1982) studied and analyzed this type of sandstone beds and declared that; the presence of very coarse sand to pebble size grades with scoured and fluted bases beds are corresponding to the traction sedimentation stage (grain-grain deposition from suspension), which is resulted from the sandy high-density turbidity currents (S1 division of Lowe). Similarly, (Pickering et al., 1986) pointed out that normal graded pebbly sandstones could form from high-concentration turbidity current, when grain by grain deposition from suspension and consequent burial is rapid, giving no time for the traction transport to be progressed on the bed. Because sediments of pebbly to fine normally graded sandstones are rich in shallow marine fauna, such as algae, they could be originated from shallow carbonate settings and these types of turbidites are often called calciturbidites. After all, the features that just illustrated are collectively good evidence to consider that pebbly to fine normal graded sandstones, are the consequence of the deposition from sandy high-density turbidity currents.

SLF-4b: Coarse-medium to fine normal graded sandstone:

Coarse to fine normally graded sandstones are many in the current studied area throughout the Tanjero Formation (lower, middle and upper part), (Fig. 1.10). The thickness of single beds varies from 5 cm to around 30 cm, and laterally the beds are extensively distributed. When they are amalgamated, they reach 2 m thick; otherwise, the association of this sublithofacies with thin to thick black grayish fossiliferous siltstone and mudstone beds (LF-8 and LF-7) could make the thickness of the packages up to 50 m. The lower contact of coarse to fine graded sandstones (SLF-4b) is with laminated siltstone (SLF-7) and calcareous mudstones (SLF-8), while the upper contact is with calcareous mudstones (SLF-8). The base surface is eroded and irregular, but the upper contact is gradational. (Fig. 2.26). Mostly the beds are tabular and sheet-like (Fig. 2.26, 2.27 and 2.28), and they are gray to yellowish gray and dark brown in color. Besides normal grading, other sedimentary structures that have been documented are flute and Load casts with small impact marks and some mud clast (rip up clast), (Fig. 2.27, 2.29 and 2.30).

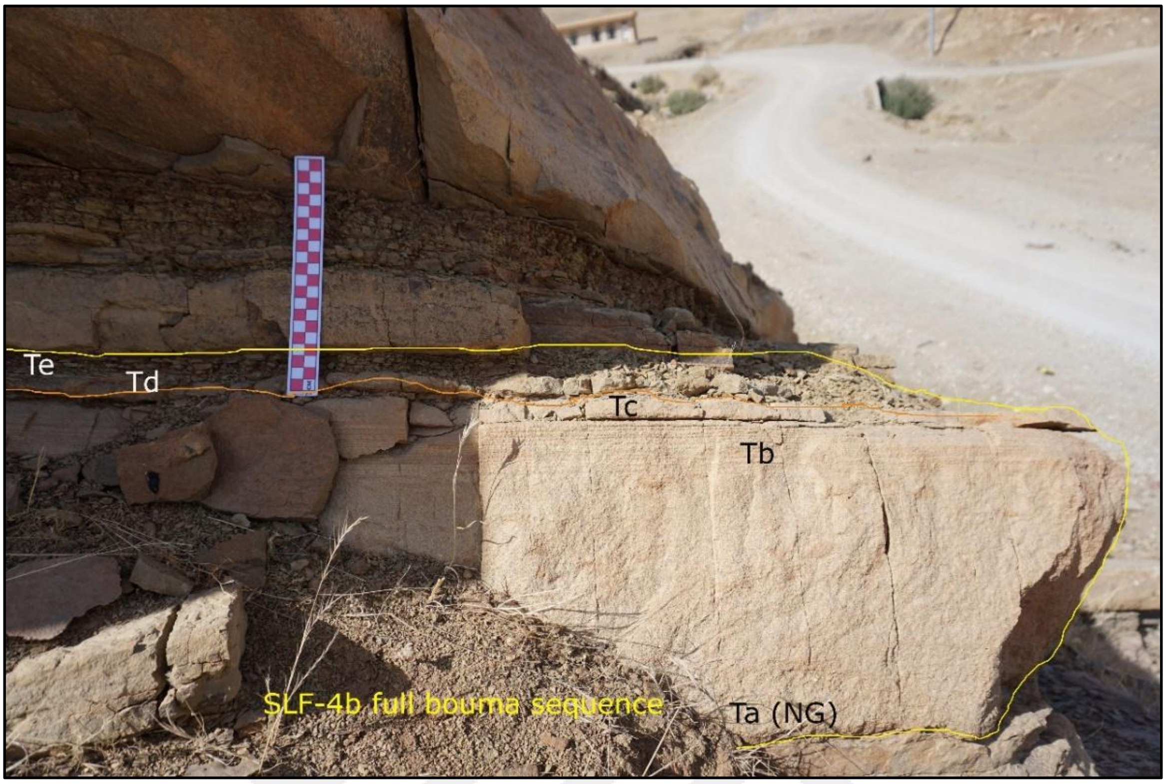


Figure 2.26. Coarse-medium to fine Normal Graded Sandstones (SLF-4b) shows full Bouma sequence Ta, Tb, Tc, Td and Te)

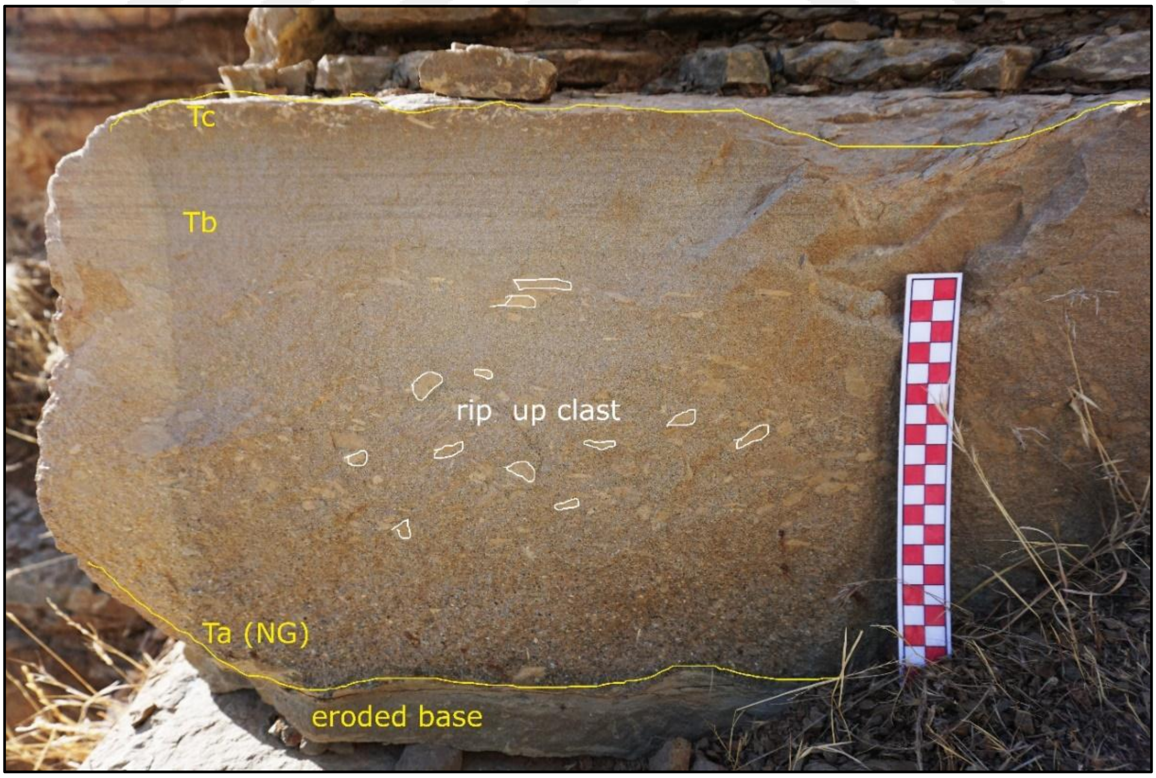


Figure 2.27. Normal graded sandstone bed (NG) with rip up clasts and separated three divisions of Bouma sequence (Ta), Tb (laminated), and Tc (convolute).

Figure 2.28. Close view of normal graded sandstone bed (SLF-4b) determined three divisions of Bouma sequence (Ta, Tb, and Tc)

Figure 2.29. Base of normal graded sandstone bed shows flute mark and load structure.

Figure 2.30. Base of normal graded sandstone bed shows plant remains.

Depositional process: Coarse-medium to fine grained normally graded sandstones, and their gradational association with overlying thinly laminated fine-grained sandstones (LF-4), structureless siltstones (LF-7), and mudstone beds (LF-8) resembles classical turbidite facies with Bouma divisions of Ta, Tb, Td, and Te, respectively. These divisions proceed by low-density turbidity current as both Ta and Tb divisions deposit through traction sedimentations, and Td and Te by way of suspension sedimentation (Lowe, 1982). Above all, Posamentier and Walker (2006) named the successions that are composed of medium to thick sandstone beds as thick bedded turbidites, which is largely of Ta division of Bouma sequence with some Tb and Tc divisions. In terms of mud-clasts, are developed from erosion at the base of a highly competent sand-laden turbidity current, and at the same time they are partially attached to the underlying substrates, which are mud beds. However, some clasts may become detached and isolated from the lower beds. In many cases this type of mud clasts is also known as 'rip-up' clasts. Also, dispersed clasts occur in both thick normal graded and ungraded units. In brief due to the grain size, normal grading and observed Bouma sequences, these sandstone beds have been interpreted as classical turbidities. Interbedding with mudstones indicates a time interval between the emplacements of successive flows.

LF-5: Coarse to pebbly grained reverse graded sandstones:

Very coarse to pebbly reversed graded lithologic units have been recorded in the middle part of the Tanjero Formation (Fig. 1.10 and 2.31). The beds are medium to thick bedded, ranging from 15 cm to more than 50 cm thick. Both contacts have relationship with many other lithofacies, including structureless sandstones (LF-2), siltstone (LF-7) and mudstones (LF-8) (Fig. 2.32). In addition, gradational and erosional-irregular natures of lower surface have been seen and wavy to straight upper surface have been seen (Fig. 2.33). Clearly, the majority of the beds are tabular and amalgamated. The thicknesses of amalgamated sets are up to 50 cm thick in many investigated areas and especially in the middle and upper part of the Tanjero Formation. In addition, along with the beds, dewatering structure have been noticed. The beds are mostly variable in color. In this lithofacies, the gross character of the sediments is coarse grained sandstone to pebbly-grained sandstone.

