SEQUENCE STRATIGRAPHIC ARCHITECTURE OF MUT BASIN ALONG RAMP TO REEFAL MARGIN TRANSITION AND ITS DIAGENETIC IMPRINT

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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.

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ABSTRACT

SEQUENCE STRATIGRAPHIC ARCHITECTURE OF MUT BASIN ALONG RAMP TO REEFAL MARGIN TRANSITION AND ITS DIAGENETIC IMPRINT

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The whole Mediterranean was a site of carbonate deposition during Miocene. Unlike other Miocene basins in the Mediteranean, the importance of Mut Basin lies in its tectonically undisturbed nature that provides excellent exposures to study sequence stratigraphic architecture and carbonate sedimentology.

Opening of Mut Basin began during Oligocene; carbonate deposition started during Early Miocene. The pre-Miocene rocks are characterized by (from bottom to top), 1. ophiolites and Mesozoic limestones, 2. Eocene lacustrine limestones, 3. Burdigalian fluvial sandstones and conglomerates. The carbonate deposition began in Miocene, settling on the preexisting topography. Carbonates have been deposited in a ramp setting, where several sequences formed. The ramp was partly subaerially exposed during Early Miocene due to relative sea level fall; however, no significant lowstand deposits were developed. The subsequent sea level rise caused transgressive deposits to overlie this ramp sequence. The patch reefs on this ramp exhibit a keep-up type depositional setting. As the transgression continued, the basin topography controlled the type of depositional setting. Hence, a transition from ramp to reefal margin type setting occurred. In landward direction the topographically low areas became back reef lagoonal part of this reefal margin. A mature reefal environment formed during highstand times, which is characterized by a rich coral fauna / algal flora in the basinward side. Some of the patch reefs of the ramp transformed into pinnacle reefs. Diagenetic alterations are mostly related to duration and degree of sea level fall, and therefore related to sequence boundaries.

The Miocene carbonates in the study area consist of six sequences which may be used for correlation with other Miocene carbonates of the Mediterranean region.

Keywords: Sequence Stratigraphy, Carbonate, Mut Basin, Reef, Diagenesis, Miocene

ÖZ

RAMPADAN RESİFAL BASEN KENARINA GEÇİŞTE MUT BASENİNİN SEKANS STRATİGRAFİK ÇATISI VE DİAJENETİK İZLERİ

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Aralık 2003, 81 Sayfa

Miyosen'de bütün Akdeniz karbonat çökeliminin olduğu bir havzaydı. Mut baseni, diğer Akdeniz basenlerinden farklı olarak, tektonizmadan etkilenmemiş olmasıyla önemli bir yere sahiptir. Bu durum, sekans stratigrafisi ve karbonat sedimantolojisi çalışmak için uygun bir ortam sağlamıştır.

Mut baseninde karbonat çökelimi erken Miyosen'de başlamıştır. Miyosen öncesi kayaçlar, alttan üste doğru: 1) ofiyolitler ve Mesozoyik kireçtaşları, 2) Gölsel kireçtaşları, 3) Nehir çökelleri ile temsil edilmektedir. Karbonat çökelimi Miyosen başında mevcut topografyada başlamış ve rampada devam etmiştir. Rampa üzerinde birkaç üçüncü derece sekans çökelmiştir. Ramp erken Miyosen'de deniz seviyesinin düşmesinden ötürü yüzeye çıkmış, ancak bu sırada belirgin bir "lowstand" çökelimi gerçekleşmemiştir. Bunu izleyen deniz seviyesi yükselimi yeni transgresif çökellerin ramp çökellerini üzerlemesine neden olmuştur. Ramp üzerindeki yama resifleri "keep up" tipinde depolanma yapısı göstermistir. Transgresyon devam ettikce, basen topografyası depolanmanın yapısını kontrol etmistir. Bunun sonucu olarak rampten bariyer resifine geçiş söz konusu olmuştur. Kara tarafında çukur yerlerde karbonat çökelen lagünler oluşmuştur. Deniz seviyesinin en yüksek olduğu zamanlarda özellikle mercan faunası / alg florası ile zengin olgun bir resifal ortam vardır. Basen tarafında ise yama resifleri kule resifine dönüşmüştür. Diyajenetik değişimler, çoklukla deniz seviyesi düşüşünün süresi ve derecesine bağlıdır, bu nedenle istif sınırları ile ilişkilidir.

Çalışma alanında altı farklı sekans ayırtlanmıştır. Bunlar Akdeniz'deki diger sekanslar ile korele edilebilirler.

Anahtar Kelimeler: Sekans Stratigrafi, Karbonat, Mut Baseni, Resif, Diajenez, Miyosen

To My Parents

ACKNOWLEDGMENTS

I am grateful to Prof. Dr. Teoman NORMAN for his guidance throughout this research. I thank Assoc. Prof. Dr. Ahmet Sami DERMAN, who inspired my interest in sedimentology, particularly in connection with carbonate sequence stratigraphy. I would also like to thank Assoc. Prof. Dr. Sevinç ÖZKAN ALTINER, who dated my samples. Many thanks to Mr. Feyyaz RUZGAR, for his tolerance during the study. Thanks go to my mother for tolerating another geologist in the family, and to my sisters, for their support. Finally, I would like to thank Kağan ATASOY for his support and motivation during the study.

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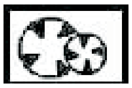
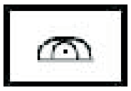
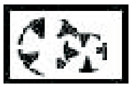
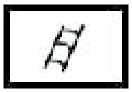
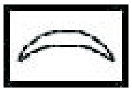
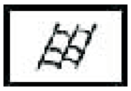
 Colonial Coral

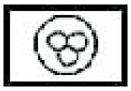
 Echinoid Plates

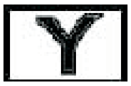
 Coral fragments

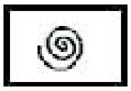
 Red Algae

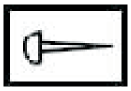
 Pelecypod

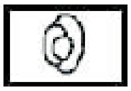
 Undifferentiated Algae

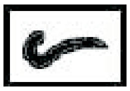
 Planktonic foram

 Bryozoa

 Gastropod

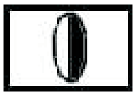
 Echinoid Spines

 Miliolid

 Oyster

 Shell fragments

 Worm tubes

 Benthic foram

HST: Highstand Systems Tract
TST:Transgressive Systems Tract
LST: Lowstand Systems Tract
MFS: Maximum Flooding Surface
SB: Sequence Boundary
CC: Correlative Conformity

S1: First sequence
S2: Second sequence
S3: Third sequence
S4: Fourth sequence
S5: Fifth sequence

M: Mudstone W: Wackstone P: Packstone G: Grainstone
B: Boundstone

CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope

Recent advances in stratigraphy and development of sequence stratigraphic concept enabled geologists to study sedimentary packages in more detail. Detailed studies have shown that development of each package is linked to interplay between sea level changes, subsidence and sediment supply (Van Wagoner et al, 1988). Early studies considered all these packages as one single carbonate unit and mapped them accordingly. The early models about Miocene carbonates of the Mediterranean region are mostly based on the studies in Western Mediterranean region; there are few papers about carbonates of Eastern Mediterranean (Esteban, 1996). Since there is a growing interest on the sea level changes and sequence stratigraphy of the region, new studies are needed, especially on the sequence stratigraphy of Miocene of Eastern Mediterranean region. These studies will shed light on the evolution of the Mediterranean during Miocene time. The aim of this study is to construct a Miocene sequence stratigraphic framework of the Mut Basin, which will contribute the understanding of the evolution and correlation of events throughout Mediterranean region during this epoch. Excellent 3D exposures of Mut basin's Miocene rocks allow sequences to be clearly defined, differentiated and mapped. This study will lead us to understand:

- Stratal relationships,
- Facies associations in a parasequence set scale (where possible),
- The diagenetic imprint of sequences.

1.2 Location of the study area

The study area is located between Silifke and Karaman, near Pamuklu and Dereköy villages, within Mut Basin which is dissected by Göksu river in southern Turkey (Figure 1.1). It can be reached through asphalt road either from the south between Mut and Kargıcak, or from the north between Mut and Çömelek.

1.3 Methods of study

A geological map (1:25000) was prepared during the field study. Five stratigraphic sections have been studied in order to document the sedimentological and sequence stratigraphic characteristics of the sediment pile.

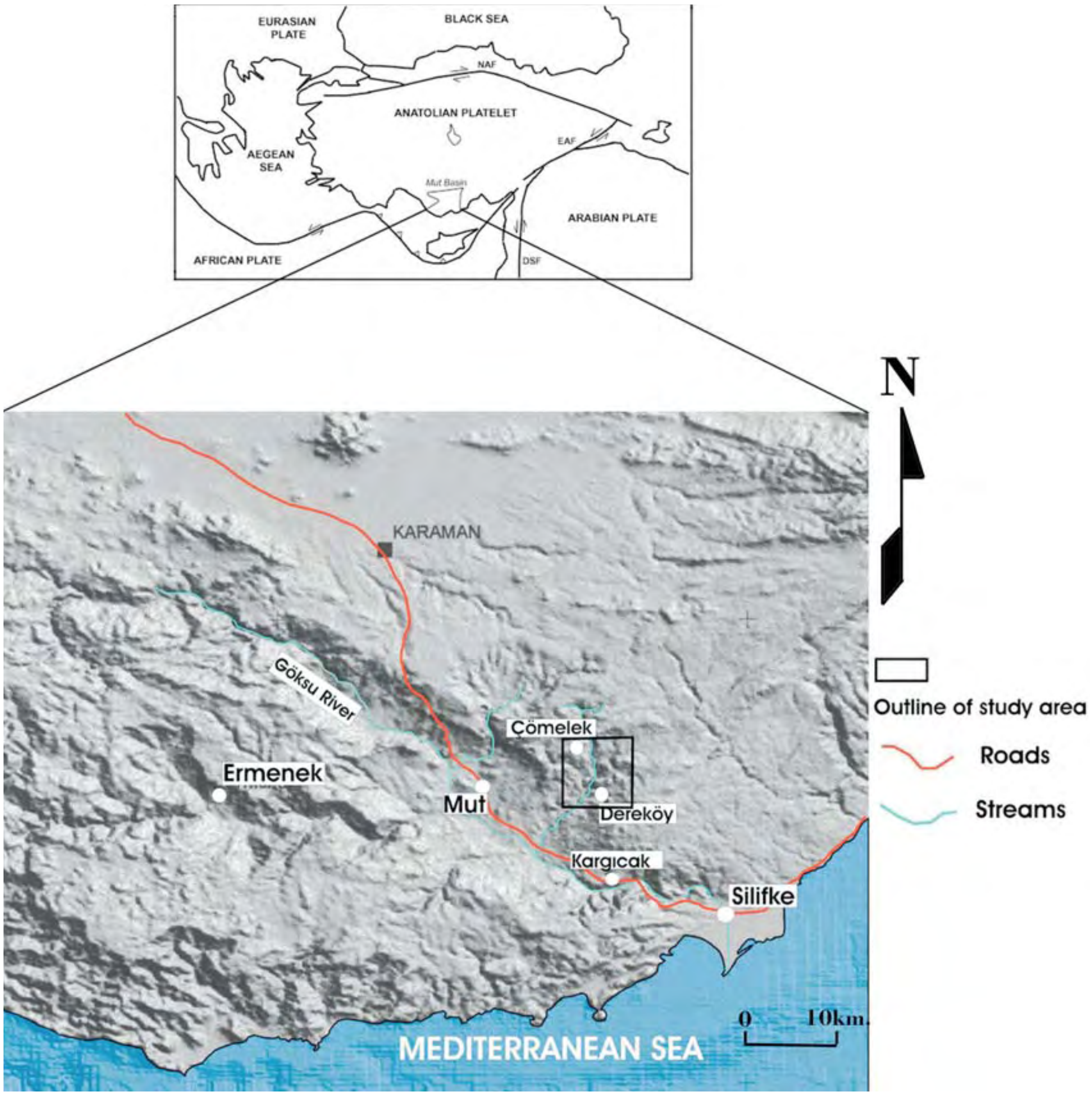


Figure 1.1: Location map of the study area.

These sections are located on the Miocene age shelf, near shelf margin and in the basinal side of the study area to see the effect of Miocene sea level changes. Facies changes and shallowing and deepening character of the sediments are recorded in order to define sequence boundaries, unconformities and correlative conformities. Truncation of bedding pattern are used to define unconformities that mark sequence boundaries. Surfaces of leaching, karstification and/or any features representing subaerial exposures are especially recorded. Red coloration has been noted as indication of possible subaerial exposure surfaces. Photomosaics are constructed to demonstrate some of the sequence boundaries and/or highstand deposits. Rocks of measured stratigraphic sections are sampled to define the facies types, and analysed both in the field and in the laboratory. A total of 54 rock samples have been collected. Rock thin sections are studied to define the changes in the sedimentary characteristics, as well as possible diagenetic imprints. The paleontological descriptions and definitions were made by Assoc. Prof. Dr. Sevinç ÖZKAN ALTINER. Detailed field descriptions are made in order to reconstruct the initial morphology of the study area. Some difficulties have been encountered during measurement of the sections, which limited both data quality and quantity, such as:

High cliffs: One of the most serious obstacles to obtain rock samples (especially from the cliff forming carbonates)

Cases of absence of continuous exposures: Difficult to trace truncated beds from the marginal areas to basinal areas. Debris flows are used to correlate inferred erosions.

1.4 Sequence Concept (Conceptual Framework)

The following paragraphs are a simplified outline of the concept of sequence stratigraphy, as applied in this study. All information has been gathered from the earlier publications of authors, to whom reference is made.

From the roots of seismic stratigraphy, sequence stratigraphy has evolved through the study of exposures, well logs and cores in the last three decades (Mitchum et al., 1977; Van Wagoner et al., 1988). Sequence

Stratigraphy is used as a tool to reconstruct the facies relationships in a chronostratigraphic framework. This framework provided new insights to reconstruct the paleoenvironment. The interplay between eustasy, subsidence and sediment supply generates genetically related rock packages bounded by unconformities on the shelf and correlative conformities in the basin. These packages are referred to as sequences. They may form from 10.000 years to 100 million years time intervals. The rock packages that form 10.000 to 100.000 years interval are referred to as cycles, 100.000 to 1.000.000 years interval as parasequences, 1.000.000 to 10.000.000 years interval as sequences and 10.000.000 to 100.000.000 years interval as megasuqences (Mitchum et al, 1977).

