SEDIMENTOLOGY AND STRATIGRAPHY OF TÜRBEYANI MARL SEQUENCES AND İNPİRİ LIMESTONES (LATE BARREMIAN - ALBIAN): IMPLICATIONS FOR POSSIBLE SOURCE AND RESERVOIR ROCKS (NW TURKEY)

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ANAR NABIYEV

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Approval of the Graduate School of Natural and Applied Sciences.

Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Vedat Doyuran
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. İsmail Ömer Yılmaz
Supervisor

Examining Committee Members

Prof. Dr. Atilla Çiner (Hacettepe Unv., GEOE)

Assist. Prof. Dr. İsmail Ömer Yılmaz (METU, GEOE)

Assoc. Prof. Dr. Sevinç Özkan Altıner (METU, GEOE)

Assoc. Prof. Dr. Kadir Dirik (Hacettepe Unv., GEOE)

Assist. Prof. Dr. Fatma Toksoy Köksal (METU, GEOE)

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Name, Last name: Anar NABIYEV

Signature:

ABSTRACT

SEDIMENTOLOGY AND STRATIGRAPHY OF TÜRBEYANI MARL SEQUENCES AND İNPİRİ LIMESTONES (LATE BARREMIAN - ALBIAN): IMPLICATIONS FOR POSSIBLE SOURCE AND RESERVOIR ROCKS (NW TURKEY)

Anar Nabiyev
M.Sc., Department of Geological Engineering
Supervisor: Assist. Prof. Dr. İ. Ömer Yılmaz

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Sedimentology, cyclostratigraphy and sequence stratigraphy of the Türbeyanı Marls (Albian) and the İnpiri Limestone (Upper Barremian-Albian) members of Ulus Formation (İnciğez, Bartın, Amasra) were interpreted in this study.

In the Türbeyanı Marls total of five different facies were defined. Marl and limestone facies are the most abundant in the succession. The depositional environment of the succession was defined as an outer shelf area. Within the pelagic marls 39 smaller order and 9 higher order cycles were recognized. These cycles correspond to the parasequences and parasequence sets of sequence stratigraphy, respectively. In the measured section only one type-3 sequence boundary was identified.

In the İnpiri Limestones great variety of limestone facies are represented. Bioclastic, peloidal, intraclastic wackestone-packstone-grainstone facies are the most abundant. Moreover, occurrence of lime mudstone, fenestral limestone, ooid packstone-grainstone, and sandstone facies are present as well. In the measured section of the İnpiri Limestones 25 fifth order and 6 fourth order cycles were defined. These cycles correspond to the parasequence sets and systems tracts of the sequence stratigraphy, respectively. Total of three transgressive and three highstand systems tract were defined. Only one type 2 sequence boundary was identified in the measured section, the rest of them are interrupted by covers.

This study revealed that the Türbeyanı Marls and the İnpiri Limestones are not economically valuable as petroleum source and reservoir rocks, respectively. The total organic carbon (TOC) values of marl facies of the Türbeyanı marls are very low, and the pore spaces observed in the İnpiri Limestone are cement filled making it unsuitable reservoir rock.

Keywords: sedimentology, cyclostratigraphy, sequence stratigraphy, Türbeyanı Marls, İnpiri Limestones, Albian, Upper Barremian, Amasra, Bartın.

ÖZ

TÜRBEYANI MARN İSTİFLERİNİN VE İNPİRİ KİREÇTAŞLARININ SEDİMANTOLOJİSİ VE STRATİGRAFİSİ : REZERVUAR VE KAYNAK KAYA YAKLAŞIMLARI (KB TÜRKİYE)

Anar Nabiyev

Yüksek Lisans, Jeoloji Mühendisliği Bölümü
Tez Yöneticisi: Yard.Doç.Dr. İ. Ömer Yılmaz

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Bu çalışmada, Ulus Formasyonu'nun (İnciğez Köyü, Bartın, Amasra) üyeleri olan, Türbeyanı Marnları (Albiyen), İnpiri Kireçtaşları'nın (Üst Baremiyen - Albiyen) sedimantolojisi, devirsel stratigrafisi ve sekans stratigrafisi değerlendirilmiştir.

Türbeyanı Marnları'nda beş değişik fasiyes belirlenmiştir. İstifte en yaygın fasiyesler marn ve kireçtaşı fasiyesleridir. İstifin çökelme ortamı dış şelf olarak belirlenmiştir. Pelajik marnlarda 39 adet düşük dereceli, 9 adet yüksek dereceli devir gözlenmiştir. Bu devirler, sırasıyla sekans stratigrafisinin "parasekans" ve "parasekans setleri"ne tekabül etmektedir. Ölçülü kesitte sadece bir adet tip-3 sekans sınırı belirlenmiştir.

İnpiri Kireçtaşları'nda çok sayıda kireçtaşı fasiyesi bulunmaktadır. En sık gözlenen fasiyesler biyoklastik, peloidal, intraklastik vaketaşı-istiftaşı-tanetaşı fasiyesleridir. Bunun yanında kireçli çamurtaşı, fenestral kireçtaşı, ooid istiftaşı-tanetaşı ve kumtaşı fasiyesleri de bulunaktadır. İnpiri Kireçtaşları'nın ölçülü kesitinde 25 adet beşinci derece, 6 adet dördüncü derece devir ayırtlanmıştır. Bu devirler, sırasıyla sekans stratigrafisinin "parasekans setleri"ne ve "sistem takımları"na tekabül etmektedir. Toplam üç transgresif ve üç yüksek deniz yüzeyi (highstand) sistem takımı belirlenmiştir. Ölçülü kesitte sadece bir adet tip-2

sekans sınırı gözlenmiş, örtü tabakası geri kalan sınırların görülmesini engellemiştir.

Türbeyanı Marnları'nın petrol kaynak kayası, İnpiri Kireçtaşları'nın ise petrol rezervuar kayası olma olasılıklarının araştırılması bu çalışmanın amaçları arasındadır. Türbeyanı Marnları'nın toplam organik karbon (T.O.K.) miktarına bakıldığında bu kayanın petrol kaynak kayası olamayacağı kadar düşük olduğu görülmektedir. İnpiri Kireçtaşları, petrol rezervuar kayası olma olasılığı göz önünde bulundurularak, incelendiğinde, kaya gözenekliliğinin kalsit çimentosuyla doldurulmuş olmasından dolayı, bu kayanın petrol rezarvuar kayası olma olasılığının düşük olduğu sonucuna varılmıştır.

Anahtar kelimeler: sedimantoloji, devirsel stratigrafi, sekans stratigrafisi, Türbeyanı Marnları, İnpiri Kireçtaşları, Albiyen, Üst Barremiyen, Amasra, Bartın.

To My Family

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CHAPTER I

INTRODUCTION

1.1. Purpose and Scope

The main subject of this study is to analyze the sedimentology, cyclostratigraphy and sequence stratigraphy of the Türbeyanı Marl and the İnpiri Limestone members (Late Barremian - Albian) (NW Turkey) of the Ulus Formation and their implications for possible petroleum source and reservoir rocks. Outcrops of the successions at road cuts around İnciğez village (Bartın/ Amasra) were suitable to study meter scale cyclic variations.

High resolution sedimentological and cyclostratigraphical analyses were performed on the samples recovered along the measured sections. These analyses included macro-microfacies determinations. Cyclic variations along the sections were used to define sea-level fluctuations, changes in sedimentary patterns and to establish cyclostratigraphy and sequence stratigraphy of the Türbeyanı Marl and the İnpiri Limestone.

1.2. Geographic Setting

The study area is located in the İnciğez village, Amasra/Bartın (NW Turkey) (Figures 1, 2, 3 and 4). The village is 15 km SE to Amasra, and 21 km NE to Bartın. The outcrops are located along the road to İnciğez village from Amasra. GPS coordinates of measured section are started from at 457042 E, 4618500 N, elevation 392m and finished at 456969E, 4618575 N, elevation 441m.

Figure 1. Location map of the studied area (MS – measured section).

Figure 2. Türbeyanı Marls along the roadcut, İnciğez village (A – Lower part of the section, SW direction; B – Upper part of the section, NE direction).

Figure 3. İnpiri Limestones along the roadcut, İnciğez village (A – N direction; B – N direction along the road).

Figure 4. Satellite snapshot of measured section (between blue lines) (Google Earth Software).

1.3. Methods of Study

In this study the field and laboratory work were done. Lithological properties, fossils, sedimentary structures and the relationships of the beds of the measured section were identified during the field study. Lithofacies was defined using hand lens. The totals of 202 samples were taken from the measured section in 140m thickness. All of the samples were studied in laboratory by several methods. Firstly, thin section of all samples were prepared and studied under microscope in order to understand the facies changes. The point counting method was conducted on samples from Türbeyanı Marl member using James-Swift point-counter in order to obtain more precise mineralogical data to identify facies changes. 500 to 2000 points were counted per sample. Different microfacies types, sedimentary structures and minerals were identified in order to recognize and trace sequence stratigraphic cycles and cyclic variations. Total organic carbon (TOC) analysis are obtained in the MAM (Marmara Research Laboratory) using Rock Eval Pyrolysis 6 machine.

1.4. Previous Work.

The Pontides, where the study area is situated, has undergone through several investigations due to existence of petroleum and coal resources. Lucius (1926), Ziglstra (1950), Fratschiner (1952), Tokay (1954), Pince (1982), Deveciler (1986), and Nejdi (1994a,b) studied the general geology of Pontides region.

Erdoğan (1963), Wedding (1968, 1969), and Taşman (1981) discussed petroleum and carboniferous gas potential in the region.

Stanissopoulos (1898), Pohl (1903), Yeğin (1912), Lucius (1931), Arni (1938, 1940a,b,c,d, 1941), Eğemen et al. (1945), Patijin (1949, 1950, 1951), Arslan (1978), Bulut et al. (1982, 1992), Nekir et al. (1996), Yavuz et al. (2000) discussed the coal basins located in the Pontides.

Tüysüz et al. (1997) discussed the general geology of Cide-Kurucaşile region. This study covers the interpretation of rock units from Carboniferous up to Eocene time interval. The study region for this thesis is also situated within this region. In this study, the author interprets the Ulus formation and its three subdivisions: Mezeci (Akman, 1992) siliciclastic formation is composed of mainly red sandstones, mudstone, and İnpiri Limestones (Barremian-Aptian) are composed of mainly neritic limestones and dolomites; and Turbeyani marls are composed of non-laminated, massive marls. The lithological composition of this formation is generally stable and in some levels contains abundant ammonite fossils and iron concretions. The precise age of this formation couldn't be determined. Akman (1992) was able to determine its age to be Late Albian-Late Senomanian by using nannoplanktons and its stratigraphic position. Turbeyani marls are believed to be equivalent to Tasmaca marls (Tokay, 1952; Saner, 1980) in Zonguldak basin. It was concluded that the formation was deposited in between shallow marine and shelf slope environments. The author also concluded that till the early Cretaceous, when the Ulus basin started to develop, the region was undeformed. The studied region has similar properties with the Zonguldak basin. They also indicate the importance of the region in hydrocarbon reservoirs point of view.

Tüysüz (1999) discussed the Cretaceous sedimentary basins of the Western Pontides. In the studied area, there are main sedimentary basins deposited on different tectonic units. The first, the Sinop Basin in the Central Pontides, is a northernly deepening basin that opened during the Barremian as an extensional basin. The second basin, the Zonguldak-Ulus Basin in the Istanbul Zone, was a single basin during the Late Barremian-Maastrichtian but was separated into two by the Devrek Basin after Maastrichtian. The Zonguldak-Ulus Basin opened during the Late Barremian by the rifting of the Late Jurassic and older basement of the Istanbul Zone. Istanbul Zone and the Central Pontides have a different pre-Upper Cretaceous stratigraphy and they were juxtaposed during the Cenomanian.

Yılmaz (2002) discussed cyclostratigraphy and sequence stratigraphy in determination of the hierarchy in peritidal and pelagic successions of Zonguldak Basin, NW Turkey. Within the inner platform carbonate-dominated successions, all measured stratigraphic sections are completely composed of shallowing-upward meter-scale cycles. Siliciclastic intercalations within carbonate-dominated sections have been observed. These cycles are composed of alternation of thin-bedded sandy limestone, sandstone or siltstone facies and thick-bedded limestone. In this study, dominant cycles are termed as the 4th order cycles attributed to Milankovitch cycles. 4th order cycles superimpose on top of each other and form 3rd order sequence packages. 4th order cycles include in them smaller-scale cycles called 5th order cycles.

1.5. Regional Geology

The Pontides is one of the compressive belts that enclose the Black Sea (Tüysüz, 1999). Geographically, the Pontides are divided into three parts: Eastern, Central and Western Pontides which also show different geological characteristics (Tüysüz, 1993). Eastern Pontides is the part that lies towards the east of Samsun; Western Pontides (Figure 5) extends to the west of Kastamonu whereas Central Pontides is the part that takes place between Eastern and Western Pontides, which corresponds to the central part of the Sakarya Zone of Okay (1989). In the another point of view, the Pontides are also separated into three zones such as Strandja Zone, İstanbul Zone and Sakarya Zone from west to east (Okay, 1989; Okay et al., 1994).

The sedimentary sequence of the Western Pontides region ranges from Paleozoic to Cenozoic. The basement units of the region start with Ordovician terrigenous siliciclastics, Devonian platform carbonates and Carboniferous turbidites (Tüysüz et al., 1997). These units are overlain by the Zonguldak Formation which mainly consists of clastic deposits (sandstone mudstone intercalation, conglomerate) with coal veins in Westphalian age (Tüysüz et al., 1997) (Figure 6). The Triassic aged Çakraz Formation containing terrigenous sediments unconformably lies over the Zonguldak Formation. Another unit of Triassic age is Çakraboz Formation. In some places the lateral contact of the last two formations has been observed. The Çakraboz Formation is Late Triassic in age and contains lacustrine limestones, marls and mudstones with varve structures. Jurassic-Early Cretaceous aged Himmetpaşa Formation composed of siliciclastic sediment, mainly sandstones, mudstones, conglomerates, gravelstone, siltstone and marls and even in some levels black shales are observed. The sandstone units are rich in coal and plant fragments, the upper claystone and marl units are rich in ammonites (Tüysüz et al., 1997). Platform-type neritic carbonates in the Late Jurassic, which were the product of the Mesozoic transgression that covered the whole Pontides, were named as the İnaltı Formation (Sunal and Tüysüz, 2002). Tüysüz (1999) suggests no evidence for a pre-Cretaceous compressional deformation of regional metamorphism in the east of Akçakoca-Bolu Line in contrast to the basement units of Central Pontides (Figure 6). The Ulus Formation, Early Cretaceous in age, is composed of four members: Mezeci clastics, İnpiri limestones, Türbeyanı marls and Ulus flyschs. Mezeci clastics

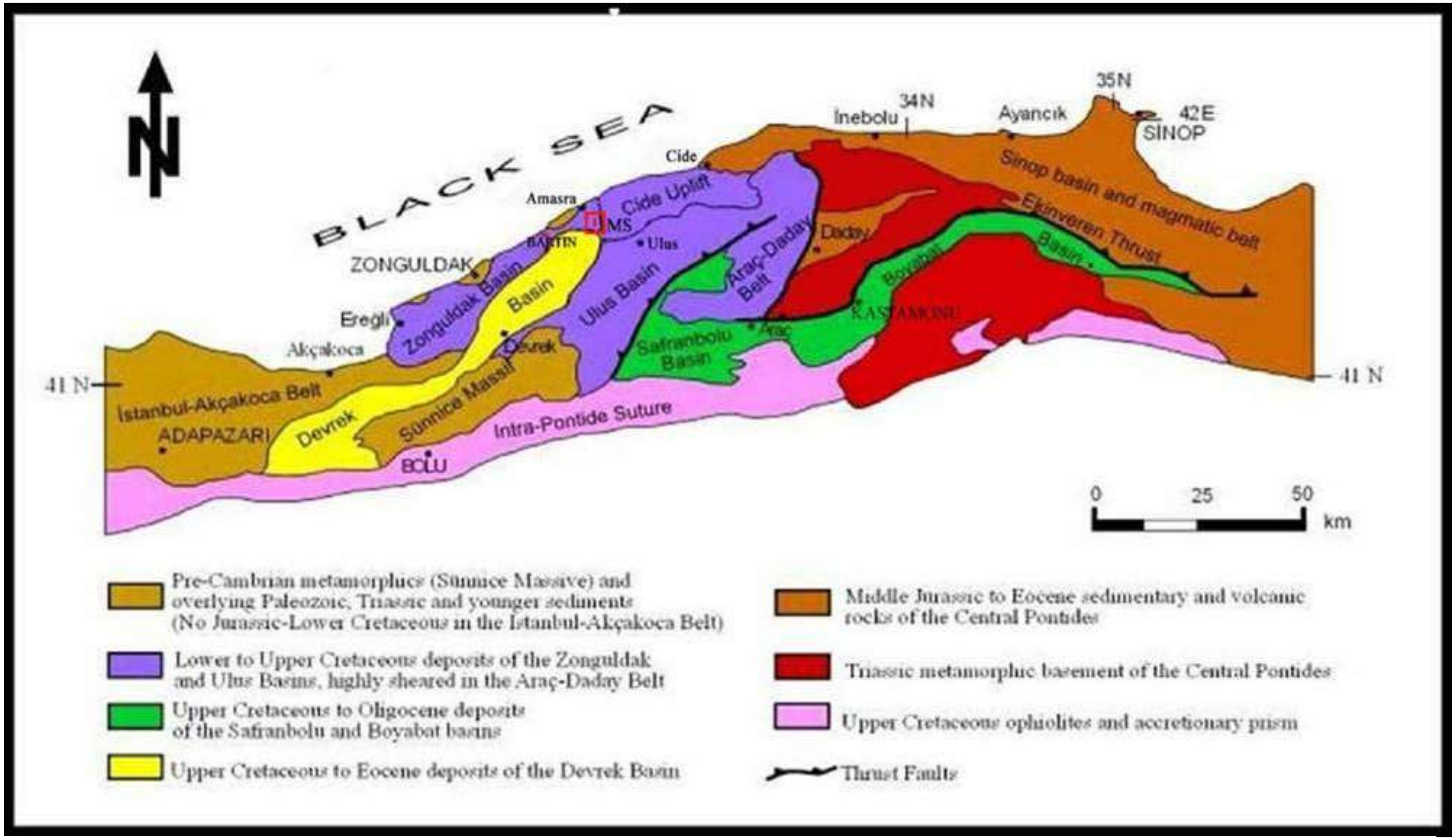


Figure 5. Tectonostratigraphic map of the Western Pontides; MS – measured section (Modified from Sunal and Tüysüz, 2002).

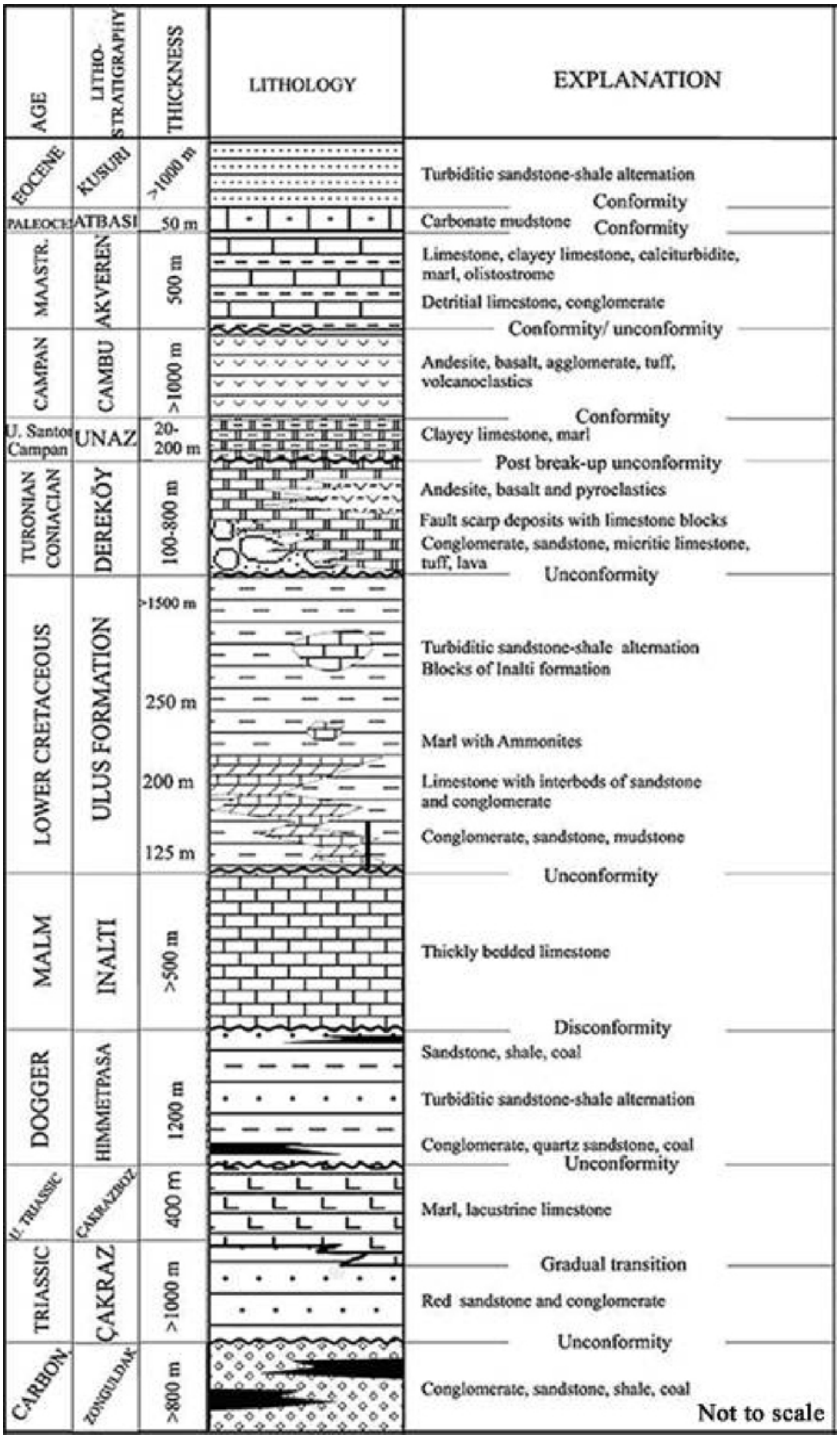


Figure 6. Generalized columnar section of the study area (vertical black line is studied interval) (Simplified from Sunal & Tüysüz, 2002).

(Akman, 1992) overlie the Çakraz Formation with angular unconformity, composed of mainly red sandstones, conglomerate and mudstones. The İnpiri limestones aged in Barremian-Aptian composed of mainly neritic limestones and dolomites, though rarely clastic deposits are also observed. The İnpiri Limestones are very rich in fossils such as rudists, gastropods, ostracods, foraminifers and algae are very common. Türbeyanı marls aged in Early Cretaceous mainly composed of green marls, though limestones and black shales are observed too. Ulus flyschs (Akyol et al., 1974) conformably lies over Türbeyanı marls and composed of turbiditic sandstone-claystones (Tüysüz, 1997).

Upper Cretaceous sequence starts with the Kapanboğazı Formation which is very thin bedded and composed of red micritic limestones. The Dereköy Formation is very widely distributed in the region and composed of clastics, carbonates, lava and tuffs. The Yenice Formation is composed of pelagic limestones, carbonate mudstones and olistostromal unit (Gökçekale Olistostromu). The Gidros limestone member is also recognized within the Yenice Formation which is composed of massive limestones. The Unaz formation is composed of clayey, pelagic limestones. At the base clayey and silty marls are dominant. The Cambu Formation (Akyol et al., 1974) is composed of lava and pyroclast and also volcanic deposits. The Akveren Formation consists of clayey limestones, marl and carbonate mudstones and calci-turbiditic sediments (Tüysüz, 1997). These formations are equivalent to each other (Tüysüz, 2004).

Cenozoic units are not very common in the region. The Atbaşı Formation represents Paleocene epoch, which is red, pink colored, thin to medium thick bedded, composed of marl and carbonate mudstones. The Kusuri Formation (Akyol et al., 1974) represents Eocene epoch, which is composed of intercalation of turbiditic sandstone and shale (Tüysüz, 1997).

Within this described stratigraphic scale, the studied section mainly consentrated on the İnpiri limestones and the Türbeyanı marls. The İnpiri limestones are very rich in fossils, mainly composed of pure limestones, dolomite grains are also observed. Oolitic limestones and sandy levels are rarely observed as well. The Türbeyanı marls almost do not change in composition, mainly composed of silty marls. Black shale level is observed at the base of the formation. Near the top of the formation it is mainly composed of the mainly limestone-mudstone alternations.

CHAPTER II

LITHOSTRATIGRAPHY

In the study area several stratigraphic units were recognized. These are the İnaltı Formation and the İnpiri Limestone (Late Barremian – Albian) and the Türbeyanı Marl (Aptian – Albian) members of the Ulus Formation (Figure x).

The Türbeyanı Marl member is mainly composed of light green and bluish colored marl deposits, the marl-limestone alternation is also common for this member especially at the upper part of the succession.

The major facies variation of the İnpiri Limestone member is consisted of bioclastic, intraclastic, extraclastic and peloidal limestone sediments. The presence of fenestral limestones, ooids, sandstones, and iron rich limestone sediments enrich this facies variation even more.

In the study area, sequence at the base starts with the İnaltı Formation which is unconformably overlain by the Türbeyanı Marls. This clearly implies that there was a break in sedimentation between the Inalti Formation and the Türbeyanı Marl member. Contacts like this have been observed in some of the outcrops in the region. According to Tüysüz et al. (1997) these units are separated from each other by angular unconformities or disconformities. Gradual transitional contact, between two formations has been indicated by Tüysüz et al. (1997) in some areas. This transition can be observed by precences of clastic limestones between two formations.

The İnpiri Limestone and the Türbeyanı Marl members can be observed in alternation. In the study area the İnpiri Limestone member overlies the Türbeyanı Marl member, however, the contact between two members is structural and observed as fault contact. However, according to Tüysüz et al. (1997) and Tüysüz et al. (2004), in some outcrops there is a gradual lateral transition of facies between these members.

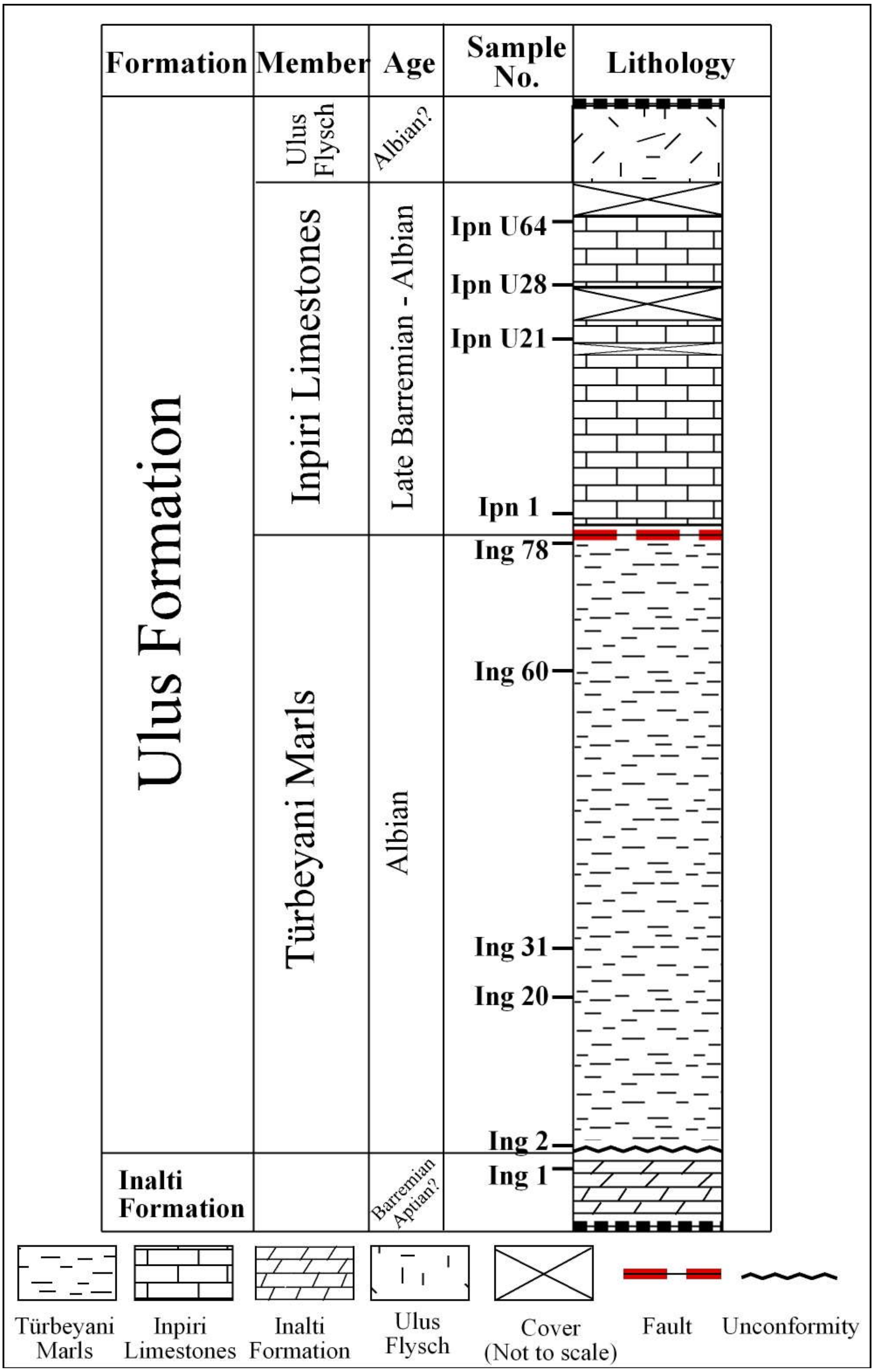


Figure 7. Generalized columnar section of the study area (not to scale).

According to Tüysüz et al. (1997) the Ulus Flysch of the Ulus Formation overlies conformably the Türbeyanı Marl and disconformably the İnpiri Limestone members.

CHAPTER III

III. SEDIMENTOLOGY

The measured section covers İnpiri Limestone and Türbeyanı Marl members of Ulus Formation. The lithofacies of the mentioned members were defined by using different tools. Firstly, they were defined in the field using hand lens. Rock samples were taken in almost every bed layer, and thin sections of all samples were prepared. These thin sections were investigated under microscope in order to define their sedimentological and mineralogical properties, and internal structures.

3.1. Türbeyanı Marls

The Türbeyanı Marl member is consisted of mainly light green and bluish colored marl sediments. The age of the succession is defined to be Aptian? – Albian. Through personnel communications with Prof. Dr. Jean-Pierre Mass by ammonite identifications, the age of the succession is assigned as Albian, and Prof. Dr. Demir Altıner defined the age of the succession as Aptian to Albian age by planktonic foraminifera. Representing facies found in the Türbeyanı Marls were classified using classification of Potter et al. (1980) and the thicknesses of these facies are greater than 10mm (Table 1). In total, 5 different microfacies were recognized within the Türbeyanı Marls. These are black shales, claystones, mudstones, limestones and marls.