Figure 2.31. Coarse to pebbly grained reverse graded sandstone (LF5) interbedded with calcareous mudstone (LF-8), sandy matrix supported conglomerates (SLF-1b); fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

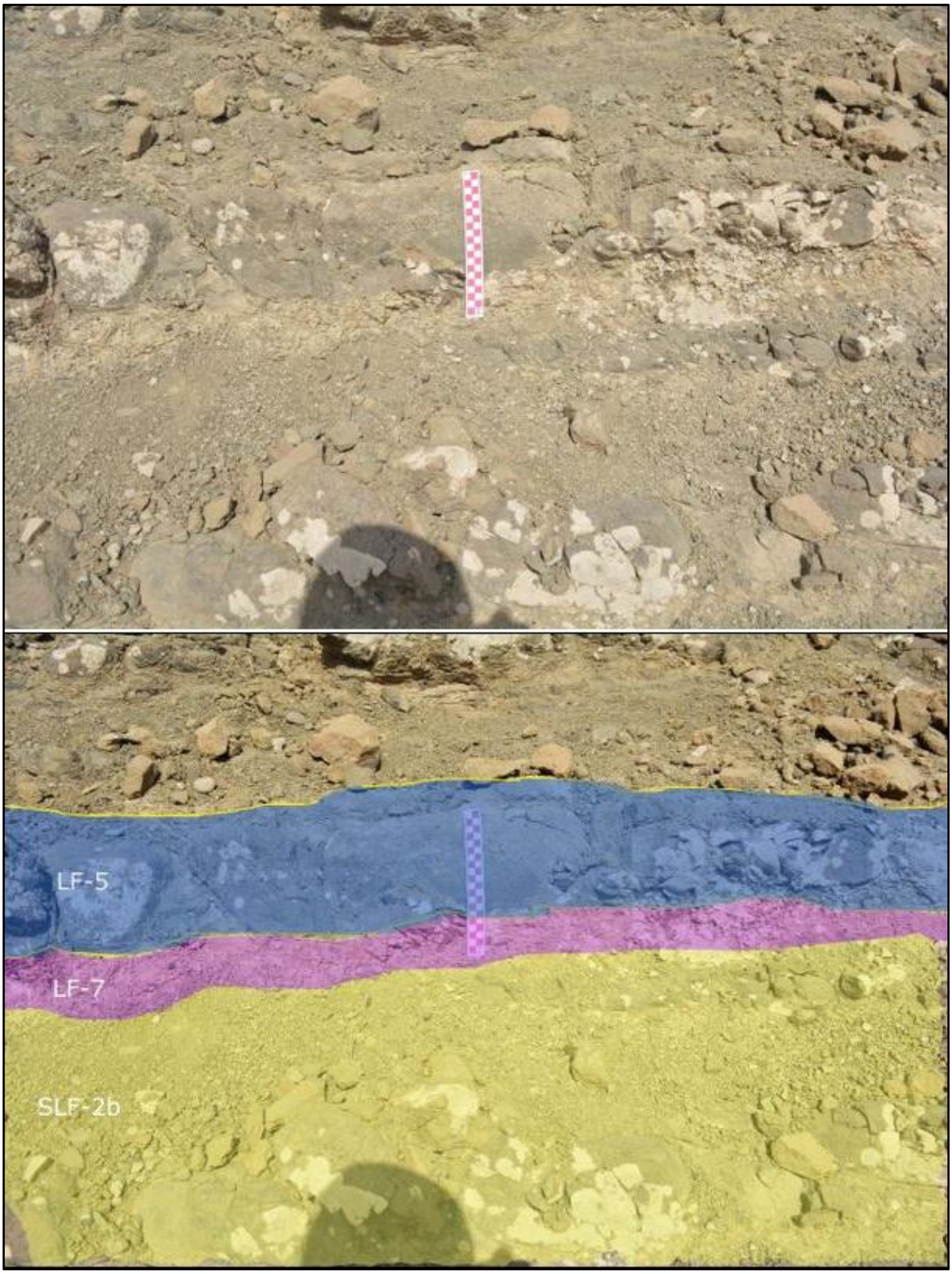


Figure 2.32. Reverse graded sandstone bed shows wavy boundary with siltstone bed (LF-7), very coarse-pebbly structureless sandstone (SLF-2b), illustrated in the lower photo.

Figure 2.33. Close view of reverse graded sandstone bed (LF-5)

Depositional process: The unique and conspicuous features observed in this reversed graded lithofacies are likely to be seen in the S1 and S2 division of Lowe (1982). This division is occurring when the unsteadiness of the sandy high-density turbidity currents increases, forcing the sediments in suspension to concentrate toward the bed incrementally. Differentiation of particles during flow also leads to the development of inverse grading in the resultant deposit (Lowe, 1976a). in addition, the presence of thick sand beds with subtle inverse grading and potential laminated-bedding at their top are likely to be characteristic of more proximal depositional settings, where depositional rates are initially high but are decreasing rapidly, and there is significant bypass.

LF-6: Laminated Sandstones:

Laminated sandstone deposits are seen in throughout the Tanjero Formation. Especially at the lower part of the Tanjero Formation is very common which interbedded with thick bedded of calcareous mudstone. The thickness of the laminated sandstone varies from 5 to 20 cm (Fig. 2.34), and where they are interbedded with the other lithofacies, such as very thick and massive beds of bluish to dark gray calcareous mudstones (LF-8) (Fig.

2.35), the packages could reach to more than 100 m in thickness. The latter case is true and very noticeable in the lower part the Tanjero Formation. Despite this, planar laminated sandstones (LF-6) have contacts with many other lithofacies; for example, they have lower contacts with fine to coarse grained structureless sandstones (SLF-2a), siltstone beds (LF-7) and amalgamated sandstone beds (SLF-2c), while their upper contacts are with Calcareous mudstone (LF-8) and siltstone beds (LF-7). Commonly the natures of the laminated beds have erosional and sharp loaded (Fig. 2.36). The beds are tabular to sheet-like in geometry. Additionally, thin and medium planar laminated sandstone lithofacies are fine to medium sand grade size, and rarely coarse sand has been detected. They are also dark gray to reddish brown in color. LF-4 deposits are rich in the sedimentary structures like load structure (Fig. 2.36).

Figure 2.34. Interbedded laminated sandstone beds (LF-6) and calcareous mudstone (LF-8), illustrated in the lower photo.

Figure 2.35. Thin bedded turbidite (interbedded laminated sandstone (LF-6) and calcareous mudstone (LF-8), illustrated in the lower photo.

Figure 2.36. Close view of laminated sandstone bed (LF-6)

Depositional process: Fine to medium grained planar-laminated sandstones (LF-6) and their conformable and gradational lower natures with normal graded sandstone lithofacies (LF-4) suggest ta and tb divisions of Bouma sequence (1962)**.** Albeit, where these laminated sediments gradationally underlie calcareous mudstone lithofacies (LF-8), they represent Td-e divisions of the Bouma**.** Divisions of Ta-b, as notably figured out by Lowe (1982), are formed by the dilute and low-density turbidity currents. To sum up, it is concluded that the deposition of planar laminated sandstones in either cases is from sandy low-density turbidity currents.

LF-7: Siltstone Beds:

Siltstone lithofacies is observed mostly in the lower part in the Tanjero Formation. However, this facies present rarely in the middle and upper part. Siltstone beds are generally, thin bedded, parallel sided. In some successions it has been seen as amalgamated thick bedded siltstone beds. Thickness of this lithofacies is variable from thin to thick bedded (2-25 cm thick). Furthermore, both upper and lower contacts are associated with the majority of the current sandstone and mudstone lithofacies (Fig. 2. 37).

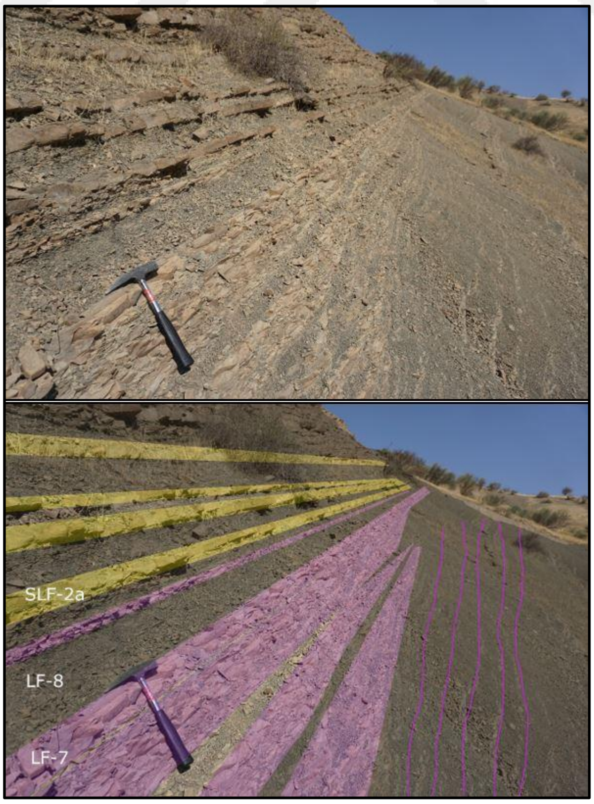


Figure 2.37. Interbedded siltstone beds (LF-7) with calcareous mudstone (LF-8), fine-coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

Their natures are sharp, straight, and erosional, but where the lithofacies is associated with the graded and bedded sandstones, it is very crudely thinly laminated and it is lower contact is gradational. On the contrary, when the siltstone is interbedding with silty and sandy mudstones, it is structureless. Generally, the beds are tabular-continuous, yellowish to brownish gray in color (Fig. 2.38).

Figure 2.38. **C**lose view of siltstone beds (LF-7), illustrated in the lower photo.

Depositional process: Siltstone beds and its association and gradational lower contact with the other fine-grained sediments, for instance fine to medium grained sandstones, thought to be deposited from dilute, low-density turbidity current (Lowe, 1982; Hartley and Otava, 2001). Siltstone beds is transported by high concentration silt dominated turbidity currents or very fluid, silty fabric flow (Pickering et al., 1986), and deposited by rapid mass deposition from a concentrated dispersion, due to a combination of increased cohesion and intergranular friction (Pickering et al., 1989). Similar facies have been interpreted as lobe fringe and outer fan deposits (Nilsen and Abbott, 1981).

Planar-finely laminated siltstone are the deposits that are resulted from low-density turbidity currents and nominated as Td provision (Bouma, 1962). Mulder and Alexander (2001) investigated that Td is mostly deposited from low-density turbidity currents that are turbulent near the bed.

LF-8: Mudstone Beds:

Dark bluish and greenish gray calcareous mudstone lithofacies (LF-8) represents the background of lower, middle and upper parts of the Tanjero Formation (Fig. 1.10). Thickness of the single interval of these calcareous mudstones is extremely variable, ranging from 5cm to more than 4m thick (Fig. 2.39).

Figure 2.39. Interbedded calcareous mudstone (LF-8) with laminated sandstone (LF-6), illustrated in the lower photo.