A sequence is defined as "a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities" (Figure 1.2). One of the important terms in this definition is unconformity. Mitchum et al. (1977) defines the term unconformity as "a surface of erosion or non deposition that separates younger strata from older rocks and represents a significant hiatus". However, Van Wagoner et al. (1988) defines

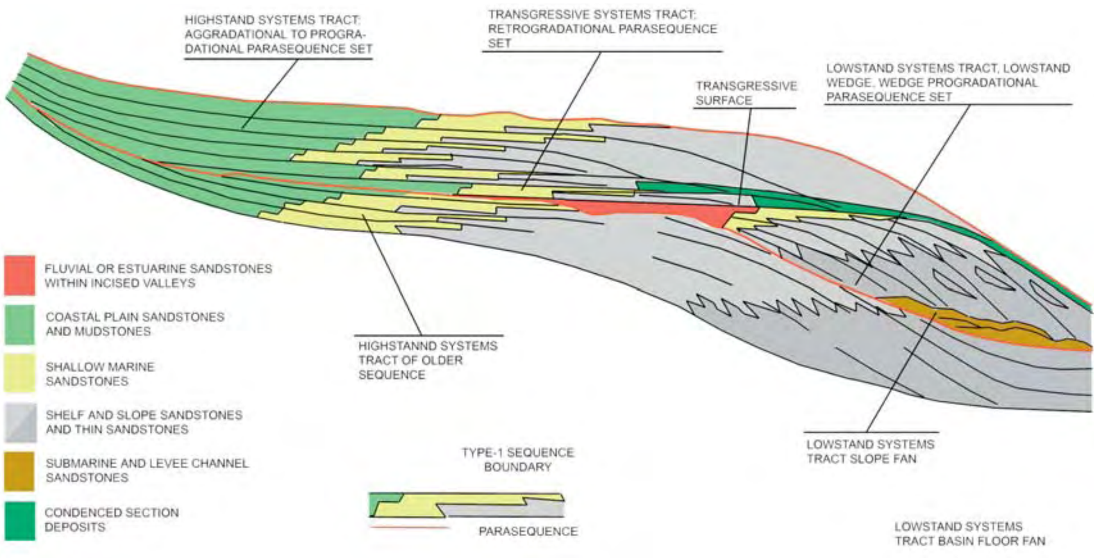


Figure 1.2: Sequence is defined as genetically related strata bounded by unconformities and their correlative conformities (between two red lines). Red lines indicate sequence boundaries. A sequence is divided into systems tract according to stratal pattern and position within the sequence as labeled (after Van Wagoner et al., 1988).

unconformity as "a surface separating younger from older strata along which there is evidence of subaerial erosional truncation or subaerial exposure with a significant hiatus indicated". So, the later definition restricts the term unconformity to subaerially exposed surfaces. The basin equivalent of this surface is defined as correlative conformity. The imprint of unconformities, which are supposed to occur due to sea level falls, can be recognized at basin margins: Incised valleys (which indicate siliciclastic input), change in diagenetic texture, basinward shift of facies, etc (Van Wagoner et al., 1988).

Sequences are divided into systems tracts, defined as "a linkage of contemporaneous depositional systems" (Fisher and McGowan, 1967). There are four types of systems tracts (Figure 1.2) which are defined according to their position in a sequence and the type of bounding surfaces (Van Wagoner et al., 1988): Highstand Systems Tract (HST), Transgressive Systems Tracts (TST), Lowstand Systems Tract and Shelf Margin Systems

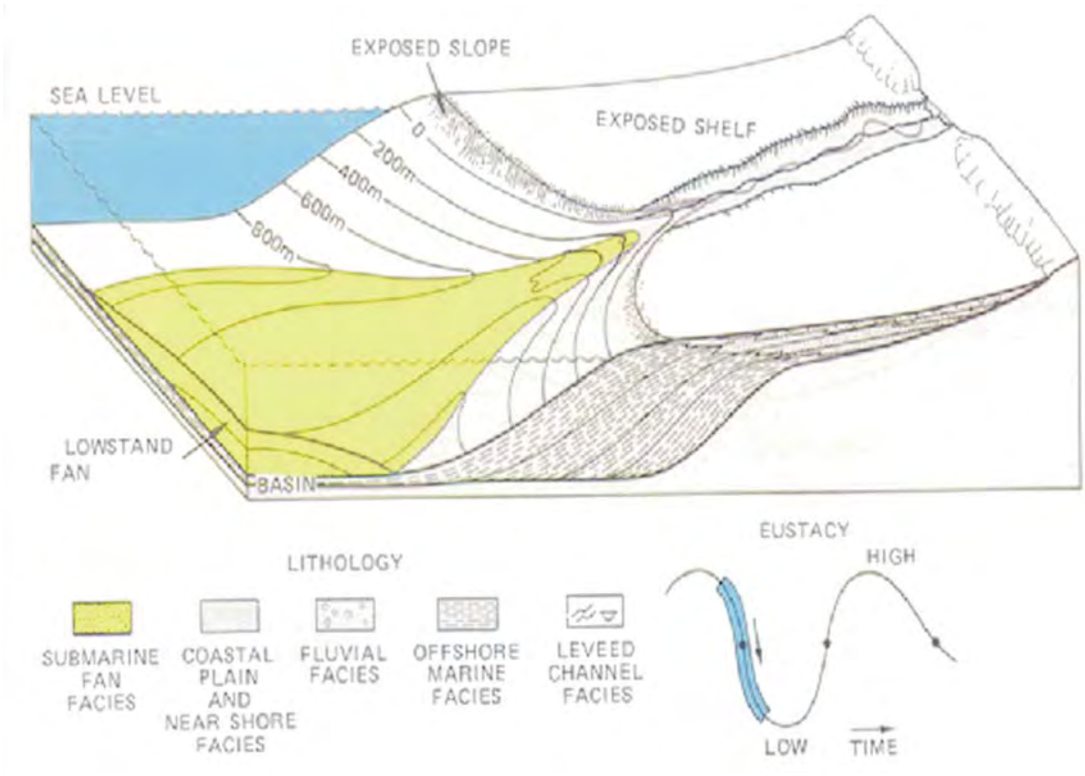


Figure 1.3: Lowstand Systems Tract is developed during the lowest position of the sea level (after Posamentier et al., 1988). During this time sea level is either below depositional shoreline break (in this case type I sequence boundary is developed) or above the depositional shoreline break (type II sequence boundary is developed).

Tract (SMST).

Lowstand Systems Tract is the lowermost systems tract which lies directly on a type 1 sequence boundary (Figures 1.2 and 1.3). It is developed when relative sea level is the lowest (Figure 1.3). Transgressive Systems Tract is the second systems tract overlying and following lowstand systems tract. It is developed during relative rise in sea level that is characterized by onlapping stratal termination patterns and one or more retrogradational parasequence sets (Figure 1.2 and 1.4). Highstand Systems Tract is the uppermost systems tract which is characterized by aggradational and/or progradational stratal pattern and progradational and/or aggradational parasequence sets (Figure 1.2 and 1.5). The Shelf Margin Systems Tract is a regressive stratigraphic unit characterized by decreasingly progradational, followed by an aggradational, parasequence stacking pattern. It overlies the highstand systems tract and is deposited on the outer part of the shelf (Figure 1.6).

Each systems tracts is divided into parasequences, which are bound-

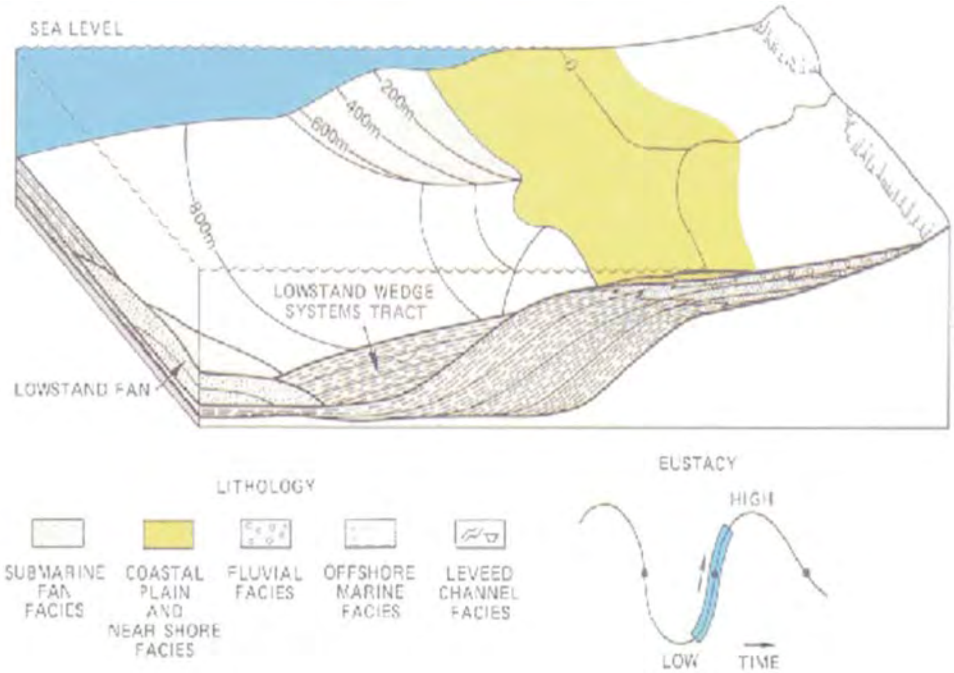


Figure 1.4: Transgressive Systems Tract is developed during rise in sea level (after Posamentier et al., 1988) It is characterised by onlapping of the stratal pattern on a sequence boundary.

ed by marine flooding surfaces. The thickness of parasequences are generally between 1 and 10 meters. However, depending on the depositional system and the sedimentologic processes it may be in decimeter scale or in tens of meters scale. For example, the parasequences of the tidal flat environment can be in decimeter scale, whereas the parasequences in the basinward shift can be tens of meters thick (like homogenous marls of Mut Basin). Nevertheless, one has to remember that the marine flooding surfaces mark the boundary of parasequences.

The basic concepts defined here are known as the "Exxon Model" of sequence stratigraphy. Many objections have risen to this model. For example, the role of tectonics is one of the most important subject of an ongoing debate in sequence stratigraphy. Geologists who object the role of (glacial derived) eustasy state that the rate of tectonic subsidence is much greater

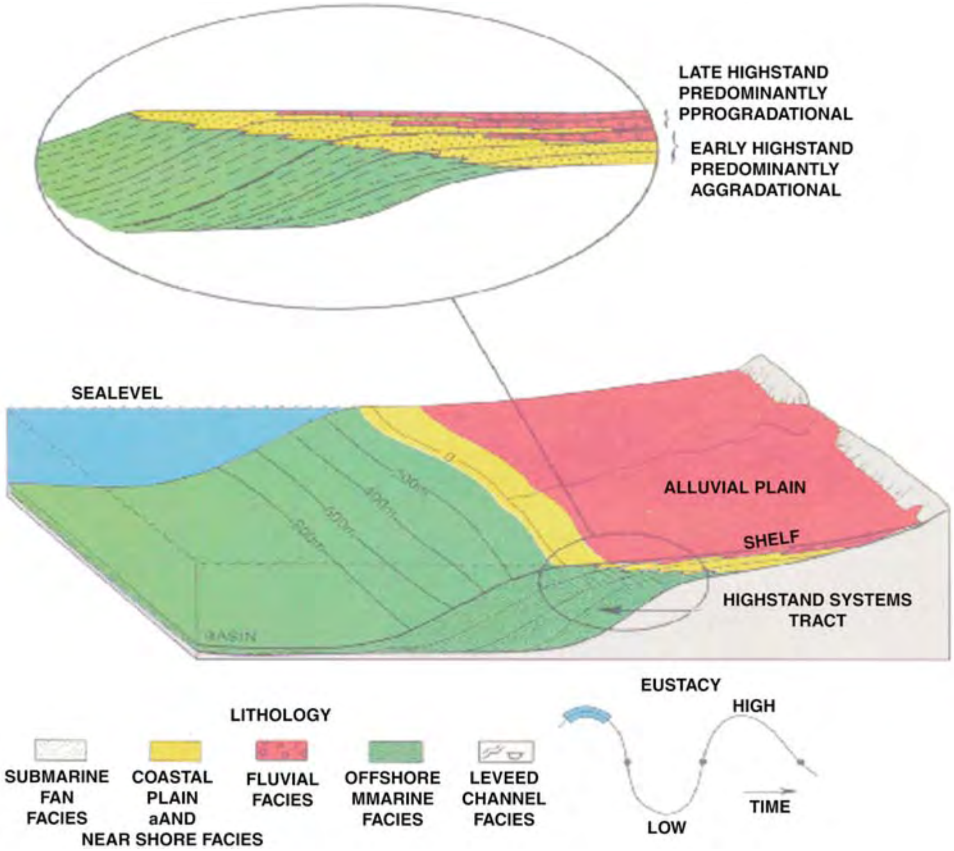


Figure 1.5: Highstand Systems Tract is developed during relative high position of sea level (after Posamentier et al., 1988) during which sediments prograde toward the basin. It is characterized by prograding or aggrading stratal pattern.

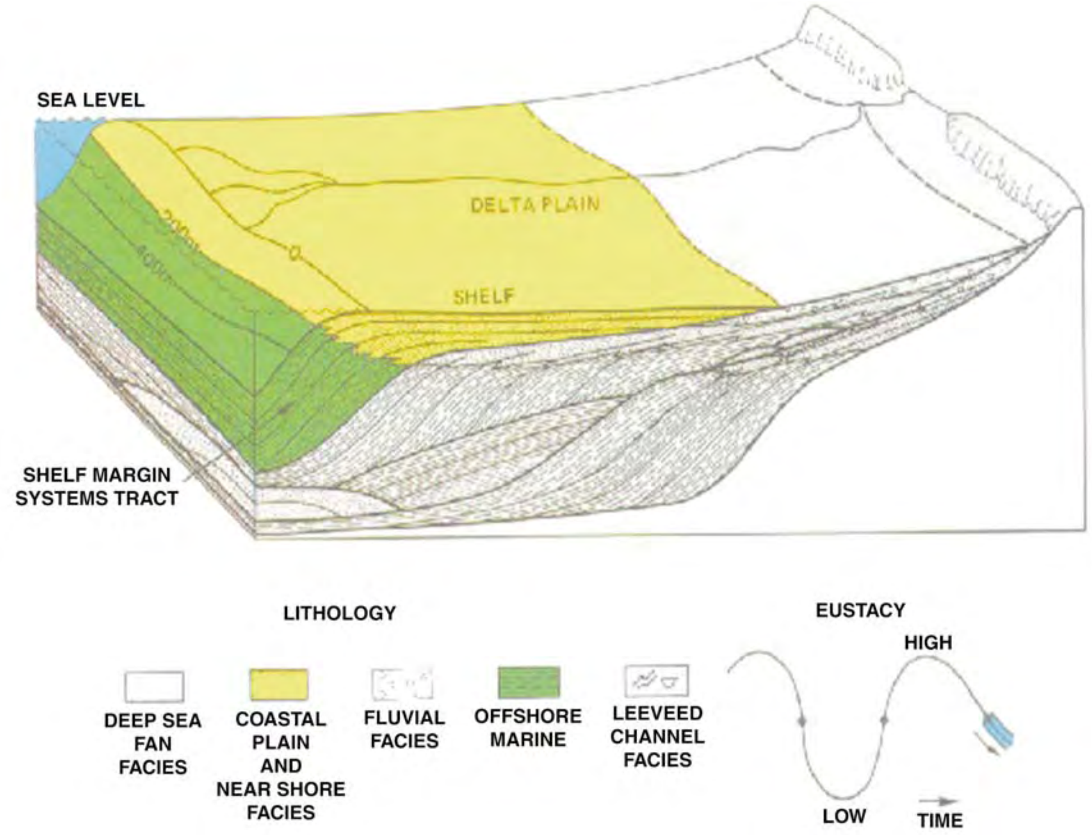


Figure 1.6: Shelf Margin Systems Tract is deposited on the outer part of the shelf and overlies a highstand systems tract (after Posamentier et al., 1988). Shelf Margin Systems Tract is commonly not capped by a widespread fluvial deposits in contrast with the Highstand Systems Tract.

than eustatic rise or fall, so that the role of eustasy can be neglected (Miall, 1991). Although the interpretation of sea level fluctuations from the rock record is a complex process, which needs detailed facies analysis and paleontological study, it is still possible to express the glacial derived eustatic imprint. (For a summary of discussions reader is referred to Emery and Myers, 1996). In basins like Mut Basin, where the stratal relationships are not tectonically disturbed and the facies architecture is well preserved, it is possible to see the eustatic imprint.