Table 1. Classification of Shale (more than 50% grains less than 0.062mm) (Potter et al., 1980) (colored area for classification).

Percentage clay-size constituents			0-32	33-65	66-100
Field Adjective			Gritty	Loamy	Fat or Slick
NONINDURATED	Beds	Greater than 10 mm	BEDDED SILT	BEDDED MUD	BEDDED CLAYMUD
NONINDURATED	Laminae	Less than 10 mm	LAMINATED SILT	LAMINATED MUD	LAMINATED CLAYMUD
INDURATED	Beds	Greater than 10 mm	BEDDED SILTSTONE	MUDSTONE	CLAYSTONE
INDURATED	Laminae	Less than 10 mm	LAMINATED SILTSTONE	MUDSHALE	CLAYSHALE
METAMORPHOSED		Degree of metamorphism LOW	QUARTZ ARGILLITE	ARGILLITE	
METAMORPHOSED		↓	QUARTZ SLATE	SLATE	
METAMORPHOSED		HIGH	PHYLLITE AND/OR MICA SCHIST		

3.1.1. Lithofacies

3.1.1.1. Marl facies

Marls are the most abundant in the Türbeyanı Marls succession (Figure 8). This facies was recognized in the field work. They are mainly light green to bluish, light to dark grey, brownish, even sometimes yellowish colored, containing mainly clay and silt size materials. Hubbard et al. (1990) define marl as a soft, loose, earthy, material that consists of varying amounts of calcium carbonate, clay, and silt size material and is formed primarily in freshwater conditions. Also Potter et al. (2005) defines marl as fine grained sediment and rock that is composed of 50% or more carbonate. Pettijohn (1957) indicates that marl is an old term loosely applied to a variety of materials, most of which occur as loose, earthy deposits consisting chiefly of an intimate mixture of clay and calcium carbonate, formed under marine or especially freshwater conditions; specifically an earthy substance containing 35-65% clay and 65-35% carbonate. Iron concretion and impregnations, plant and coal fragments are very common in this succession. This facies as a marl was recognized in the field using HCl acid, proving it has calcium carbonate content in it. The calcium carbonate content of marls was not defined, that is why mudstone classification was used for all marls using point counting data.

3.1.1.2. Mudstone facies

Mudstones are very abundant in the Türbeyanı Marls and they participate throughout the measured section, from bottom to the top of the succession, mainly with intercalation of claystone and limestone. This facies was differentiated from claystone facies with point-counting method. The facies containing matrix between 33-65% have been defined as a mudstone facies according to Potter et al. (1980) classification. Twenhofel (1939) defines mud as a general term that

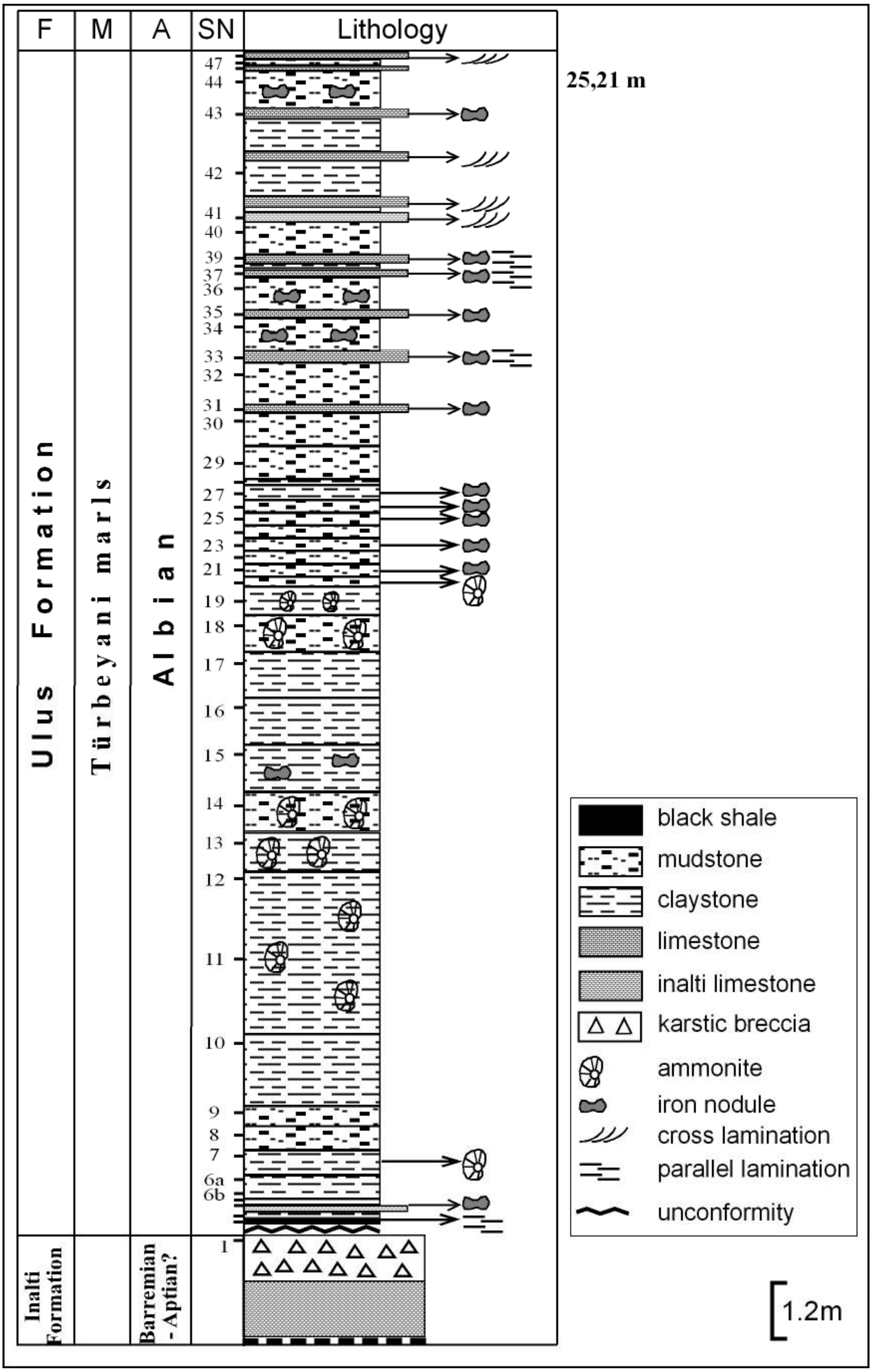


Figure 8. Lithologic column of Türbeyanı Marl (Ing); F-formation, M-member, A-age, SN-sample number.

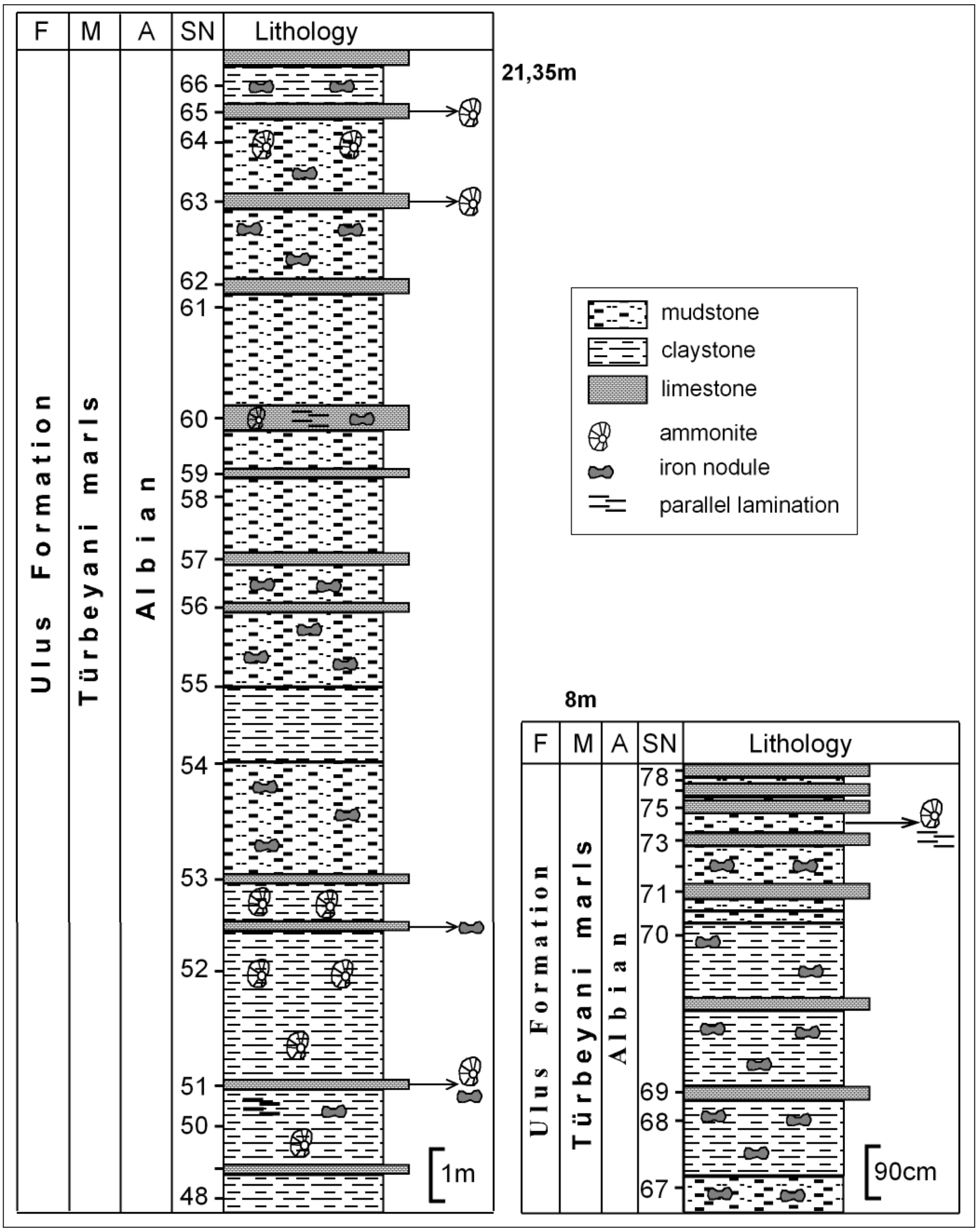


Figure 8. Continued.

includes clay, silt, claystone, siltstone, shale, and argillite, and that should be used only when the amounts of clay and silt are not known or specified or cannot be precisely identified: or “when a deposit consists of an indefinite mixture of clay and silt, and sand particles, the proportions varying from place to place, so that a more precise term is not possible”. Potter et al. (2005) identifies mud as a field term for any soft plastic, silt-clay mixture with more than 50% of its size fraction smaller than four micrometers. While there is little disagreement here, it is the naming of the “hard rock” equivalents of mud that have been proposed to replace shale as the general generic term for fine-grained argillaceous rocks. Potter et al. (1980) classification (Table 1) is used in this study for mudrocks and claystones.

No sedimentary structures (lamination) are observed in this facies. They are all massive, from thin to medium thick mudstone layers intercalated with other layers with no discordance. Their thicknesses vary between 10-210cm range, averaging 1m thickness. This facies is not very rich in fossils. In some levels only ammonite fossils were recognized and they are very rare. Only in Ing 20 level ammonites are very abundant (Appendix B).

There are several minerals recognized in mudstone facies. These are quartz, feldspar (orthoclase), opaque minerals, muscovite, glauconite, and biotite is very rarely observed, iron occurrences are common as well. Quartz and orthoclase are the most common ones among the mentioned minerals and they are observed throughout the succession, in all facies types and all layers (Appendix A). Their percentage value ranges between 15.7 (Ing 9) – 44.7% (Ing 23), but mostly they are above 20%. Second most common mineral in mudstone facies is muscovite mineral. They are observed in all mudstone layers and their value ranges between 0.5 (Ing 77) – 5.5% (Ing 9). Their percentage does not show any change along the succession. Opaque minerals would be the next most abundant mineral in mudstone facies. At the lower mudstone layers they have higher values than the upper layers, they show general decrease towards the top of the succession. The percentage value changes between 0.7 (Ing 32) – 6.6% (Ing 9). Glauconite is another common mineral for mudstone facies and they range between 0.1(Ing 36) – 1.9% (Ing 20). Although in point counting process, at lower mudstone layers, glauconite minerals weren't counted due to their rare distribution, they are observed to be present in microfacies analyses process. Iron occurrence is very common in mudstone facies as well. They occur as iron impregnations and iron nodules. Their percentage range between 0.1 (Ing 14) – 5.7% (Ing 8 original) and they show nearly even distribution along the mudstone layers.

3.1.1.3. Claystone facies

The claystones of the Türbeyanı Marls are very common in the succession. They occur throughout the succession intercalating with mudstone and limestone facies and they are very similar to mudstones facies in composition. Claystone facies are massive, non bioturbated and they are intercalating with other layers. Shrock (1948a) describes it as a somewhat unctuous, conchoidally fracturing sedimentary rock composed largely of clay mineral (Bates et al., 1980, p116). As mentioned above, in this study Potter et al. (1980) classification (Table 1) was used and claystone is defined as the facies which matrix contain clay size material more than 66%. This facies has been differentiated from mudstone facies with the same method which applied to latter one. Claystone facies are thin to medium thick layered like mudstone facies, and its thickness varies in 10-360cm range, generally near to 100cm thickness. Like its definition implies, there was not recognized any sedimentological structure.

Fossils in this facies are not very common and only ammonite fossil were rarely found in claystone facies.

Mineralogy in claystone facies is nearly the same as in mudstone facies. Quartz and orthoclase are most abundant in claystone facies as well. Their percentage range between 10.2 (Ing 6a) – 26% (Ing 68) and their percentage nearly stays constant along the succession. Naturally they are less distributed compared to mudstone facies. Muscovite flakes are very common in this facies, their percentage ranges between 0.5 (Ing 48) – 7.8% (Ing 6a). They show general upward decrease in percentage. Opaque minerals are common too, their percentage range between 0.5 (Ing 66) – 7.3% (Ing 15) and like muscovite minerals, they show upward decrease in percentage along the succession. Glauconite minerals are present here too, but they are very less observed compared to other minerals and their percentage range between 0.1 (Ing 38) -0.7% (Ing 27). Like in mudstone facies, at the lower claystone facies, glauconite minerals weren't counted in point counting process due to their rare occurrence, but they are present as they have been observed during microfacies analyses. Iron occurrence is very common and characteristic feature of claystone facies like in mudstone facies. Their percentage range between 0.1 (Ing 16) – 4.1% (Ing 52), but they are mainly happen to be under 1% (Appendix A).

3.1.1.4. Limestones

The representing limestone layers are mixed with siliciclastics in composition and they are abundant in the Türbeyanı Marls as well. This facies starts to occur from the middle part of succession, from Ing 31. They mainly intercalate with mudstone and claystone facies. Here limestones are mainly matrix supported and are mixed with siliciclastic materials. They are usually light to dark grey, bluish, beige colored, very well packed, containing iron nodules and impregnations and plant fragments. In some levels peloidal structures have been recognized. Lamination is quite common for this facies, lightly to well thin and cross laminations have been observed. Ammonite fossils are common in this facies; they are mainly dissolved and replaced by calcite cement. Their thicknesses are much less than the mudstones and claystone facies, ranging 8-25cm interval. This facies is rich in minerals as well, including quartz, orthoclase, muscovite, opaque and Glauconite (Appendix A). Quartz and orthoclase are most abundant like mudstone and claystone facies. Their percentages remain almost the same throughout the succession, ranging between 14.6 (Ing 69) – 33.7% (Ing 63). Muscovites are very common in this facies too, they occur in almost every limestone level and they show upward decrease in volume along the succession, their percentage range between 0.3 (Ing 78) – 4.9% (Ing 39). Opaque minerals are abundant too, they also occur in every limestone layer, but they increase in volume towards the top of the succession and their percentage range between 0.1 (Ing 35) – 5.2% (Ing 69). Glauconite minerals occur in all limestone facies, although in some levels they are shown to be absent due to the reason stated in mudstone and claystone facies. As mentioned above, iron volume is present as well and they increase along the section towards the top.

3.1.1.5. Black shales

In studied section black shales are observed only in one level which is sampled as Ing 2. It is very dark grey to black colored, very well, and thin laminated and rich in organic content. Some carbonate clasts are also found in Ing 2 sample. Wignall (1994) defines black shales as consisting of finely laminated shales commonly containing organic carbon of up to 1-20 % by weight. It is mainly matrix supported, but also contains some mineral content. Quartz and orthoclase are most abundant in black shale; here they contain nearly 14% of total volume. Other minerals like opaque, muscovite, and iron are present too. Opaque and iron together contain 4.2% of total volume which is very common for black shales. Compared to other mentioned facies types, black shales aren't as rich in minerals as others. Quartz and orthoclase are most abundant, muscovite and opaque minerals are present as well, their percentage is very little. Moreover iron nodules are present in black shale facies.

Black shales develop in oxygen-deficient basins, where the water column becomes stratified, commonly with surface waters having near-normal oxygen saturation levels of 6-8.5 ml O_2/l , and bottom waters which may be oxygen deficient, with levels ranging from 1 to 0 ml/l of dissolved oxygen (Doyle et al., 1988). It is generally agreed that stratification occurs because of differences in temperature or salinity between the lower and upper levels of the water column, generally producing high-density bottom waters and low-density surface waters. Mixing may occur periodically (Doyle et al., 1988).

3.1.2. Depositional Environments

Depositional environments have been defined in various ways; however, all definitions of environment have in common an emphasis on the physical, chemical, and biological conditions of the environment. A depositional environment is thus characterized by a particular geomorphologic setting in which a particular set of physical, chemical, and biological processes operates to generate a certain kind of sedimentary deposit (Boggs, 2001, p257).

There is İnaltı (upper part of the formation is Barremian? according to taken samples) formation below the Türbeyanı Marls (Figure 9). The contact between these two formations is very important in order to understand the depositional environment of the Türbeyanı Marls and its evolution. In the uppermost part of İnaltı formation karstic breccia has been observed. This formation is rich in pyrite and it has pyrite lenses, disseminated pyrite and iron encrustation along the karstic contact. There is a time gap/hiatus between these formations according to the ages of both formations. Above this karstic breccia there is a very thin, yellow colored, a layer of sandy material exist. The Türbeyanı Marls lie just above this karstic breccia, at the base they start with black shales (Ing 2), meaning it was deposited in a deep waters where there is very low rate of sedimentation and dysoxia or anoxia. Most probably it is because during that time there was a sudden drowning of base units, causing in sudden transgression which is also in turn causes sediment starvation. Occurrences of glauconite minerals in black shale also support the idea of low rate of sedimentation and sudden transgression. Within the regional geology of the area it may represent a sudden extension causing sudden subsidence and in turn sudden rise of sea level.

The black shale at the base is overlain by a claystone facies meaning a slight fall in sea level and/or slight increase in rate of sedimentation and/or tectonic rise. Right above, there is a very thin grey colored limestone/rigid marl/sandy iron oxide layer overlies claystone facies, which may indicate

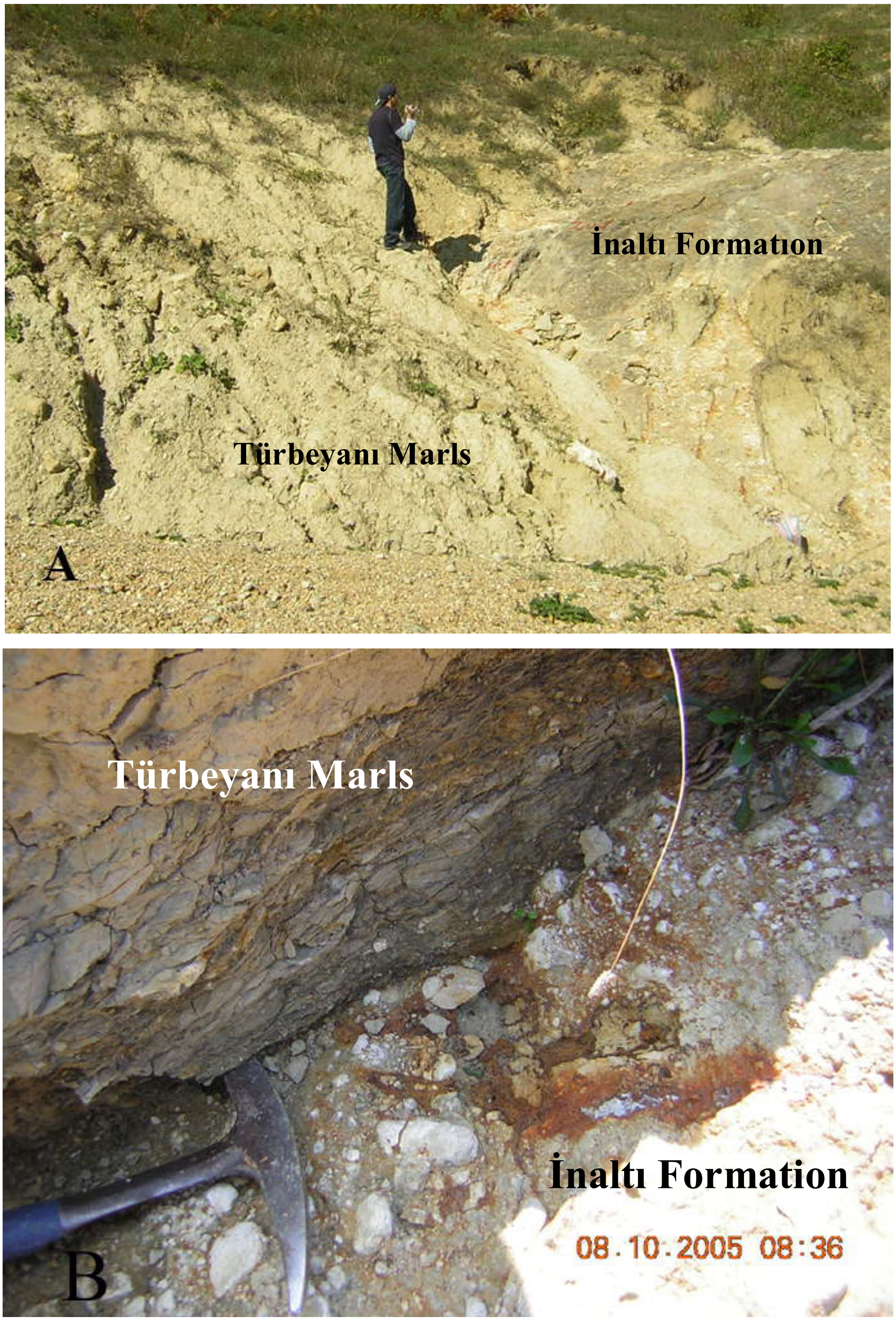


Figure 9. The contact between the Türbeyanı Marls and the İnaltı Formation (A-distance view; man for scale (170cm), B – close view, hammer for scale (15cm)).

fall in sea level and/or increase in rate of sedimentation, tectonic subsidence and shallowing upward. Another black shale layer occurs just above the previously mentioned layer, indicating there was another rise in sea level, drowning of basement units, slow rate of sedimentation and dysoxic/anoxic condition at the bottom of water column. Intercalation of mudstone and claystone facies overly black shale facies, there is a sudden increase in their thickness indicating the increase in rate of sediment influx and/or in accommodation space. This could be caused by either climate affecting the siliciclastic input or relative sea level fluctuation and tectonic subsidence affecting the accommodation space or all of them. These thick mudstone and claystone layers later are replaced by thinner ones. This may indicate that the rate of sediment influx was very low; occurrence of glauconite also supports this idea. From this level to top limestone facies start to occur. Intercalation of thick marl and thin limestone facies occurs starting from this level to top of the measured section. In some levels marl layers get even thicker that means rate of sediment influx was very high. The causes could be the same, like climate and/or tectonic subsidence relative fall in sea level. Relatively thin limestone layers are rich in glauconite minerals, having more volume than in mudstone and claystone facies. Being much thinner and having more glauconite minerals compared to mudstone and claystone facies, limestone facies are deposited in quiet environment where there is less sediment influx in the basin. Towards the upper part of the succession mudstone and claystone facies are getting thinner, almost same as limestone layers. This could be related to relative rise in sea level, climate and/or decrease in rate of tectonic subsidence.

In this study it was defined that the Türbeyanı Marls were deposited in outer shelf. One of the main reason of this conclusion is the occurrence of ammonite fossils which is the indicator of the outer shelf environment. Moreover, occurrence of glauconite minerals, precipitation of marl (claystone/mudstone) and mixed limestone facies and existing grain sizes being mostly silt size helps to define the depositional setting as outer shelf. Flysch succession within the Ulus Formation (Tüysüz et al., 1997), which is composed of mainly turbiditic sandstone-shale alternations, transitionally overlies the Türbeyanı Marls. This also implies that depositional position of the Türbeyanı Marls can be situated mainly outer shelf.

Tüysüz et al. (1997) have defined that the Türbeyanı Marls were deposited in shallow marine/shelf slope environment due to Türbeyanı Marls overlying shallow marine the İnpiri limestones, having slightly lateral angular transition, and the occurrence of glauconite minerals and ammonite fossils.

3.2. İnpiri Limestone

3.2.1. Lithofacies

The İnpiri Limestone member is mainly consisted of beige and white colored limestone, red and grey limestone facies are present as well. Great varieties of limestone facies are recognized. Packstone, grainstone, wackestone, mudstone and fenestral limestones are the most abundant, ooid, siltstone and sandstone facies are recognized as well. Although Tüysüz et al. (1997) reports the occurrence of abundant dolomite deposits in İnpiri Limestones, in the study area only in a few levels few rhombohedral dolomite grains were recognized in thin sections. Representing facies found in İnpiri Limestones were classified using Folk's (Figure 10) and Dunham's (Figure 11) classifications (Tucker, 2001, p129). Tüysüz et al. (1997) defines the age of the succession as Late Barremian-Albian according to found *Orbitolina, Neotrocholina, Siphovalvulina,* Valvulinidae, Textulariidae and Miliolidae fossil species.

3.2.1.1. Mudstone facies

Mudstone facies of the İnpiri Limestones are not very abundant along the succession (Figure 12). This facies is mainly composed of white, beige, and light-grey colored, intraclastic, extraclastic, and peloidal material. Foraminiferal and algal mudstones (Ipn U 52, 63) were recognized too. Silt and sand size quartz minerals were very common in mudstone facies. This facies was defined by visual estimation using Dunham's limestone classification, which is mainly

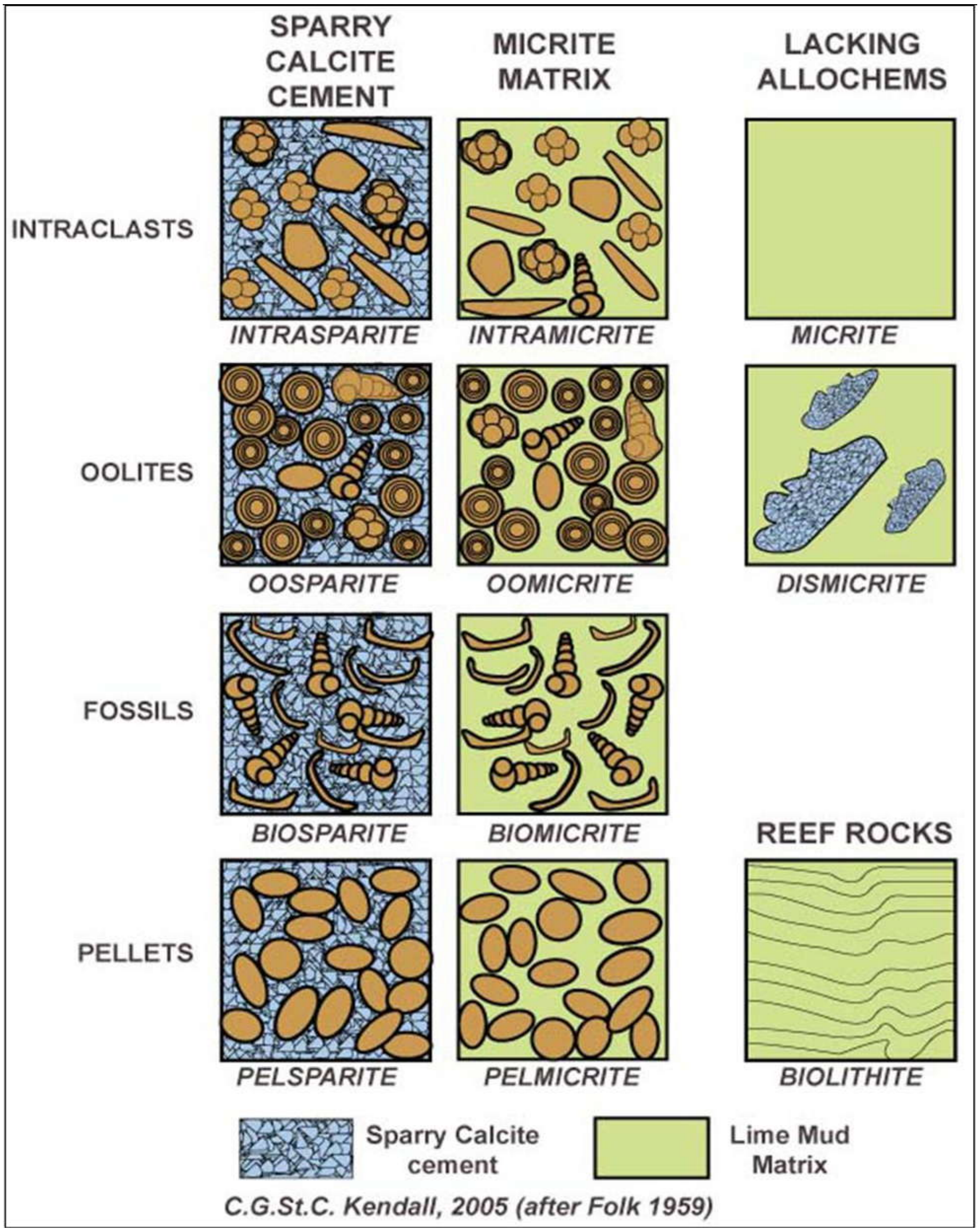


Figure 10. Classification of limestones based on composition (Folk, 1959) (Photomicrographs by C. G. St. C. Kendall, 2005).