In general, these mudstones (LF-8) are rich in micro fossils. Besides foregoing trace fossils, SLF-7a sediments have an abundance of planktonic foraminifera and indistinguishable fragments of the other fauna. Generally, calcareous mudstones are structureless and friable. However, in the scenario of silty mudstones, they show very subtle to crude thin-laminated beds and distinct fissility (Fig. 2.40), respectively.

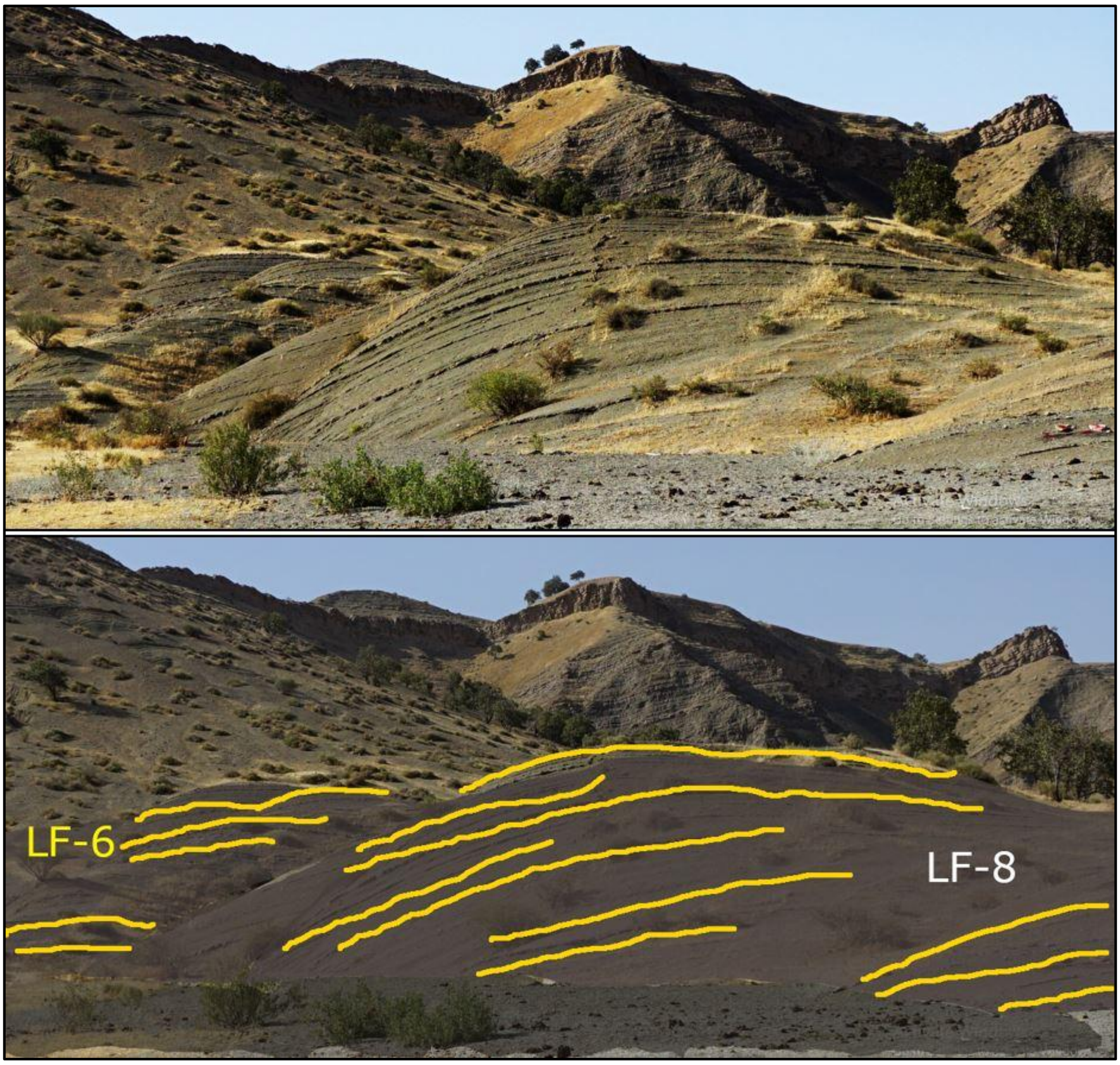


Figure 2.40. landscape view of the lower part of Tanjero Formation shows interbedding between laminated sandstone (LF-6) and calcareous mudstone (LF-8), illustrated in the lower photo.

Depositional process: Presence of marine fauna, such as planktonic foraminifera, within these types of mudstones and their Intermixing with turbidites could lead to the suggestion that these mudstones in Tanjero Formation are of hemipelagic origin. The hemipelagic deposits are very fine-grained sediments that have a great percentage of both biogenic and terrigenous fractions (Stow and Piper, 1984; Stow et al., 1996). Storm effects and turbidity currents may cause reworking of shelf and slope deposits, maintaining very fine grains as clay and silt grade sizes in suspension for a while before settling by the action of gravity (Nichols, 2009). Based on these criteria, the dark gray calcareous facies are interpreted as being deposited by suspended sediment fallout and periodic low-energy currents.

LF-9: Chaotic-distorted lithofacies;

Chaotic- distorted facies is observed in the middle and upper part of the Tanjero Formation. These deposits consist of the mixture of calcareous mudstone and slumped blocks of sandstone beds (Fig. 2.41).

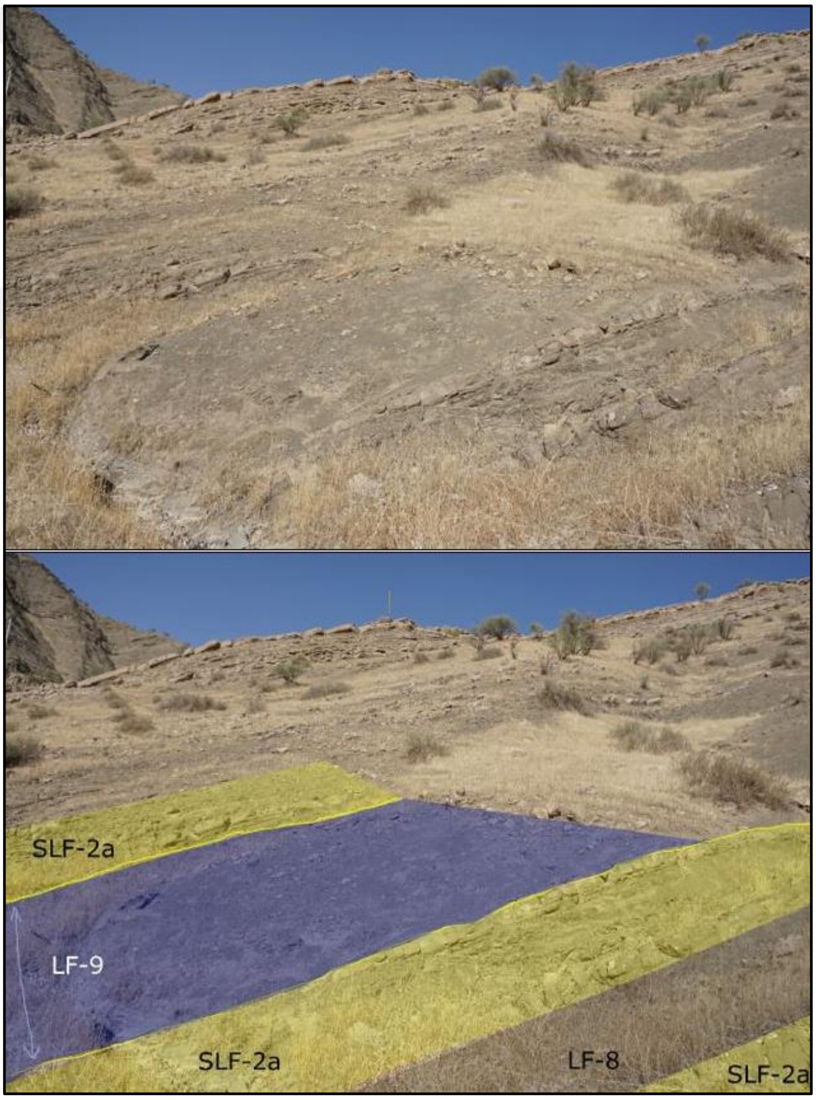


Figure 2.41. Chaotic- distorted deposits (LF-9) interbedded with structureless sandstone beds (SLF-2a), calcareous mudstone (LF-8), illustrated in the lower photo.

Sandstone beds are discontinuous, highly contorted in geometry, and as figured out before some beds are undisturbed while others are internally highly contorted. The clasts are poorly to moderately sorted, rounded to sub-rounded, and they are of different origins and even including bioclasts of shallow marine environments (Fig. 2.42).