1.5 Previous Studies

Although there are many early studies (Blumenthal, 1956; Erünal-Erentöz, 1958; Akarsu, 1960; Bizon et al., 1974; Özer et al., 1974; Koçyiğit, 1976, 1978), Gedik et al., (1979) was the first to establish the stratigraphic framework of the Mut Basin. Later studies followed Gedik et. al. (1979)'s stratigraphic nomenclature.

Biju-Duval et al. (1977), Demirtaşlı et al (1983), Dercourt et al. (1986), Dewey et al. (1973, 1989), Esteban (1996), Gökçen (1984), Görür et al (1995), Lemoine (1978), Pampal (1986), Rehault et al (1984), Robertson et al (1996), Tanar (1989), Tanar and Gökçen (1990) and Ziegler (1988) review the geology of Mediteranean region.

Şafak (1997) studied the ostracod fauna of the Late Miocene-Pliocene sequence of Karaman region. She states that similar fauna exist in the Neogene formations of Adana and Antalya basins; also, it can be correlated with the fauna of Tunusia, Algeria and Greek islands.

Bassant (1999) studied the Burdigalian carbonate - siliciclastic sedimentary systems of Mut Basin from a sequence stratigraphic perspective. However, his interpretation is different from the concept of Exxon type sequence stratigraphy. He uses cycle boundaries rather than sequence boundaries in order to differentiate rock packages. A cycle boundary is "placed at the turn around from progradation to retrogradation, which occurs within, or at the top of lowstand systems tract, whereas the sequence boundary is placed at the base of the lowstand."

Atabey et al. (2000) proposed a new lithostratigraphic framework for the Miocene Mut Basin. However, for Miocene he followed Gedik et al. (1979)'s nomenclature. Hence, in this study nomenclature of Gedik et al (1979) is used.

Most recent study is that of Jonsons (2001), who examined and modeled carbonate deposits on the Ermenek shelf and used it as an analog model for the carbonate reservoir in south China sea.

CHAPTER 2

STRATIGRAPHY OF MUT BASIN

2.1 Regional Geology

Mut Basin is one of the Miocene basins of southern Turkey (Figure 2.1). It is surrounded from the south by Alanya massif, from the north Bolkar mountain, from the west Alanya and Bozkır nappes. In the east it is separated from the Adana Basin by the Ecemiş fault zone. In the Late Oligocene to Early Miocene the Mut, Adana and Antalya basins formed (Kelling et al., 1995a). In the Mut Basin, Kelling et al. (1995b), suggest an Early Oligocene phase of crustal extension, probably associated with orogenic collapse. Mut Basin was a site of carbonate deposition like adjacent Adana and Antalya basins (Bassant, 1999). In Serravalian, Eurasia-Arabia collision started (Bassant, 1999) which represents the start of the present Neotectonic regime (Şengör et al., 1985). At this time southern Turkey is uplifted by epeirogenic processes to its present elevation of 1-2 km. above sea level. Marine regression across the southern Turkey started from the Late Serravalian onwards, with deposition of Tortonian evaporites in the west and in the south (Yetiş et al., 1995). As opposed to tectonic deformation of Adana and Antalya basins, Mut basin was uplifted without any major deformation. Its initial basin geometry is still preserved, which allowed examination of undisturbed stratal relationships of sediments. The precise basin dynamics are currently the subject of discussion in the literature (Bassant, 1999).

In this study, pre-Miocene rocks are referred to as "basement", which consists of Paleozoic shales, limestones and quartzites, Lower - Middle Triassic conglomerates, Jurassic - Cretaceous dolomitized limestones, Upper

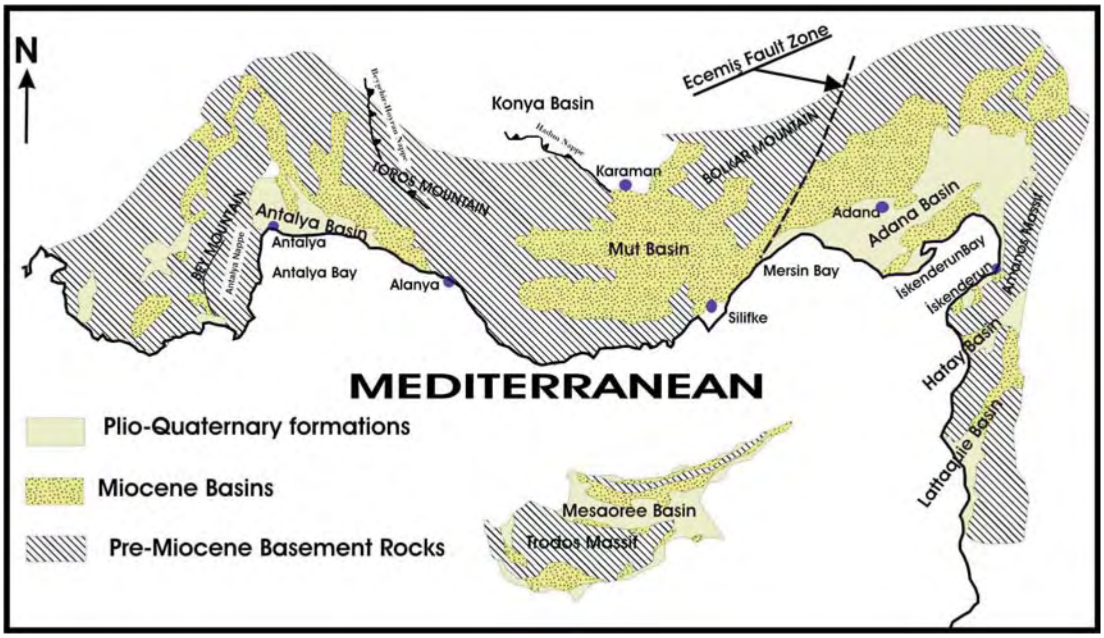


Figure 2.1: Miocene basins of southern Turkey (Simplified from Özer et al., 1974 / Not to scale).

Cretaceous mudstones and conglomerates, Upper Cretaceous ophiolites. Above these, Eocene marls, shales, sandstones and conglomerates exist, ending with a major erosion surface (Figure 2.2).

In this study the accepted stratigraphic nomenclature for the Mut basin is that of Gedik et al. (1979). Twelve formations are distinguished (Figure 2.2), nine formations making up the "basement". Ovacık formation of Ordovician age is the oldest rock unit observed in the basin and consists of schists with quartz arenite bands. Hırmanlı formation unconformably overlies Ovacık formation and is characterized by black colored, laminated graptolite bearing shales of Silurian age. Akdere formation of Middle - Late Devonian is made up of coralline limestone that was deposited in a shallow marine environment. The shale, sandstone and quartz arenite interbedded with oolitic limestones of Belpınartepe formation indicates that shallow marine conditions continued during Carboniferous-Permian time. Kızılkuzlukdere formation of Early and Middle Triassic is characterized by shale and marl interbedded shallow water carbonates. Late Triassic was the time of terrestrial sedimentation. Therefore, Boztepe formation unconformably overlies

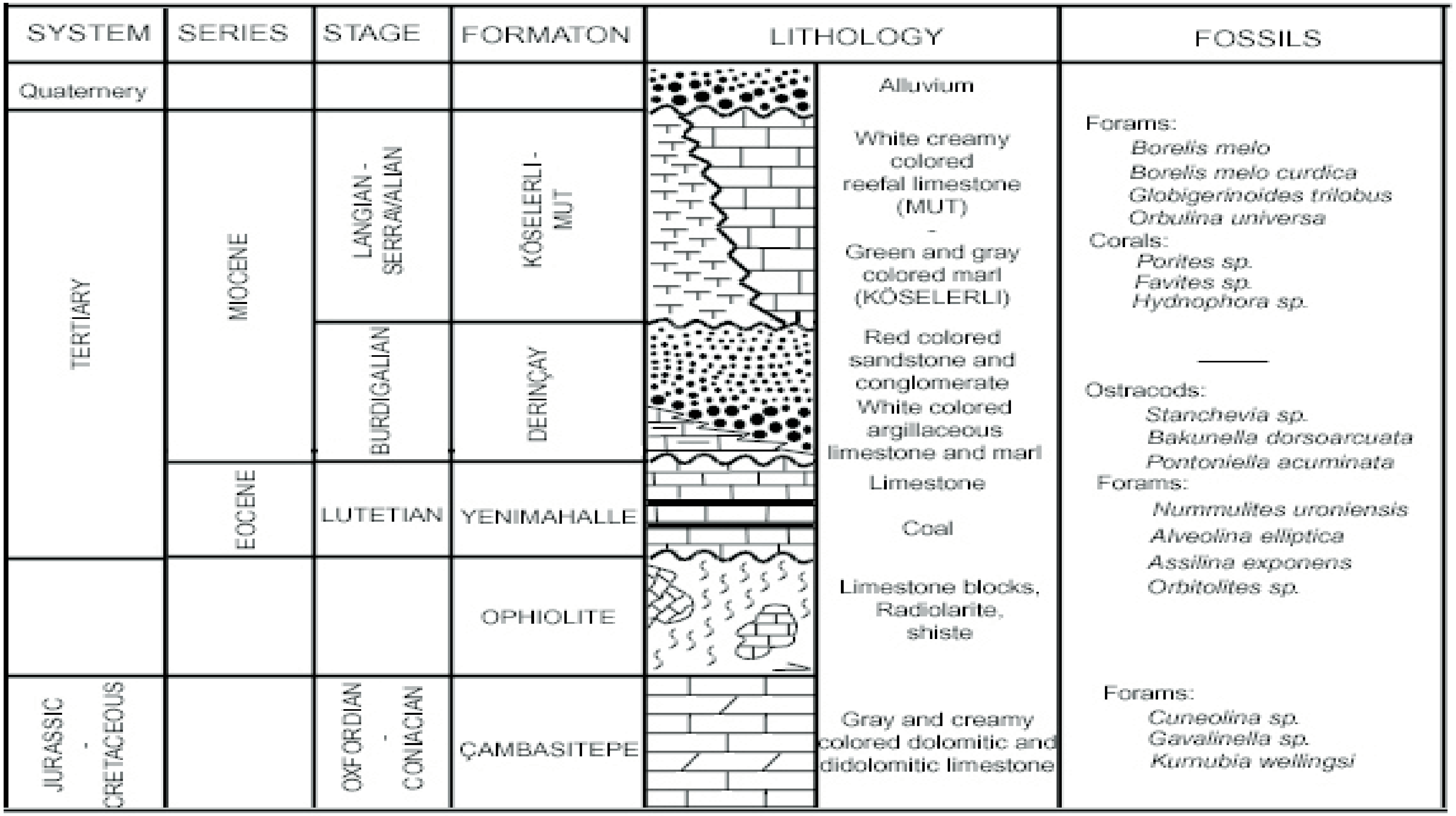


Figure 2.2: Generalized stratigraphic section of the study and surrounding areas. Not to scale. (Modified from Gedik et al., 1979)

Kızılkuzlukdere formation. A new transgression began in Late Jurassic and continued until Early Cretaceous, which resulted in the deposition of carbonates of Çambaşıtepe formation (Gedik et al., 1979). Late Cretaceous was the time of extensive ophiolite obduction in most of the Anatolia as a result of the closure of Neotethyan Oceans (Şengör and Yılmaz, 1981). This ophiolitic melange forms the basement of Eocene and Miocene rocks in the region. Ophiolitic melange is characterized by limestone blocks of Permian-Cretaceous age, peridotites, gabbro, pillow lavas and tuffs.

After the emplacement of ophiolitic melange in the region, the area was uplifted and remained as a subaerial continent until subsidence and Eocene transgression. Following the transgression turbiditic sediments were deposited near Ermenek. Yenimahalle formation represents these turbidites, comprising interbedded shales, sandstones and conglomerates. This Eocene sediments mark the end of "basement" succession. Oligocene is the time of erosion which produced the irregular topography. Derinçay formation of Late Burdigalian unconformably overlies Eocene Yenimahalle formation. Derinçay formation consists of fluvial conglomerates, sandstones and lacustrine limestones.

A new transgression after Burdigalian, resulted in the deposition of Mut and Köselerli formations. Mut formation is deposited in a shallow marine setting along marginal areas, while Köselerli formation was being deposited in slope and basinal setting. Gedik et al. (1979) mapped Mut formation as a single unit. This study indicates that it is made up of several carbonate packages, most of which are separated by erosional unconformity surfaces. These will be described and discussed in the following chapter.

2.2 Statigraphy and structure of the study area

In the study area only three units exist (Figure 2.3); the "Basement", the Mut formation and the Köselerli formation. The "Basement" rocks here consist of limestones of Jurassic-Cretaceous age and ophiolitic melange (peridotite, gabbro, pillow lava and tuff). The relations between these two rock groups are not very clear in the study area. In the surrounding areas, howev-

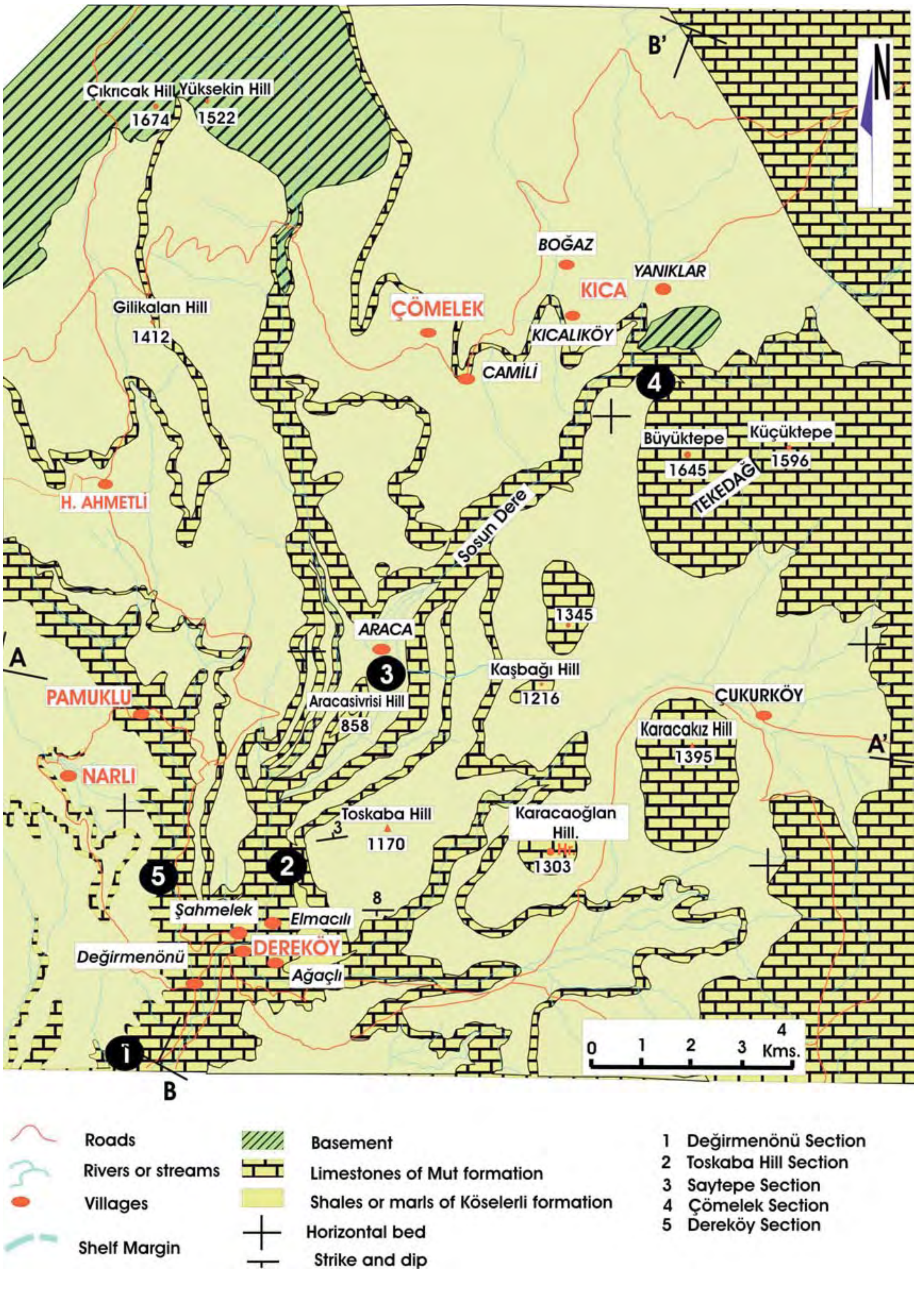


Figure 2.3: Geological map of the study area.