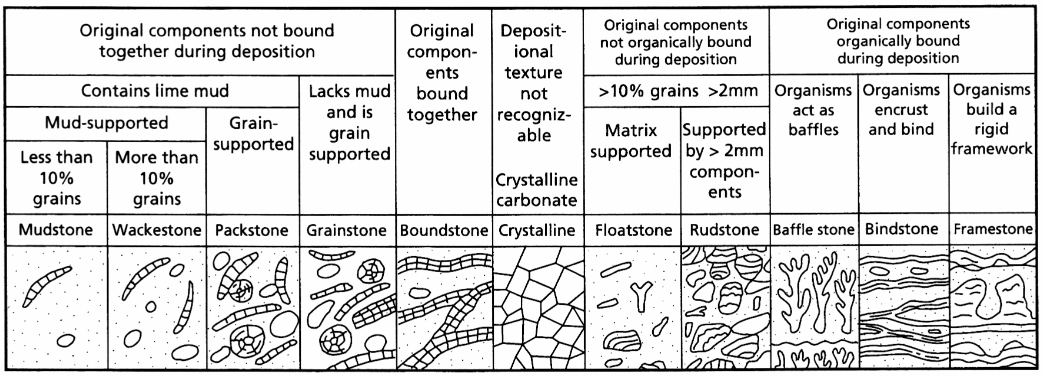


Figure 11. Classification of limestones based on depositional texture, Embry A. F. and Klovan J. E. (after Dunham R. J., 1962).

composed of micritic matrix and contains few grains, less than 10%. If Folk's limestone classification is used, some of the mudstone facies (Ipn U 29, 30, 40) could be classified as a dismicrite or fenestral limestone and in this study such facies classified as a fenestral limestone facies. Mudstone facies are thin to medium thick layered, and its thickness varies in 10-70cm range, generally near to 30cm thickness. Some of the mudstone facies contains birds-eye and stromatolitic structures (Ipn U 63).

3.2.1.2. Wackestone facies

Wackestone facies is one of the low abundant facies along the measured section. This facies is light grey to white colored, mainly peloidal (Ipn U 32) and foraminiferal (Ipn U 50) in composition. Silt and sand size quartz minerals are very common for this facies. In Ipn U 34 wackestone is intercalated with quartz arenite laminations. This facies was defined by visual estimation using Dunham's limestone classification, which is mainly matrix supported and grains floating in a matrix. If Folk's limestone classification is used, Ipn U32 is classified as pelmicrite, Ipn U 50 as biomicrite. Wackestone facies are thin in thickness and it varies in 10-30cm range.

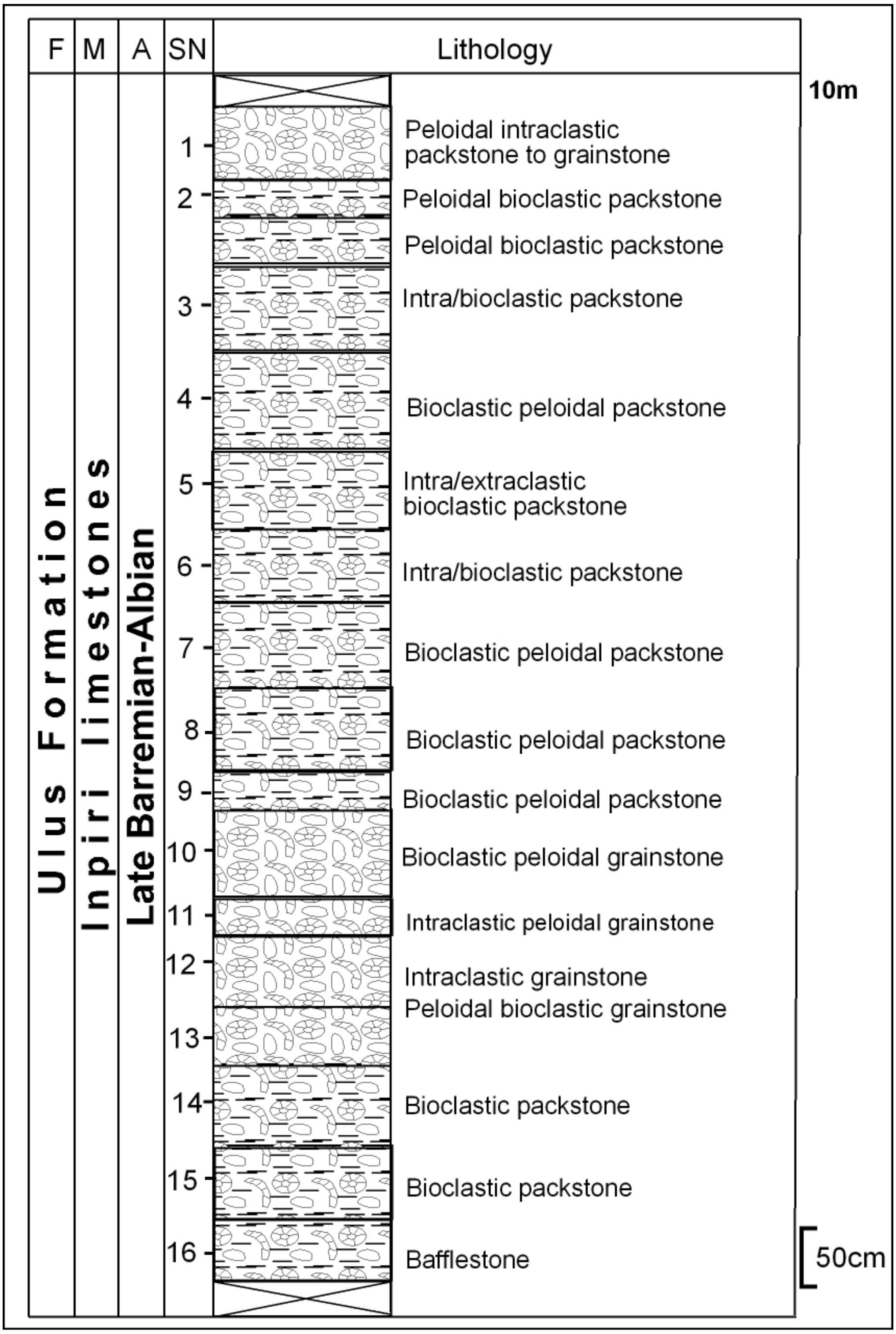


Figure 12. Lithologic column of the İnpiri Limestone (Ipn).

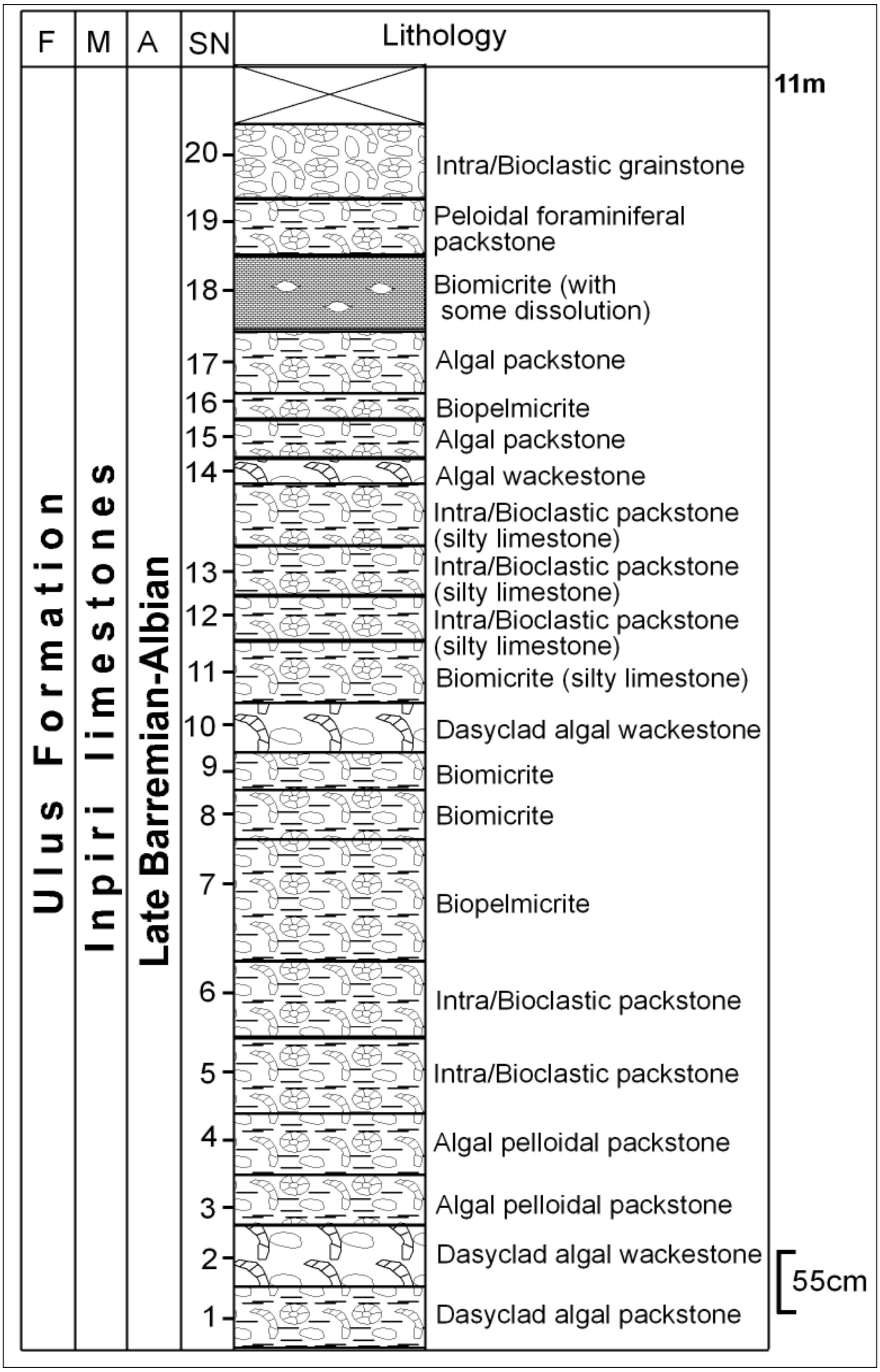


Figure 12. Continued (Ipn U).

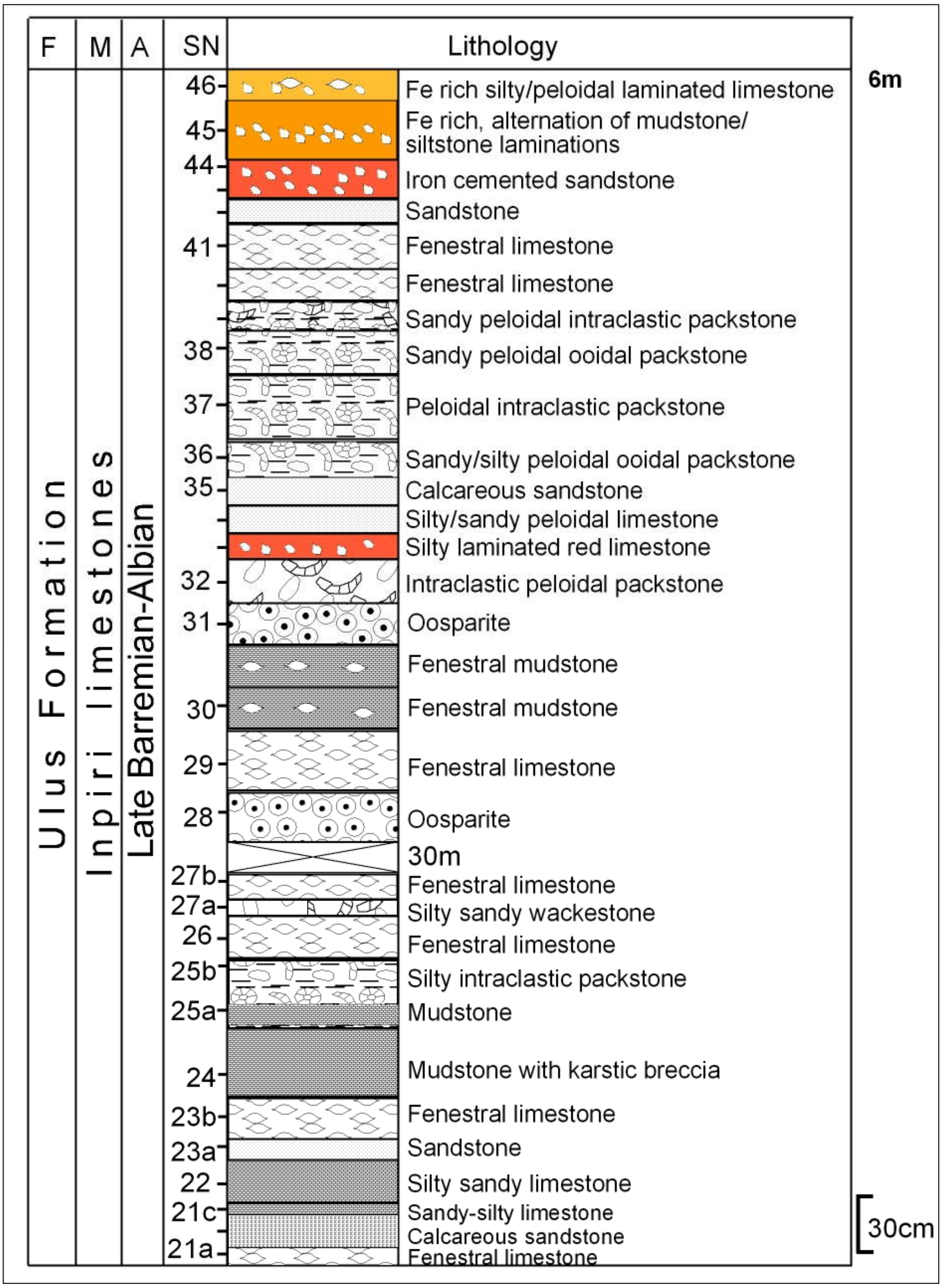


Figure 12. Continued (Ipn U).

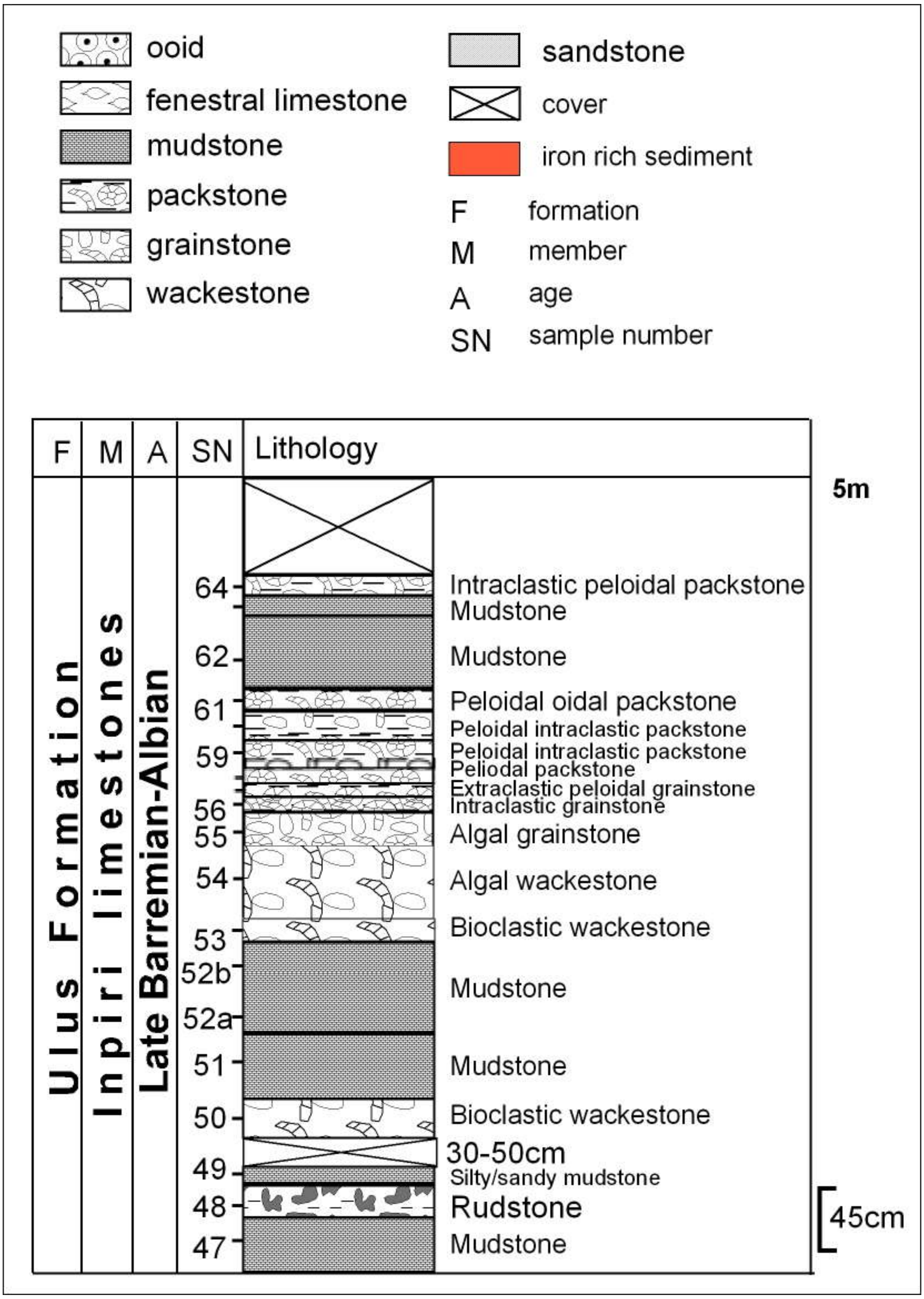


Figure 12. Continued (Ipn U).

3.2.1.3. Packstone facies

Packstone facies is the most abundant facies in the İnpiri Limestones. It is mainly light beige, white, grey and sometimes yellow colored, and is composed of mainly bioclasts, peloids, extraclasts, intraclasts, conglomerates, and plant fragments. In some samples, packstone facies are completely composed of bioclastic material such as foraminiferal (Ipn 3, 4, Ipn U 57), dasyclads algal (Ipn U 1, 4, 5), and gastropodic packstone facies (Ipn U 7, 11, 15) were recognized. Silt and sand size quartz minerals are very common in this facies. In samples Ipn U 25, Ipn U 27 intercalation of packstone and mudstone was observed, mudstone at the bottom overlain by packstone facies. This facies was defined by visual estimation using Dunham's limestone classification, which is mainly composed of micritic (sometimes sparry calcitic, (Ipn 1, 11)) matrix and grains are in contact. If Folk's limestone classification is used, most of the samples would be classified as biomicrite, also intramicrite, biointramicrite, intrapelmicrite and biopelintramicrite, and fenestral facies were observed as well. Packstone facies are thin to medium thick layered, and its thickness varies 10-100 cm in range, generally near to 50cm thickness. In some samples, birdseyes (Ipn U 60, 61) and stromatolitic (Ipn U 25, 59) sedimentary structures were observed.

3.2.1.4. Grainstone facies

Along the İnpiri Limestones several grainstone facies were recognized. This facies is mainly light-beige, beige and white colored, and is composed of bioclasts, peloids, and intraclasts. This facies is also rich in mostly foraminifers and oncolites. Silt and sand size quartz minerals are very common in this facies. This facies was defined by visual estimation using Dunham's limestone classification, which is mainly composed grains and lacks mud. If Folk's limestone classification is used, most of the samples would be classified as biosparite and pelsparite. Grainstone facies are thin layered, and its thickness varies 8-60 cm in range.

3.2.1.5. Fenestral limestone

This facies is mainly abundant at the upper part of the İnpiri Limestones starting from Ipn U 21, where fenestral fabric caps the layer which is composed of three different facies: thin (2cm) mudstone bed at the bottom, 10 cm thick sandstone bed in the middle and 5 cm thick fenestral fabric at the top. This facies is mainly composed of fenestral fabric, also rare pellet grains and stromatolites are observed as well. Silt and sand size quartz minerals are very common in this facies. This facies was defined using Folk's limestone classification, which is composed of micritic matrix with cavities (usually spar-filled) such as birdseye limestones.

Tebbutt et al. (1965) have defined fenestra as a primary or penecontemporaneous gap in rock framework, larger than grain-supported interstices. Fenestrae may be open cavities, or may be completely or partially filled by surface-derived internal sediment, diagenetic internal sediment (e.g. crystal silt) or cements. Fenestrae have no apparent support in the framework of primary grains composing the sediment. Demicco and Hardie (1994, p60) have defined fenestra as a hole of any shape in a rock or unconsolidated sediment that is not of an intergranular nature.

3.2.1.6. Ooid facies

Ooid facies are observed in only three samples along the succession, more precisely at the upper part of the İnpiri Limestones. Ooid grains are micritic in composition which is the indication of the shallow marine environment (Flügel, 2004, p144). According to Popp and Wilkinson (1983) micritic fabric may be restricted to certain laminae or it occurs everywhere in the cortex of originally calcitic or originally aragonitic ooids. Aragonite ooids can be transformed to micritic and microsparitic ooids by in-situ calcitization. The micritic fabric results from the activity of microborers or from recrystallization, leading to a microgranular mosaic consisting of small calcite crystals and displaying neither concentric nor radial microfabrics. Pellets, quartz and feldspar grains were also observed in this facies. Ooid facies was recognized using Folk's limestone classification, both oosparite (Ipn U 28) and oomicrite (Ipn U 31, 36) were recognized. Flügel (2004, p142) defines ooids as spherical and egg-shaped carbonate or non-carbonate coated exhibiting a nucleus surrounded by an external cortex, the outer part of which is concentrically smoothly laminated.

3.2.2. Depositional environment

Analyzed sedimentological features of the İnpiri Limestones allow us to conclude that depositional environment of the measured succession corresponds to the peritidal environment and its three subdivisions: supratidal, intertidal and subtidal zones. Folk (1973) defines the term peritidal to describe a variety of carbonate environments associated with low-energy tidal zones, especially tidal flats. Peritidal carbonates (carbonate sediments formed "around the tide") are supratidal, intertidal and subtitle sediments formed in marginal-marine and shoreline depositional environments (Flügel, 2004, p745).

Subtidal zone is the permanently submerged area seaward of the tidal flats and it may be strongly influenced by wave action and tidal currents, but most tidal flats are associated with protected low-energy lagoons and restricted bays. Intertidal zone lies between the normal low-tide and high-tide levels, and is alternately flooded by marine water and exposed. Supratidal zone is frequently flooded, usually during high spring tides and by storms, and can be very wide on low-relief prograding coastlines. It is characterized by prolonged exposure but its nature is ultimately controlled by the prevailing climate (Tucker and Wright, 1990, p137).

The most characteristic features of the İnpiri Limestones are birdseyes structures/fenestrae, peloids, fecal pellets, stromatolites, ooids, oncoids, mud cracks, karstic brecciation, also abundant bioclasts like foraminifers, dasyclad algae, and gastropods and corals are present as well. Moreover, occurrence of abundant quartz minerals and sometimes siltstone and sandstone laminations are also very common in the İnpiri Limestones.

Fenestrae (or birdseyes) are one of the most common features of peritidal deposits. They are mainly formed by desiccation and shrinkage or air and gas bubble formation (Shinn, 1968), but they also commonly occur with stromatolites and form by the irregular growth processes of the microbial mats (Monty, 1976; Playford and Cockbain, 1976). Fenestrae are characteristics of the upper intertidal and supratidal zones (Tucker and Wright, 1990, p143).

Peloids are polygenetic grains composed of micro- and cryptocrystalline carbonate and are commonly devoid of internal structures but may contain fine grained skeletal debris and other grains. They are common in shallow-marine tidal and subtidal shelf carbonates and in reef and mud mounds, but are also abundant in deep-water carbonates (Flügel, 2004, p110).

Fecal pellets are rounded, usually fine grained particles caused by organisms that eat mud, digest organic matter from the mud and excrete the non-digested lime-mud. They accumulate in temperate intertidal and subtidal settings, also in deep-marine environments (Flügel, 2004, p111).

Stromatolites are laminated benthic microbial deposits (Riding, 1999) and they occur in marginal marine and shallow subtidal environments but also in deep subtidal and basinal environments (Flügel, 2004, p749).

Ooids are spherical and egg-shaped carbonate or non-carbonate coated grains exhibiting a nucleus surrounded by an external cortex, the outer part of which is concentrically smoothly laminated. As stated above in the İnpiri Limestones ooids are micritic in composition and according to Flügel (2004, p144) micritic ooids are deposited in shallow marine settings.

Oncoids are unattached, rounded, mm- to cm-sized, calcareous or non-calcareous nodules that commonly exhibit a micritic cortex consisting of more or less concentric and partially overlapping laminae around a bio- or lithoclastic nucleus. Ancient marine oncoids are believed to be formed in many different settings, and one of the most associated settings is peritidal setting (Flügel, 2004, p121).

Mud cracks are formed by drying out of subaerially exposed mud. They are common in supratidal and upper intertidal zones (Demicco and Hardie, 1994, p49).

Karstic brecciation occurs when the seafloor is subaerially exposed and this zone corresponds to the supratidal setting.

Biota of the İnpiri Limestones is very rich and some of them are important indicators of the depositional setting, as in dasyclad algae could be found in open lagoons, protected but open bays and in the shelter of ridges. Many dasyclad limestones (mostly grainstones and packstones) were formed in open-marine lagoonal or back reef environments. Dasyclad algae are shown to be deposited in all three sub-zones of peritidal zone (Flügel, 2004, p749). Foraminifers can be observed from intertidal zone down to the deep sea (Table 2).

Analyzing the above interpretation, the depositional setting of the measured section of the İnpiri Limestones corresponds to peritidal environment.

Varol and Akman (1988) defined six microfacies types in the İnpiri Limestones. These are mudstone-dolomite-dolomitic mudstone microfacies, laminated peloidal wackestone-grainstone microfacies, orbitolinidic-algal wackestone and grainstone microfacies, peloid-ooid grainstone microfacies, reefal bioclastic wackestone-packstone microfacies and bioclastic wackestone microfacies. These defined microfacies are similar to the defined microfacies by with Tüysüz et al. (1997) and according to these microfacies the depositional environment for the İnpiri Limestones was defined as shallow water setting similar to protected shelf lagoon environment (Figure 12).

Table 2. General summary of criteria used in differentiating supratidal, intertidal and shallow subtidal carbonates. The relative frequencies of diagnostic features should not be taken as the only possible truth! (Flügel, 2004).

	Supratidal	Intertidal	Shallow subtidal
Sedimentary structures			
Fine-scale lamination	common	abundant	rare
Desiccation structures	abundant	abundant	absent
Tepees	abundant	rare	absent
Flat-pebble conglomerates	rare	common	rare
Collapse breccias	abundant	abundant	absent
Biogenic structures			
Microbial/algal mats	abundant	abundant	rare
Stromatolites	rare	abundant	common
Burrows	rare	abundant	abundant
Fenestral fabrics			
Irregular and laminoid birdseyes	abundant	abundant	rare
Tubular root voids	abundant	common	rare
Sedimentary grains			
Peloids	common	abundant	common
Fecal pellets	rare	abundant	abundant
Benthic peloids	rare	common	absent
Mud intraclasts	common	abundant	common
Black lithoclasts	common	common	absent
Non-skeletal oncoids	rare	common	common
Skeletal oncoids	rare	common	common to abundant
Ooids	absent	common	common
Cortoids	absent	common	abundant
Aggregate grains	absent	common	abundant
Biota: Characteristic groups			
Benthic foraminifera	very rare	rare to common	common to abundant
Ostracods	rare	rare	common
Gastropods	rare	common to abundant	common to abundant
Bivalves	absent	rare	common
Calcareous algae	absent	rare	common to abundant
Cyanobacteria	common	abundant	common
Biota: Diversity	very low	low	high
Diagenetic criteria			
Gravitational cement	abundant	common	absent
Meniscus cement	common	common	absent
Vadose pisoids	abundant	rare	absent
Carbonate surface crusts	abundant	common	absent
Fine-grained dolomite	common	common	common
Gypsum/anhydrite-carbonate associations	abundant	abundant	rare
Pedogenic structures	abundant	rare	absent

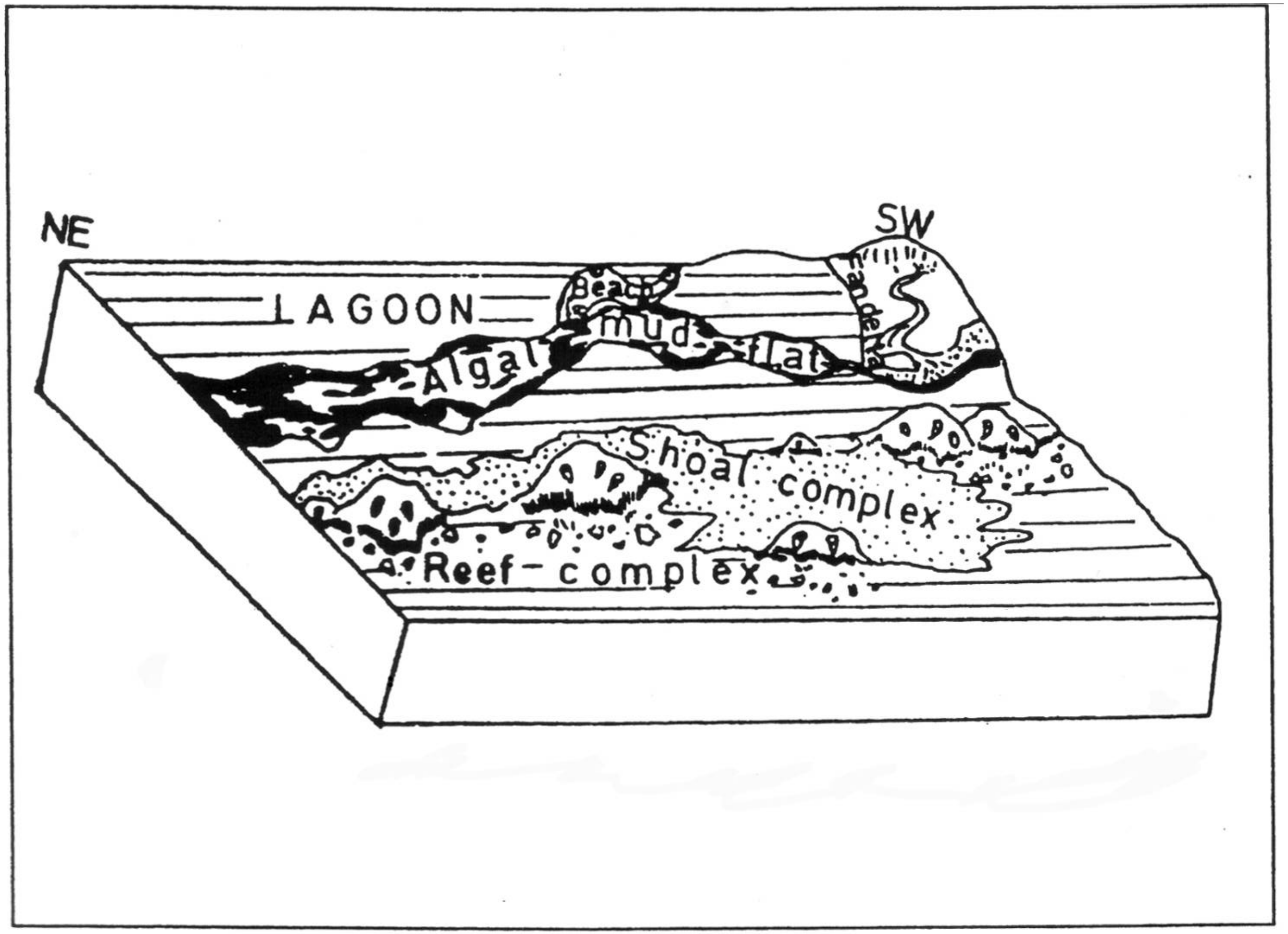


Figure 13. The model showing the depositional environment of the İnpiri Limestones (Varol and Akman, 1988).