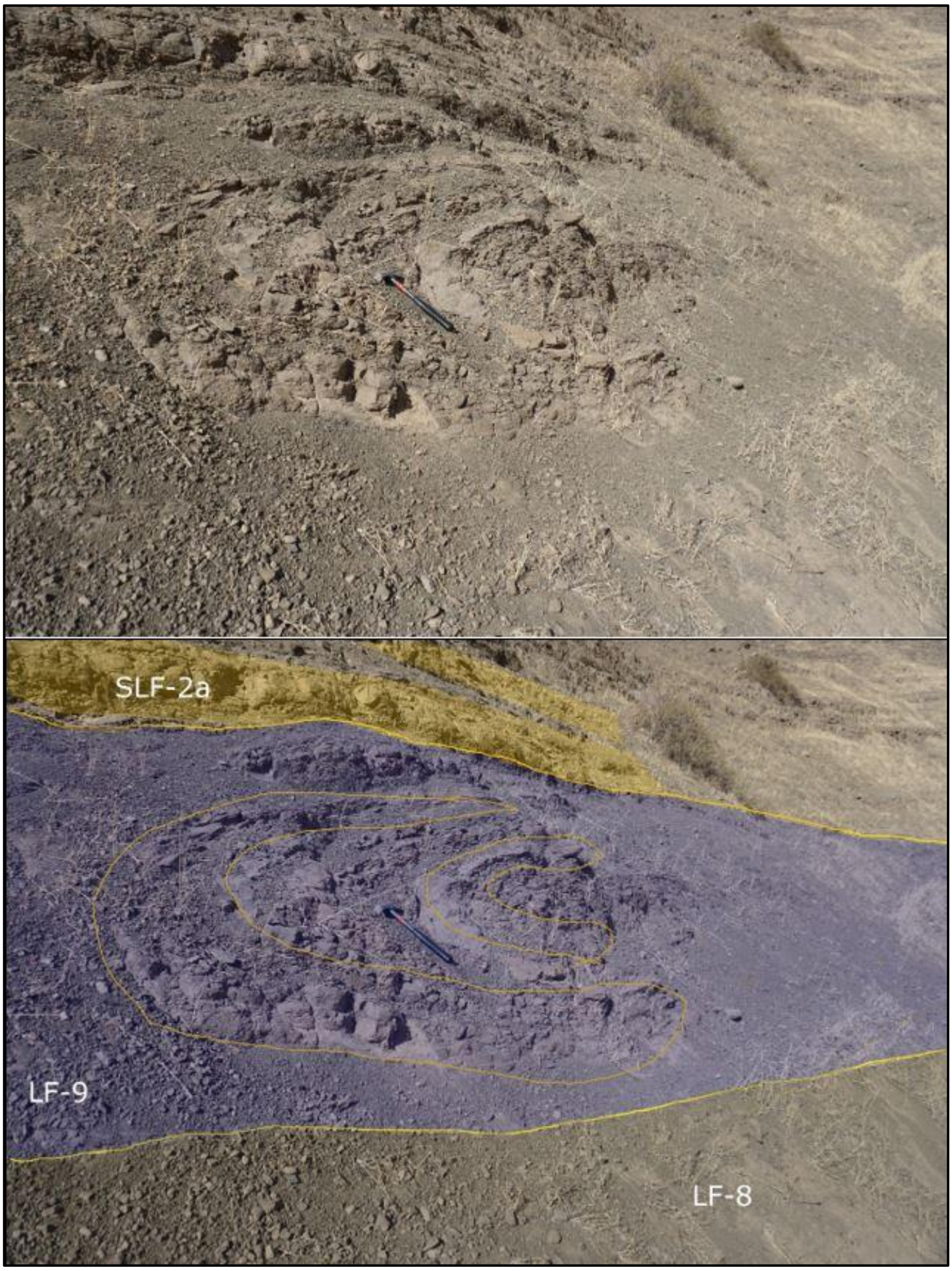


Figure 2.42. Close view of chaotic-deformed deposits (LF-9) interbedded with calcareous mudstone (LF-8) and fine- coarse structureless sandstone (SLF-2a), illustrated in the lower photo.

Depositional process: The current distorted lithofacies are ubiquitously bordered by undeformed strata above and below, relating to the suggestion that they are formed due to syn-depositional processes and not as the result of tectonic deformation (Stow et al., 1996). Folding, dislocation, and deformed lamination of the beds are very likely driven by gravity-induced sediment slumping when the sediment shear strength is exceeded and in-situ liquefaction and fluidization; the latter is more commonly associated with brecciation (Pickering et al., 1986). Slumps may form in shallow neritic depth (quake sheets), so that they are not necessarily diagnostic of flysch facies (Bouma, 1962). But as it is associated with typical deep marine facies, it is concluded that this facies in the study area through Tanjero Formation is deposited in slope-deep marine environment.

Table 2-1: Summary of facies analysis**.**

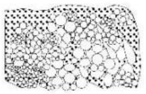
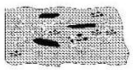
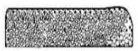
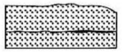
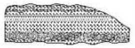
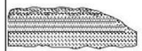
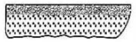
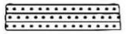
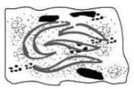
Lithofacies (LF)	Sublithofacies (SLF)	Figure	Thickness	Geometry of Beds	Boundaries				Description (sedimentary structure (s) and dominant Textures (Grains)	Depositional Process / Interpretation
					Contacts		Nature			
					Lower	Upper	Lower	Upper		
LF-1 Conglomerates	**SLF-1a Pebbly to Sandy matrix supported Conglomerates**		6	Lenticular, Channel-like	SLF-2c	SLF-2c	Eroded base	Straight	Sedimentary, igneous, and metamorphic rock types. Pebbles are rounded and subrounded, well sorted.	Cohesive debris flows of Lowe (1982), high density turbidity currents or debris flows rapid sedimentation of grains
	SLF-1b Sandy matrix supported Conglomerates		14	Lenticular and Irregular	SLF-2c LF-8	SLF-2c	Wavy and eroded	Wavy and straight	Generally Conglomerate is lacking internal organization with big folded blocks of sandtone and mudstone. Pebbles are small granules to big blocks, poorly sorted and they are subangular to subrounded.	Debris flows/ Tractional flow under subaerial conditions
	SLF-1c Muddy matrix supported Conglomerates		30	Tabular, Channel-like	LF-2	LF-2	Wavy and eroded	Wavy and straight	Slump structure, poorly sorted pebbles.	Cohesive debris flows of Lowe (1982), high density turbidity currents or debris flows rapid sedimentation of grains
LF-2 Structureless Sandstone Beds	**SLF-2a Fine-coarse Structureless Sandstone**		180 m	Tabular shape,	LF-8, LF-1 SLF-2c LF-7	LF-8 SLF-2c LF-7 LF-1	Wavy base,	Straight, wavy,	Thin to medium bedded Sst beds, rich in plant remains, dark grey to light brown color. Amalgamated beds rarely occur. Load structure.	Low-density turbidity current (Ta) (Arnold H. Bouma (1962), tbt, decreasing turbidity current!
	SLF-2b Very Coarse-Pebbly Structureless Sandstone		60 m	Tabular to sheet-like, lenticular shape	LF-8	LF8	Erosional Wavy base,	Straight, wavy,	Peebly thin bedded Sst, pebble size (1-7mm), chaotic thick bedded, fusulinida and shell of fossils occur, mud clasts,	High-density turbidity current, (Lowe, 1982)

Table 2.1: Continued.

	SLF-2c Amalgamated Structureless Sandstone		300 m	Tabular shape, lenticular, Pinchout	LF-8, LF-7, LF-1, SLF-2a	LF-8, LF-7, SLF-2a	Wavy, erosional base	Straight, wavy,	Thick bedded amalgamated Sst beds, burrow trace fossils, flute mark structure, tool mark, load structure, some beds filled with fossil shells. (Large Ammonite) and (Oysters)	Density turbidity current increased!
LF-3 Deformed Sandstone Beds			10 m	Irregular, wavy shape	LF-8, SLF-2c	LF-8	Wavy, erosional base	Wavy	Thick bedded Sst beds, deformed,	Loading and high density turbidity
LF-4 Normal Graded Sandstone Beds	**SLF-4a Pebbly to fine Normal Graded**		80 m	Tabular, lenticular	LF-8, SLF-2c	LF8, SLF-2c	Wavy eroded base	Wavy and straight	Thick bedded pebbly Sst bed, eroded base, rip uap mud clasts,	Some Ta, Tb, Tc, S1 lowe
	SLF-4b Coarse-medium to fine Normal Graded		170 m	Tabular to sheet-like,	LF-8, LF-7, SLF-2c	LF-8, LF-7	Straight and wavy erosional base	Straight and wavy	Thin to thick bedded, normal gradeded, some of them rich in trace fossils and plant materials, load structure.tool mark, flute mark.	Low-density turbidity current (Ta and Tb) (Arnold H. Bouma (1962), Ta,Tb and Tc, ta-te full bouma sequence
LF-5 Reverse (inversely) Graded Sandstone Beds – Coarse to Pebbly grained			10 m	Tabular	SLF-2c, LF-8, LF-7	SLF-2c, LF-8, LF-7	Wavy base	straight	Inversely graded. Grains are angular to subrounded, mud clasts, light grey to yellow color.	Ta, Tb, S1, S2, Ta, R3, S1, S2
LF-6 Laminated Sandstone Beds			90 m	Tabular, wavy, parallel and continuous	LF-8, LF-1, LF-7	LF-8, SLF-2c, LF-7	Wavy, erosional, irregular, loaded bases	Sharp straight	Thin bedded (1-10 cm), fine to medium grained, laminated Sst beds, Load structure exist in some beds, interbedded with mudtone, conglomerates.	Low-density turbidity current (Tb) (Arnold H. Bouma (1962)
LF-7 Siltstone Beds			50 m	Tabular to sheet-like continuous, or lenticular discontinuous	LF-8, SLF-2a	LF-8, SLF-2b, SLF-2a	Eroded and Wavy	Straight and wavy	Thin to medium bedded siltstone interbeded with mudstone and thin bedded sandstone	Low-density turbidity current (Arnold H. Bouma (1962)
LF-8 Mudstone Beds			300	Background of most of other lithofacies					Thick bedded, Grey to dark grey-green color, laminated and scattered shape	Low-density turbidity current (Arnold H. Bouma (1962)
LF-9: Chaotic-Distorted Lithofacies			25	Highly distorted	LF-8, LF-2a	LF-8, LF-2a	Eroded base	Irregular	Contorted- Distorted Slump structure, course to pebbly sand grade size, pebbles are rounded to sub-rounded, poorly sorted	Gravity- induced sediment slumping

2.2 FACIES ASSOCIATIONS (FA)

Facies Association consist of groups of facies genetically related to one another and which have some environmental significance. The facies comprising an association are generally deposited in the same broad environment, in which there are several different depositional processes operating. Facies associations are sets of genetically related facies, all of which have certain depositional settings (Collinson, 1969; BOGGS, 1995). The necessity for facies associations in the present study is that most of the individual facies could be formed in many different depositional settings; although equally some are indicative of particular sedimentary environments. Sedimentary facies recognized here are grouped together as per their stratigraphic positions, together with additional information such as sedimentary structures, architecture of the beds, textures. Accordingly, five sedimentary facies associations have been recognized (Table 2.2), and they are mentioned in the following sections and in the (Fig. 2.43) of the depositional model.

FA-1: Slope Deposits:

Slope deposits have been seen in the middle and upper part of the studied area. The thickness of this deposits is around 300 m in the middle part and 100 m in the upper part of the Tanjero Formation. Both lower and upper boundaries generally are with Inner fan (FA-2). The facies association (FA-1) consists of conglomerates (LF-1), very coarse-pebbly structureless sandstone beds (SLF-2b), calcareous mudstone beds (LF-8) and chaotic-distorted lithofacies (LF-9). Chaotic- distorted beds, slump structure and calcareous mudstone beds are predominant. Geometry of the succession is highly variable, Irregular, lenticular to channel-like laterally, and fining-thinning upward vertically. In the facies section we mentioned that internal brecciation, folding and lateral translation of the beds (LF-9) have been referred as a result of gravity-induced sediment slumping (Pickering et al., 1986). Also, matrix-supported conglomerates (SLF-1c) formed as a consequence of rapid deposition of grains by frictional freezing of the cohesive debris flows or high-density turbidity currents Lowe (1982). Then as well, pebbly mudstone lithofacies development is due to freezing of cohesive debris flows of the gravelly subaqueous density flow processes. Chaotic-distorted lithofacies (Slump structure) (LF-9) and Debris flow deposits (LF-1) are prominent lithofacies in the feeder channel and slope areas (Walker, 1978).