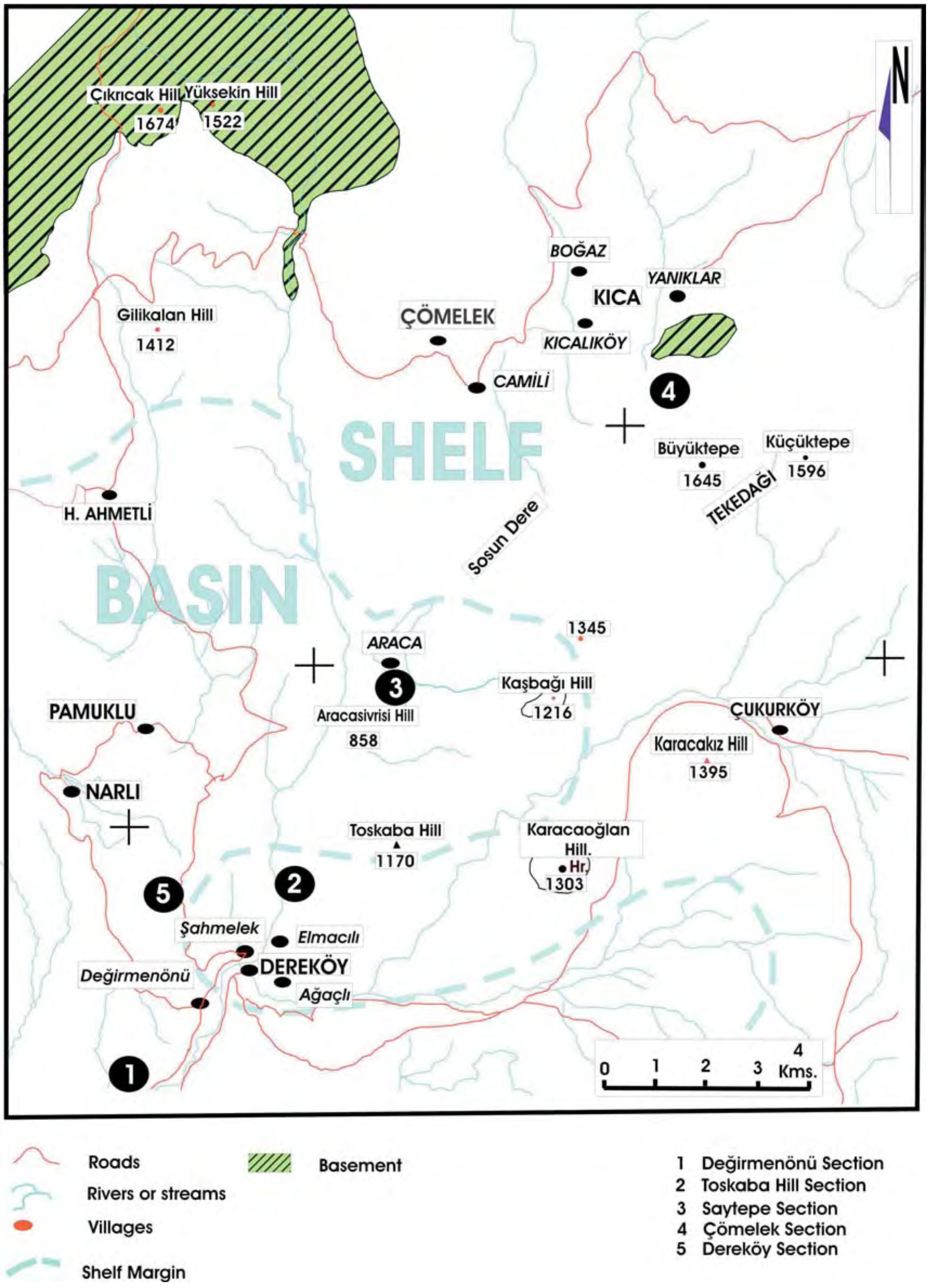


Figure 2-4:Relative position of the shelf margin inthe study area during Miocene.

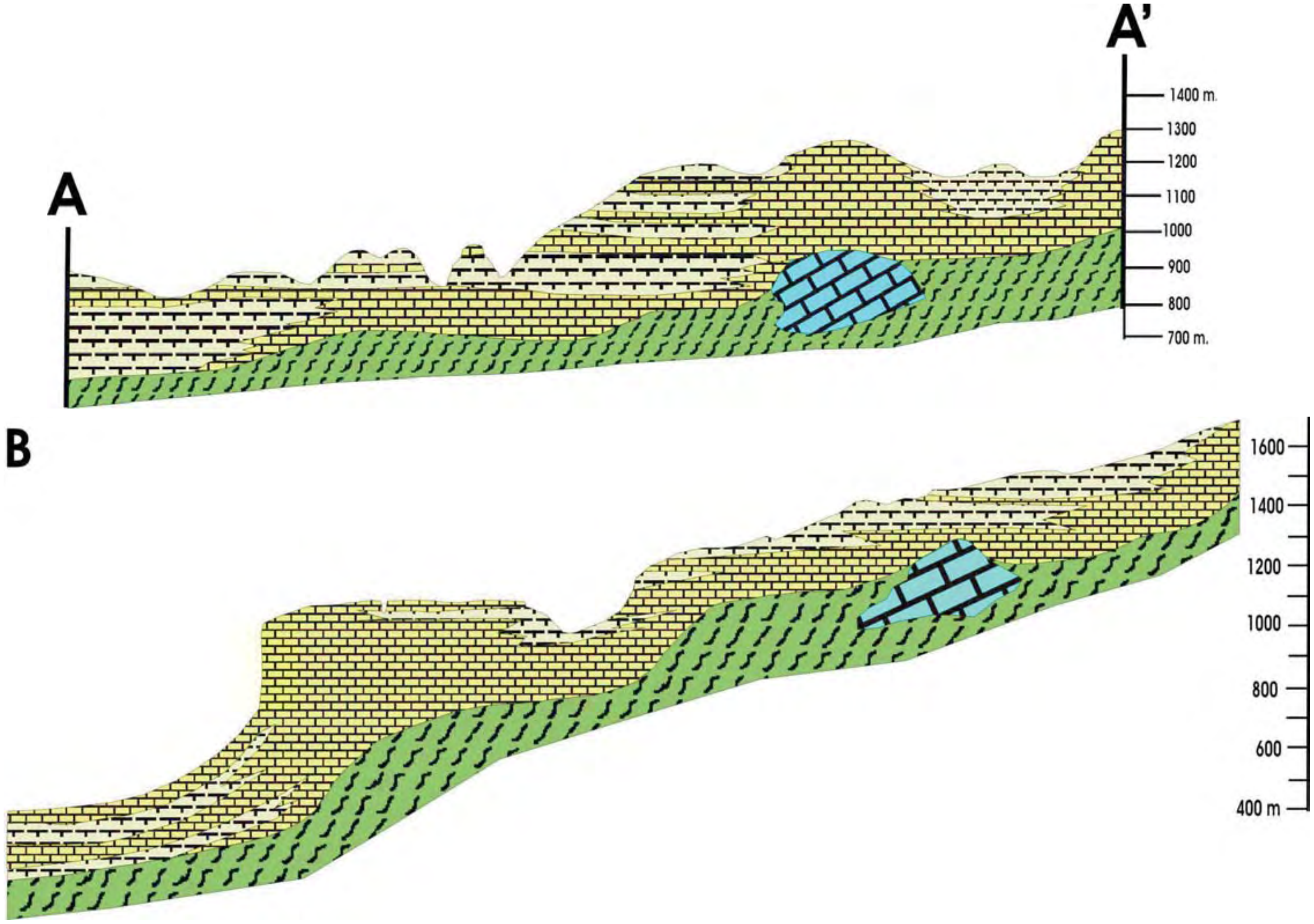


Figure 2.4: Cross Sections produced from the geologic map of the study area.

er, large blocks of limestones of various ages are present within the ophiolitic melange.

Gedik et al., (1979) are defined, described and published Mut formation, although Sezer (1970) first used the name "Mut limestone limestone" as a lithostratigraphic unit. Since it is widely accepted as Mut formation, it will be used as is in this study. According to Gedik et al., (1979), Mut formation consists dominantly of limestone containing occasionally sandstone and conglomerate beds. Limestones are white, cream coloured, medium hard, contains abundant algae, foraminifers, echinoids, lamellibranchia, gastropods, corals as fossils. They interpreted that it was deposited as a reefal complex. Mut formation unconformably overlies Paleozoic and Mesozoic formations. In Göksu valley however, it grades downward into Derinçay formation. It grades laterally and vertically into Köselerli formation. Thickness of the Mut formation varies from 150 metres to 1100 metres. Defined benthic and planctonic fossil groups yield Langhian-Serravalian age (Gedik et al., 1979; Tanar, 1989).

The Mut formation, in the study area, consists of reefal and platform type carbonates. Reefal carbonates are present as patch, pinnacle and barrier reefs. Reefal carbonates laterally grade into basinal shales of Köselerli formation toward the south and into platform and/or lagoonal carbonates(Figure 2.4, 2.5 and 2.6). Locally siliciclastic sediments developed toward north. These siliciclastic sediments are very thin and are not mapped separately.

Köselerli formation is first defineda and described by Gedik et al., (1979) from Köselerli village along Mut-Silifke road. It consists dominantly of marls, but contains argillaceous limestone, sandstone and conglomerate

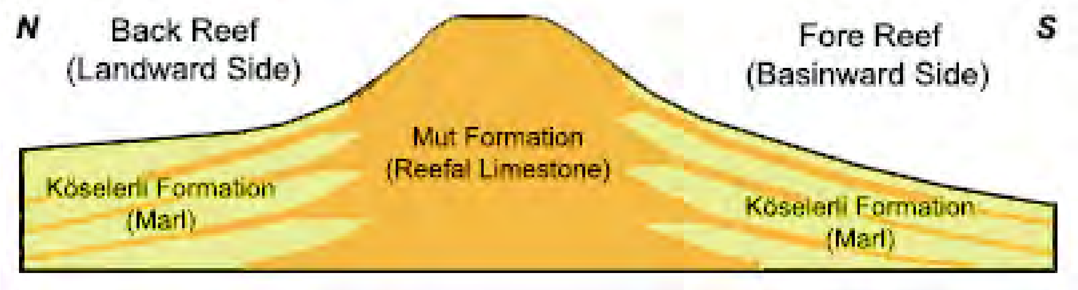


Figure 2.6: Sketch illustrating the relationship between Mut and Köselerli formations (Not to scale).

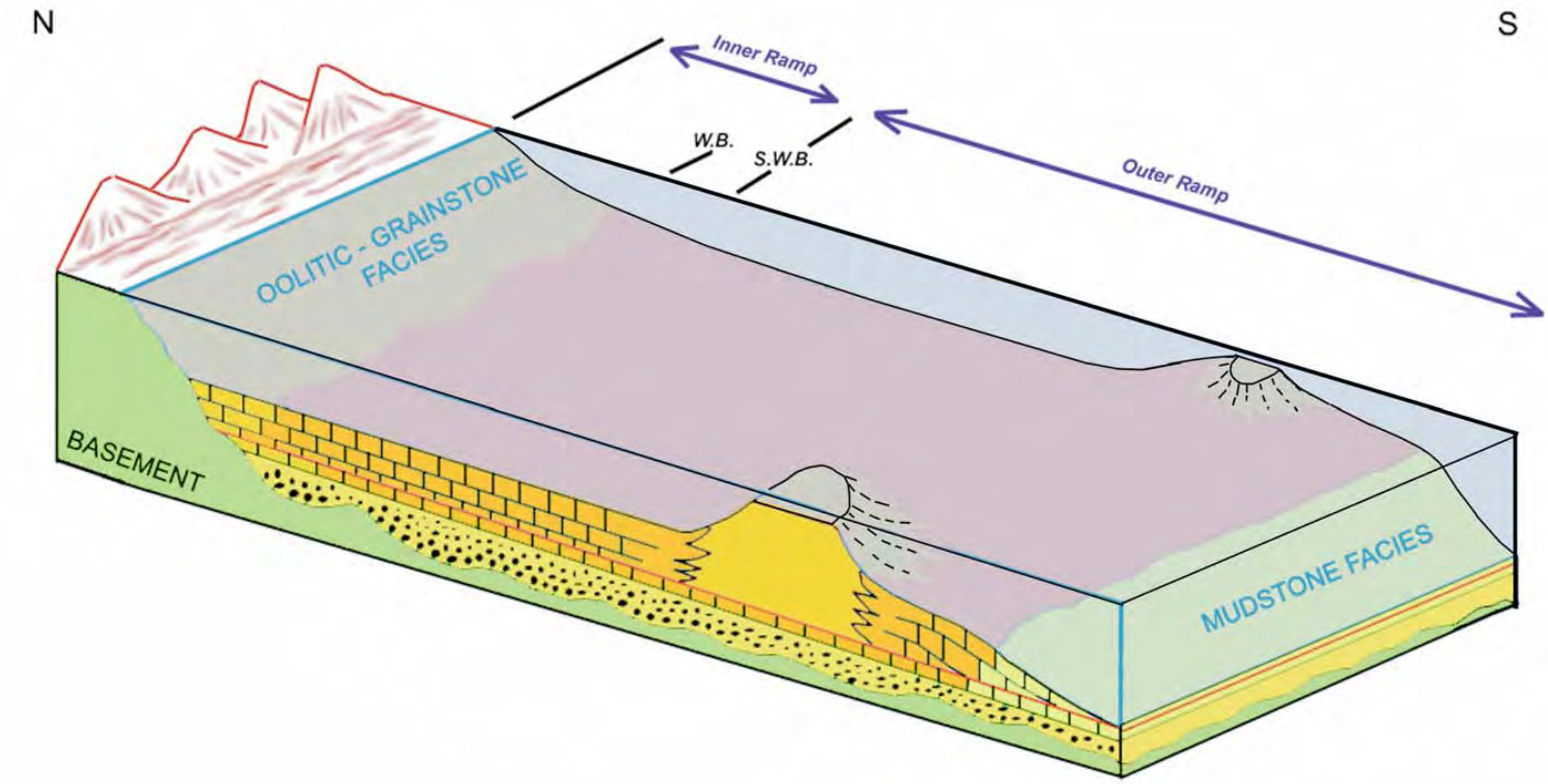


Figure 2.7: Schematic block diagram to show the facies distribution of the ramp setting (Not to scale). (WB: Wave Base; SWB: Storm Wave Base).