CHAPTER IV

CYCLOSTRATIGRAPHY

Cyclostratigraphy is the study of cyclic depositional patterns produced by climatic and tectonic processes. It deals with minor, relatively short-period (high-frequency) sedimentary cycles (mainly Milankovitch cycles) and has become a field of great interest because of its linkage with climate change and its potential to complement and refine chronostratigraphy and stratigraphic correlation (Einsele, 2000, p359).

Variations in the Earth's distance and inclination to the Sun, Moon and nearby planets were proposed by Milutin Milankovitch in 1941 to explain the alternating ice ages of the Pleistocene (Potter et al., 2005, p214). He reasoned that these orbital variations caused changes in the solar energy (insulation) intercepted by the Earth and thus in its global temperature. These orbital variations known as Milankovitch cycles of which there are three – eccentricity (404, 128, and 98 ka), obliquity (54, 41 and 29 ka) and precession (24, 22 and 19 ka). These frequencies are collectively known as the Milankovitch parameters. Milankovitch cycles have been called "pace maker" of cyclic sedimentation and stratigraphy, because they are widely considered to be the principal causes of the rhythmic deposition (excluding the annual cycle of glacial varves and the shorter cycles in tidal rhythmites). Such rhythmic couplets include claystone – marlstones, marlstones – limestones, shales – siltstones, claystones – diatomites, and claystone – evaporites (Potter et al., 2005, p215).

4.1. Türbeyanı Marls

The total studied thickness of the Türbeyanı Marls is 55m. The succession is mainly composed of marl (mudstone and claystone) and limestone facies, and there is black shale occurrence at the bottom. Field descriptions and point counting data have been applied in order to understand and differentiate existing cycles. The color, layer thickness, facies types that defined in the field are the major factors that have been used to define cycles. As for point counting data, in some levels, where field description data could not define cyclicity, point counting method was very useful to differentiate cycles. The data obtained from matrix, quartz/orthoclase, muscovite, opaque, glauconite and iron nodules show relative changes through the defined cycles. In total five types of main cycles and four sub-type cycles (Figure 14) were recognized in the Türbeyanı Marls.

Cycle type A. It is observed at the bottom of the succession, starts with dark grey-black colored, well laminated black shale interval, reflecting transgressive condition of cycle, continues with grey colored, laminated claystone facies and capped by limestone/marl facies which shows the transition to highstand period of cycle.

Cycle type B. This type of cycle at the base starts with grey to dark grey, greenish colored claystones and is overlain by grey to dark grey colored mudstone facies. This cycle type also indicates system change from transgressive condition to highstand condition. Moreover, another reason could be the low rate of sedimentation which occurs during that time, which could be originated from either climate or tectonic activities.

Cycle type C. This type of cycle is the intercalation of mudstone facies. At the base it starts with dark grey-black colored, mudstone facies containing black coal fragments and bluish to black colored metallic nodules exist. At the top, mudstone facies is grey to light grey colored and contain more carbonate.

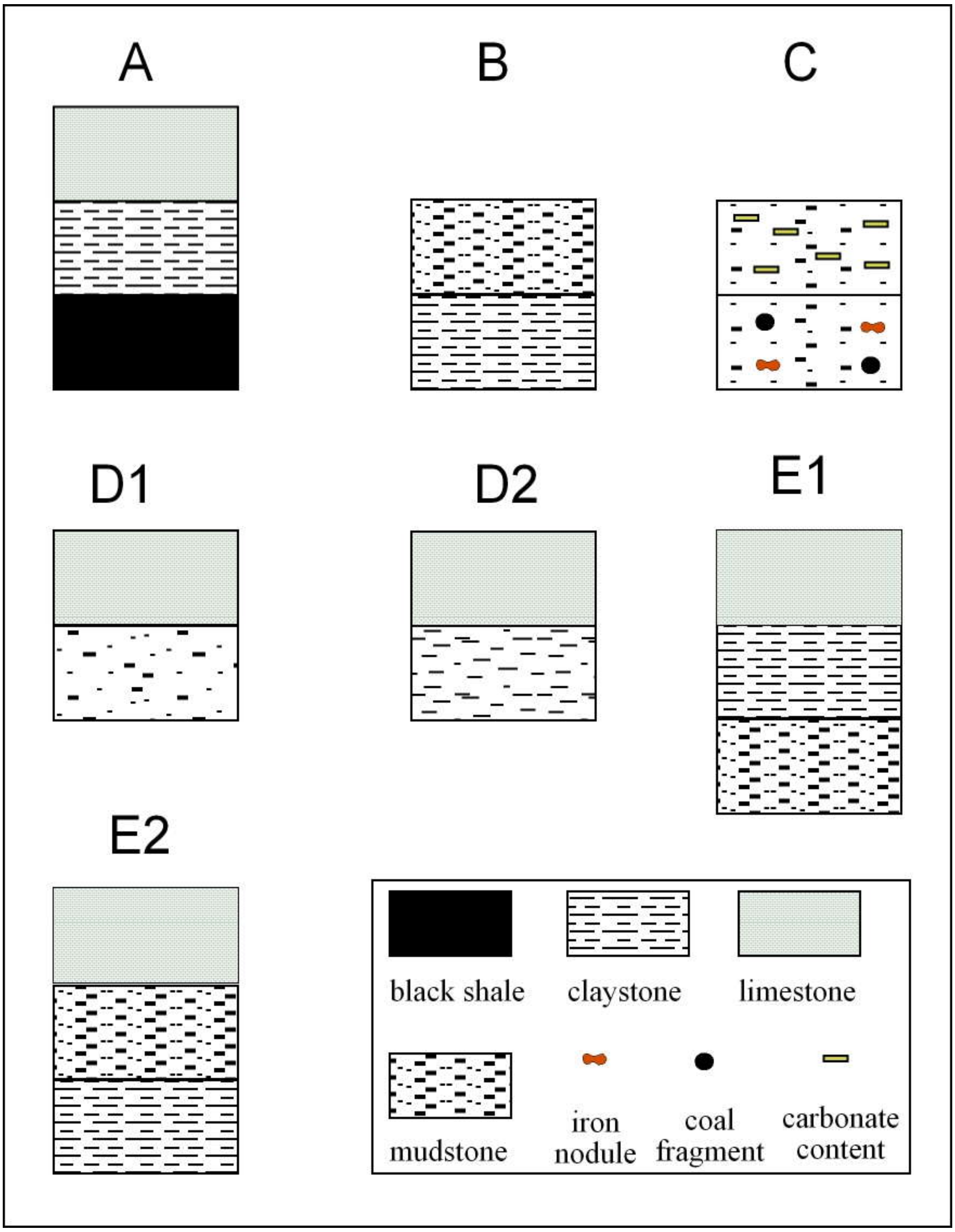


Figure 14. Main and sub-type cycles of the Türbeyanı Marls.

The possible reason for it would be the climatic changes, and relative rise in sea level.

Cycle type D. Two sub-types have been defined in this type, namely, D1 and D2. D1 at the base starts with light grey to grey, bluish, greenish, brownish colored, thick mudstone facies and at the top capped by grey to dark grey, beige colored, well packed, thin silty limestone facies cap the cycle. In D2 type the only difference is that at the base the cycle starts with claystone facies and capped by the limestone facies same as in D1 type.

Cycle type E. Two sub-types have been defined, E1 and E2. E1 cycle type at the bottom it starts with dark grey colored mudstone facies and is overlain by dark grey colored claystone facies. At the top it is capped by beige-light grey colored silty limestone facies. E2 cycle is similar to E1 cycle, the only difference is that at the bottom it starts with claystone facies, overlain by mudstone facies and at the top capped by limestone facies.

In the succession total of 39 fifth order cycles (Figure 15) were recognized. As the ages of lower and upper boundaries are difficult to determine, the duration of the determined cycles are unknown. Meter scale cycles have been identified along the measured succession of the Türbeyanı Marls (Figure 16) using both field and laboratory data. However, the variations of point counting data do not match with the variation of the cycle types. These meter-scale cycles are equivalent to 4^{th} and 5^{th} order of Milankovitch cycles.

It was generally accepted that the cause of the intercalation of limestone beds and softer interlayers represents a direct response to changes in environmental conditions, such as (1) productivity cycles of the calcareous plankton (e.g., Seibold, 1952; Wendler et al., 2002); (2) dilution cycles, that is, fluctuations in the influx of terrigenous non-carbonate material (e.g., Sarnthein, 1978); (3) cyclical changes in input of carbonate mud from adjacent shallow-water carbonate factories (e.g., Pittet and Strasser, 1998; Munnecke and Westphal, 2004); (4) dissolution cycles of the calcium carbonate sediment fraction (e.g., Flugel und Fenninger, 1966); or (5) redox cycles at the sea floor (Damholt and Surlyk, 2004). In many cases, a combination of two or more of these mechanisms

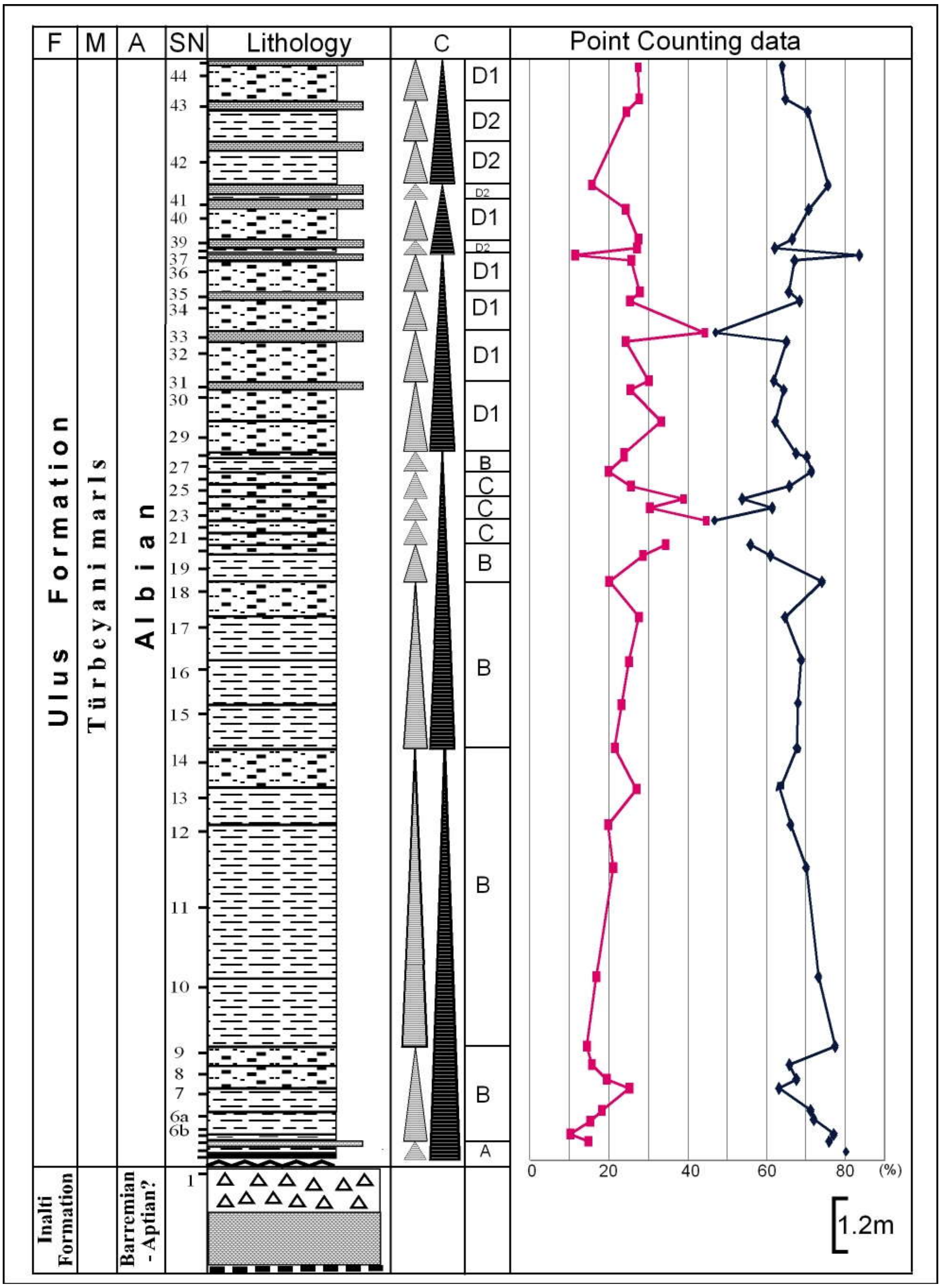
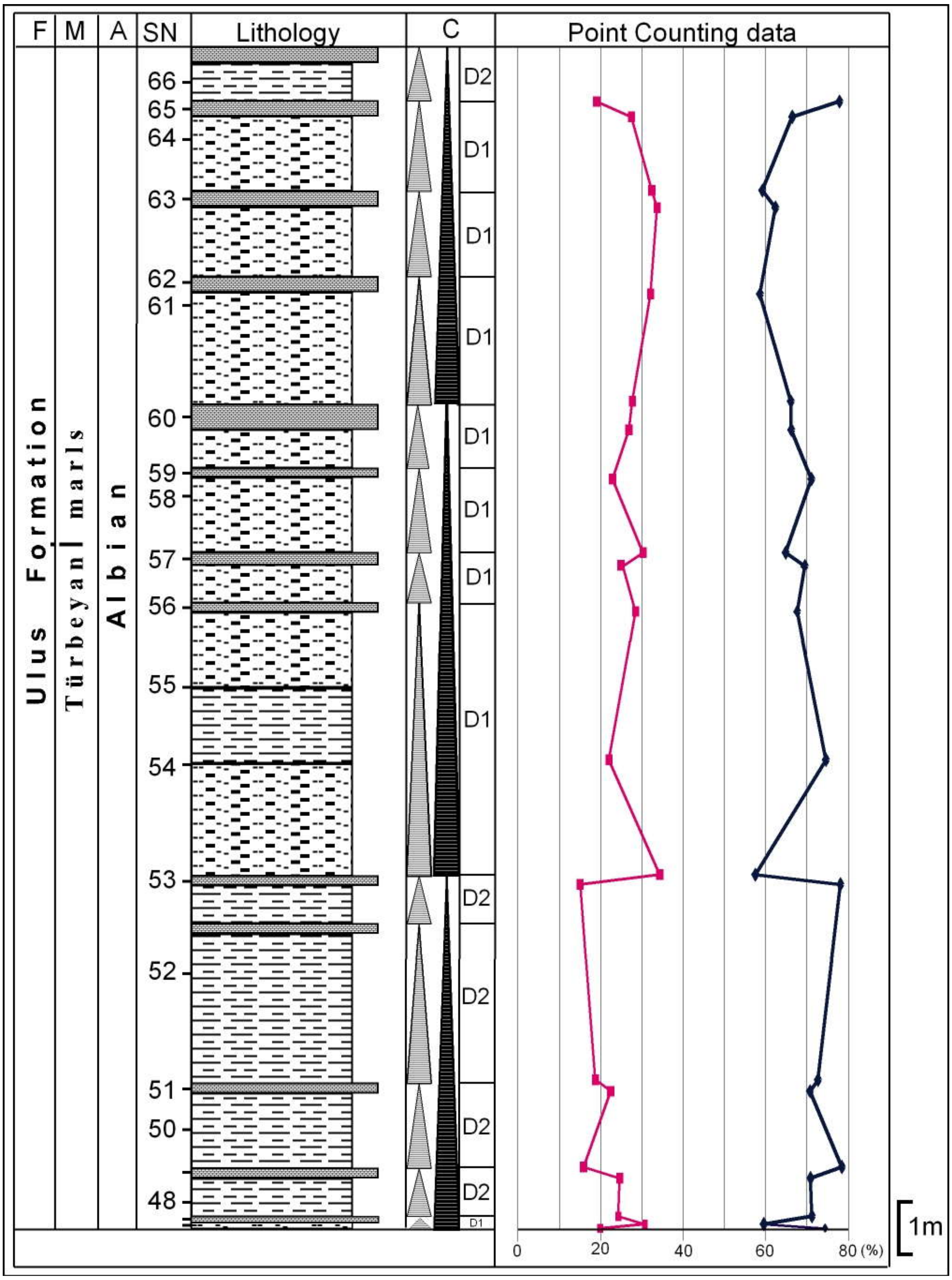


Figure 15. Cycles recognized in the Türbeyanı Marls.



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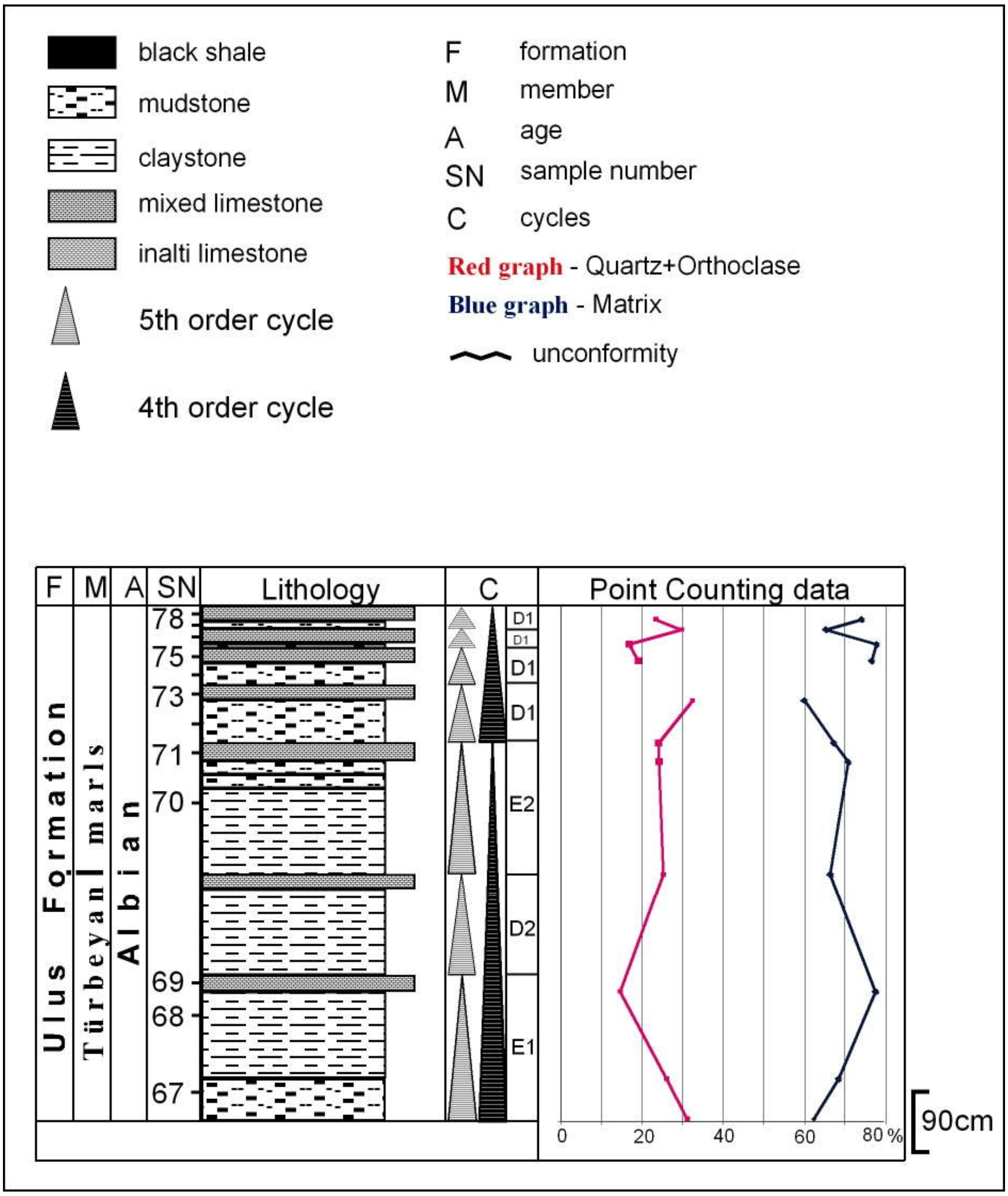

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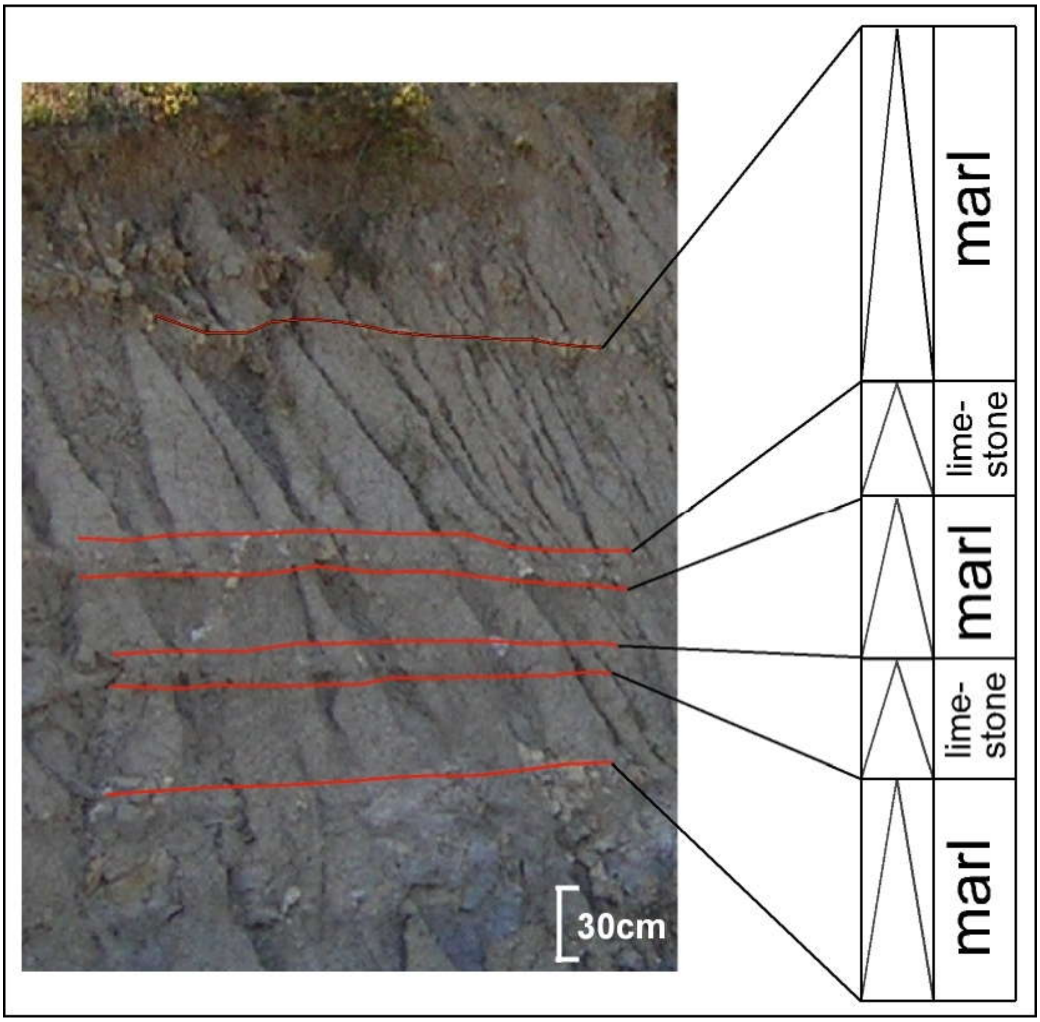


Figure 16. Field view of cycles of the Türbeyanı Marls.

was assumed. The basic assumption of all these models, however, is the same: that environmental fluctuation is faithfully translated into the rock record (Westphal, 2006).

The Türbeyanı Marls at the base start with type A cycle and overlain by type B cycle. As already mentioned in previous chapter, the base of the succession represent the sudden transgressive environment, sudden drowning, followed by short regression. The reason for mudstone layer being thinner than the claystone layer could probably be originated from the unstable tectonism during that time.

B type cycles are represented by three relatively thick claystone layers at the base and capped by relatively thinner mudstone layers, as mentioned above, which could be originated from tectonic activities of that period. Type C cycles are composed of intercalation of homogeneous facies, differentiated only by the color and some coal fragments found in dark colored facies. The main reason for this could be the oxygen content of the water column at the bottom of the basin. The less oxygen contents the darker and more organic become the layers. Type D1 and D2 are the most abundant in the succession. The mudstone/claystone and limestone alternations are observed very clearly in the field. The varying thickness of these layers only is enough to recognize cycles. Generally mudstone/claystone layers are relatively very thick, and limestone layers are thin. Silty, sandy, and clayey limestones are well packed, light grey – beige colored and they participate up to the top of the succession. The depositional mechanism would be very simply for this cycle. The major factor affecting this cycle would be the climate, during the warmer climate more siliciclastic material would be transported down to the basin and causing in deposition of marl (mudstone/claystone) layers. During cold climatic periods, carbonate precipitation is less disturbed by siliciclastic input, meaning thinner, mixed limestone layers would be precipitated. Also, it could be mentioned that during this all time, carbonate precipitation could be stable, only rate of siliciclastic input changes along the succession. Near the top of the succession mudstone/claystone layers are getting thinner, even at some level thinner than limestone layers, thickness of limestone layers are nearly stable though. The reason for this could be climatic changes, in other words, in dry climatic period of time less sediment transportation would occur. Differential compaction could be also possible reason. E1 and E2 type cycles are represented by marl (mudstone/claystone) and limestone facies. Mudstone and claystone facies are capped by limestone facies at the top.

Milankovitch cycles are usually easy to define. The limiting age of the succession can be divided by total number of cycles. Unfortunately in the studied outcrop the base and the top of the Türbeyanı Marls are both bounded by unconformities. At the base, the succession overlies the karstic breccia and at the top the Türbeyanı Marls are detached from the İnpiri Limestones by a fault surface.

The long term cycles of the 1st and 2nd order are caused by global tectonics or more regional tectonic motions (rifting, subduction, magmatism, mountain building, etc.) affecting the volume of the ocean basins. The 4th and higher order cycles are ascribed to the build up and melting of continental ice, i.e. the change in oceanic water volume. The mechanism responsible for the common 3rd order cycles is not so clear (Einsele, 2000, p356).

The systems tracts of third order sequences can often be subdivided into parasequences or parasequence cycles. The time periods of parasequences range from about 0.01 to 0.5 Ma and thus are 10 to 100 times shorter than those of third order cycles. These short periods lie within the range of the Milankovitch frequency band and glacio-eustasy caused by drastic climatic change. Fourth order cycles represent eustatic variations around the long eccentricity cycle (E2) with a period of about 0.4 Ma. Cycles of shorter periods (0.02 to 0.1 Ma) are ascribed to the 5th or 6th order. A clear boundary between these higher orders is difficult to set. Parasequences of Milankovitch type occur periodically, but time duration of these periods may change with time (e.g. from approximately 100 to 40 ka or from 40 to 20 ka). The sedimentological expression of these cycles can be significantly modified when the orbital signals are superimposed on third order cycles (Einsele, 2000).

4.2. İnpiri Limestones

Cyclicity of the measured section of the İnpiri Limestones was defined using field description and microfacies analysis of samples under microscope. The succession is mainly composed of bioclastic, peloidal packstone/grainstone facies, also occurrence of fenestral limestones, lime mudstone, ooids, sandstone facies are present. The color, layer thickness, facies types that defined in the field are the major factors that was used to define cycles. As for laboratory study, visually estimated the oscillation of amount of sand and silt size quartz grains was very useful to differentiate cycles. Moreover, visually estimated micrite/calcite ratio of matrix, changes in abundance of bioclastic, intraclastic and extraclastic content were used in differentiating cycles as well. The total studied thickness of the İnpiri Limestones is 30m. Different types of cycles are observed in the measured section based on the detailed analysis of microfacies and grouped into nine main and sixteen sub-types cycles (Figure 17).

Cycle type A. This type cycles are characterized by the intercalations of the bioclastic intraclastic extraclastic peloidal packstone-grainstone facies showing fluctuating of the sea level. According to internal variations, within cycle A, four sub-type cycles are identified. A1 type cycles are represented by the intercalations of bioclastic intraclastic extraclastic peloidal packstone facies. A2 type cycles at the base start with bioclastic peloidal packstone facies and overlain by intraclastic bioclastic peloidal grainstone facies at the top. A3 type cycles similar to A2 type cycle, only in this case at the base it starts with similar grainstone facies and overlain by similar packstone facies at the top. A4 type cycles starts with the bioclastic peloidal packstone facies at the base and overlain by the bioclastic wackestone facies at the top.

Cycle type B. This type cycles are similar to type A cycles, the only difference is that type B cycles are silty in composition, which could be caused by climatic and/or tectonic activities or sea-level fall. Two sub-types were defined within this type cycles, B1 and B2. B1 at the base starts with the intercalations of the intraclastic bioclastic packstone facies and overlain by the algal wackestone and packstone facies. B2 type cycle starts with silty bioclastic packstone facies at the base, algal packstone in the middle and capped by the bioclastic packstone facies.

Cycle type C. C type cycles are mainly characterized by the fenestral limestones, sandstone and lime mudstone facies, which is the indication of the major sea level fluctuation causing subaerial exposure. It is divided into two sub-type cycles, C1 and C2. C1 at the base starts with fenestral limestone, calcareous sandstone and sandy-silty limestone facies and capped by silty-sandy limestone facies. C2 type facies at the base starts with sandstone and fenestral limestone facies and overlain by lime mudstone with karstic breccia.