FA-2: Inner Fan Deposits:

Inner fan deposits (FA-2) are present in the lower, middle and upper part of the studied area, (Fig. 1.10). Regarding to their thickness, it is changing; ranging from 38 m in the middle part to more than 100 m in the upper part. Both lower and upper boundaries generally are with mid fan (FA-3), slope deposits (FA-1) and outer fan (FA-3), (Table. 2.2). The key lithofacies that represent current successions are structureless very coarse-pebbly sandstones (SLF-2b), pebbly to fine normal graded sandstones (SLF-4a), coarse to pebbly inverse grade sandstones (LF-5), amalgamated structureless sandstone beds (SLF-2c) and matrix-supported conglomerates (SLF-1b and SLF-1c). Besides, thin beds of coarse to fine grained sandstones (SLF-4b), deformed sandstone beds (LF-3), laminated sandstones (LF-6), Siltstone beds (LF-7) and mudstone beds (LF-8) make subordinate contributions. Geometry of the succession is highly variable, lenticular to channel-like laterally, each of which is pinched-out in silty-sandy mudstones, and fining-thinning upward vertically. Correspondingly, load structure and mud clasts have been observed in bases of some beds.

In the facies section, the major lithofacies of this succession have been described as a consequence of the cohesive debris flows (LF-1), traction sedimentation (SLF-4a), and traction-carped sedimentation (LF-5), all of which are formed due to sandy high-density turbidity current (high density turbidity S1-3 of Lowe, 1982). All together represents channel fill deposits, which are usually pass laterally into the mid fan successions (Einsele, 2000). Conversely, other lithofacies have been ascribed to the classic turbidites (Ta, Tb divisions of Bouma sequence, 1962). Combining these lithofacies with hemipelagic sediments (LF-8), upward thinning and fining sequences, and channel-like geometry of the beds, are the distinctive aspects of the inner fan deposits (Walker, 1978; Stow et al., 1996).

FA-3: Middle Fan Deposits:

Middle fan deposits (FA-3) have been recorded in the middle part of Tanjero Formation. Thickness of the sediment's extents from 100 m to more than 200 m, both lower and upper boundaries of the Mid Fan are with inner fan deposits (FA-2). The principal lithofacies and sublithofacies that this association is composed of are both fine-coarse structureless sandstone (SLF-2a) and pebbly to fine normal graded sandstone (LF-4), (Table. 2.2). As well as, the entire package is well intermixed with medium to thick beds of calcareous mudstone and siltstone (LF-8 and LF-7). The most striking features that have been observed from FA-3 succession are coarsening and thickening upward sequences and increase in sand/mud ratio in the same trend, which are almost well developed.

Lithofacies that have recorded in the mid fan deposits (FA-3) are previously interpreted as a result of deposition from decreasing of low-medium turbidity currents (SLF-2a and SLF-4b), *en masse* deposition from sandy high-density current (SLF-2b), and finally traction sedimentation due to sandy high-density turbidity current (SLF-4a). Intercalating of such sediments with mudstone deposits (LF-8), upward amalgamation and thickening-coarsening sequences, and lenticular and channel-like geometries of the beds in their upper parts**,** are the major features of the mid fan deposits (cf. model of Walker, 1978; Howell and Normark, 1982).

FA-4: Outer Fan Deposits:

Outer fan deposits have been seen in the lower part of the Tanjero Formation. The thickness of outer fan association is around 60 m (Table. 2.2). The lower boundary is with basin plain (FA-5) and upper boundary is with inner fan (FA-2). The main lithofacies and sublithofacies that make up the association are both normal graded and structureless fine to medium grained sandstones sublithofacies (SLF-4b and SLF-2a), thin to medium bedded laminated sandstone and siltstones (LF-6 and LF-7), all within the calcareous mudstone background (LF-8). The beds vertically are un-channelized, unamalgamated, and slightly thickening upward. Also, laterally they show continuous tabular to sheet like geometries. Thin bedded turbidites are common in this association.

As mentioned before in this chapter, all the lithofacies that construct this association of the present study are deposited by the means of low-density turbidity currents of Bouma (1962). Remarkably, Howell and Normark (1982) figured-out that poorly developed thickening-upward units are typical of outer fan successions.

FA-5: Debrite Deposits:

Debrite deposits constitute lower, middle and upper parts of the Tanjero Formation. This association present throughout the formation. The main lithofacies and sub lithofacies which represent this association are Sandy matrix supported conglomerates (SLF-1b), muddy matrix supported conglomerates (SLF-1c) and choatic- distorted (LF-9) (see Table 2.1). The common visible feature of this association is debris flow. The beds geometry is varying such as; lenticular, channelized and tabular. In general, the base boundaries are wavy and eroded. The major lithofacies of this association have been described as a consequence of debris flow and chaotic distorted deposits. Debris flow deposits in Tanjero Formation showing free-floating large clasts and pebbles suspended in sandstone and mudstone matrix.

Beds that contain both turbidite and debrite facies document the exist of both low and high sediment concentration flow facies within a single event (Haughton et al., 2003; Talling et al., 2004; Amy et al., 2005b). Mass transport deposits such as debris flow and slump are an important component of many slope channel system as multiple scales (Mayall and Stewart, 2000; Posamentier and Kolla, 2003; Mayall et al., 2006; Armitage et al., 2009). Furthermore, there is some evidence that slump and debris flow deposits are most common of a channel system (Mayall and Stewart, 2000; Posamentier and Kolla, 2003; Mayall et al., 2006). The debrite deposits derived from high energy flows are commonly composed of sandstone and mudstone in various grain size, resulting in poorly sorted deposits of SLF-1b and SLF-1c.

Table 2.2: Summary of facies associations.

Facies Association (FA)	Stratigraphic distribution and their thicknesses (m)	Boundaries		LF and SLF	Depositional process and their deposits		Changes of Facies	
		Lower	Upper				Vertically (Thickness)	Horizontally (Geometry)
FA-1: **Slope**	U-Tanjero F.– 98 m L-Tanjero F.- 290 m	FA-2	FA-2	SLF-1a SLF-1b SLF-1c SLF-2b LF-8 LF-9	Debris flows and Turbidity currents	Tab & S1-3	Irregular	Horizontal folding, highly brecciated and deformed
FA-2: **Inner Fan**	U-Tanjero F. - 130 m M-Tanjero F. - 134 m L-Tanjero F. – 71 m	FA-4 FA-1 FA-3	FA-1 FA-3	SLF-1b SLF-1c SLF-2c SLF-2b LF-3 LF-4 SLF-5 SLF-6 SLF-8	High Density turbidity Currents	Tab & S1-3	Finning-thinning upward	Lenticular, channel-like & pinch-out
FA-3: **Mid Fan**	M-Tanjero F.- 352 m	FA-2	FA-2	SLF-2a SLF-2b LF-4 LF-6 LF-7 LF-8	Low to Medium Density Turbidity Currents	Tab, Tad & Tde	Coarsening-thicking upward	- Irregular, tabular in lower part - Amalgamated and channel-like in middle & upper part
FA-4: **Outer Fan**	L-Tanjero F.- 61 m	FA-5	FA2	SLF-4b SLF-2a LF-6 LF-7 LF-8	Low to Medium Density Turbidity Currents	Tab, Tcd, Tce & tbt	Poorly developed thickening upward, un-channelized and un-amalgamated Sst beds	Tabular, continuous and sheet-like
FA-5: **Debrite Deposits**	Tanjero F.- 65 m	FA-1 FA-2 FA-3	FA-1 FA-2 FA-3	SLF-1b SLF-1c LF-9 LF-8	High Density Turbidity Currents	Debris flow and slump structure	Irregular	Channel-like and deformed

2.3 PALAEOFLOW DIRECTIONS

A palaeocurrent indicator is evidence for the direction of flow at the time the sediment was deposit which is referred to the palaeoflow. The Palaeoflow data are used in conjunction with facies analysis and provenance studies to make paleogeographic reconstructions. The data are routinely collected when making a measured section (Fig. 1.10). The palaeoflow directions of Tanjero Formation have been determined in different area through sedimentary structures such as; flute mark, grove mark, ripple mark and pebble imbrications (Al-Rawi, 1981; Karim, 2004; Karim and Surdashy, 2005a). Palaeoflow direction of Tanjero Formation in different area have been recorded via flute casts, groove casts, ripple marks and cross bedding; N45W in Rawandoz area and N85W in Dokan area and N45W around Sulaymaniyah (Al-Rawi, 1981). In addition, he concluded that the source area is from the east and the main direction of transport is northwest and west. Palaeoflow direction of Tanjero Formation have been determined in Sulaymaniyah, Azmar-bchkola valley, Darbandikhan and Chwarta area which is the direction is toward south and south west (Karim, 2004). Palaeoflow data (flute mark, groove marks, tool mark and pebble imbrication) were collected through measured section across the study area. The number of measurements that were collected are 55 data (Fig. 2.43, 2.44 and 2.46). These data have been plotted in rose diagrams, where the vector mean is also shown. Also, data that were collected in beds dipping more than 25° were corrected before their interpretation with rose diagrams. Several unidirectional sedimentary structures:

2.3.1 Unidirectional sedimentary structures:

Unidirectional sedimentary structures are the structures which give a clear, single direction of paleo flow direction and their value ranges from 0 to 360 degrees. Flute mark and Pebble imbrication have been used as unidirectional sedimentary structures to indicate palaeoflow direction in the Tanjero Formation which is frequently toward S35W as shown in (Figure 10 and 11). All recorded data mentioned in the below table (Table. 2.3). In addition, the data of unidirectional sedimentary structures were plotted on the rose diagram (Fig. 2.45)

Figure 2.43. Base of the sandstone bed shows flute mark- unidirectional sedimentary structure in the Tanjero Formation.

Figure 2.44. Conglomerate bed show imbrication- unidirectional structure in the Tanjero Formation.