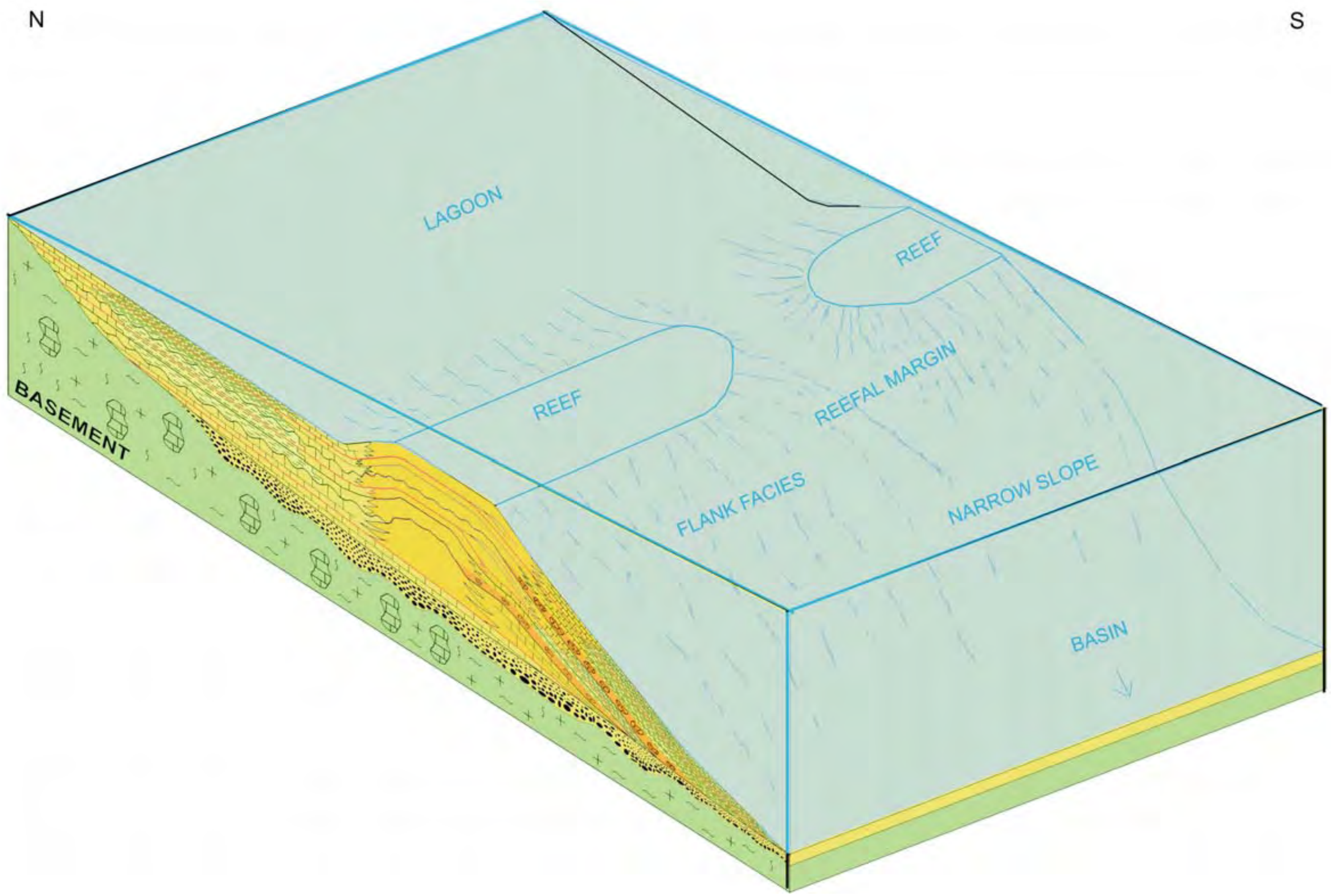


Figure 2.8: Schematic block diagram showing the depositional environments of reefal margin which has developed on a previous ramp (Not to scale).

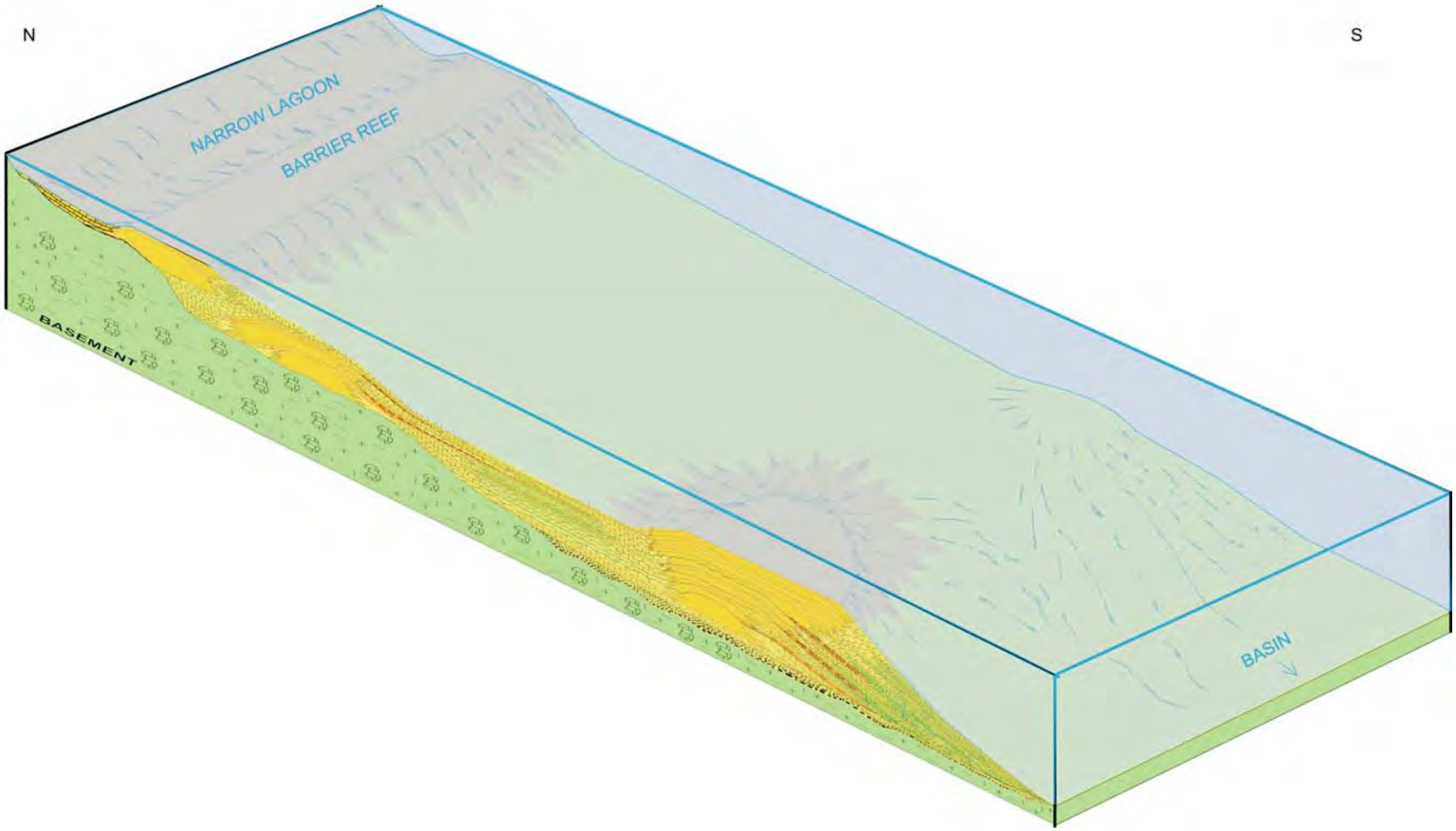


Figure 2.9 Schematic block diagram illustrating the transition of a patch reef to pinnacle reef and landward migration of reefs (Not to scale).

interbeds. Marls are gray- green coloured, soft and brittle. It has been interpreted as the basinal equivalent of Mut formation, therefore it grades laterally and vertically into Mut formation. It shows local unconformable relation where directly overlies the basement. Thickness varies from 150 to 1100 metres. Benthic and planctonic forams yield Langhian-Serravalian age (Gedik et al., 1979; Tanar, 1989), but Late Burdigalian age also reported from Silifke area (Gökten, 1976).

Köselerli formation, in the study area, consists of marls and shales and forms basinal equivalents of the Mut formation. Within the Köselerli formation, large volumes of carbonate debris flow sediments are present, possibly derived from the reefs developed along the margin of the basin.

The petrographic analyses indicate that the microfacies of limestones of Mut formation change from boundstone to mudstone depending on the energy of the environment. Carbonate grains are composed of skeletal particles, intraclasts and lithoclasts. Fragments of foraminifera, coral, bryozoa, echinoids and algae, which are typical fauna of reef environment, constitute the skeletal particles. The detailed facies description is given in chapter 3.

Stratigraphic relations give important clues about the paleogeography of Mut Basin. The depositional trend of Mut formation progrades from south to north. This indicates that hinterland was at the north of the basin and the southern part is flooded earlier. With the development of reefal margin the lagoon was developed in north of the basin. Continuous transgression resulted with the deepening of southern parts. Hence, the transformation of shallow marine setting to deep marine setting occurred. The horizontal beds of Mut formation terminate against basement, indicating irregularity of the paleotopography. Figures 2.6, 2.7 and 2.8 represent suggested models for the depositional environment of the study area.

Mut Basin was not tectonically active during Miocene (Bassant, 1999). Therefore the geological structure in the study area is essentially horizontal to sub-horizontal with dips ranging from 0^{o} to 8^{o}. However, minor faults do exist in the basin; these occur as NW-SE oriented strike slip faults (Demir, 1997). The general structure of the study area is shown in the cross sections (Figure 2.4) based on the geological map (Figure 2.3)

CHAPTER 3

SEQUENCE STRATIGRAPHIC ARCHITECTURE OF THE STUDY AREA

In order to define field relations of the rock bodies with the pre-existing topography of the basin and stratal geometries within the sedimentary pile, four stratigraphic sections have been measured (Figure 2.3) and one section is studied, with estimated thicknesses, owing to inaccessibility of the out-crops. Each section represents different part of the basin and related facies types. These sections are:

1. Değirmenönü section, mostly includes stratigraphically lower part of the Mut formation, representing early phase of deposition,
2. Toskaba Hill section, corresponds to the stratigraphically upper part of the formation, representing sediments deposited after the initial phase of the transgression,
3. Saytepe section corresponds to relatively deeper marine sedi ments between two thick carbonate accumulations,
4. Çömelek section shows carbonate sediments, interpreted as repre senting the shallow part of the system, which is very sensitive to the changes in water depth,
5. Dereköy section includes mostly marly sediments with thick car bonate interlayers, interpreted as representing slope and/or base of slope areas.

3.1 Değirmenönü Section

Description

This section is located 2 km southwest of Değirmenönü village (Figure 2.3). Section is composed of limestones and marls. Details are given in Figure

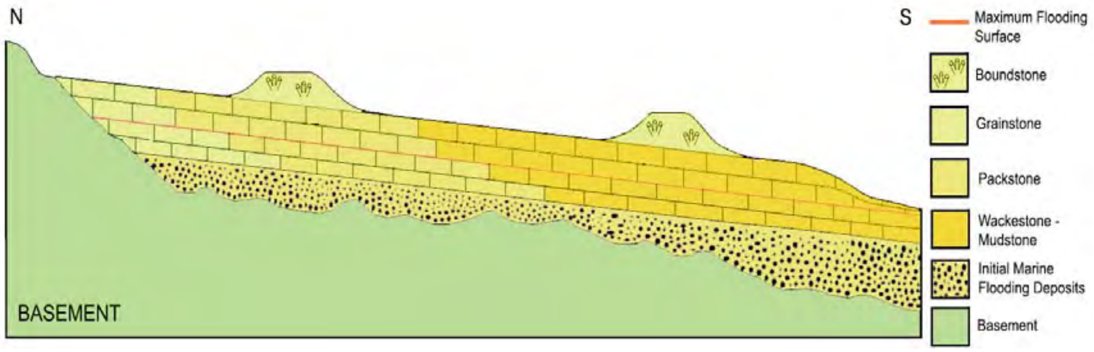


Figure 3.1: Sketch illustrating facies associations and the patch reefs of the ramp observed at the section (No scale).

Interpretation

Gray coloured quartz sandstone overlying red to pink sandstone and conglomerates represent the initial marine flooding surface (transgressive surface). After this initial marine flooding packstone/wackestone type carbonate deposition prevails. Overlying marl indicates a deepening and drowning of the carbonate. This carbonate/marl cycle is repeated three times, ending with a thick (5-6 m) marl level, which represents the maximum flooding time. The bedsets below maximum flooding surface exhibit parasequences of TST, each of which shows a shallowing upward trend. The bedsets above maximum flooding surface represent parasequences of HST. While marl and packstone indicates early highstand, the following grainstone and boundstone is indicative of late highstand conditions.