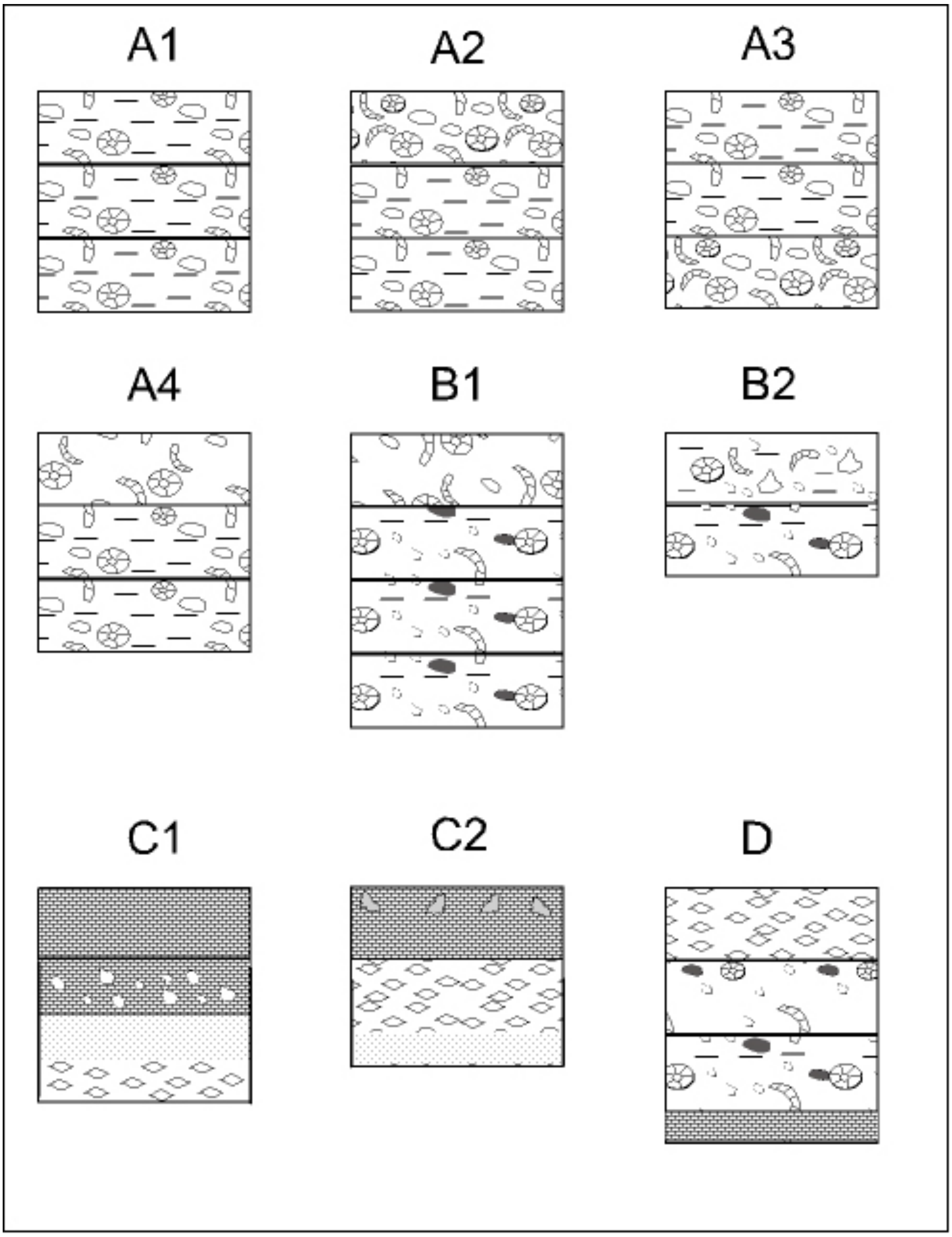
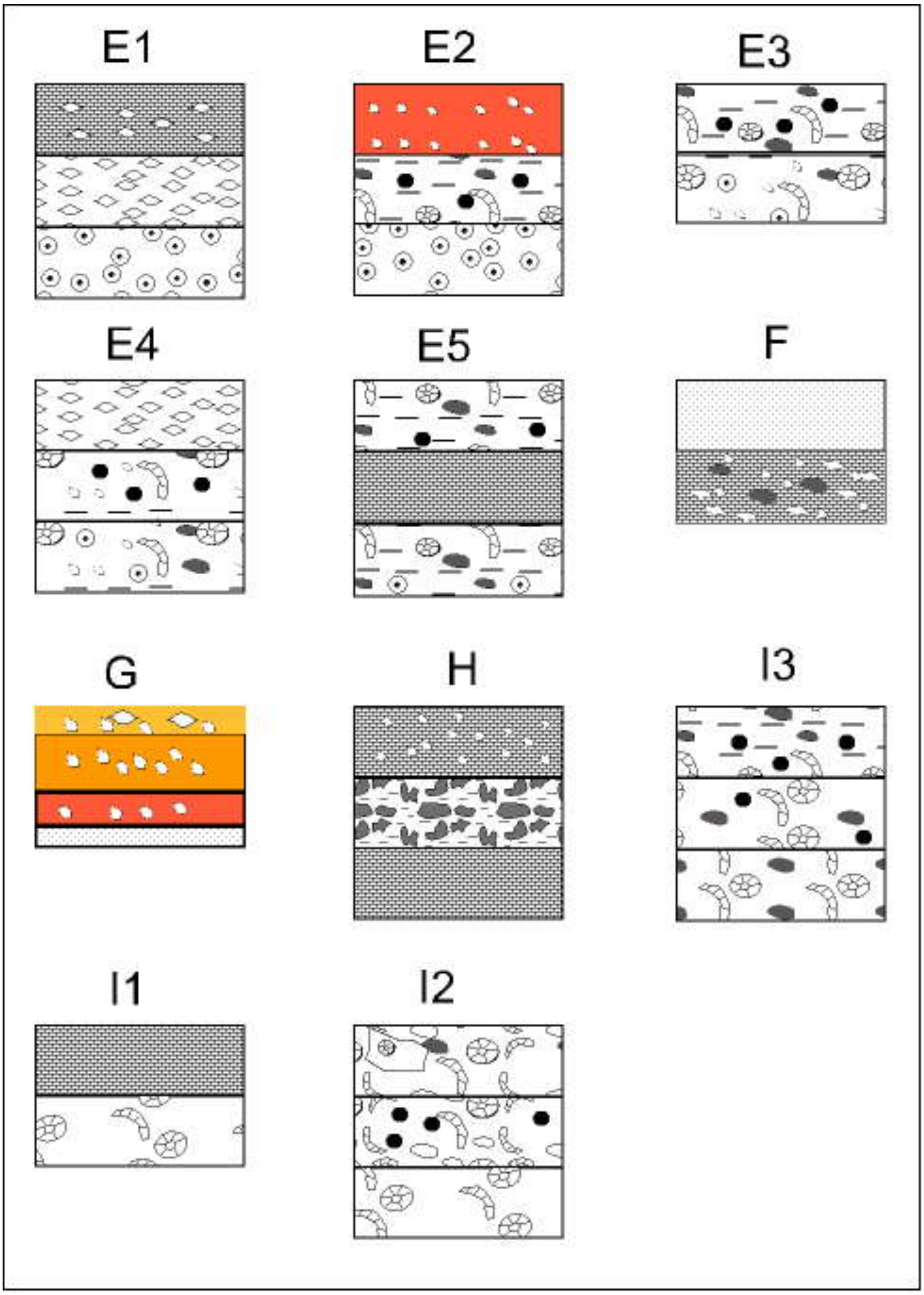


Figure 17. Main and sub-type cycle of the İnpiri Limestones.



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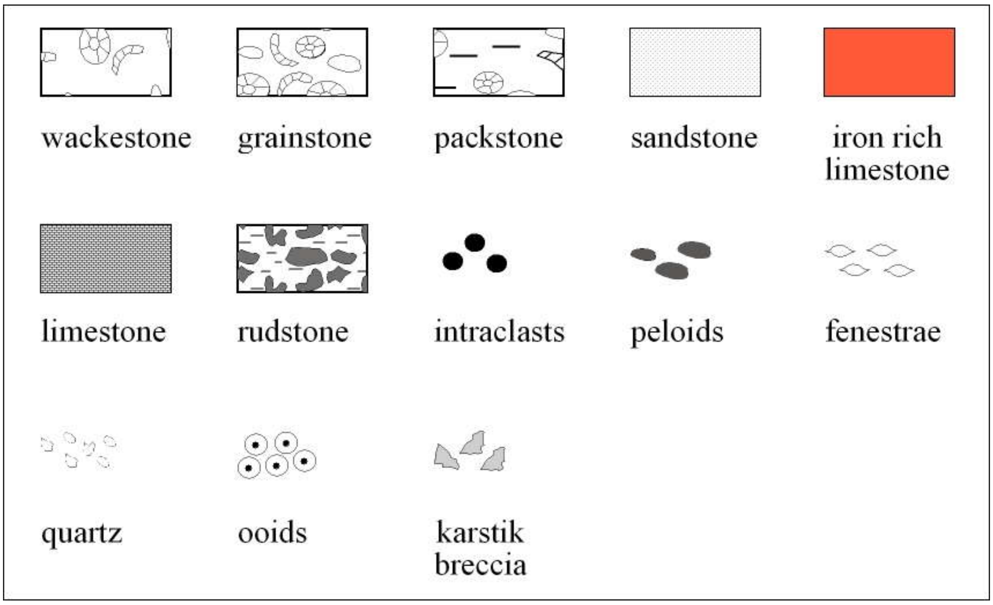

Figure 17. Continued.

Cycle type D. This type cycle starts with mudstone and silty intraclastic packstone facies, overlain by silty sandy wackestone and capped by fenestral limestone, indicating shallow marine environment and the terrestrial influence.

Cycle type E. This type cycle is characterized by the ooid facies at the base and subdivided into five sub-type cycles. E1 at the base starts with ooid grainstone facies, overlain by fenestral limestone and capped by fenestral lime mudstone facies. E2 cycles at the base start with ooid grainstone, overlain by intraclastic peloidal packstone and capped by silty laminated red limestone facies. E3 cycle starts with sandy-silty peloidal ooidal packstone facies and capped by peloidal intraclastic packstone facies. E4 cycles start with sandy peloidal ooidal packstone facies, overlain by sandy peloidal intraclastic packstone and capped by fenestral limestone facies at the top. E5 cycles at the base start with peloidal ooidal packstone, overlain by lime mudstone and caped by intraclastic peloidal packstone facies. This is the shallowing-upward type cycle, which could be caused mainly by the sea level change.

Cycle type F. This type cycle at the base starts with silty-sandy peloidal limestone and capped by calcareous sandstone facies, indicating shallow marine environment and minor sea level fluctuations.

Cycle type G. G type cycle starts with sandstone facies at the base and overlain by iron rich silty peloidal limestone facies at the top. This type cycle is the indication of the shallow marine environment and terrestrial influence.

Cycle type H. This type cycle starts with lime mudstone at the base, overlain by rudstone facies and capped by silty-sandy lime mudstone facies, which is the indication of the shallow marine environment and the general sea level fall.

Cycle type I. This type cycle is characterized by bioclastic peloidal wackestone at the base and three sub-types were defined in this cycle. I1 at the base starts with bioclastic wackestone and capped by lime mudstone facies at the top. I2 type cycle starts with bioclastic wackestone at the base, overlain by algal wackestone, algal grainstone, and intraclastic grainstone and capped by extraclastic peloidal grainstone facies at the top. I3 cycle starts with peloidal wackestone and capped by peloidal intraclastic packstone facies. This type cycle is mainly the indication of sea level fluctuation.

Meter scale cycles were identified along the measured succession and these meter-scale cycles are equivalent to 5th and 4th order of Milankovitch cycles (Figure 18, 19). In the succession total of 25 fifth order and 6 fourth order cycles were defined. Milankovitch cycles of the İnpiri Limestones are difficult to define due to presence of thick cover. But if the covers are not taken into consideration, rough calculations may be possible. Assuming that the bounding ages of the İnpiri Limestones are Upper Barremian and Albian age, the total age roughly would be 27.9 million years. By dividing the total age of the succession to the number of defined fifth order cycles, the rough age of each cycle would be 1Ma. This result is unlikely to be true because 1Ma old cycles are ascribed to third order cycles (Einsele, 2000, p356).

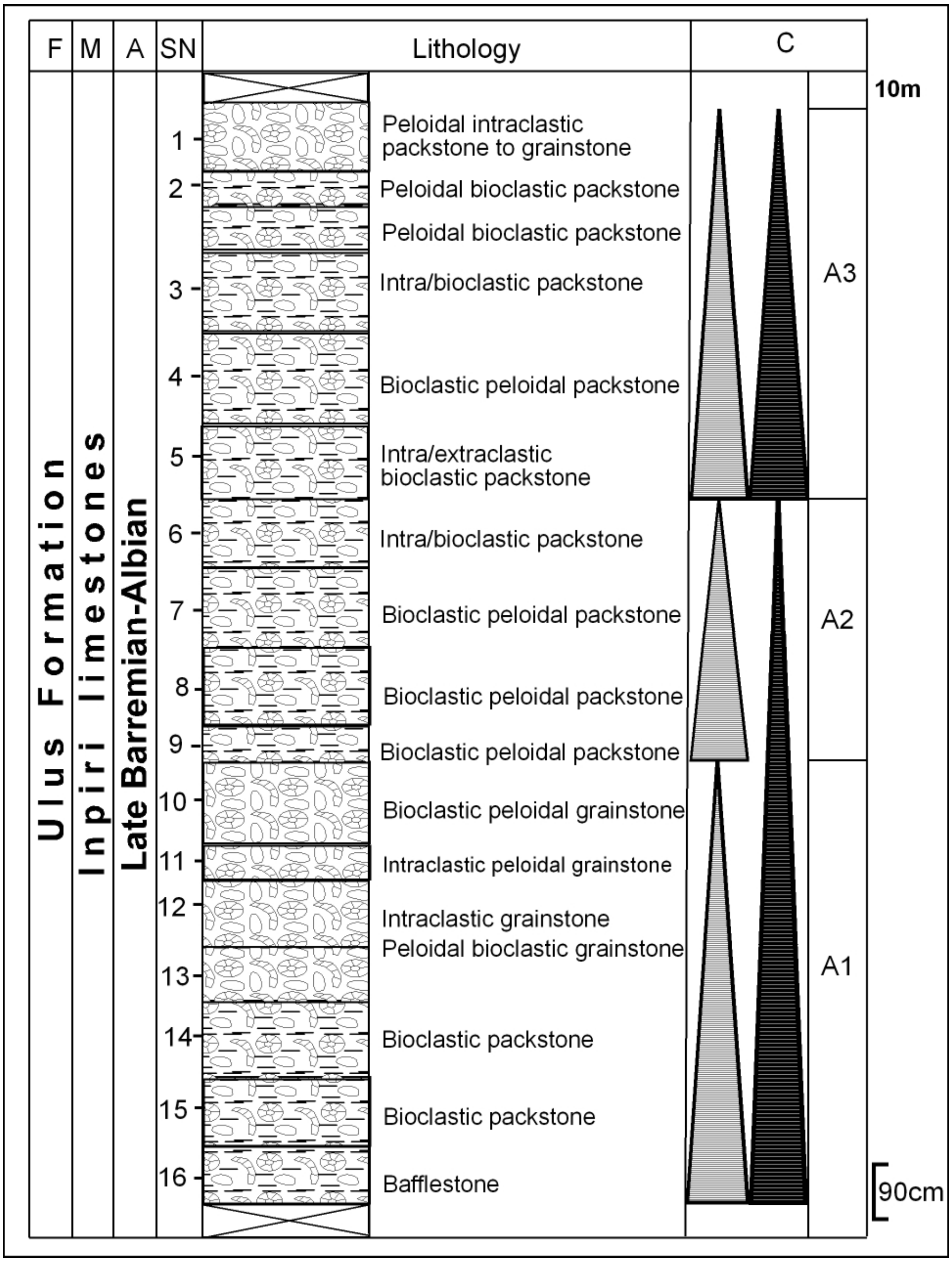

Figure 18. Cycles recognized in the İnpiri Limestones (Ipn).

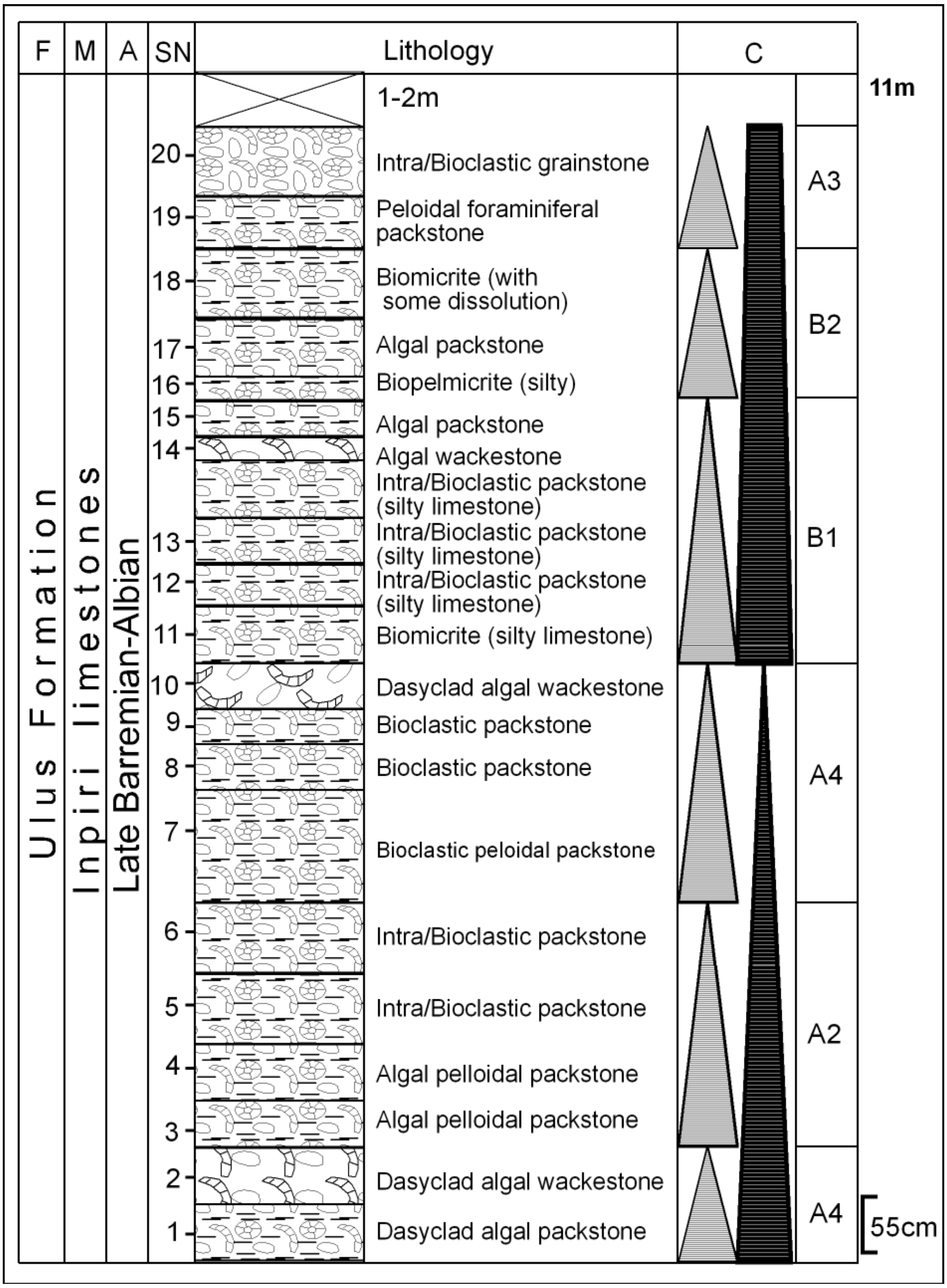

Figure 18. Continued (Ipn U).

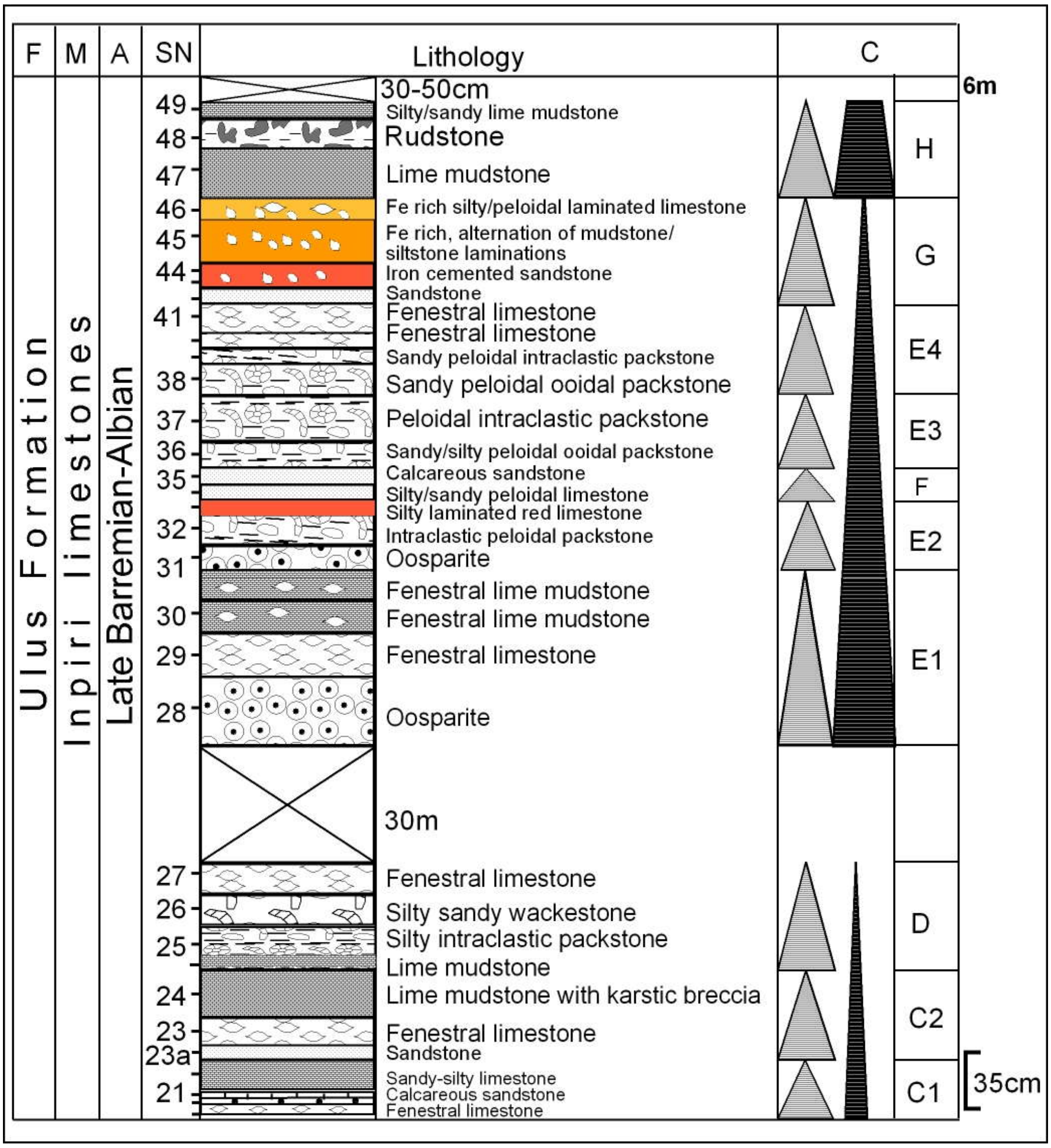

Figure 18. Continued (Ipn U).

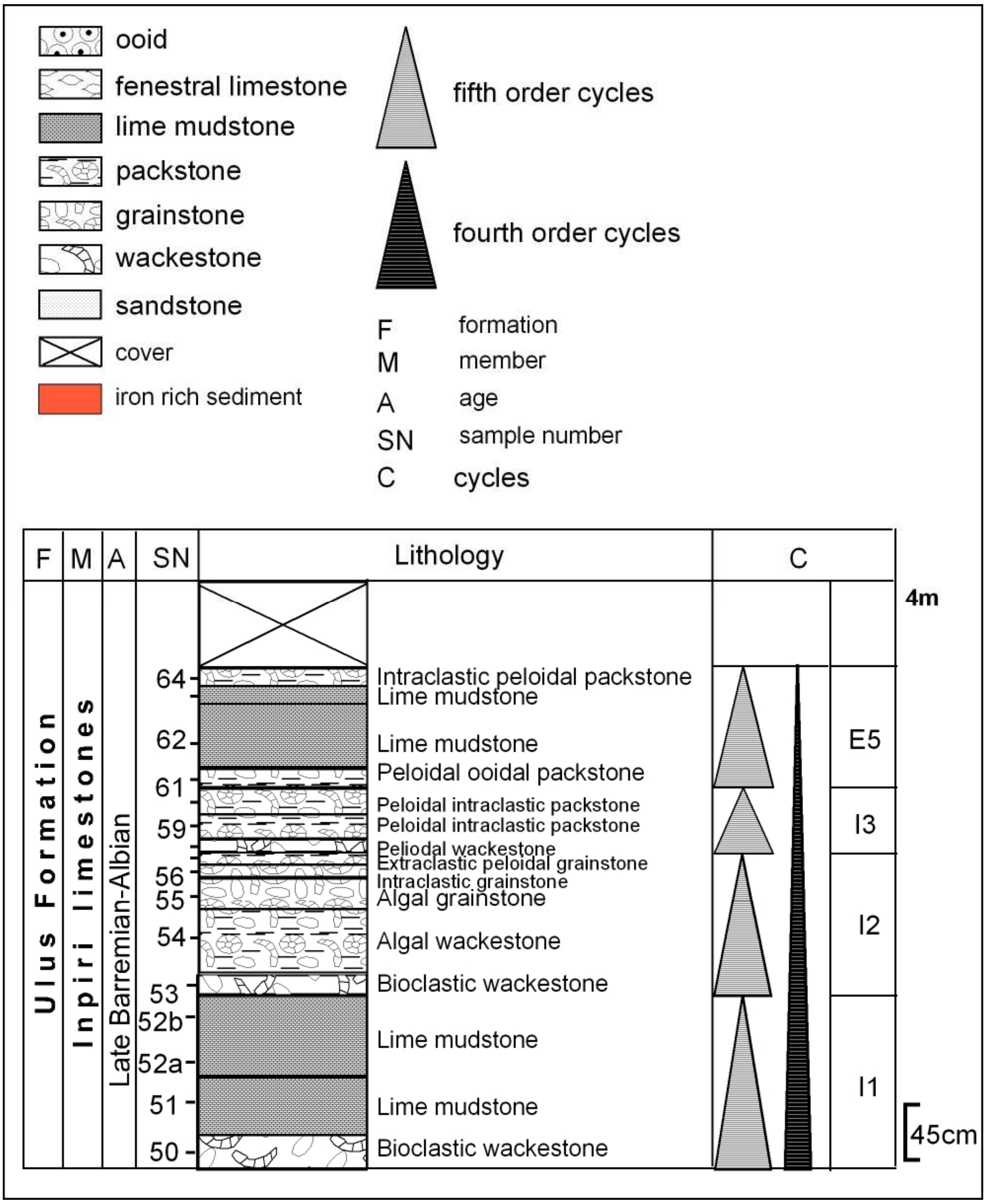

Figure 18. Continued (Ipn U).

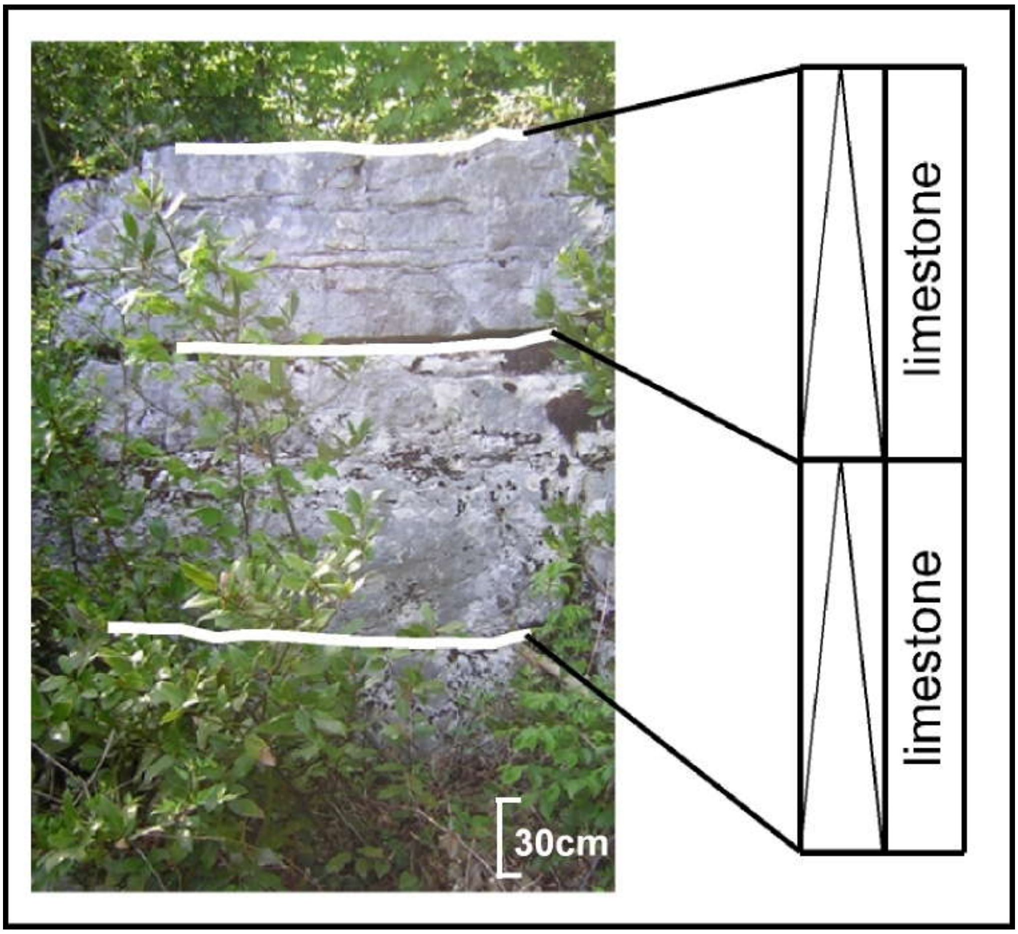

Figure 19. Field view of cycles of the İnpiri Limestones.

CHAPTER V

SEQUENCE STRATIGRAPHY

Sequence stratigraphy is a descriptive tool used by stratigraphers to establish or predict the spatial patterns of deposition of a constrained sedimentary succession deposited during a single sea-level rise and fall cycle. Sequence stratigraphy is defined as a stratigraphic method that uses unconformities (sequence boundaries) and their correlative conformities to package sedimentary successions into spatially and temporally constrained sequences (Vail et al., 1991; Emery and Myers, 1996). Any unconformity bounded "sequence" can then be divided internally into smaller-scale genetically related units (systems tracts) deposited during individual phases of sea-level change (i.e. transgression, high-stand, regression, and low-stand). This method is a powerful tool in modern stratigraphic studies because it integrates many aspects of stratigraphy including seismic stratigraphy, lithostratigraphy, cyclostratigraphy, event-stratigraphy, and biostratigraphy into a single stratigraphic framework. The development of a sequence stratigraphic framework for any given depositional basin provides the stratigrapher not only with a temporal framework for studying depositional change, but it also provides a spatial framework. An important aspect of sequence stratigraphy is its use in basin analysis through the establishment of very low-resolution (megasequence scale) to very high-resolution depositional spatio-temporal patterns (parasequence scale).

5.1. Türbeyanı Marls

As already mentioned, the Türbeyanı Marls overlie the İnaltı Formation unconformably. Below the unconformity surface the rock unit is composed of karstic breccia; an indication of subaerial exposure of the İnaltı Formation. The

Türbeyanı Marls start with black shale layer, as interpreted in previous chapters, indicating there was a sudden drowning of carbonate platform, resulting in sudden transgressive regime, which in turn causes low rate of sedimentation – sediment starvation in the basin. This unconformity surface is defined to be type-3 sequence boundary. According to Schlager (1989) type-3 sequence boundary forms particularly on drowned carbonate platforms, when the rate of subsidence exceeds even the most rapid fall of sea level during a particular eustatic cycle.