Table 2.3. 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				

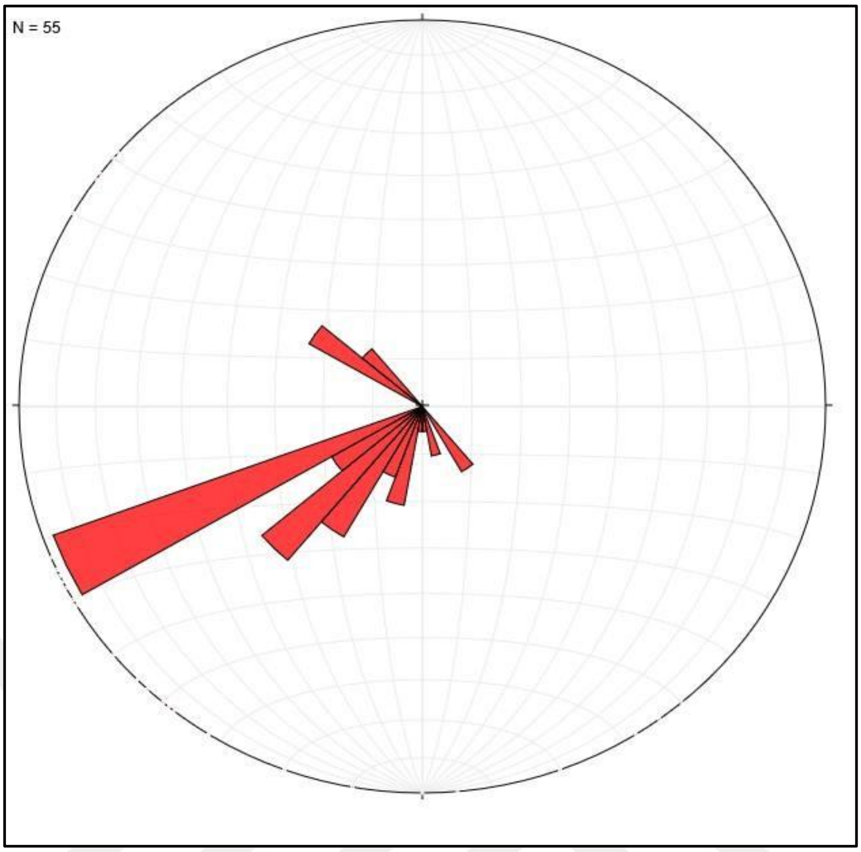


Figure 2.45. Shows the rose diagram of unidirectional palaeoflow of Tanjero Formation which is toward south west in Sirwan gorge, around Darbandikhan town northeastern of Iraq.

Figure 2.46. Sandstone beds shows flute mark- unidirectional structure and tool mark- bidirectional structure in Tanjero Formation.

Figure 2.47. Sandstone beds shows tool mark and load clast in Tanjero Formation.

2.3.2 Bedding Plane:

The bedding planes of the Tanjero Formation also have been recorded and plotted on the Steronet which is toward to northeast and southwest, and it is shown in the (Table 2.4), (Fig. 2.6).

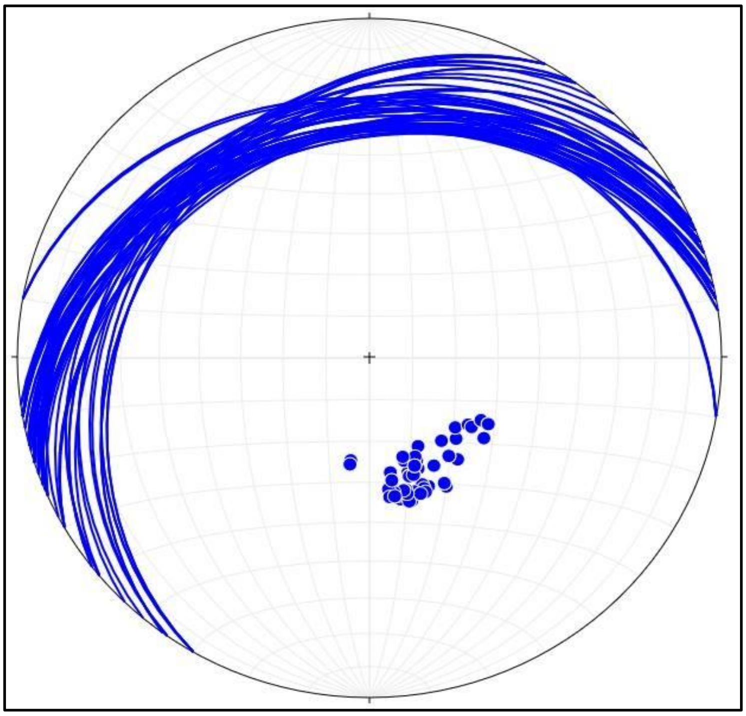


Figure 2.48. Shows the plotting bedding planes of sandstone beds in the studied site on stereonet by using georose software.

Table 2.4. Summary of Tanjero Formation 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	**66**	260	30

3. DEPOSITIONAL ENVIRONMENT

The Tanjero Formation is a unique clastic formation which is characterized by sedimentological features in the region (chapter 2). There are some points which are proved that Tanjero Formation was deposited in deep marine environment such as: the presence of deep marine trace fossils; lithofacies characteristics and facies association; No observation of mud cracks; The presence of marine microfossils like planktonic foraminifera of deep marine environment, this is supported by Kassab (1975); Al-Shaibani et al. (1986); Abdel-Kireem (1986b). It is preferable to give some information about different environments in the deep marine sediments in general, before the discussion of the Tanjero Formation deposition environment.

Among the great variability of the marine territory, recognized three fundamentally different environments, each with their own mixture of sedimentary, tectonic and morphological features (Stow, 1982). These are slope aprons, submarine fans and basin plains (Stow et al., 1985). Both data from modern oceanographic surveys and studies of ancient submarine fans are used to construct generalized physiographic models composition of these parts: slope / feeder channel/ canyon, inner (upper) fan, middle fan, outer (lower) fan and basin plain; sub environments of deposition include channels, channel thalweges, levees and inter channel and fringe areas (D.G.Howell and W. R. Normark, 1982). Walker (1966) was the first who recognized the submarine fan by using echo-sounding surveys. Fan beds may overlie oceanic crust, other marine strata, cratonic crystalline rock, or even by interbedding with nonmarine beds. Fans constructed of resedimented mass flow material derived from lacustrine, continental slope and rise and abyssal plain settings; so the bathymetrically nonrestrictive term “submarine fan” rather than the often used “deep-sea fan” is preferred for marine occurrences, an “sublacustrine fan” for the nonmarine occurrences (D.G.Howell and W. R. Normark, 1982).

There is some factor which have a big role for any particular submarine fans nature such as; basin configuration (eg. Confine or nonconfined); basin axis gradient; tectonic setting (both local and global); source sediment type, size and flux; climate; and sea-level stability. This statement is true for slope fan as well. The morphology and depositional character of submarine fan systems are strongly controlled by the composition of the material supplied, particularly the proportions of gravel, sand, and mud present. On this case submarine fans are very much like other depositional systems such as deltas which also show considerable variability depending on the grain size distribution in the material supplied. The term submarine fan is restricted to fan shaped bodies which is deposited by mass-flow, mainly turbidity current processes. Deep marine sediments are distinctive construction features which is start from slope to basin plain (Shanmugam and Moiola R. J., 1988). In general, the deep marine sediments are divided to slope (slope apron or slope fan), submarine fan (inner, middle, outer) and basin plain. Deep marine sediments are those deposited in water depths more than 200 m. (Van Wagoner et al., 1988) defined Basin floor fans as fan-shaped bodies with lobate form of broad aerial extent, deposited in the deepest portions of the basin, and Slope fans as fan shaped bodies which develop in shallower, base of the slope settings, and are associated with a change in bathymetric gradient between the base of the contemporaneous continental slope and upper portion of the basin floor. Slope fan lithofacies represent channel-fill and levee environments on base-of-slope fans (King, et al., 1994; Slatt et al., 1998; Browne et al., 2000; Browne and Slatt, 2002).

According to the facies association, Tanjero sediments was most likely deposited in either submarine fan or slope fan system in Sirwan Valley, East of Darbandikhan town, (Fig. 3.1 A, B and Fig. 3.2 C, D).

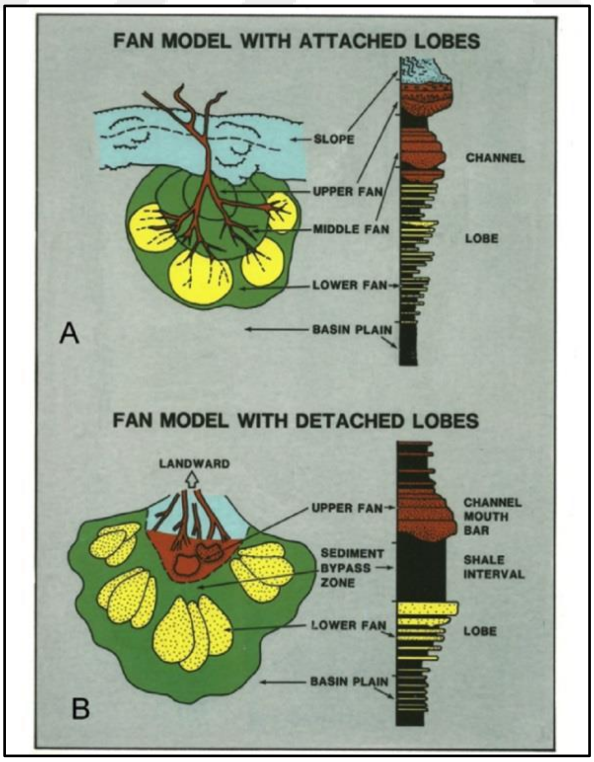


Figure 3.1. A-The classic deep marine fan model, depositional lobes are attached to feeder channels; B-Subsequent fan model, depositional lobes are detached from feeder channels, proposed by Mutti and Ricci Lucchi (1972).

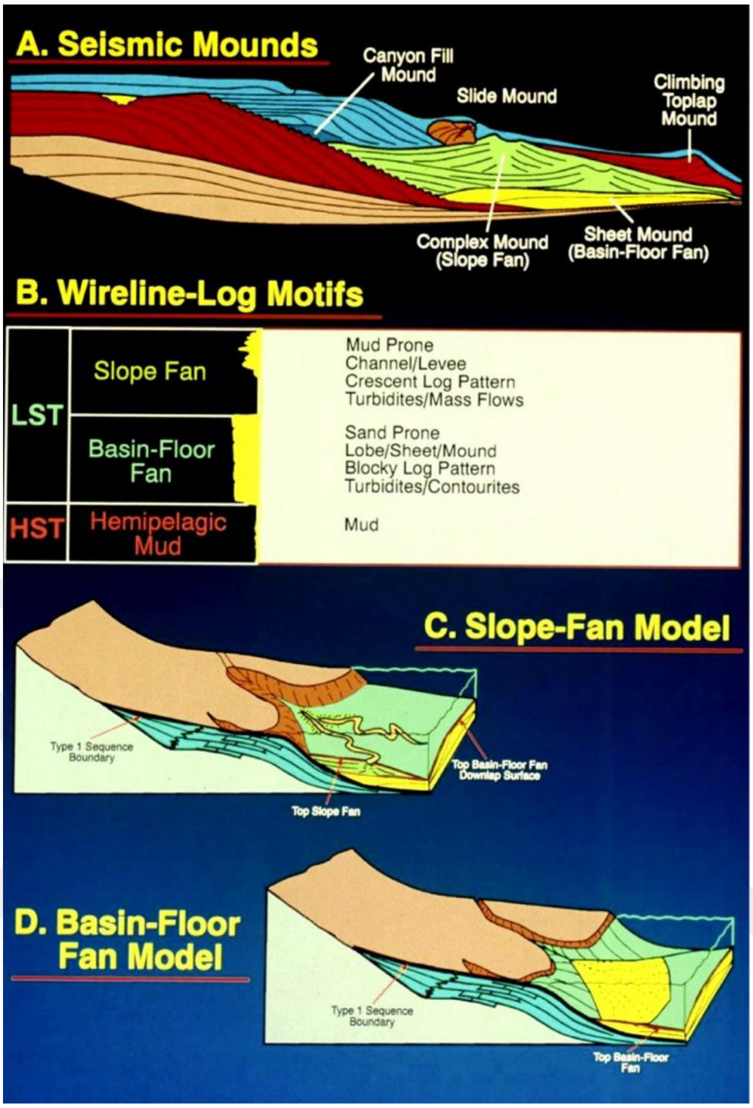


Figure 3.2. Conceptual sequence-stratigraphic fan models. A-Seismic geometries showing basin-floor fans (sheet mound) and slope fans (complex or gull-wing mound); B-Wireline-log motifs showing blocky motif of basin-floor fans; C-Slope-fan model; D-Basin-floor fan by Vail et al. (1991). After Shanmugam et al. (1995).