The continuous flooding and progressive deepening does not allow skeletal grains to accumulate. Deposition of mud free facies depend on the water depth and energy of the environment. When water depth increases, energy level effective on the sediments drops considerably and muddy facies dominates (Wilson, 1975). Hence, the facies below MFS indicate that during transgressive times the whole area is characterized by muddy facies. On the other hand, during highstand times the areas above wave base is characterized by high energy facies. The areas under wave base is characterized by packstone - wackestone facies. Mudstone is the characteristic facies of the outer ramp. However, there are lenticular limestone bodies which represent

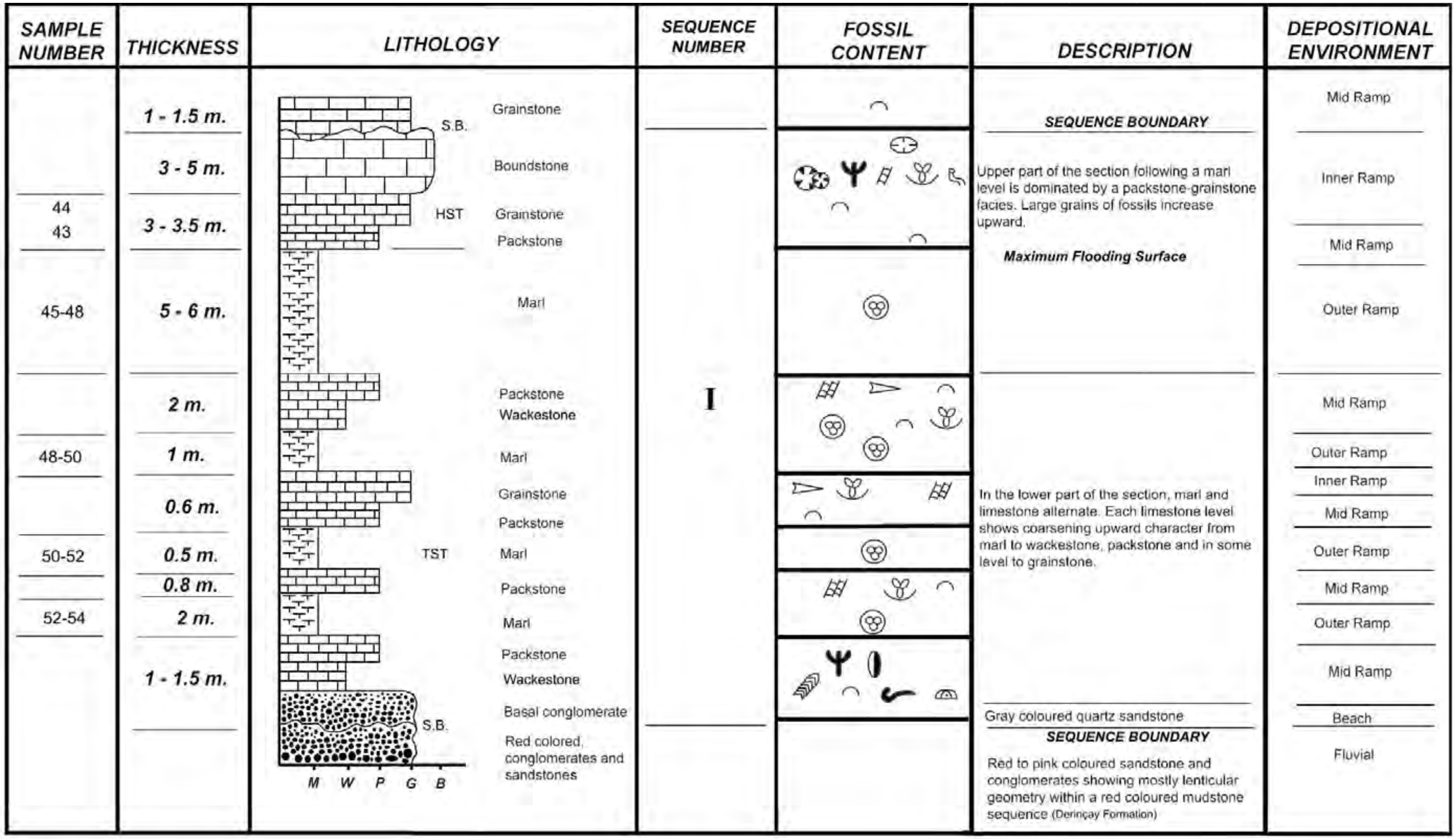


Figure 3.2: Measured stratigraphic section of Değirmenönü section (Not to scale).

the patch reefs on the ramp as boundstone (Figures 3.1 and 3.2).

3.2 Toskaba Hill Section

Description

Toskaba hill is located in the north of Dereköy and east of Pamuklu villages (Figure 2-3). It is made up of massive limestone at the center and bedded carbonates at the flanks, forming a dome shaped morphology (Figure 3.3). Due to high cliff face, the following descriptions are based on observations on a section along a N-S direction.

The carbonates at Toskaba hill is about 300 m thick. The carbonates rest on the "basement" rocks with an unconformity. Lower part of the carbonates is dominated by coarse carbonate breccia, onlapping northwards on the steep slope of the "basement" rocks. Approximately 300 m. thick massive carbonate overlies the breccia bed. Toward north, shallow water carbonates with rubbles from the reefal carbonates are seen. Away from Toskaba hill, in all directions, grain size gets progressively finer. Toward the south, they grade into marl in a short distance (~1 km.). This horizontal depositional trend continues upward as long as carbonate deposition continued. At the top of the hill, carbonates are massive at the center of the dome shaped morphology (Figure 3.3). The massive part here is dominantly made up of coral/algal facies and laterally grades into very thick bedded carbonates of grainstone-packstone character and finally into marls and carbonate wackestone-packstone facies at the southern flanks of the Toskaba hill.

Within the massive carbonate at Toskaba hill, there are several levels of karstified surfaces marked by large cavities (Figure 3.4). These surfaces separate thick and massive accumulation of carbonates and can be correlated with more pronounced surfaces where subaerial exposures are marked with erosional truncations in the north. Away from the Toskaba hill toward south, these thick carbonate levels are separated by marl levels and thin out toward the south (Figure 3.5). In the south marl dominates. Further south, it becomes difficult to distinguish carbonate levels from the marls, as they become con-

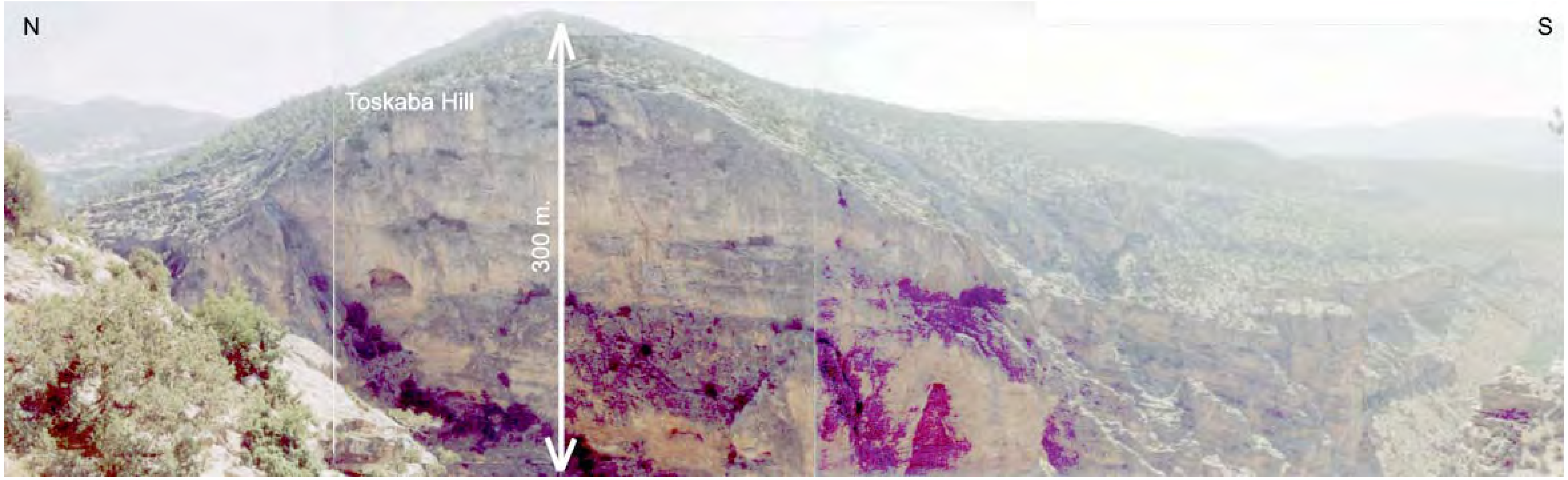


Figure 3.3: Reef complex at Toskaba hill. Subsequent development of reef core transformed patch reef to a pinnacle reef.

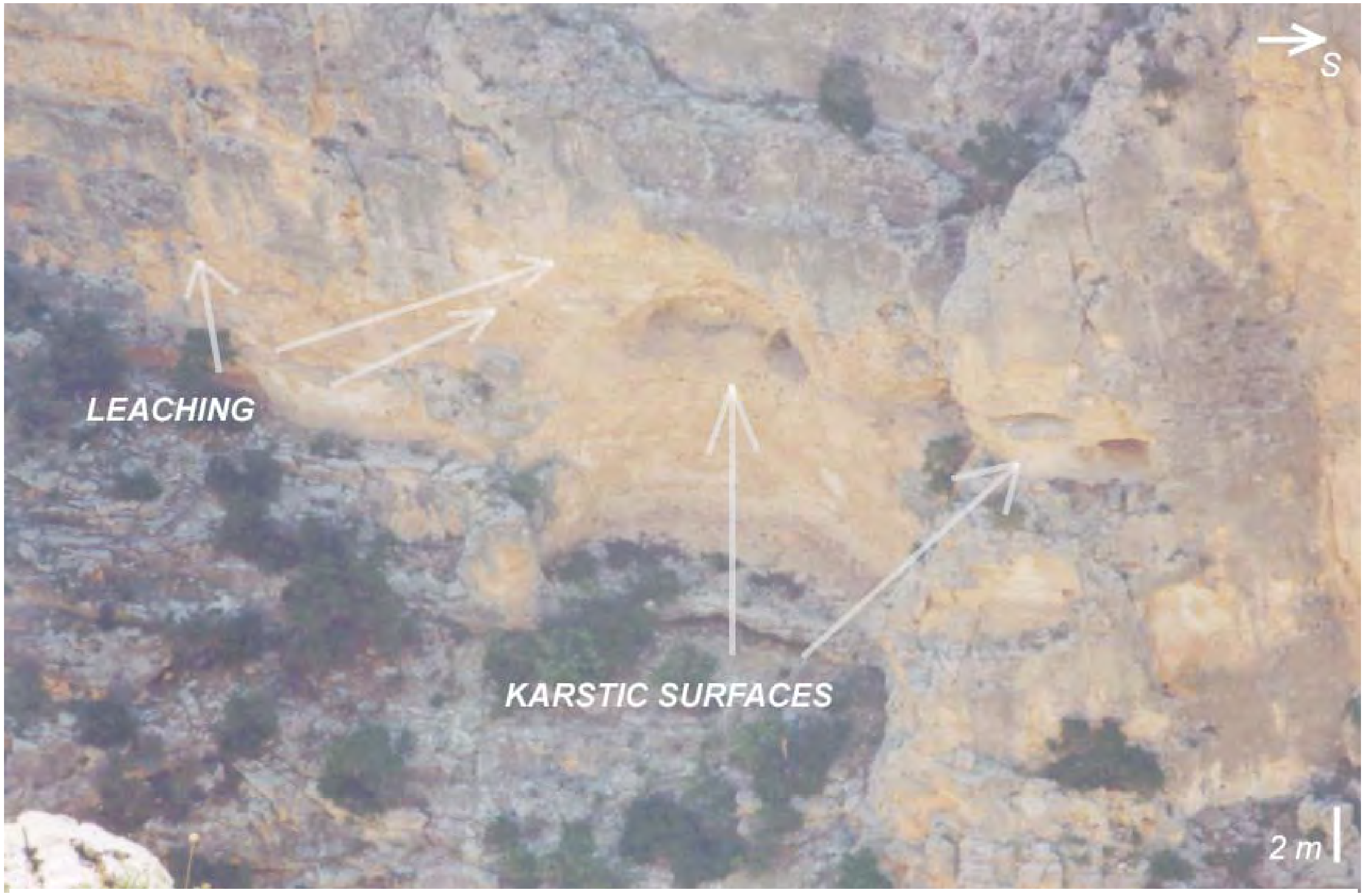


Figure 3.4: Karstic features (vugs, solution channels etc.) developed on the reefs at Toskaba hill due to subaerial exposure (Close view of figure 3.3).

formity surfaces.

Interpretation

Stratigraphic and facies relations stated above indicate that carbonate deposition started as reefal carbonate at the edge of a paleoslope. These reefal carbonates grade into fine grained sediments (mainly marl) toward south and grade into shallow water carbonates (mainly rudstone, grainstone and packstone) toward the lagoon in north.

Deposition of carbonate began on a surface with a rubble of angular carbonate grains indicating slope scree on an irregular surface of the "basement". Although there are patch reefs at outer ramp, carbonates did not form a continous reefal margin. Hence they were deposited in an area without a reefal margin. The patch reefs at the outer ramp keep pace with sea level rise. The base of Toskaba hill represents one of these patch reefs. Other patch reefs can be observed near Karacaoğlan hill (2 km to the east) and Karacakız hill which is located outside the study area. Karstified and leached surfaces indicate occasional termination of deposition possibly with subaerial exposure (Esteban and Klappa, 1983). Introduction of meteoric water causes leaching and karstification on the exposed surface of the carbonate. Dolomitization, siliciclastic input on the unconformity surface and correlation of unconformity surfaces from Çömelek area to the Toskaba hill indicate that karstic surfaces in the Toskaba hill are not recent features. So this surface is representing the first time gap and unconformity within the thick carbonate at Toskaba hill section. The leaching and karstification do not continue into basinal marl and fine grained sediments. This relation also suggest that although carbonate deposition terminated during subaerial exposure, deposition of carbonate renewed on the same location when sea level rose again. Deposition kept up with the sea level rise until the next fall. The accumulation of carbonate at the same location transformed this patch reef to a pinnacle reef.

By using the leaching surfaces and correlating of sequence boundaries at the north, five sequences are differentiated at this massive carbonate body,

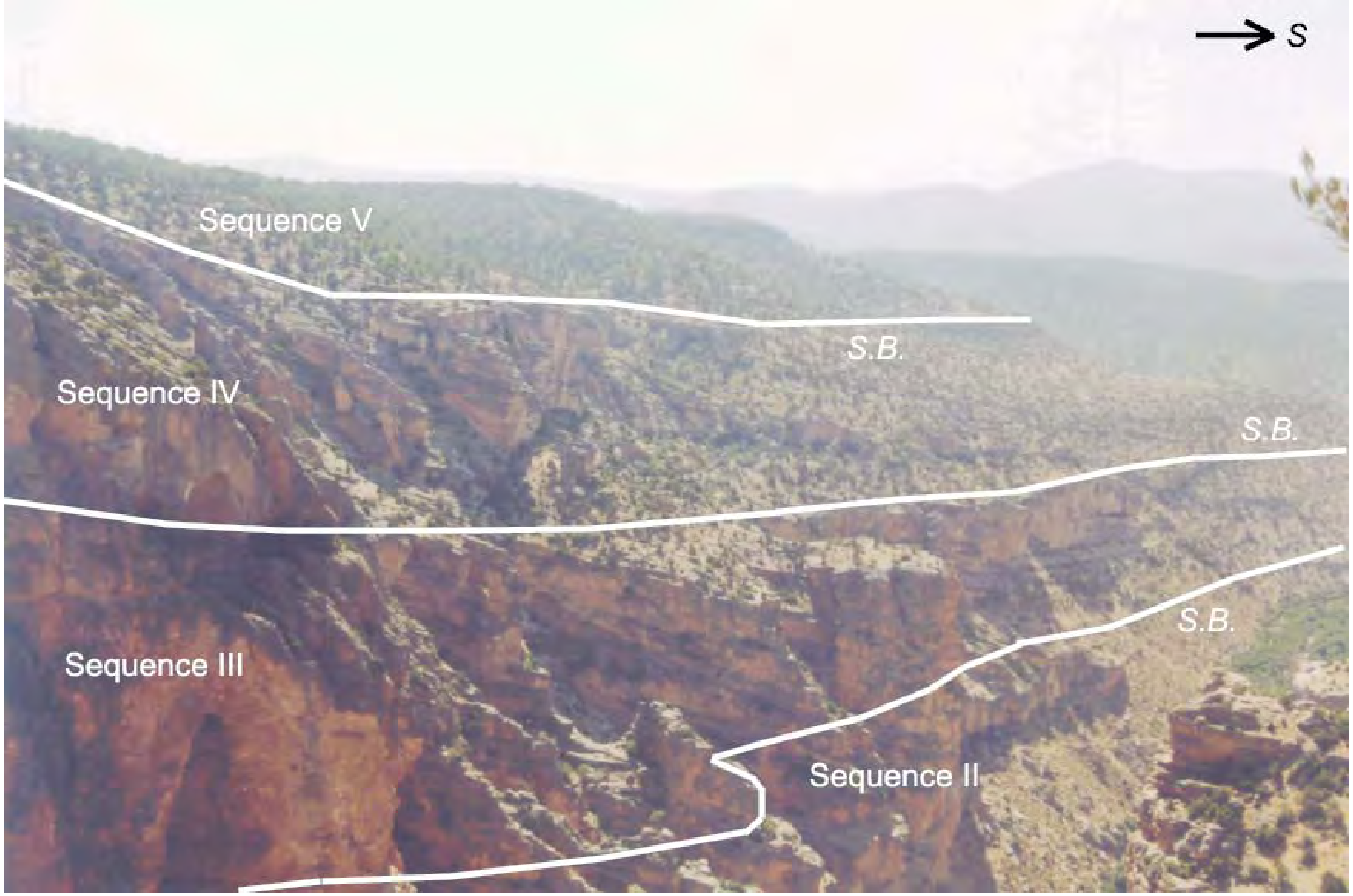


Figure 3.5: Carbonate reef flank facies observed in Tosakaba hill become thinner and change into shales in a basinward direction, toward south.

four of them shown in Figure 3.5.