In the succession transgressive systems tract start with black shale (Figure 20). Transgressive systems tract is characterized by one or more retrogradational parasequences sets. Parasequences within the transgressive systems tract onlap onto the sequence boundary in a landward direction and downlap onto the transgressive surface in a basinward direction. The top of the transgressive systems tract is the downlap surface. The downlap surface is a marine-flooding surface onto which the toes of prograding clinoforms in the overlying highstand systems tract downlap. This surface marks the change from a retrogradational to an aggradational parasequences set and is the surface of maximum flooding. Black shale is overlain by the cyclic alternation of claystone and mudstone facies. Mudstone facies are capping claystone facies at the top of each cycle, indication these cycles are the result of fluctuation of sea level during the transgressive systems tract. The thickness of mudstone facies in these cycles are thinner relative to claystone facies; this may result from sea level fall causing less accommodation space and/or by dry climatic conditions causing less sediment transportation to the basin. These cycles are continued with relatively thinner cycles of mudstone facies alternations. Upper capping layers of these cycles are relatively richer in carbonate content according to field observations. The uppermost layer of the last cycle of the alternating mudstone facies is the maximum flooding surface, as it could be defined from the thickness variations of facies, also upper boundary of transgressive systems tract. This systems tract is composed of two parasequence set.

Lastly mentioned cycles are continued with the alternations of claystone limestone facies, indicating there is a significant change of depositional

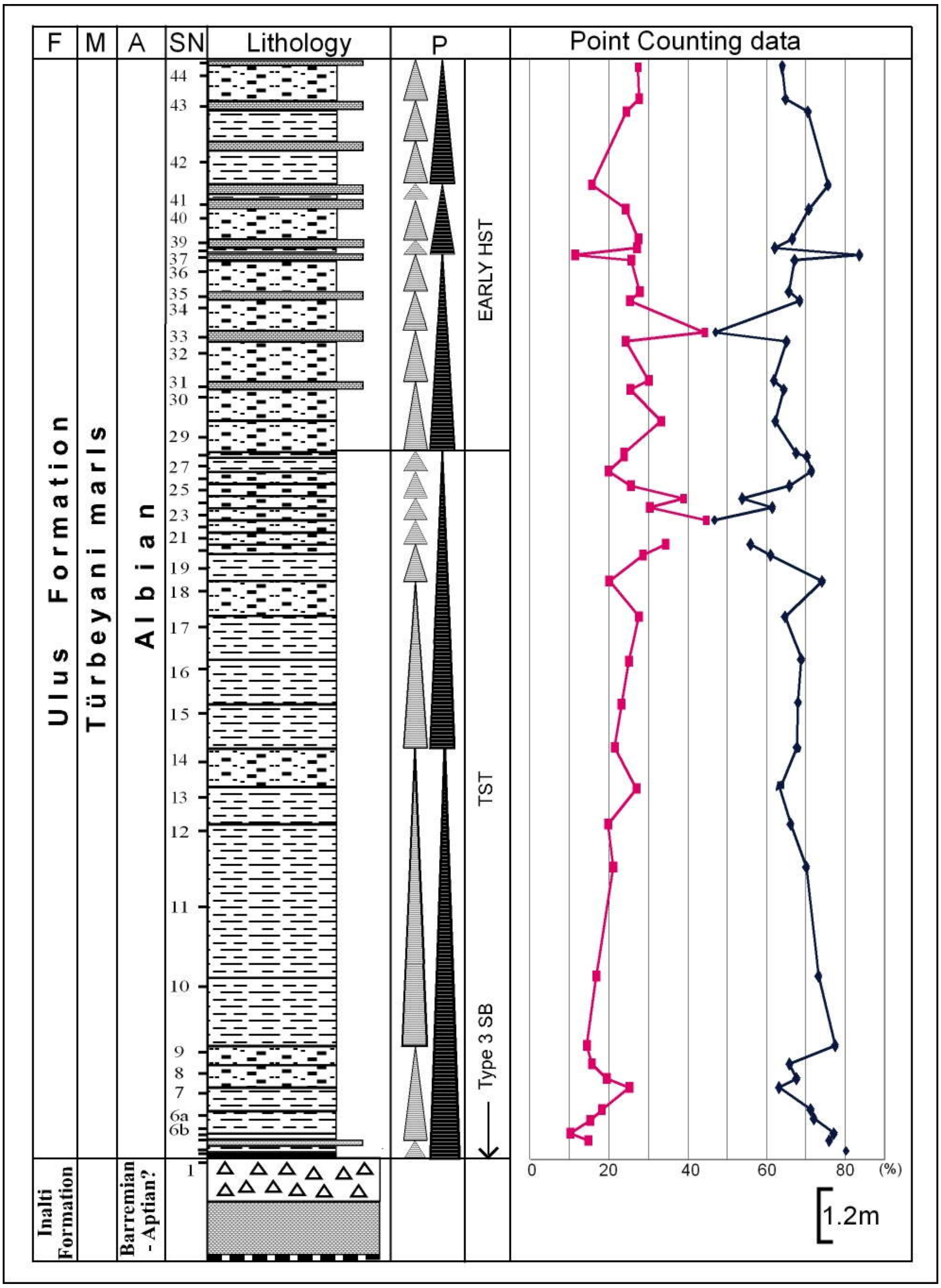

Figure 20. Sequence stratigraphic units of the Türbeyanı Marls.

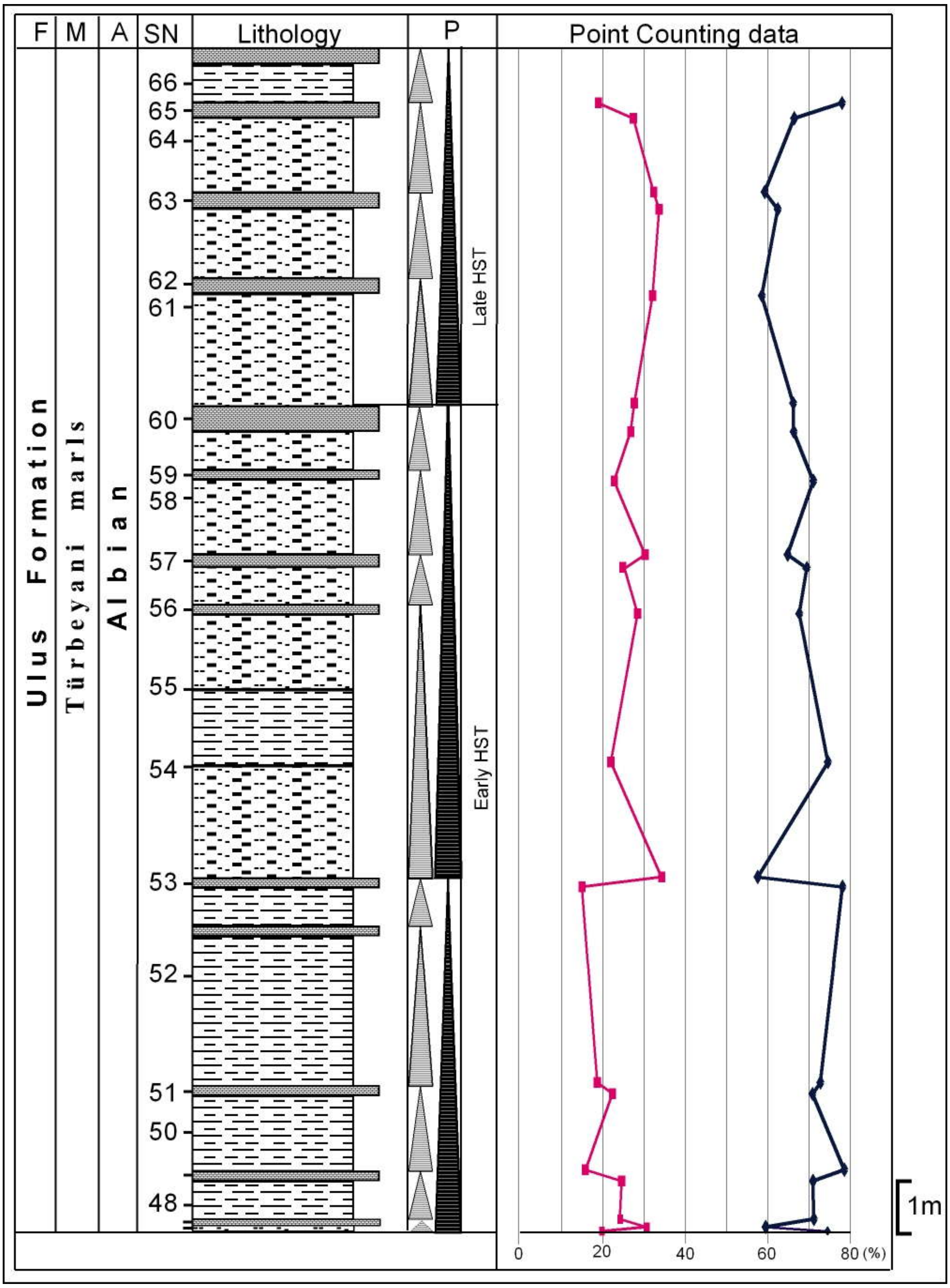

Figure 20. Continued.

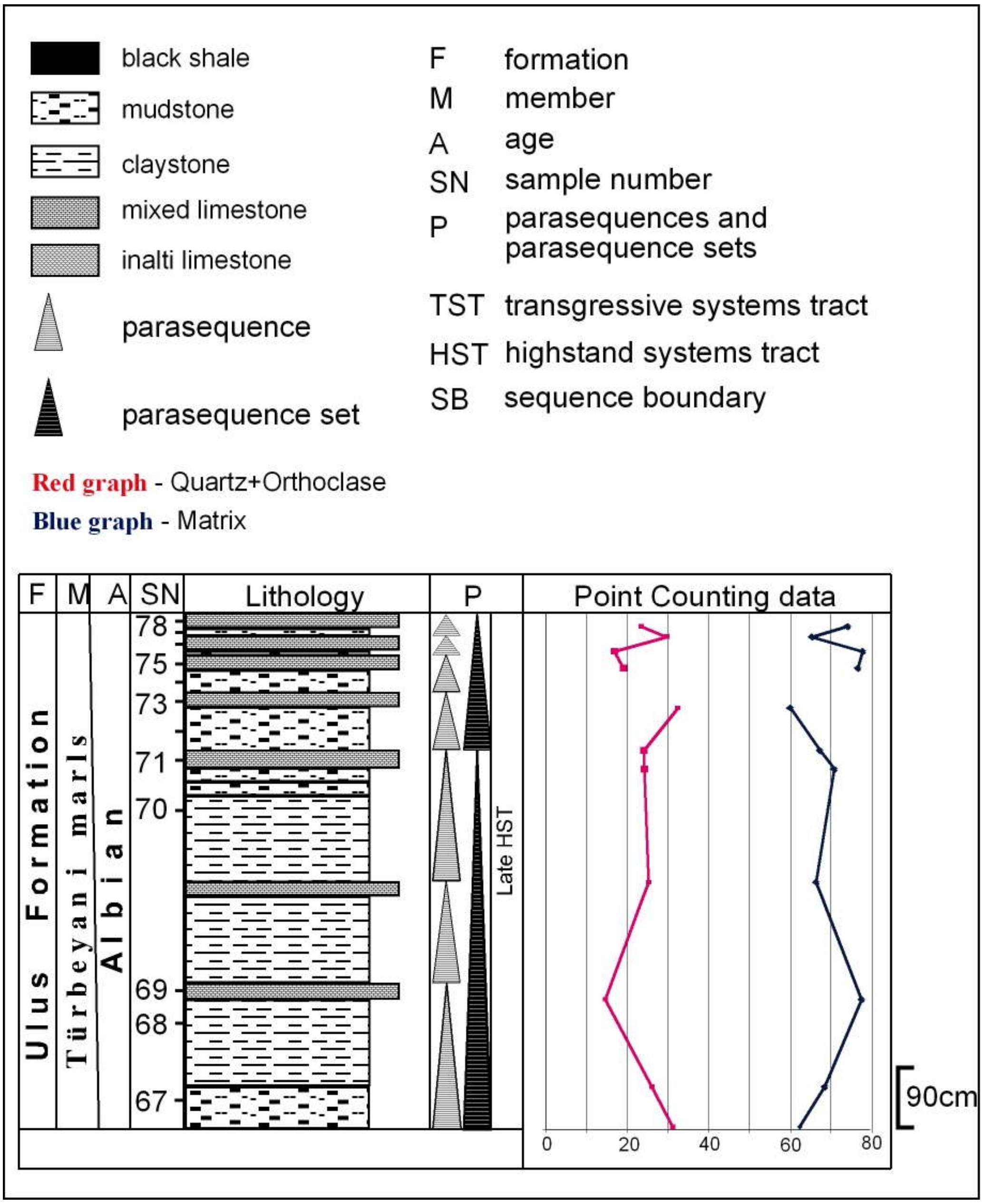

Figure 20. Continued.

environment. This sign is the indication of the beginning of the highstand systems tract. Highstand systems tract is commonly widespread on the shelf and may be characterized by one or more aggradational parasequence sets that are succeeded by one or more progradational parasequence sets with prograding clinoforms geometries. Parasequences within the highstand systems tract onlap onto the sequence boundary in a landward direction and downlap onto the top of the transgressive or lowstand systems tracts in a basinward direction. In the measured section the highstand systems tract is entirely composed of parasequences of limestone-marl alternations. Along the section the thickness of parasequences of highstand systems tract shows variations. Generally parasequences at the base are composed of thicker marl (mudstone/claystone) facies and capped by relatively thinner limestone facies. At the top of the section the thickness of intercalating marl facies get much thinner with relative to thickness of limestone facies. This could be the result of dry climatic conditions and/or loss of accommodation space caused by tectonic uplift. The uppermost part of highstand systems tract is cut by fault, making it difficult to define its upper boundary. This systems tract is composed of 7 parasequence sets. Both thickness variation of layers and quantitative measurements were used to define sequence stratigraphic units. Quantitative measurements on the relative ratio of quartz and feldspar content, as well as other minerals', display parallel fluctuations with parasequences and parasequence sets. Especially in parasequence sets' contacts the differences in minerals' ratios distinctively change. There is only one sequence observed in the measured section. Starting with transgressive systems tract at the base and overlain by a highstand systems tract till the top of the section.

5.2. İnpiri Limestones

Sequence stratigraphic interpretation of the İnpiri Limestones was conducted using field descriptions and microfacies analysis of the thin section samples. Total of 25 parasequence sets, three transgressive systems tract and three highstand systems tracts were defined within the measured section of the İnpiri

Limestones. The sequences defined in the measured section are type 2 sequences. Type 2 sequence boundaries are formed when the rate of eustatic fall is less than or equal to the rate of basin subsidence at the platform/ bank margin (Wagooner et al., 1988), as a result the outer-platform and platform margin may experience brief subaerial exposure (Sarg, 1988). According to Vail et al. (1984, 1991), the sequence boundary corresponds to the erosion surface created by sea level drop, or to the base of the lowstand deposits overlying deeper facies. Commonly, lowstand sediments are missing altogether, and transgressive deposits mark the beginning of a new sequence.

The Ipn section of the İnpiri Limestones is composed of one transgressive systems tract at the base and one highstand systems tract at the top, which complete sequence (Figure 21). Type of this sequence is difficult to define since the bottom of the section is covered, making it difficult to define sequence boundary. The facies distributions of the section do not vary much along the section. To differentiate systems tract from each other the quartz content of facies was used. Quartz minerals are almost absent in transgressive systems tract, but starting from the bottom of the highstand systems tract abundance of quartz minerals is observed. The abundance of quartz minerals is the indication of the sea-level fall which in turn is the indication of transition from transgressive to highstand systems tract.

Ipn U section of the İnpiri Limestones at the bottom starts with transgressive systems tract (Figure 21). Intercalation of bioclastic wackestone-packstone facies with almost no or very less quartz minerals indicates that the environment is transgressive. These facies are overlain by bioclastic wackestone packstone facies rich in silt size quartz minerals. This shows the transition from transgressive to highstand systems tract. Near the top of the highstands systems tract occurrence of fenestral limestone and sandstone facies are the indicators of the shallowing upward of the depositional setting. Shallowing upward is observed till the cover which bounds the highstand systems tract at the top. The occurrence of cover again makes it difficult to define type of sequence boundary.

Over the cover highstand systems tract is dominant with ooidal packstone-

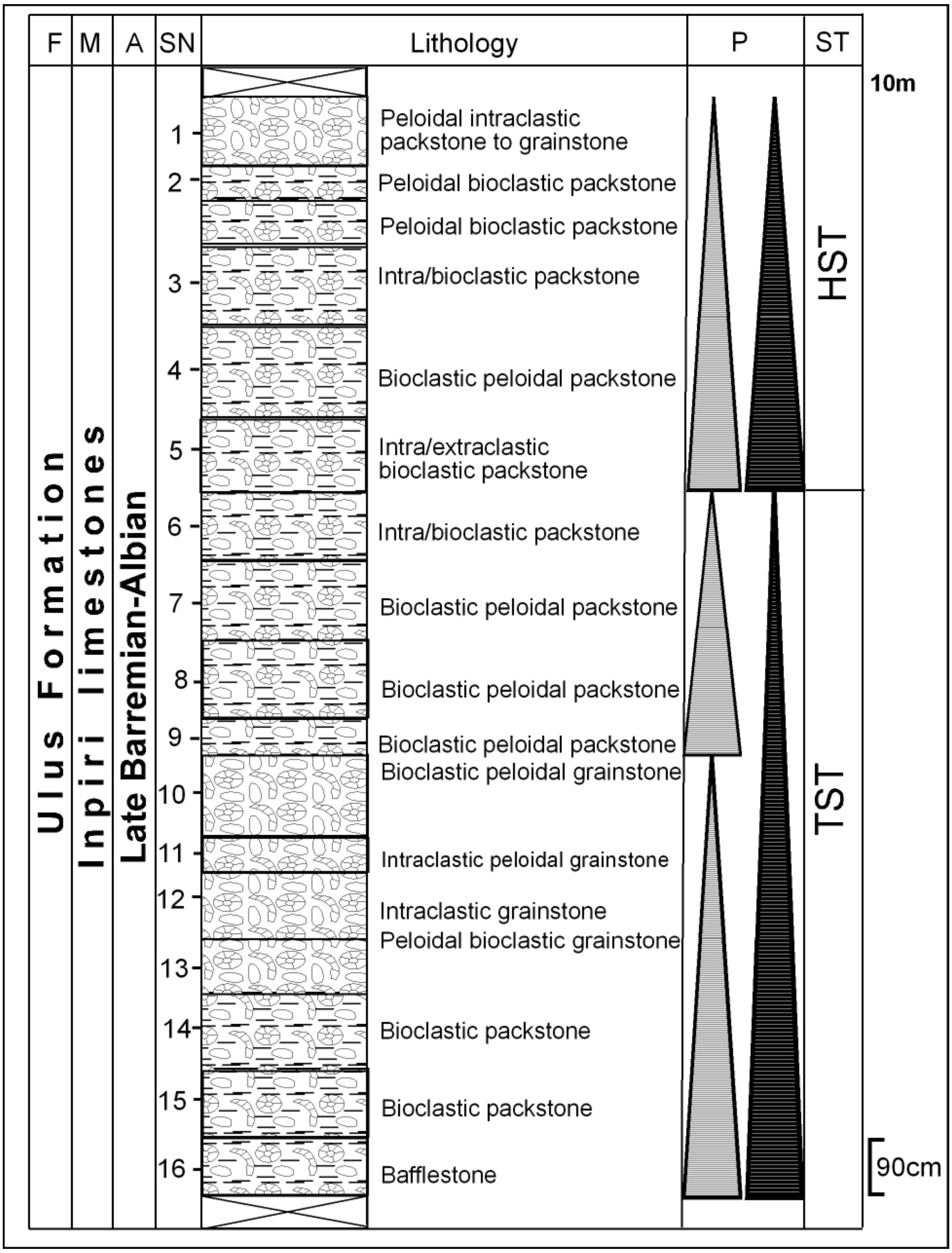

Figure 21. Sequence stratigraphic units of the İnpiri Limestones (Ipn).

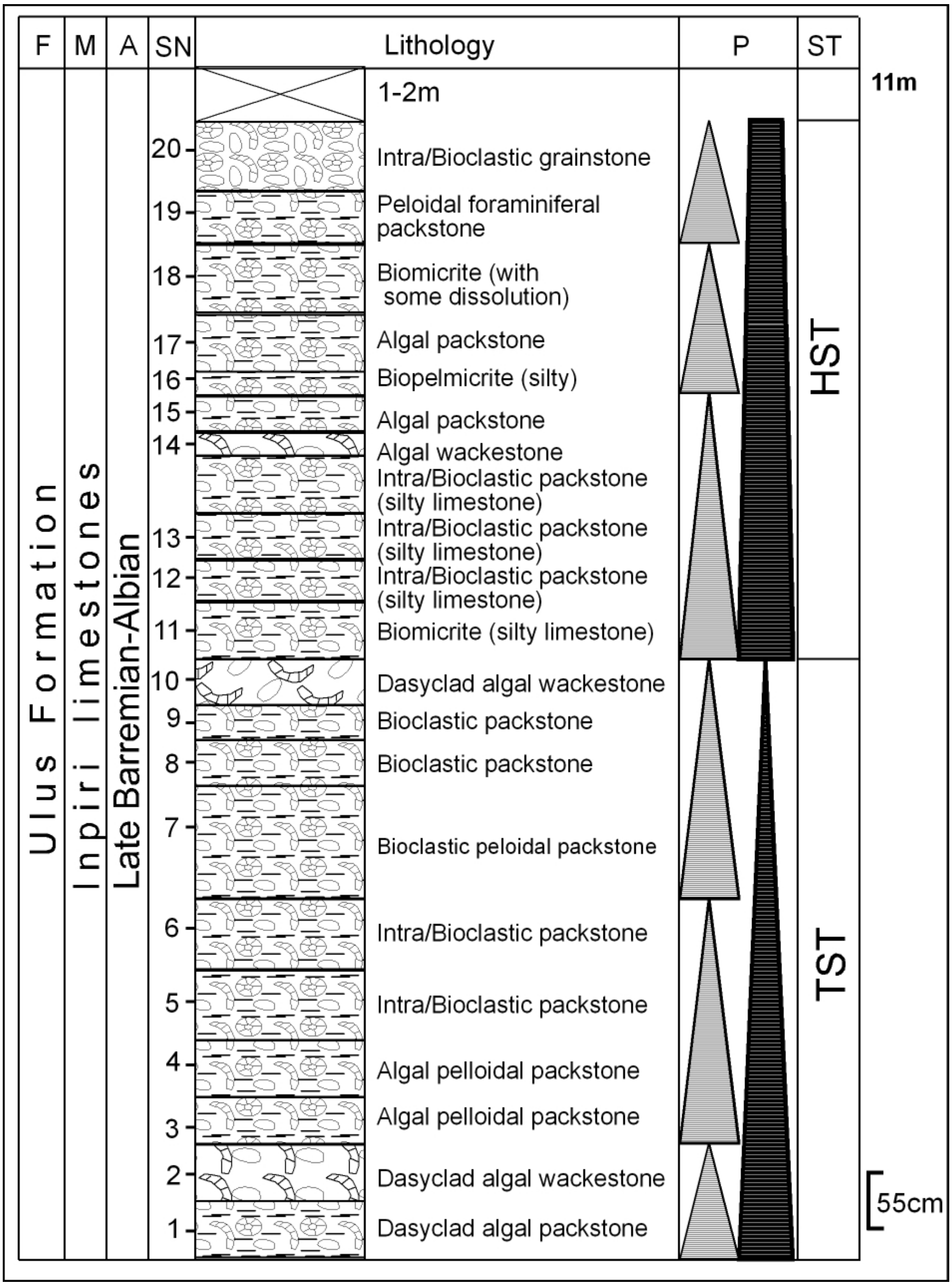

Figure 21. Continued (Ipn u).

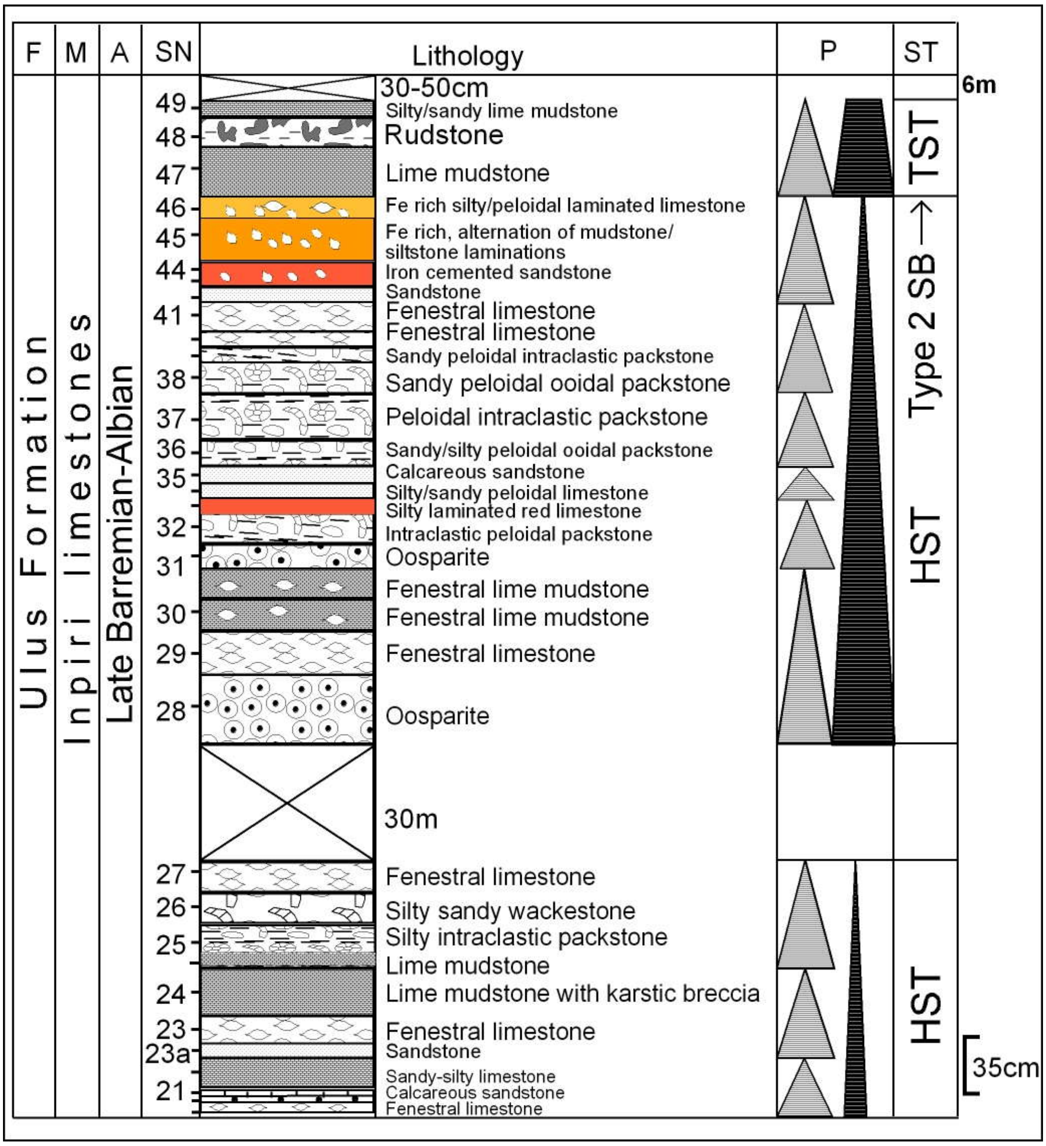

Figure 21. Continued (Ipn u).

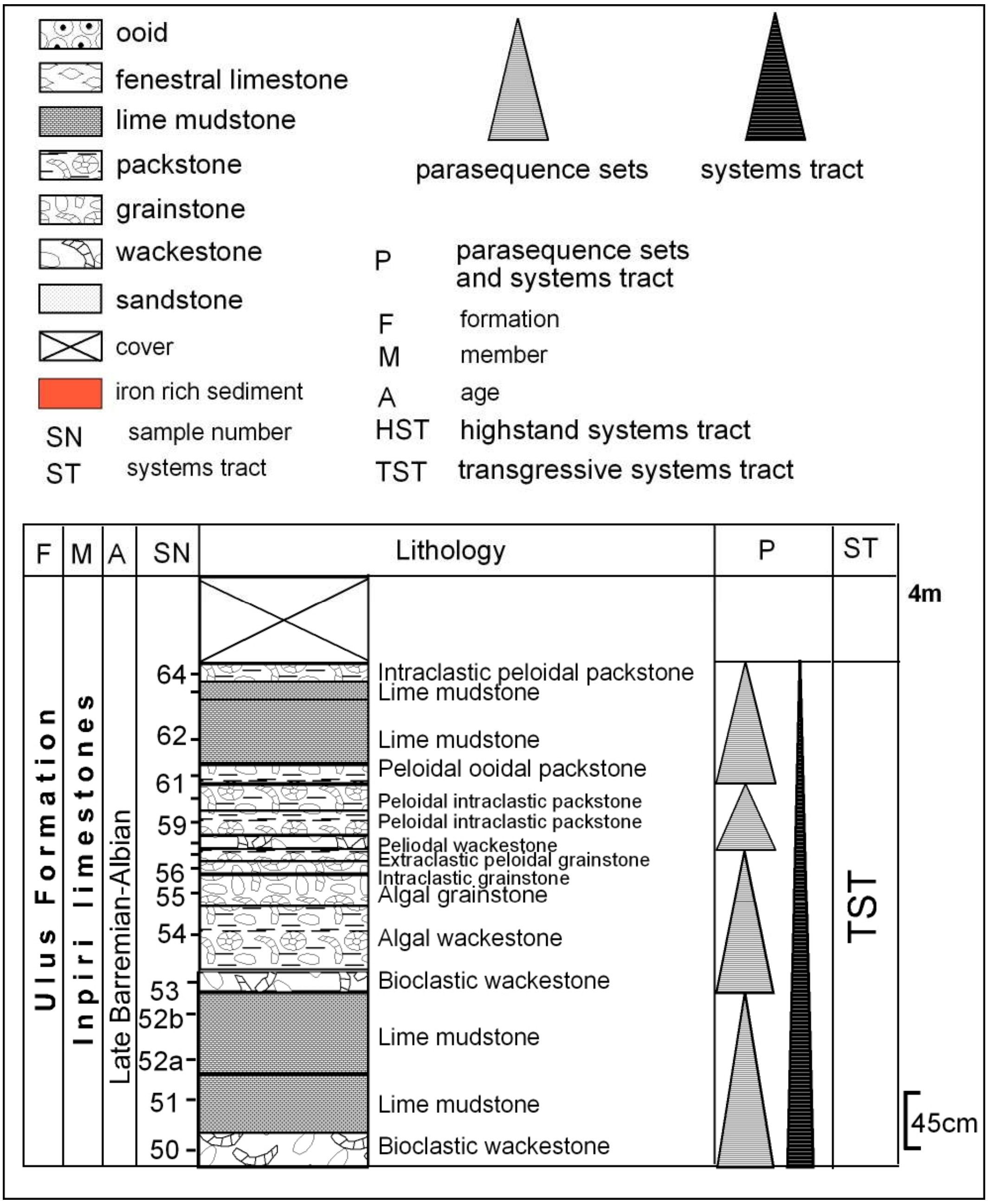

Figure 21. Continued (Ipn u).

grainstone, fenestral limestones and sandstone facies. At the top of the systems tract iron rich sandstone and sandy-silty limestone facies which are the indicators of shallow marine environment. Moreover, iron rich red sediments show that terrestrial influence is present and there may be short term subaerial exposure. Additionally, the uppermost boundary of this highstand systems tract could be defined as a type 2 sequence boundary.