Van Wagoner et al. (1988) defined Basin floor fans as fan-shaped bodies with lobate form of broad aerial extent, deposited in the deepest portions of the basin, and Slope fans as fan shaped bodies which develop in shallower, base of the slope settings, and are associated with a change in bathymetric gradient between the base of the contemporaneous continental slope and upper portion of the basin floor. Galloway (1998) defined the slope fan as an onlapping mixed sand or mud apron supplied across a bypassing upper slope.

From facies and facies association distribution, the lithology properties and sedimentary structures changes from the lower part to the upper part of the Tanjero Formation in the study area, due to changing the sea level and/ or tectonics. In general, the thickness of the beds and grain size of sandstone beds increase from lower part to upper part in the measured section of the Tanjero Formation. In addition, the debris flow and conglomerate beds increase from lower to upper part. In the lower part rarely observed debris flow, while in the middle and upper parts it is common. Lower part of the Tanjero Formation in the Sirwan area consists of thin bedded siltstone and sandstone beds interbedded with thick hemipelagic calcareous mudstone. Sandstone beds in the lower part have to divisions of the bouma sequence (Ta; normal grading or massive, and Tb; laminated layers) which are formed due to dilute and low turbidity currents according to Lowe (1982).

Different types of fossils had been seen in the middle part of the Tanjero Formation, fossils like large Forams and Gastropods are density concentrated in some beds of biogenic limestone. These fossils lived in the shallow marine (Einsele, 1998). It is deposited during maximum landward extent of marine condition of the Tanjero Formation. It means these fossils transported from the shelf and resedimented in the deep marine environment.

In General, the paleo flow directions (Table. 2.3) are NE to SW in the Tanjero Formation. They are generally parallel to the tectonic strike of the beds. It means that the source area is more likely located toward current location of Iran.

Hemipelagic sediment regularly cover slope and adjacent basin floor topography (Stow & Piper, 1984). On the upper slope, where suspended sediment presume are commonplace, accumulation rates can be consequential, and suspension deposits play a major role in slope progradation and aggradation. Where sediment accumulation rates are low, the hemipelagic sediments consist of big amount of pelagic debris, high organic carbon content and abundant pelagic fossils (Stanley, 1985). According to these criteria the Tanjero sediments represent slope fan system. In the middle part of the Tanjero Formation in the Sirwan area, the thickness of sandstone beds and grain size increased. Amalgamated sandstone beds are common. The thin bedded turbidite also observed. Furthermore, the thinning upward sequences (Channelized cycle) which are present in the middle and upper parts of the Tanjero Formation is distinctive of the proximal turbidite (Ricci-Lucchi, 1975). In the middle and upper parts of the formation the chaotic-distorted lithofacies were observed (LF-9) with conglomerate beds (LF-1), reflect the steep slopes of the basin walls, which corroborates the proximal turbidite. These facies mostly resemble the proximal turbidite (Mc Bride, 1964; Walker, 1966; Walker, 1967; Link, 1975).

Also, debris flow observed in the middle and upper parts of the Tanjero Formation. Slump and debris flow very common in slope environment. The contorted and slump beds is caused by gravity before the consolidation of sediments (Selley, 1982). The sandstone beds with well-developed Bouma sequence divisions (Ta, Tb, Tc, Td, and Te) have been observed in the middle part of the formation which represent middle fan. Furthermore, a lot of thinning upwards sequence have been seen in the middle and upper parts which represent inner fan turbidite sediments.

From the forgoing discussion it may be deducted that the lower part of the section represents the upper slope while middle and upper parts represent slope fan (Inner, middle and outer fan), (Fig. 3.3 and Fig. 3.4).

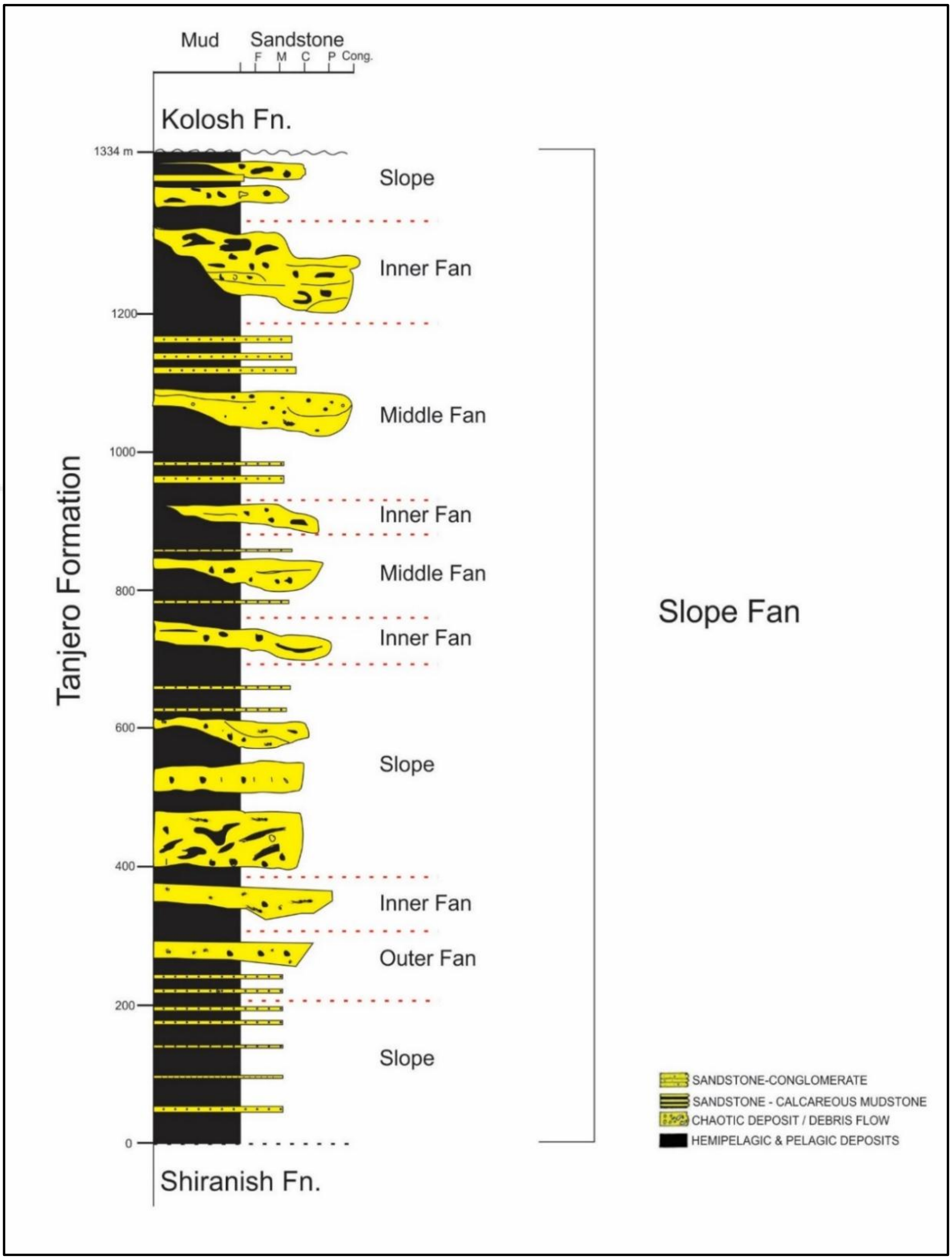


Figure 3.3. General slope fan model of Tanjero Formation

Generally, the just mentioned characteristics are for detailed studied section which is Sirwan Valley section. Anyway, for observation other less studied sections, including Soran, Dokan, Hiranunazanin, Sulaimany Darbandikhan, it can be observed that both grain size and thickness of the Tanjero sediments decreases from Sirwan section toward Soran section. Similarly, sand/mud ratio decrease as well (Fig. 4.1).