3.3 Saytepe Section

Description

This section is located between Toskaba and Saytepe hills, along the eastern slope of Sosun Dere valley (Figure 2.3). Detailed description of this section is given on Figure 3.6.

Interpretation

The section starts at the base with several cycles, each of which shows a shallowing upward character. At the bottom the repetition of packstone - grainstone facies cycles indicates sea level oscillations. Lack of muddy facies and presence of diverse fauna make these cycles representations of the parasequences of HST of Sequence I (Figure 3.6). Shallowing upward character and development of leaching porosity suggest subaerial exposure and therefore an unconformity (sequence boundary). Although the sequence boundary is clearly identifiable, it is not easy to decide whether it is a type 1 or type 2 sequence boundary, from this section alone. Sequence II begins with marls indicating an abrupt deepening. The top of this marl level is the upper boundary of TST. When traced laterally, the overlying strata downlaps on to this surface. Sandy packstone - siltstone repetition at dm to m scale thicknesses characterizes the parasequences of HST. The top of this cycle ends with oyster bed which marks deposition in a lagoonal environment. The top of this bed is truncated which indicates an unconformity surface. The overlying 2.7 m. thick sandstone and siltstone alternation is interpreted to represent lowstand deposits, marking the base of the Sequence II. Very thick (about 100 m.) marl deposition occurred during TST time interval, with a 2 m thick sandy marl unit in the middle. The overlying packstone-grainstone facies represent the HST of this sequence. Overlying chaotic breccia bed indicate an erosion along the shallow basin margin suggesting lowstand sediments. So, the surface underlying the breccia is interpreted as a sequence boundary.

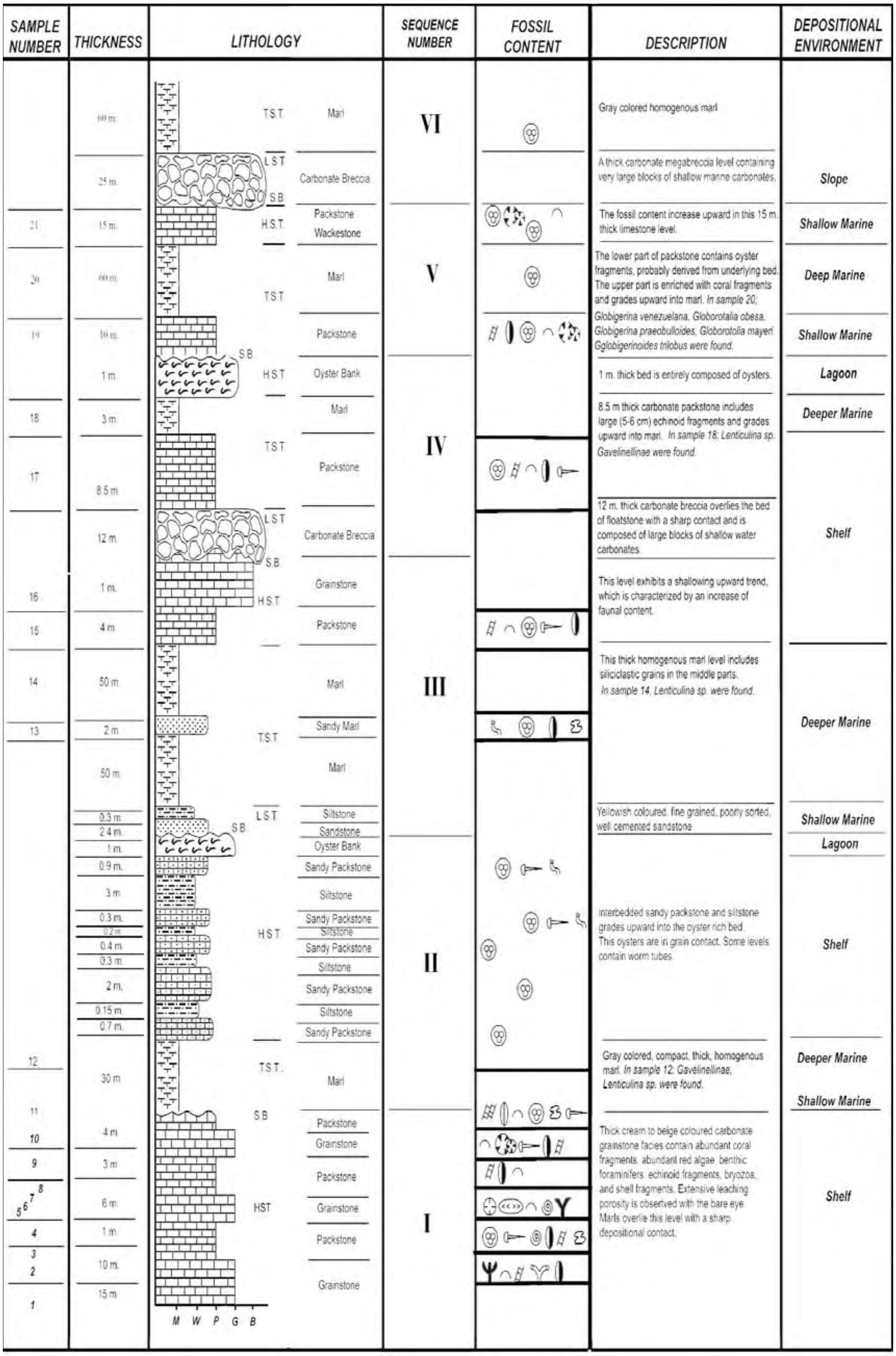


Figure 3.6: Measured stratigraphic section of Saytepe section (Not to scale).

Figure 3.7: 1 m. thick oyster bank caps HST of sequence IV.

Figure 3.8: The accumulation of oysters indicate a lagoonal environment, at the top of Sequence IV.

Sequence IV begins with packstone facies and due to rise in sea level (TST) and increase in relative depth ends with marl. HST is characterized by 1 m. thick oyster bank, interpreted to be deposited in a lagoonal environment and/or brackish water environment (Figure 3.7; 3.8). The top of oyster bed is truncated, marking the upper sequence boundary.

The base Sequence IV is characterized by transgressive deposits composed of 10 m. thick packstone and 60 m. thick marl. The overlying wackestone-packstone facies are the deposits of HST. Sequence V is topped by a breccia bed, which marks the drop in sea level, and the base of the next sequence.

3.4 Çömelek Section

Description

The Çömelek section (Figure 2.3) is located 4 km. east of Çömelek village. The details of the measured section are given in Figure 3.9.

Interpretation

This area represents the shoreline of the sequence (Figure 2.3). Because it is the shallowest part of the sequence, it is susceptible to erosion when sea level drops. The floatstone facies of HST is interpreted to be deposited in a lagoonal environment (Figure 3.10). Truncation observed at the top of this facies represents an unconformity surface. Red to pink color is another evidence of subaerial exposure. So, the top of this facies is a sequence boundary. Overlying 5 m. thick packstone facies represents the TST deposits of the next sequence, followed by mudstone deposited in a back reef environment, which constitutes the HST deposits.

As the sea level felt, the limestone became exposed to the air. Rain, having absorbed atmospheric CO2 which made it slightly acidic, slowly dissolved the carbonate, leaving the original grains of sand as a thick, reddish soil, forming Terra Rosa (Figure 3.9) . The presence of karstic surface at the top of this carbonate mudstone and terra rosa indicate subaerial exposure.

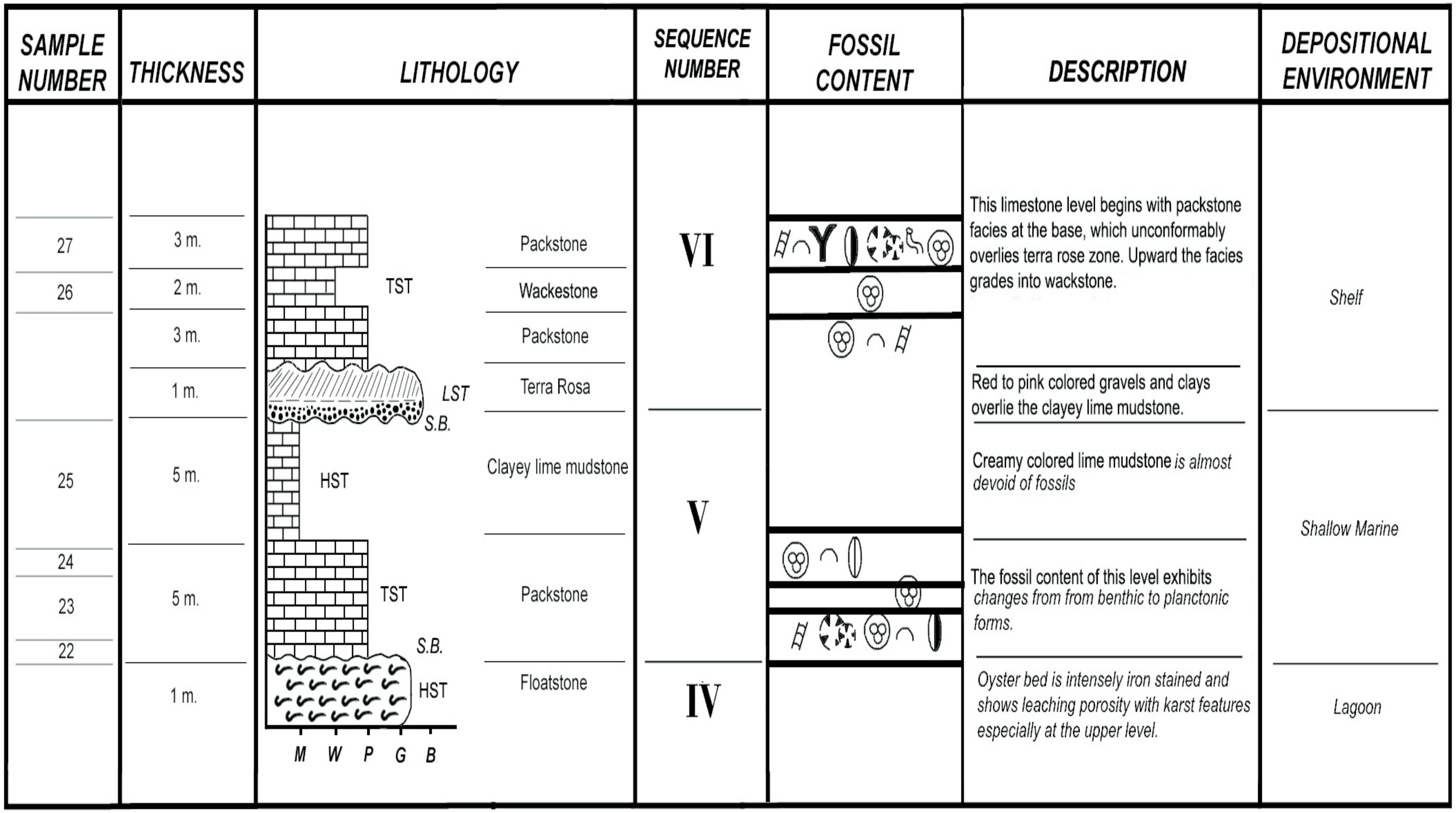


Figure 3.9: Measured stratigraphic section of Çömelek section (Not to scale).

Figure 3.10: The top of HST is capped by floatstone facies. The red to pink color indicates iron impregnation, which is related to subaerial exposure.

Interbedded siliciclastic material also supports this interpretation (Figure 3.11; 3.12). Erosion surface developed at this level should mark a type 1 sequence boundary.

This area is about 1 km east of the reefal margin, possibly on part of a narrow shelf behind a reefal margin (Figure 2.3). Presence of planktonic fossils suggest that normal marine circulation and/or storm surges brought planktonic organisms to backreef area. This shallow shelf would be exposed when sea level dropped under the shelf edge resulting in the karstic surface and

Figure 3.11: Unconformity surface marks the boundary between two sequences. Çömelek section, above clayey lime mudstone in Figure 3.9 (Pencil 15 cm.).

Figure 3.12: Red to pink color is dominant below the unconformity surface, suggesting effects of subaerial exposure.

advancement of fluvially transported material onto the shelf.

3.5 Dereköy Section

Description

This section is located 2.5 km. northwest of Dereköy village (Figure 2.3). Dereköy measured section is composed of limestone and marls. Details are given in Figure 3.13.

Interpretation

This section is marl dominant, which suggest that the area is in a relatively deeper part of the basin. Erosional surfaces observed in the shallow part of the basin can not be traced and followed into this area, because they lose their identity due to continuous deposition in the deeper part of the basin. In other words, an unconformity surface transforms to correlative conformity (CC) surface. Large carbonate breccia beds, however, represent lowstand deposits. These are deposited during the fall of the sea level below the shelf edge. Coarser grained sediments within marls may indicate shallowing of the sea during which coarse grained sediments were shed to the basinal areas from the shallow marine areas. Amount and thickness of the coarse grained material and breccias indicate amount of the sea level fall which defines the amount of the area exposed. Such surfaces have been interpreted as correlative conformity surfaces (Van Wagoner et al., 1988).