Lastly, at the top of the succession transgressive systems tract overlies type 2 sequence boundary. Lime mudstone and bioclastic packstone and grainstone facies are dominant in this systems tract. This systems tract continues till the top of the measured section and is cut by cover.

Presence of covers in the measured section makes it impossible to define and interpret sequence boundaries. Only in Ipn U46 sample clear type 2 sequence boundary is observed.

CHAPTER VI

IMPLICATIONS FOR POSSIBLE SOURCE AND RESERVOIR ROCKS

In this study the Türbeyanı Marls and the İnpiri Limestones members of Ulus formation were investigated in order to determine their possibility of being source and reservoir rocks, respectively.

Türbeyanı Marls are mainly composed of grey to dark grey, black colored marl facies which at first sight could be thought as a possible petroleum source rock. There is only one black shale layer identified at the base of the succession. In order to evaluate the possibility of succession being source rock total organic carbon (TOC) values are essential. TOC values of several samples from the lower part of the succession were obtained and unexpectedly they were very low. The values range between 0.07 – 0.46%, which are considered very low for being a source for hydrocarbon generation. According to Bissada (1982) potential and/or effective petroleum source rocks contain a minimum of 1% organic carbon, independent of lithology. By comparing this result to the upper part of the succession, it is easy to say that the lighter colored, more silt size material containing layers of the succession are not possible petroleum source rocks too. Heterogeneity within the Türbeyanı Marl sequences, the influx of silt and sand size contents, less amount of black shales, low ratio of TOC content at the bottom of the succession helps us to draw a conclusion that this formation is not possible petroleum source rock.

The İnpiri Limestones are observed to overlie the Türbeyanı Marls, also in some areas there is a lateral transition of these formations (Tüysüz et al., 1997).

The İnpiri Limestones are considered as a possible reservoir rock in the studied area. This formation is mainly composed of beige colored peritidal limestone facies, mainly intercalation of bioclastic, intraclastic, extraclastic, peloidal wackestone, packstone, grainstone and lime mudstone facies. Fenestral and ooidal limestone and sandstone facies were also recognized. The facies analyses of the samples of the measured section were studied under microscope. The pore spaces observed in the thin section are all filled by calcite cement. Especially in fenestral limestones, sandstone and ooidal grainstone-packstone facies, which could be possible reservoir rock units of the succession, are well calcite cemented. From this point of view it is possible to say that the İnpiri Limestone member is not suitable as possible reservoir rock. However, porosity and permeability factors should be measured for precise determination.

If the TOC values of the Türbeyanı Marls are sufficient enough and pore spaces of the İnpiri Limestone are cement free, at some certain levels the İnpiri Limestones could be possible petroleum reservoir rocks. Especially in Ipn section where grainstone facies are present (Ipn 10 - Ipn 13 (2m)) and in Ipn U section the facies between Ipn U 28 and Ipn U 46 (4m), composed of mainly ooidal grainstone-packstone, fenestral limestone and sandstone facies are potential petroleum reservoir rocks. At the lateral contact of the Türbeyanı Marls and the İnpiri Limestone where intertonguings are highly possible, stratigraphic traps could be present, where generated oil could be trapped.

CHAPTER VII

CONCLUSIONS

Sedimentology, cyclostratigraphy and sequence stratigraphy of the Türbeyanı Marls and the İnpiri Limestones were studied in this research. The following results have been obtained in this study.

The total studied thickness of the Türbeyanı Marls is 54.56 m. In this range 5 facies were recognized in the studied section. These are marl, claystone, mudstone, limestone and black shales. Marls of the section are classified using shale classification (Potter et al., 1980) since their carbonate content was not obtained. Marl occurs throughout the studied section and their thickness show variations, ranging from centimeter to meter scale. Claystone facies also occur throughout the section, showing similar properties to marl facies. Mudstones facies, like marl and claystone facies are represented along the studied section. They also have similar characteristics to those mentioned above. Limestone facies are mixed with siliciclastic in composition. Their thicknesses are thinner relative to claystone and mudstone facies. Limestone facies occurs starting from the middle part of the succession. The succession is mainly composed of alternations of marl (claystone/mudstone) – limestone facies. Black shale facies is observed only in the lowermost part of the succession, showing very good lamination and rich in organic content.

During detailed petrographic analysis several minerals were recognized in the studied section. These are quartz, orthoclase, muscovite, opaque, glauconite and iron. Quartz and orthoclase are most abundant in all facies. They show nearly constant percentage along the succession. Opaque minerals are also very abundant in the studied section. They show higher percentage especially in the lower part of the succession. Muscovites are also characteristic mineral of the succession. They are represented in all facies throughout the studied section. Their percentage is slightly more in the lower part of the section. Glauconite minerals are one of the most important minerals of the succession as they are key mineral to defining the depositional environment of the succession. They occur throughout the succession, but they are very rare in the mudstone and claystone facies of lower part of the succession. Glauconite minerals show higher percentage especially in limestone facies which would be coincident to the upper part of the studied section. Iron is observed mostly in iron nodule form, also as iron impregnations. They are present throughout the succession and they show slightly higher percentage at the upper part of the succession.

In this study depositional environment of the Türbeyanı Marls was defined as an outer shelf, by interpreting the unconformable boundary between the Türbeyanı Marls and the Inalti formation. Moreover occurrence of glauconite minerals, participation of black shales and ammonite fossils, and grain sizes being mostly silt size indicates that the depositional environment was located in outer shelf area. However, Tüysüz et al. (1997) claimed that the Türbeyanı Marls were deposited in shallow marine/shelf slope environment because of overlying shallow marine İnpiri Limestones, slightly lateral angular transition, having glauconite minerals, and containing ammonite fossils.

Identification of cycles and cyclic variations is another purpose of this study. A total of 39 small (5^{th}) order and 7 higher (4^{th}) order cycles were recognized. The 5^{th} order cycles are equivalent to parasequences and 4^{th} order cycles are equivalent to parasequence sets of sequence stratigraphy. Five different type cycles and four sub-type cycles are observed in the studied section according to order of their base and cap facies. These are A, B, C, D, E main types and D1, D2, E1, E2 sub-types.

High resolution sequence stratigraphy study within the succession has resulted in the recognition of one type-3 sequence boundary, one transgressive and one highstand systems tracts. Total of 39 parasequences and 9 parasequence sets were defined in the studied section.

The İnpiri Limestones mainly composed of bioclastic, peloidal, and intraclastic wackestone-packstone-grainstone facies. Moreover, occurrence of lime mudstone, fenestral limestone, ooid packstone-grainstone, and sandstone facies are present as well. Total thickness of the measured section is near to 30m.

The depositional environment of the İnpiri Limestones is defined as a peritidal environment due to occurrence of birdseyes structures/fenestrae, peloids, fecal pellets, stromatolites, ooids, oncoids, mud cracks, karstic brecciation. Moreover, occurrence of abundant quartz minerals and sometimes siltstone and sandstone laminations are also indicators of shallow marine environment.

In the İnpiri Limestones 25 small (5^{th}) and 6 higher (4^{th}) order cycles were recognized, nine main type and sixteen sub-type cycles are recorded. These are A, B, C, D, E, F, G, H, I main types and A1, A2, A3, A4, B1, B2, C1, C2, E1, E2, E3, E4, E5, I1, I2, I3 sub-types.

Within the measured section of the İnpiri Limestones three sequences were recorded, but due to occurrence of covers only one type-2 sequence boundary could be recognized along the succession. Three transgressive and three highstand systems tract were recognized within the sequences.

This study revealed that the Türbeyanı Marls are not economically valuable petroleum source rock. The TOC values of marl facies of the Türbeyanı Marls are below sufficient value. The result of this research shows that the İnpiri Limestone member is not suitable as reservoir rock, however, porosity and permeability factors should be measured for precise determination.

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APPENDIX A

Point counting data obtained from the samples taken from the Türbeyanı Marls.

Table A1

Components / Sample Numbers	Quartz+ Orthoclase, (%)	Muscovite, (%)	Matrix, (%)	Glauconite, (%)	Bioclast, (%)	Cement, (%)	Iron, (%)	Opaque, (%)	Facies
Ing 1		-	-	-	-	-	-	-	limestone
Ing 2		-	-	-	-	-	-	-	black shale
Ing 3	15.5	2.6	80.2	0.3	0.2	-	-	3	claystone
Ing 4	-	-	-	-	-	-	-	-	marl
Ing 5	14.8	4.8	76				2.6	1.6	claystone
Ing 6a	10.2	7.8	77.2				4	0.8	claystone
Ing 6b	15.2	5.8	72.1				2.5	4.2	claystone
Ing 7	18.2	3.5	71.3				3.7	2.7	claystone
Ing 8	25.2	3.9	63.3				0.9	6.1	mudstone
Ing 8 original	19.4	4.7	67.7		0.1		5.7	1.9	mudstone
Ing 9	15.7	5.5	65.9				6	6.6	claystone
Ing 10	14.4	2.3	77.5				0.5	4.5	claystone
Ing 11	16.8	3.1	73.3				0.9	5.3	claystone
Ing 12	21.1	2.5	70.2		0.1		0.9	4.5	claystone
Ing 13	19.8	6.1	66.2				0.7	5.5	mudstone
Ing 14	27	4.1	63.5				0.1	4.3	claystone
Ing 15	21.5	2	67.8				0.5	7.3	claystone
Ing 16	23.2	3.7	68.1				0.1	4.5	claystone
Ing 17	25.1	1.8	68.9		0.1		1.1	2.5	mudstone
Ing 18	27.6	2.9	64.8				1.5	3	claystone
Ing 19	20.1	2.7	74.2				0.9	1.9	mudstone
Ing 20	28.6	2.5	61.1	1.9	0.7		1.3	3.5	mudstone
Ing 21	35.7	2.9	56	0.3			2.5	2.1	mudstone
Ing 22	-	-	-	-	-	-	-	-	mudstone
Ing 23	44.7	2.5	46.8				1.9	3.7	limestone

Table A2

Components / Sample Numbers	Quartz+ Orthoclase, (%)	Muscovite, (%)	Matrix, (%)	Glauconite, (%)	Bioclast, (%)	Cement, (%)	Iron, (%)	Opaque, (%)	Facies
Ing 24	30.4	3.8	61.5				0.5	3.5	mudstone
Ing 25	38.9	3.9	53.9				1.3	1.5	mudstone
Ing 26	25.6	2.3	65.9				3.5	2.3	mudstone
Ing 27	19.9	3.7	71.5	0.7	0.5		2.1	0.9	claystone
Ing 28	23.8	1.7	70.3	0.3			1.3	1.9	claystone
Ing 29	23.8	3	67.6	1.6			2.8	1.2	mudstone
Ing 30	33.2	1.5	62.3	0.3			1.1	1.1	mudstone
Ing 31	25.5	2.7	64.5	0.1		6.1		0.3	limestone
Ing 32	30.1	2.5	62			1.9	2.3	0.7	mudstone
Ing 33	24.3	3.3	65.2	0.1	0.3	2.3	2.1	1.7	limestone
Ing 34	44.3	4.9	47.1				1.9	1.5	mudstone
Ing 35	25.3	1.7	68.5		0.7	1.7	1.3	0.1	limestone
Ing 36	27.8	2.3	65.8	0.1			2.5	1.1	mudstone
Ing 37	25.7	3.7	67.2	0.1			0.9	1.9	limestone
Ing 38	11.4	2.7	83.7	0.1	0.1		1.1	0.5	claystone
Ing 39	27.2	4.9	62.2	0.1	0.5	2.5	0.1	1.7	limestone
Ing 40	27.5	2.1	66.7				2.1	1.1	mudstone
Ing 41	24.3	2.5	70.8		0.1		0.5	1.3	limestone
Ing 42	15.7	4.3	75.7		0.1		1.9	1.9	claystone
Ing 43	24.4	2.1	70.6				0.9	1.5	limestone
Ing 44	27.7	3.5	64.9	0.1			2.1	1.1	mudstone
Ing 45	27.3	4.3	64				2.5	1.5	limestone
Ing 46	19.8	2	74.4	0.8			2	1	mudstone
Ing 47	30.6	2.1	59.5	0.5			5.2	1.7	limestone
Ing 48	24.2	0.5	71.2				1.5	2.1	claystone
Ing 49	24.6	0.9	70.9	0.5	0.3		1.7	0.5	claystone
Ing 50	15.8	1.1	78.5	0.1			3.3	0.7	claystone

Table A3

Components / Sample Numbers	Quartz+ Orthoclase, (%)	Muscovite, (%)	Matrix, (%)	Glauconite, (%)	Bioclast, (%)	Cement, (%)	Iron, (%)	Opaque, (%)	Facies
Ing 51	22.4	0.7	70.8	0.1			2.5	2.9	limestone
Ing 52	18.8	2.9	72.7				4.1	1.1	claystone
Ing 53	15	3.7	78.1				0.9	1.9	limestone
Ing 54	34.3	3.1	57.5				3.3	1.1	mudstone
Ing 55	22	1.3	74.6	0.1			0.5	0.9	claystone
Ing 56	28.4	1.5	67.6				0.9	1.3	limestone
Ing 57	25.3	1.7	69.5	0.1			1.5	1.5	limestone
Ing 58	30.3	0.9	64.8			0.7	1.9	0.9	mudstone
Ing 59	22.8	0.5	71.1	1.5			2.3	1.3	limestone
Ing 60	26.8	0.9	66.2	0.9	0.5		2.7	1.3	limestone
Ing 61	27.6	1.7	66.1	0.7			2.3	1.3	mudstone
Ing 62	32.1	3.5	58.6	1.9			0.9	2.5	limestone
Ing 63	33.7	0.7	62.4	0.9	0.1		0.3	1.3	limestone
Ing 64	32.4	4.1	59.2	0.7			1.5	1.7	mudstone
Ing 65	27.4	3.5	66.4	0.1			0.3	1.9	limestone
Ing 66	19	1.1	77.9	0.3			0.7	0.5	claystone
Ing 67	31.2	4.1	62.3	0.1			0.9	0.9	mudstone
Ing 68	26	1.1	68.5	0.1			0.7	3.1	claystone
Ing 69	14.6	1.3	77.6	0.5	0.3			5.2	limestone
Ing 70	25.2	3.9	66.4	0.3			2.5	1.3	claystone
Ing 71	24.2	0.7	70.8	0.3	0.3		0.1	3.1	limestone
Ing 72	24.1	1.9	67.3	0.3			4.1	1.9	mudstone
Ing 73	32.4	2.3	60	0.3	0.1		0.9	3.3	limestone
Ing 74	-	-	-	-	-	-	-	-	mudstone
Ing 75	19.1	0.5	76.6	0.9			0.9	1.5	limestone
Ing 76	16.8	0.7	77.8	0.5			1.9	1.9	limestone
Ing 77	29.7	0.5	65.3				2.1	2.1	mudstone
Ing 78	23.4	0.3	74.1				0.7	1.1	limestone

APPENDIX B

Ammonite photographs

Ammonite fossils, external molds and casts displaying whorls, ornamentations and sutures have been observed within the beds and are observed as taking place in certain levels.

Ammonites found in Ing 20 level.

Plate 1

a) external ammonite mold displaying ornamentations or riibons and few whorls on the internal pot of the broken mudstone, pen for the scale.

b) small pieces of external mold of ammonite displaying ribbon ornamentation

Plate 2

a) small pieces of external mold of ammonite displaying ribbon ornamentation.

b) small pieces of external mold of ammonite displaying ribbon ornamentation.

Plate 1

Plate 2

APPENDIX C

Thin section photographs

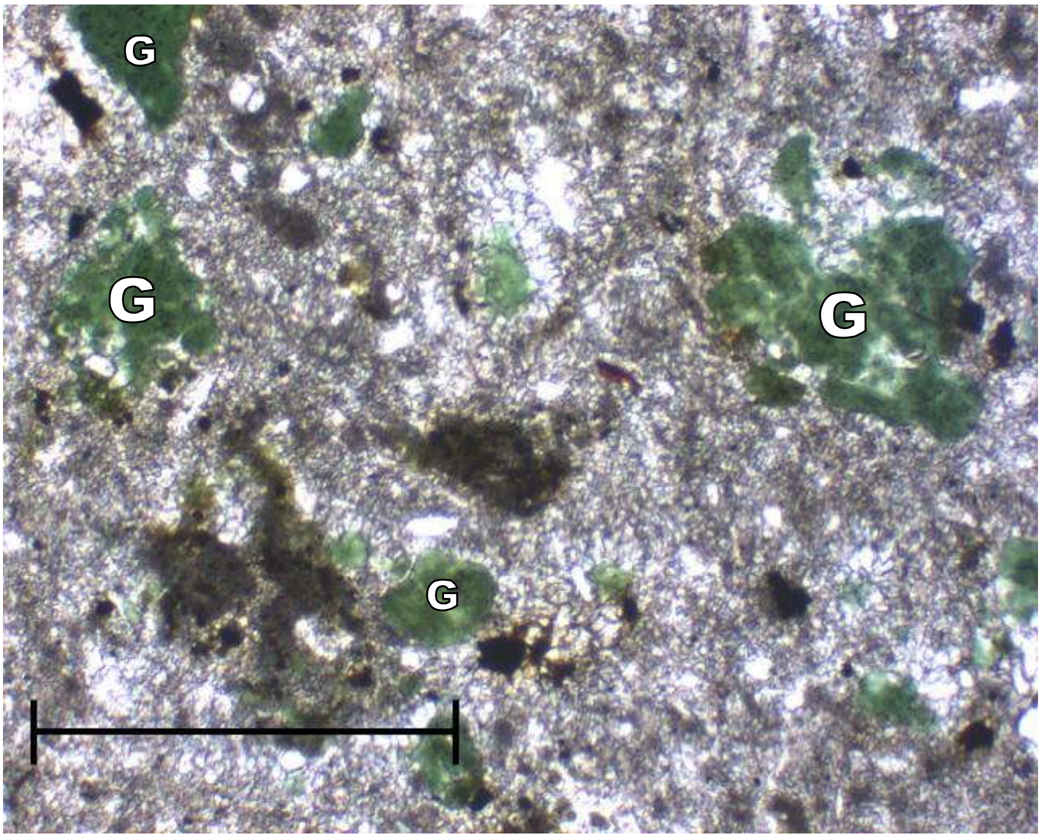

Figure C1. Calcareous sandstone with glauconite, G - glauconite, Sample number: Ing 1, Scale bar = 0.5mm.

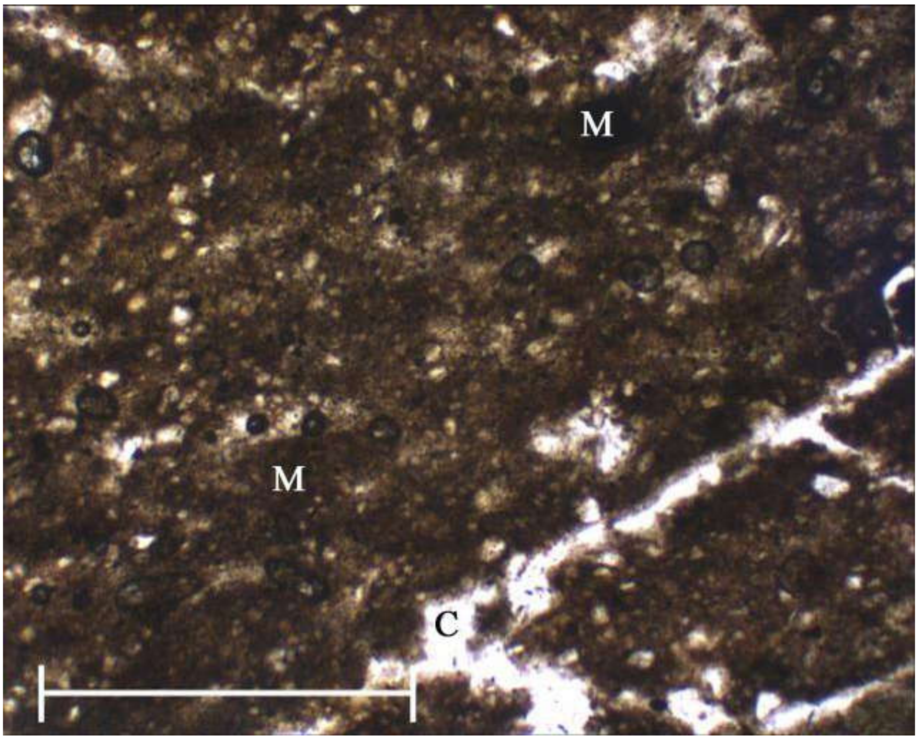

Figure C2. Black Shale, M - matrix; C - crack, Sample number: Ing 2, Scale bar = 0.5mm.

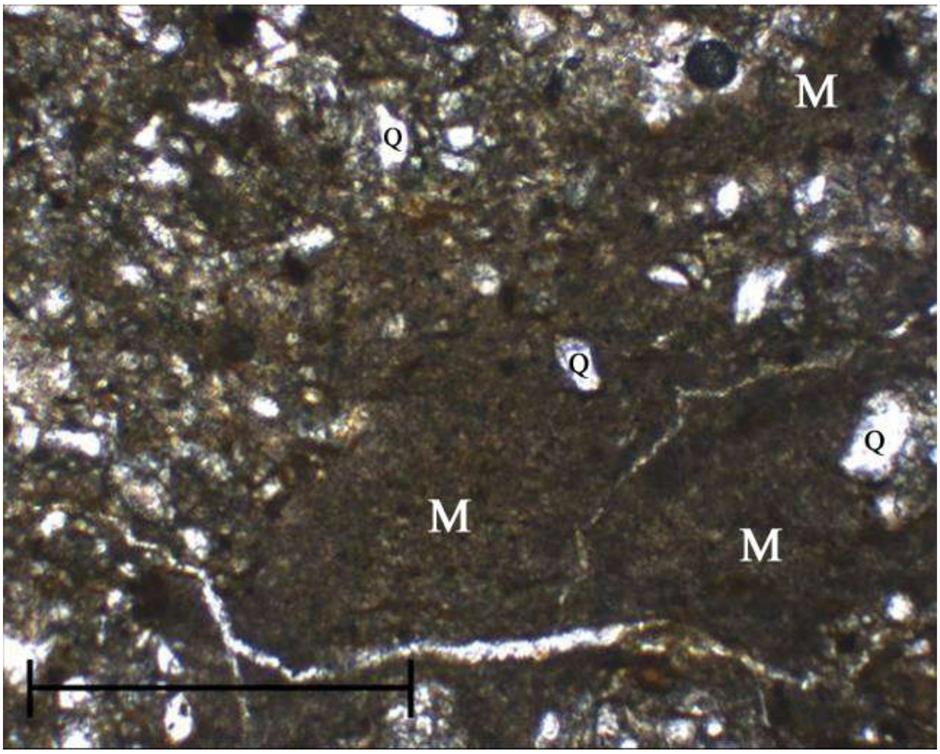

Figure C3. Claystone, M - matrix; Q - quartz, Sample number: Ing 49, Scale bar = 0.5mm.

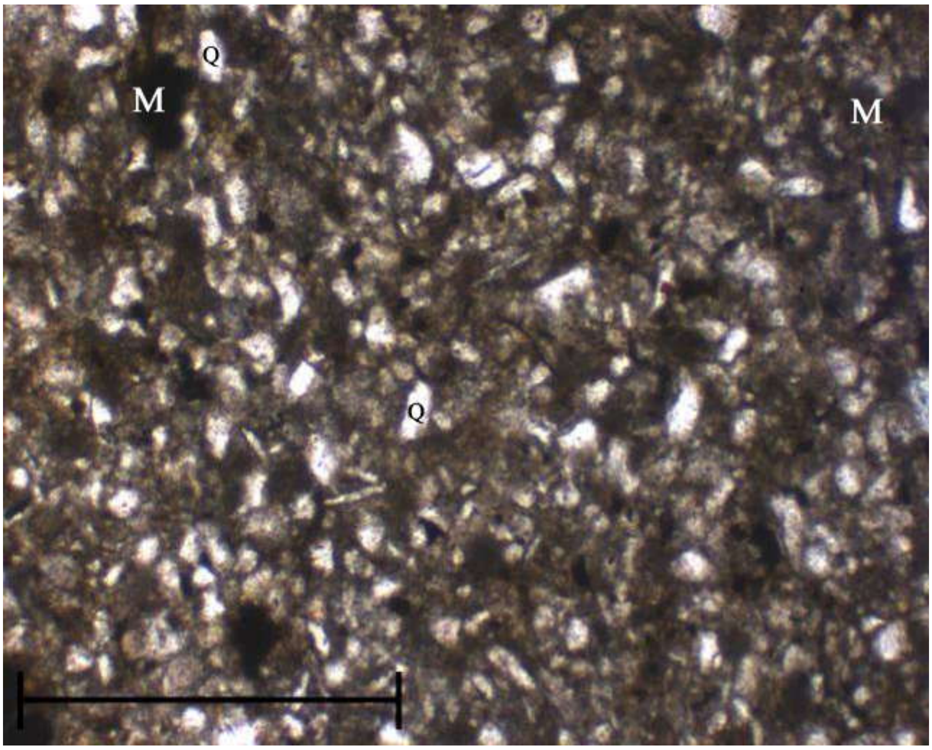

Figure C4. Mudstone, M - matrix; Q - quartz, Sample number: Ing 18, Scale bar = 0.5mm.

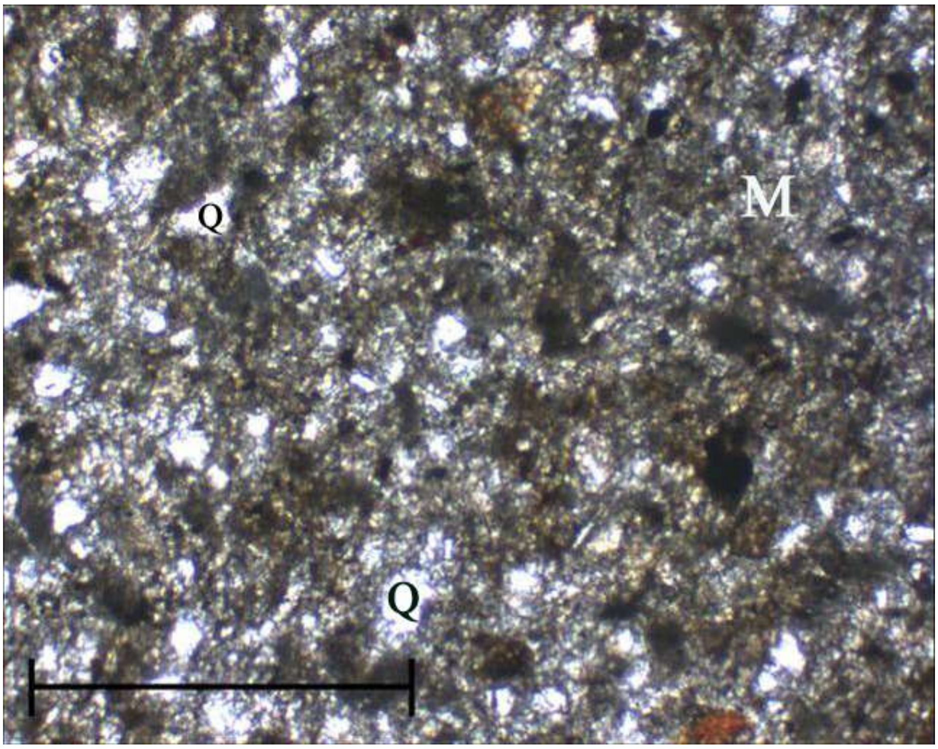

Figure C5. Limestone, M - matrix; Q - quartz, Sample number: Ing 69, Scale bar = 0.5mm.

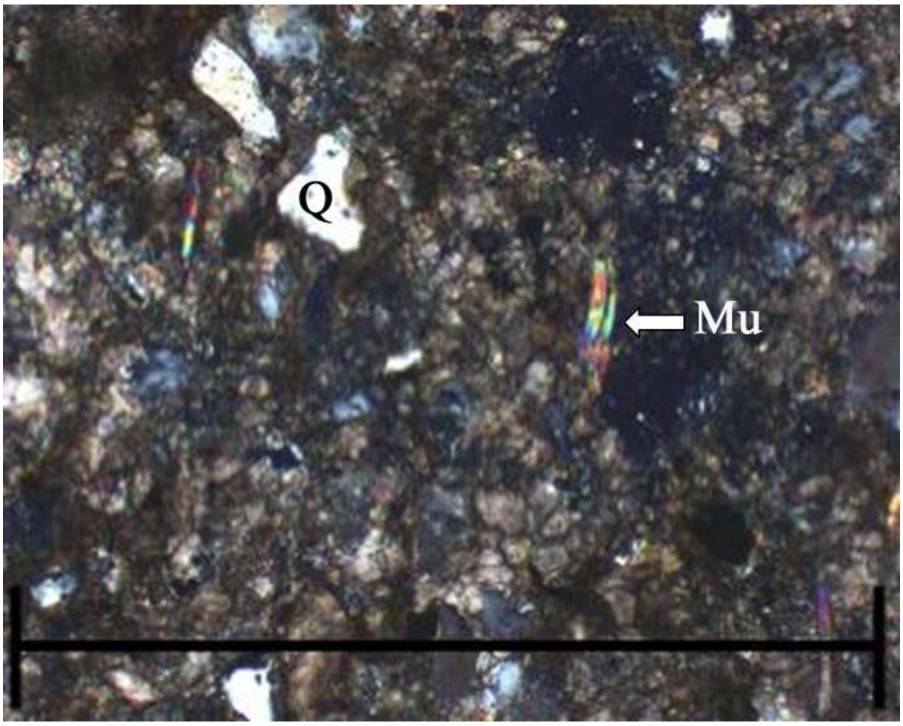

Figure C6. Mudstone with Muscovite, Mu - muscovite, Q – quartz, Sample number: Ing 39, Scale bar = 0.25mm.