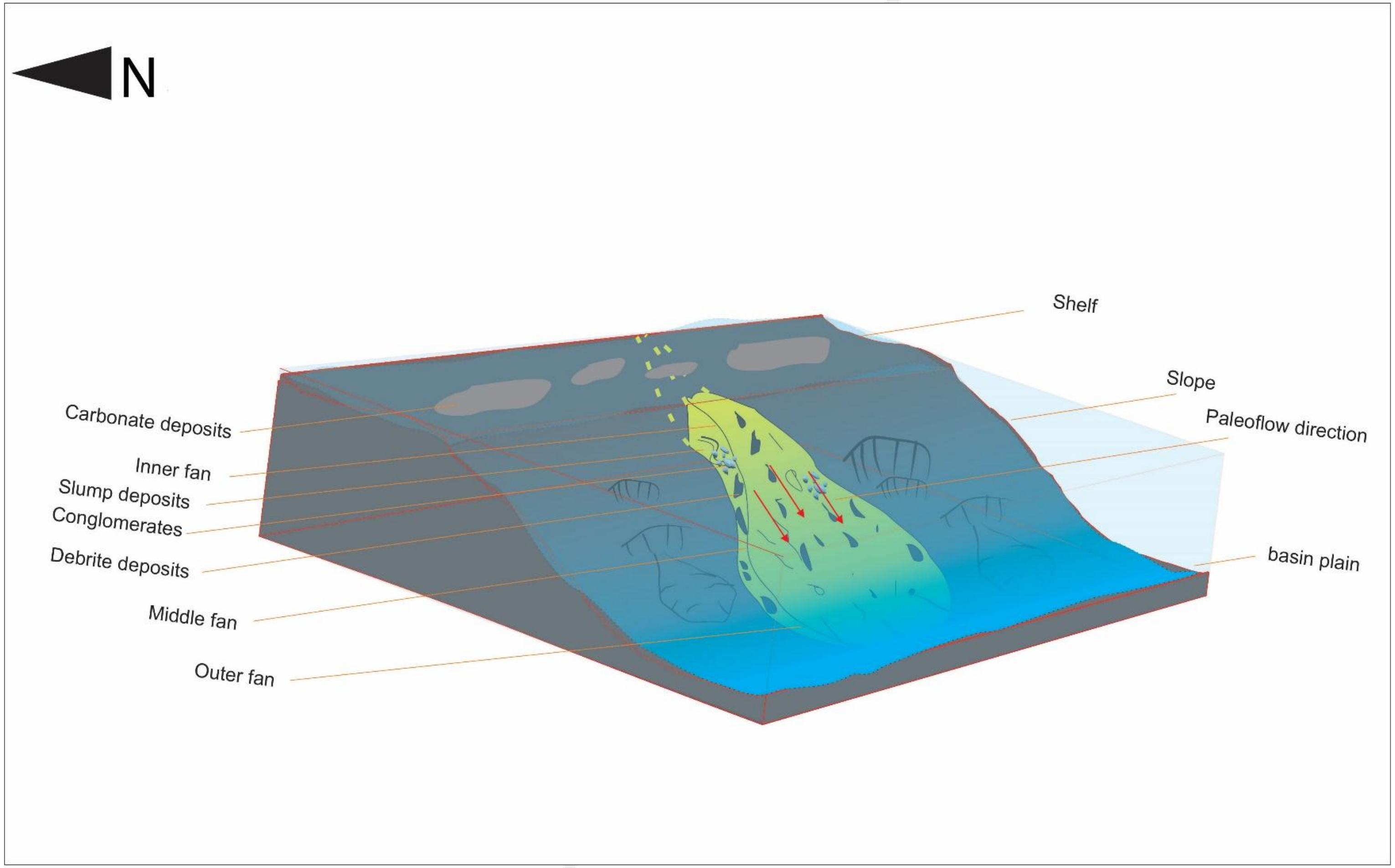


Figure 3.4. Schematic view of Slope fan

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

From field observations, lithofacies and facies associations, paleoflow data and depositional components of the Tanjero Formation, it can be concluded that:

1. According to the paleoflow direction, which are SW and NW, as well as, the thinning of the Tanjero deposits from Sirwan Valley section toward Soran section, it seems that the source area of the clastic formation is more likely derived from sediments in the current location of Iran.

2. One of the main characteristics of the geometry of the Tanjero sediments is a wedge-shaped clastic body. This may show that the deposition of such sediments in foreland basin.

3. Among visited and studied sections, the Sirwan Valley section represents the thickest one. This could result in the conclusion that this section was deposited in the foredeep part of the foreland basin (Fig. 4.1)

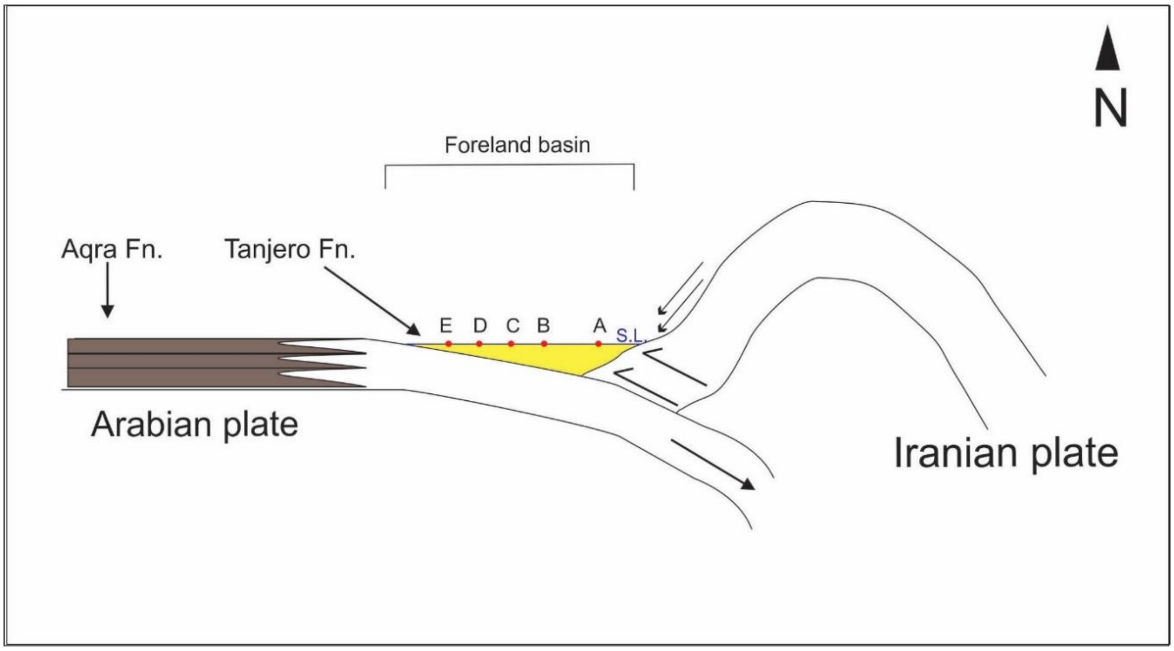


Figure 4.1. Foreland basin model of North Iraq at the result of Arabian plate subduction beneath Iranian plate, (A: Sirwan valley section; B: Darbandikhan area; C: Sulaimani area; D: Dokan area; E: Soran area).

4. The richness of Tanjero sediments in shallow marine fossils and bioclasts, indicates that the deep marine feeder channel passed through and cut carbonate depositional system before enters deep-marine depositional system.

5. Both vertically and laterally, the Tanjero sediments, are highly variable. This may due to the physiography of the basin.

6. As mentioned in the geological setting section in the first chapter, during late Cretaceous, the whole area was tectonically unstable. This led to the change in the physiography of the whole basin sediments, resulted from uplifting and subsidence in some areas. Therefore, it can be inferred to the tectonic activities were the main agent in the development of Forland basin in such period of time and deposition of deep-marine Tanjero sediments.

7. Presence of shallow-marine reefal Aqra Formation lens in some areas, such as in Said Sadiq county, in some areas, the lens of shallowmarine and reefal Aqra Formation are found within the sediments of Tanjero Formation. This could be resulted from the change in sea-level.

8. According to lithofacies, Tanjero Formation in Sirwan Valley divided to nine lithofacies and eight sub lithofacies: LF-1: Conglomerate; SLF-1a: Pebbly to Sandy matrix supported Conglomerate; SLF-1b: Sandy matrix supported Conglomerate; SLF-1c: Muddy matrix supported Conglomerate; LF-2: Structureless Sandstone beds; SLF-2a: Fine-coarse Structureless Sandstone; SLF-2b: Very coarse-Pebbly Structureless Sandstone; SLF-2c: Amalgamated Structureless Sandstone; LF-3: Deformed Sandstone Beds; LF-4: Normal Graded Sandstone Beds; SLF-4a: Pebbly to fine Normal Graded Sandstone Beds; SLF-4b: Coarse-medium to fine Normal Graded Sandstone Beds; LF-5: Reverse (inversely) Graded Sandstone Beds-Coarse to Pebbly grained; LF-6: Laminated Sandstone Beds; LF-7: Siltstone Beds; LF-8: Mudstone Beds; LF-9: Chaotic-Distorted Lithofacies.

9. All facies are grouped into five facies associations based on standard models of deep-marine environment: FA-1: Slope; FA-2: Inner Fan; FA-3: middle Fan; FA-4: Outer Fan; FA-5: Debrite Deposits.

10. From the interpretation of these facies and facies associations, it is concluded that the Tanjero sediments in Sirwan Valley is deposited as Slope Fan with NE-SW axis (Fig. 3.4).

4.2 Recommendations

For the future studies, the recommendations are the following:

1. Investigate new sections across the whole area to show the exact lateral and vertical distribution of the Tanjero Formation.

2. Both lower and upper boundaries need to be studied in detail, and especially the upper contact with Kilosh formation. The letter represents Cretaceous/ Tertiary boundary.

3. Construct detail mapping of the Tanjero sediments in the whole area.

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WORK EXPERIENCE

March 2018 – now	**Project engineer in Newpark DF company**
Main Activities	Writing and Preparing drilling fluids program, prepare and submit drilling fluids tenders (Technical and Commercial). Arranging and attending technical meeting with clients. Preparation of different kind of water-based mud and doing pilot test. All laboratory checks related to mud and treat mud related issues such as mud contamination. Logistic supervising work staff, chemical order and shipment.
1/April 2014 – 15/April 2017	**Supervisor/ Senior drilling fluids engineer in DQE company**
Main Activities	Prepare drilling fluids program, daily mud report to DSV, and recap. Preparation of different kind of water based mud. All laboratory checks related to mud and treat mud related issues such as mud contamination. Logistic supervising work staff, chemical order and shipment.
1/ July 2012 – March 2014	**Drilling Fluids Engineer in Petrochem company**
Main Activities	Prepare drilling fluids program, daily meeting with clients about filed work. Giving ideas and instructions to the field engineers. Logistic supervising work staff, chemical order and shipment..
17/ July 2010 – 01/ May 2012	**Drilling Fluids Engineer GKPI company**
Main activities	Perform fluid engineering tasks and calculations; prepare daily chemical cost sheet. Make chemical delivery tickets and back load tickets.

EDUCATION

2002 – 2006	
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TRAINING

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Name of Training Provider	Alison Advance learning
Name	**Human Resources**
Name of Training Provider	Alison Advance learning
Name	**Drilling fluid technology and drilling operation**
Name of Training Provider	Hi-tech fluid system sponsored by gulfkeystone international company. 3 months program. http://www.hitechfluid.com
Name	**Field Project management inc. MS project**
Name of Training Provider	European Technology and Training Centre ETTC One month http://www.ett-iraq.net
Name	**Introduction to fire alarm and automatic fire extinguishing systems**
Name of Training Provider	Talon company- one week

IT SKILLS

Microsoft office (word, excel, powerpoint, outlook)
Adobe (Photoshop, InDesign, Illustrator)
Corel Draw.

OTHER CERTIFICATES

General HSE awareness. Certificate of English course include IELTS exam in British Council-Erbil. Certificate of English language proficiency include TOEFL exam curriculum in university of Salahaddin. Certificate of English conversation language course in Canadian centre-Dec.2009. Certificate of computer training course (ICDL). Certificate of training in the field of Email Communication, in AGEF center. Certificate of training course (Capital Investment Project) by USAID organization.

MOTHER TONGUE **Kurdish**

OTHER LANGUAGES

	English	**Arabic**	**Turkish**
Reading skills	Very good	Very good	Intermediate
Writing skills	Very good	Very good	Intermediate
Verbal skills	Very good	Very good	Intermediate

SOCIAL ACTIVITIES Hobby Photographer

DRIVING LICENSE(S) I have international driving license.

REFERENCES Will be provided upon request