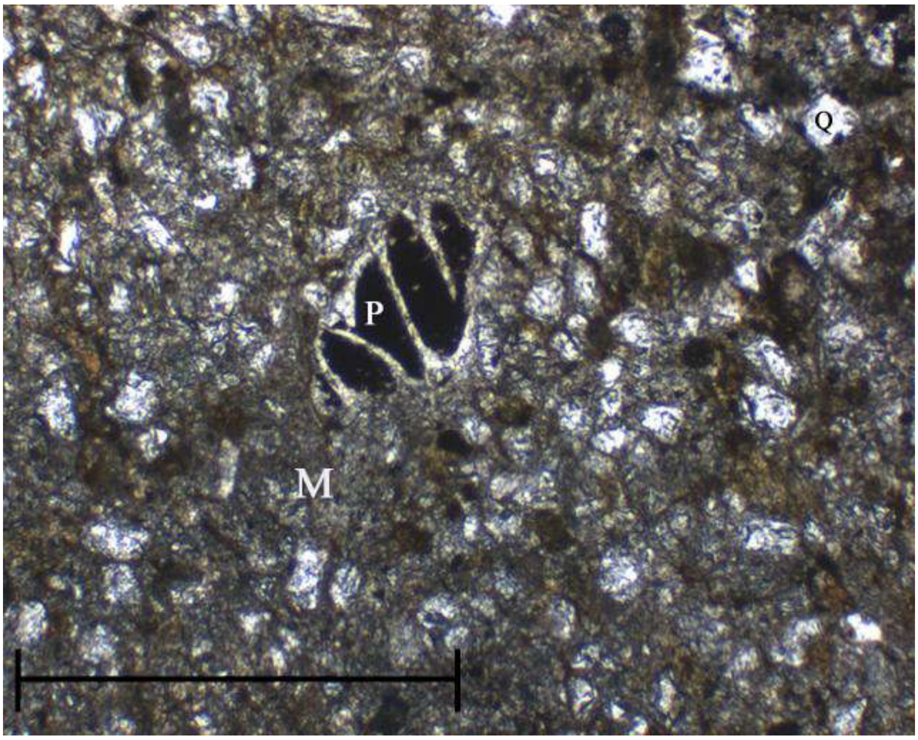

Figure C7. Pyritized fossil, Q - quartz, P - pyrite, M – matrix, Sample number: Ing 48, Scale bar = 0.5mm.

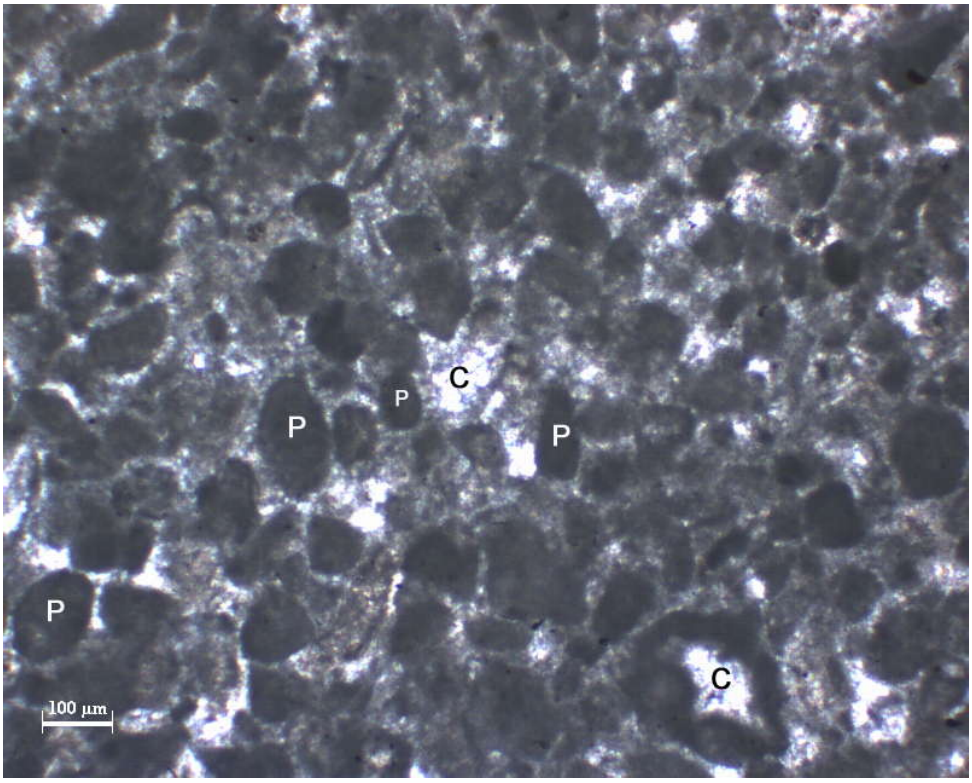

Figure C8. Peloidal grainstone (poorly washed), P - pellets, C- calcite, Sample number: Ipn 8.

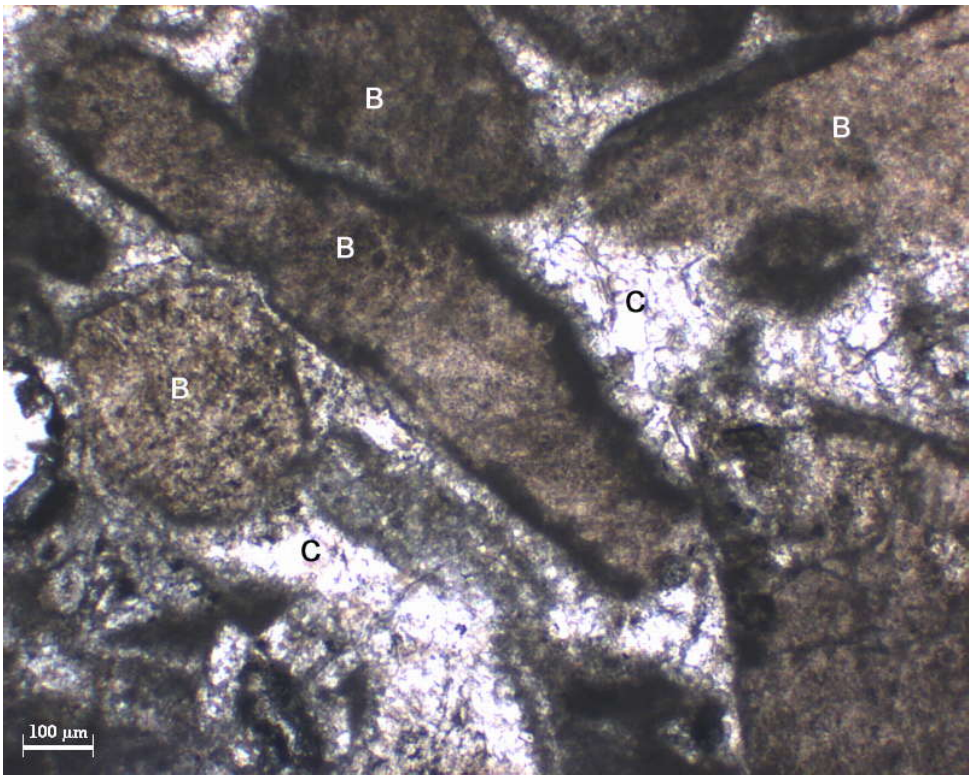

Figure C9. Bioclastic grainstone, B - bioclast, C –calcite, Sample number: Ipn 10.

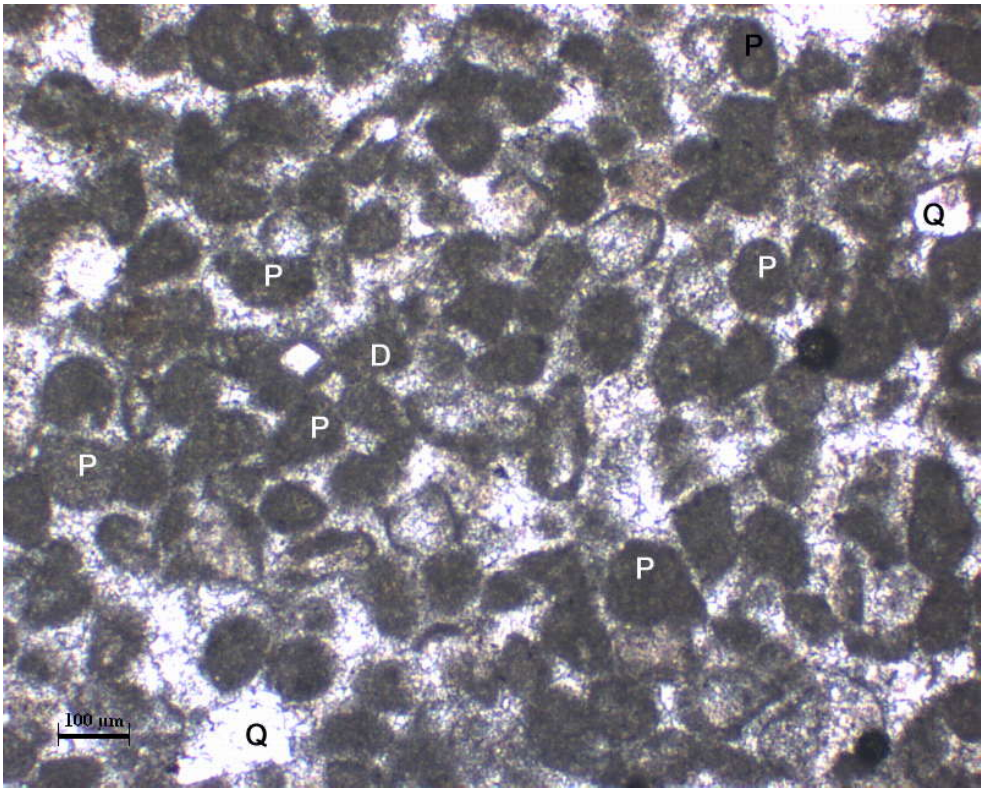

Figure C10. Peloidal grainstone, Q - quartz, P - pellets, D - dolomite, Sample number: Ipn 12.

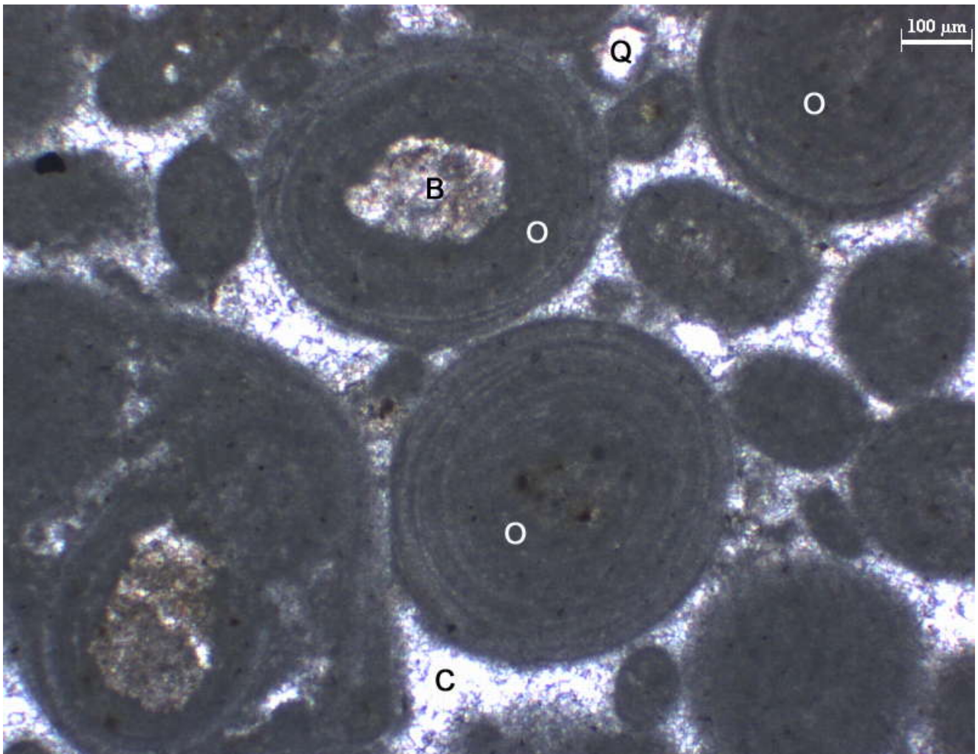

Figure C11. Ooid grainstone, O - ooid, Q - quartz, C- calcite, Sample number: Ipn U 28.

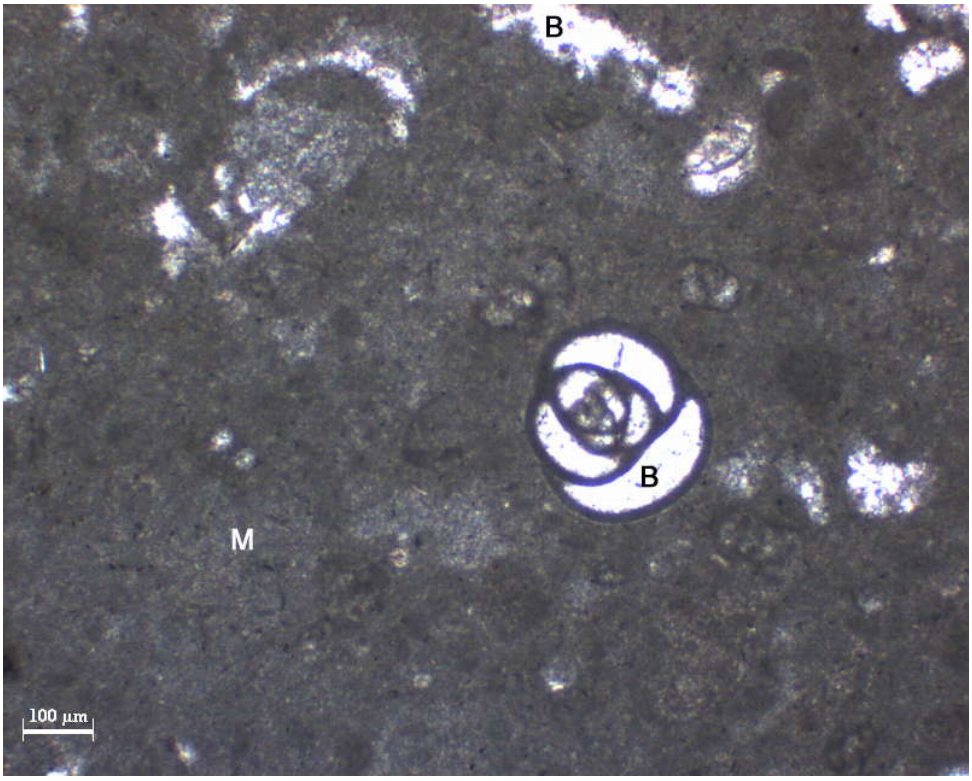

Figure C12. Biomicrite, M - matrix, B - bioclast, Sample number: Ipn U 2.

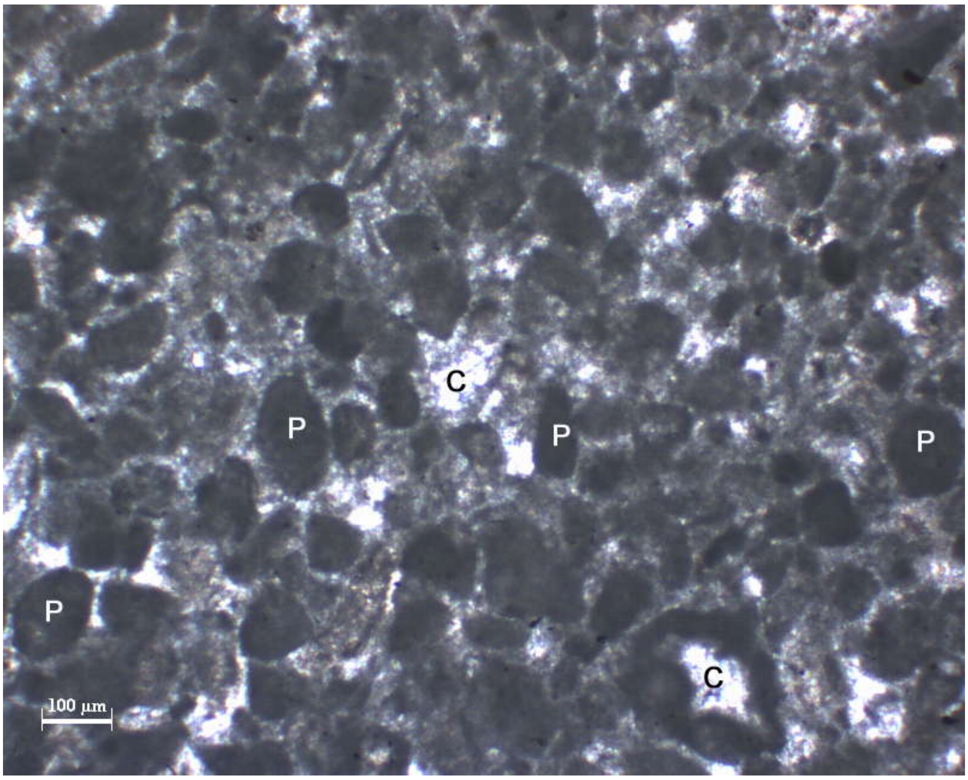

Figure C13. Peloidal packstone (poorly washed), P-pellet, C- calcite, Sample number: Ipn U 8.

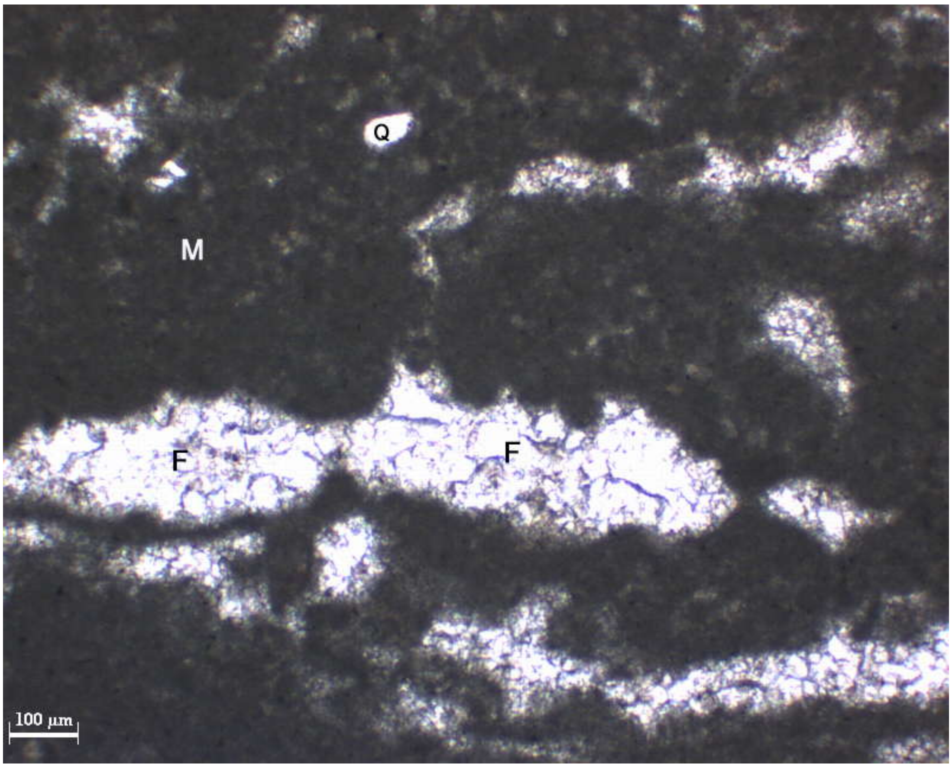

Figure C14. Fenestral limestone, F- fenestrae, M- matrix, Q- quartz, Sample number: Ipn U 21a.

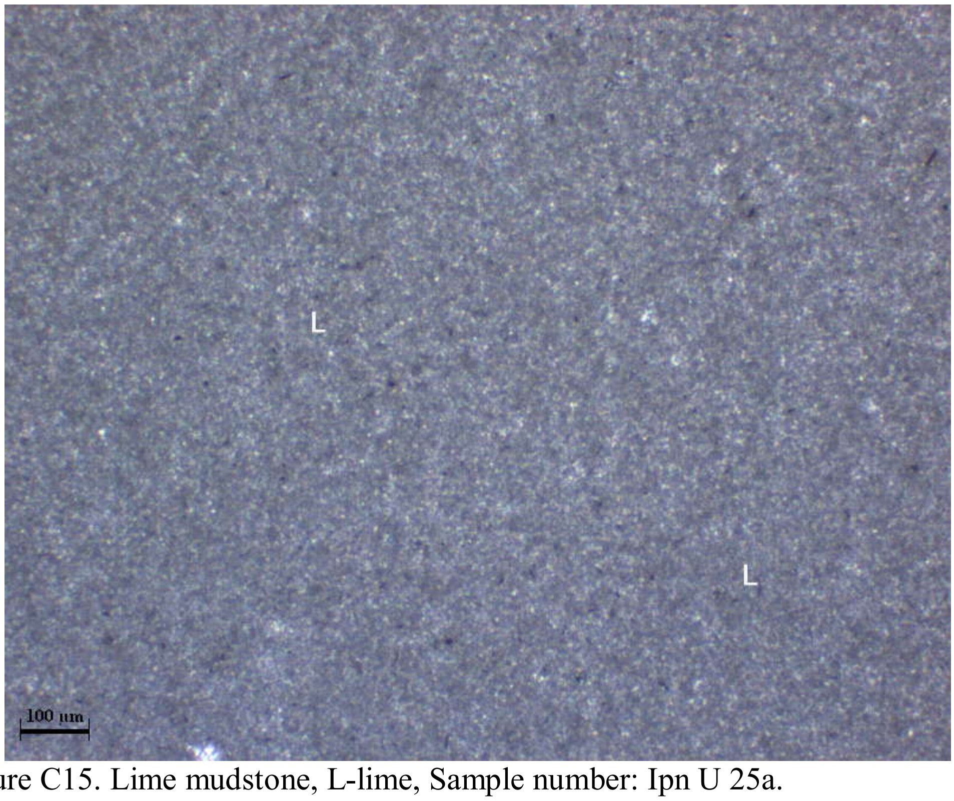

Figure C15. Lime mudstone, L-lime, Sample number: Ipn U 25a.

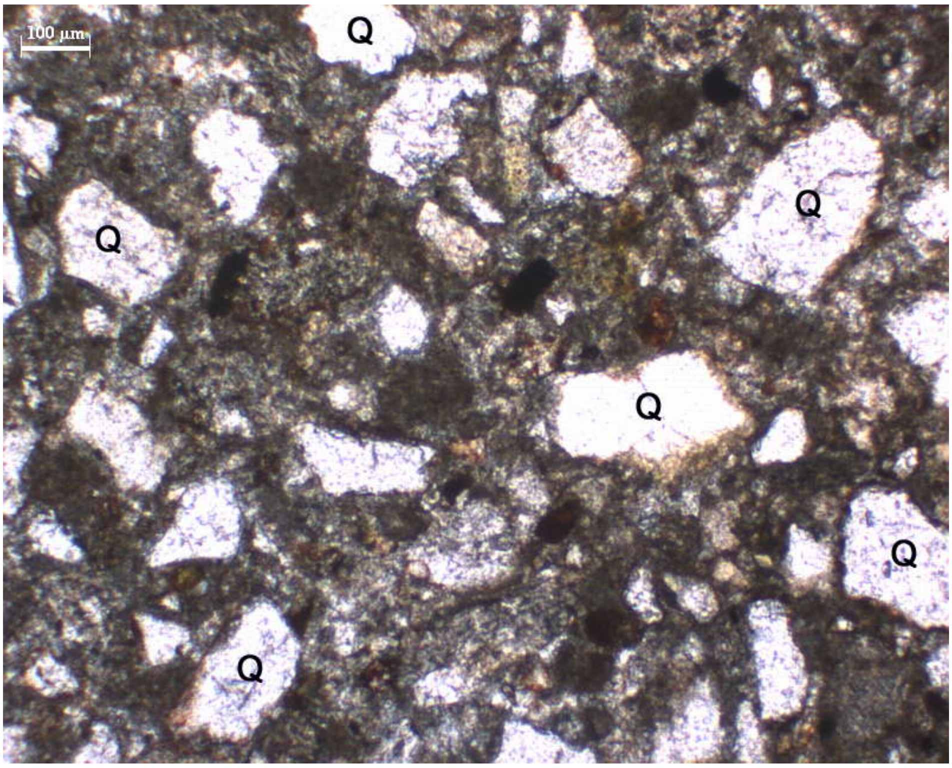

Figure C16. Sandstone (plane polarized), Q- quartz, Sample number: Ipn U 43.

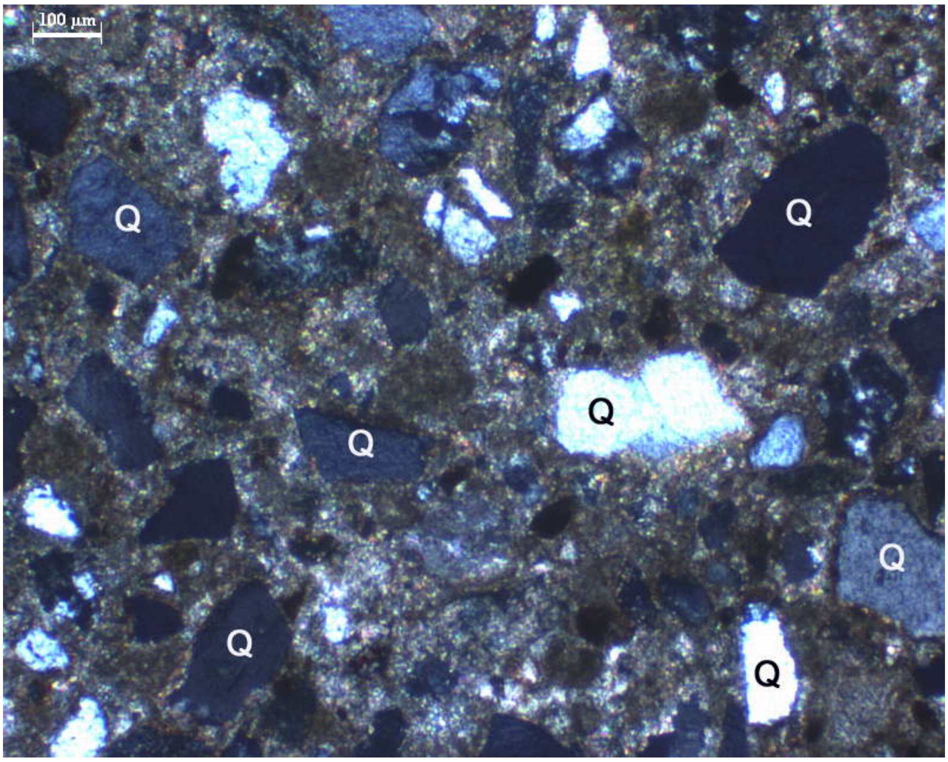

Figure C17. Sandstone (cross polarized), Q- quartz, Sample number: Ipn U 43.

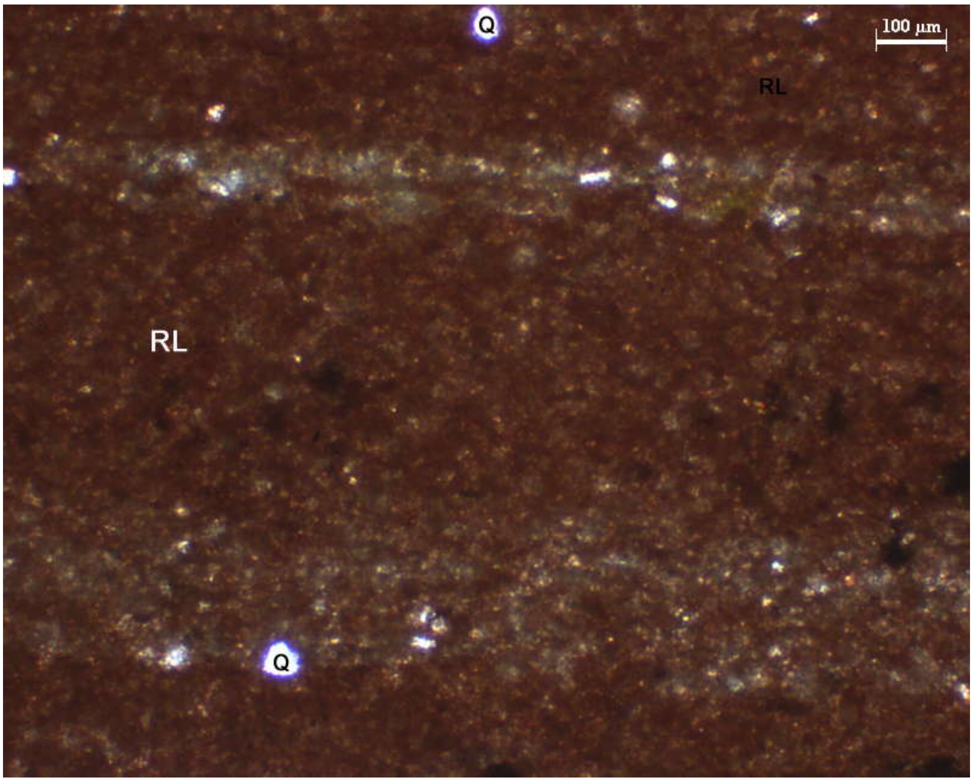

Figure C18. Silty laminated red limestone, RL- red limestone, Q- quartz, Sample number: Ipn U 33.

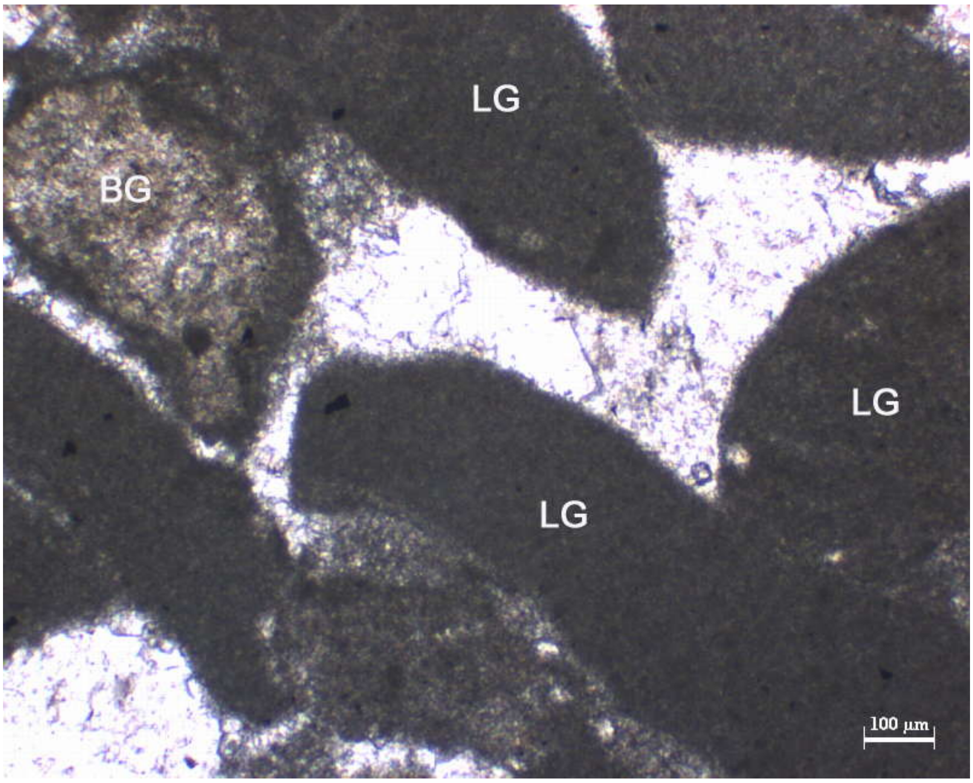

Figure C19. Rudstone, BG - bioclastic grain, LG - lime mud grains, Sample number: Ipn U 48.