Sequence boundaries are defined by using features such as truncation, karstification or development of terra rosa. However, correlative conformity surfaces do not exhibit such features. Due to this reason, sequence boundaries in basin areas are defined by tracing unconformity surfaces in the field. First, second, third and fourth correlative conformity surfaces mark a sharp depositional contact between limestones and overlying marl. Transgression causes deepening of the environment. Hence, marls are interpreted to represent TST deposits. When the rate of sea level rise decreases or stillstand conditions prevail grainy facies developed. Therefore, packstone facies in the

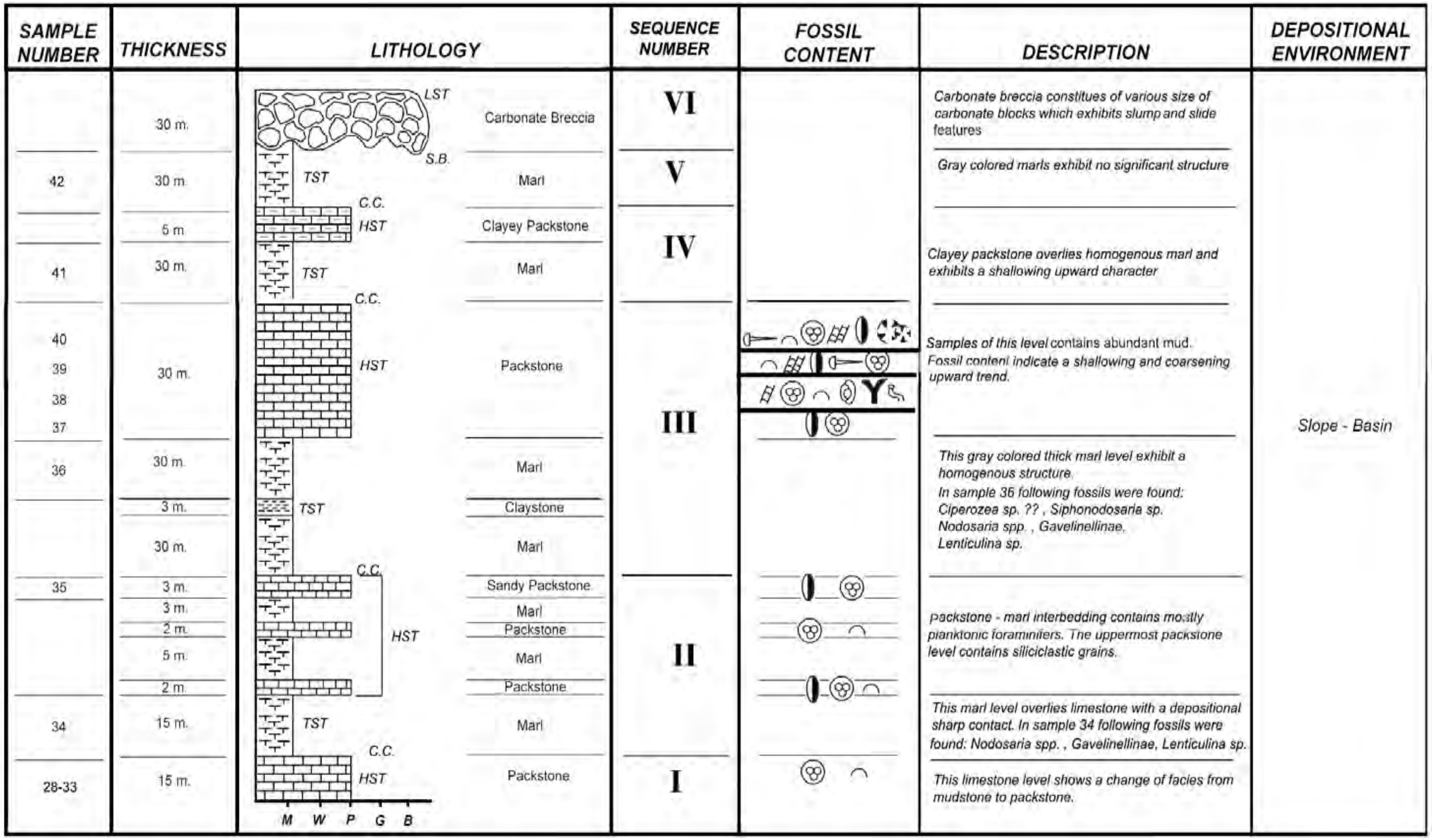


Figure 3.13: Measured stratigraphic section of Dereköy section (Not to scale).

section is interpreted as HST Deposits. As mentioned above Dereköy section represent basinal area. Hence, lowstand deposits does not exist in the section, except Sequence VI. The 30 m. marl level at the top of this section has a truncated surface at the top. This truncation is related with the sea level fall which produced the following 30 m. thick carbonate breccia level.

CHAPTER 4

DIAGENETIC IMPRINT OF SEQUENCES

Carbonate sediments are more susceptible to diagenesis than most silicate minerals (Boggs, 1995). There are relatively few studies about the relationship between sequence stratigraphy and diagenesis of siliciclastic deposits, compared with carbonates (Ketzer, 2002).

The diagenesis of carbonate sediment is controlled by the original facies, mineralogy, climate, sea level change and burial history (Moss and Tucker, 1996). As the carbonates are deposited, precipitated, buried, eroded, exposed and reburied, they interact with water of marine, meteoric and deep subsurface origin. Each of these fluids affects the sediments or rock in a special way and leaves a unique diagenetic signature (James and Choquette, 1990). If carbonate sediments are exposed subaerially to percolating meteoric water two reactions occur:

a. Water controlled meteoric diagenesis that is driven by the reaction between the carbonates (regardless of composition) and meteoric water of differing temperature and/or amount of dissolved CO_2 which causes formation of caves and other karst features, local development of spelean carbonates and calcrete development (James and Choquette, 1990),

b. Material controlled diagenesis that is driven by the reaction between mineralogy of differing solubilities and meteoric water results in the transformation of aragonite and high magnesium calcite to low magnesium calcite (James and Choquette, 1990).

As carbonate sediments undergo progressive burial and are subjected to increasing temperature and pressure during and after lithification, they go through a variety of modification. These include; 1) mechanical and chemical compaction during which porosities may be sharply reduced; 2) cementation by carbonate, sulphate and silica minerals; 3) conversion of metastable forms of $CaCO_3$ to low Mg calcite; 4) decomposition as well as bio and thermo-chemical transformation of organic matter.

A generalized diagenetic scheme for the Miocene carbonates of Mut basin is based on the study of thin sections and field observations which concentrated on macro scale features like karst dissolution, infiltration of iron rich clays and fluids, and input of siliciclastics, indicating fresh water input to the basin.

Thin sections study point to two major groups:

1. No evidence of solution or precipitation in deep water facies.
2. Fresh water diagenesis and/or leaching features.

The first group of carbonates has been interpreted as being deposited in deepwater, while the second group is generally interpreted as being deposited in a shallow water environment (Bebout et al., 1979)

Each sequence in the study area shows different signs of diagenesis. In Sequence I of ramp setting, along the Mut-Karaman road, show only calcite cement of equant type. There are syntaxial overgrowths. All pore spaces in the upper part of the sequence I is dominated by calcite cement. The crystal size increase toward pore center. There is little leaching porosity observed in thin section (Figure 4.1), but on the surface, extensive leaching porosity can be seen. It is not certain whether it is a recent development or a result of the sample size from which thin section is made.

On Sequence II, leaching porosity is evident. Large grains are leached (Figure 4.2) and some of the grains are neomorphosed. However, the argillaceous structure of packstone facies in this sequence did not allow water to easily penetrate. Hence, such porosity is formed in grainstone facies.

On Sequence III syntaxial overgrowth is common, especially, in the shallow water facies. In the relatively deeper water facies, only little effect of

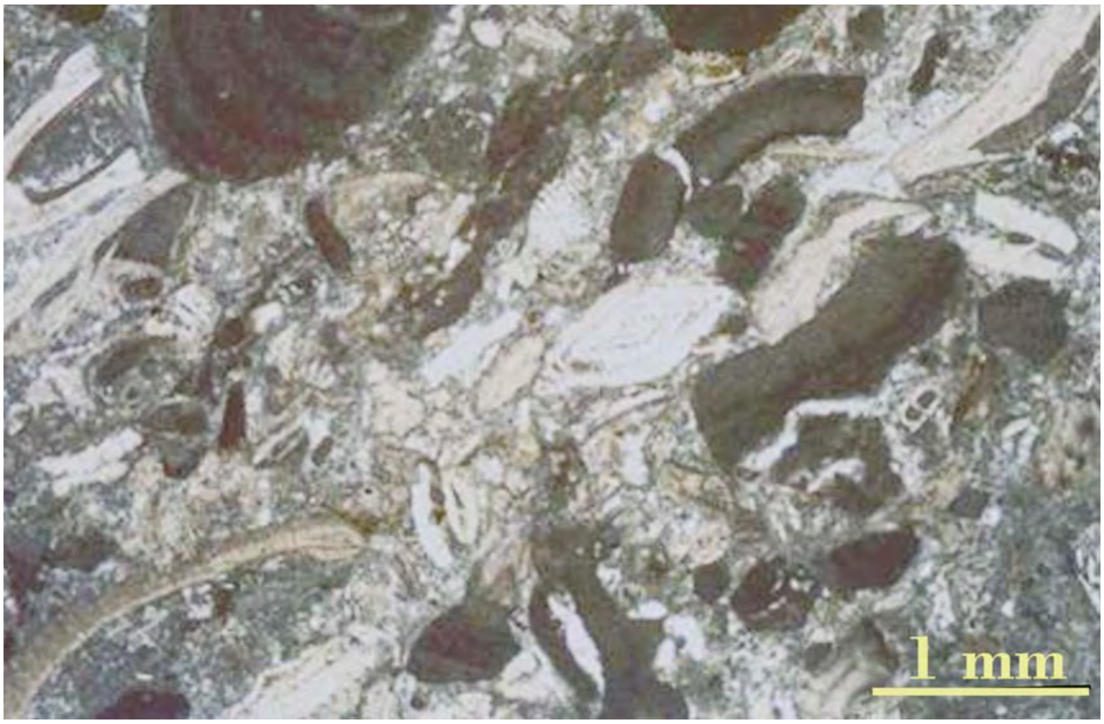


Figure 4.1: On the ramp sequence (Sequence I) little porosity is present. Present pore spaces are filled by calcite cement. There are some leaching. This may be due to low porosity and permeability. Sample number 43 (Plane light x2.5).

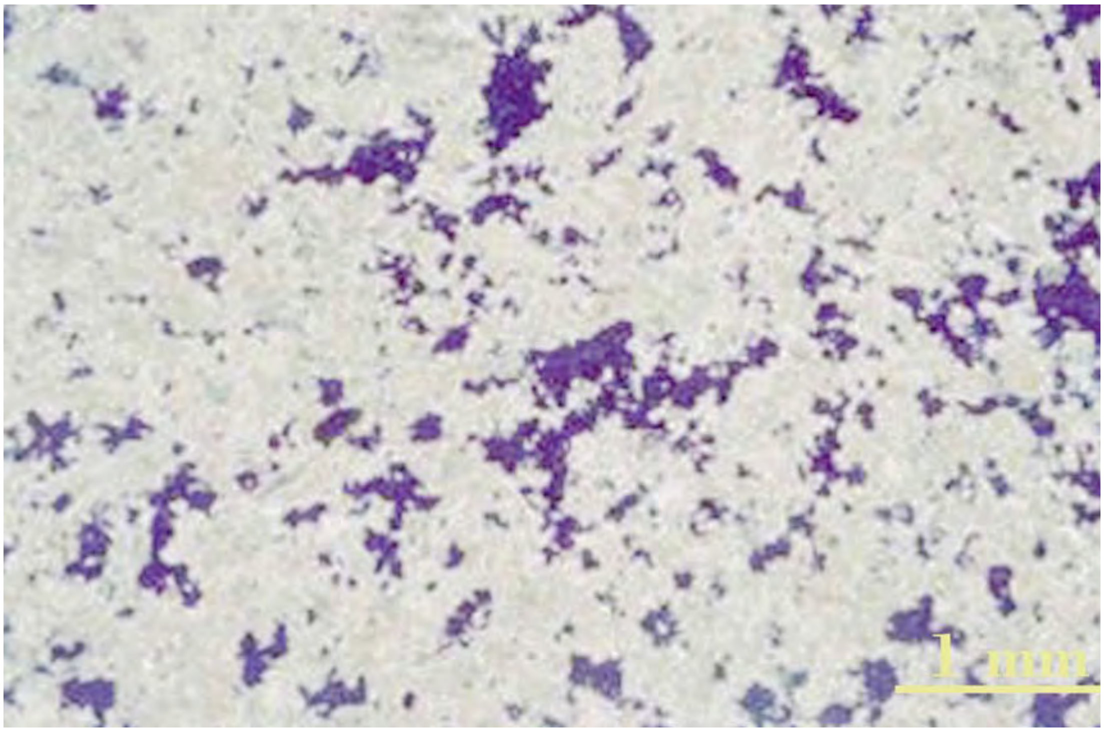


Figure 4.2: On Sequence II extensive leaching developed. This is possible either in phreatic zone when water is undersaturated with respect to calcite and/or in vadoze zone. Sample number 10 (Plane light, x2.5).

the diagenetic changes are observed. Locally micropore spaces are filled with iron oxide staining (Figure 4.3) which may indicate that water during subaeri-

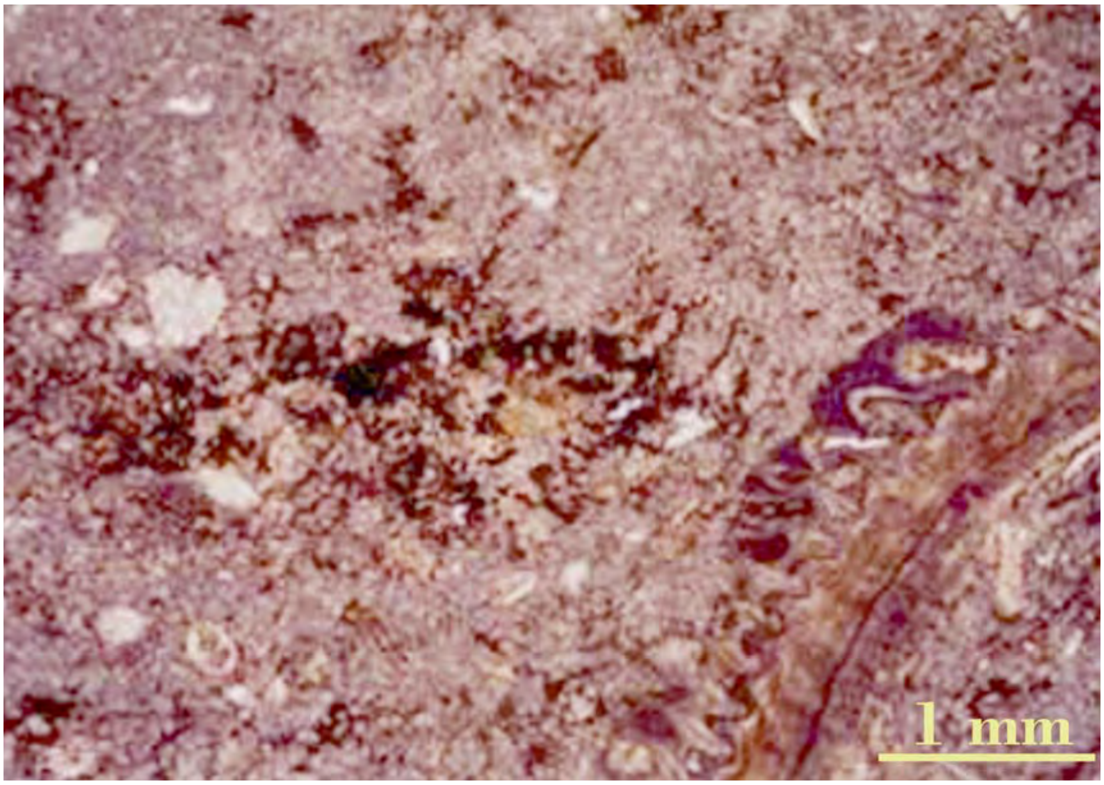


Figure 4.3: Iron oxide filled micropores are common along some surfaces. (Plane light, x2.4).

al exposure was rich in iron that can be attributable to humid climate. Mineralogically selective dissolution is common in the shallow marine limestone especially red algae, and some bivalve shell fragments are selectively dissolved and porosity was created.

On Sequence IV, extensive leaching is developed in shallow water areas, while only minor diagenetic effect is observed. In thin sections, micropores are impregnated by iron oxide. Figure 5.5 shows a big truncation surface indicating that sea level fell considerably. Large caves are developed. Especially corals, which are made of aragonite, dissolved and extensive pores are developed (Figure 4.4). Eroded material is transported downslope and deposited on the slope or at base of slope.

Sequence V has limited extend when compared to other sequences. Highstand Systems Tract of the sequence is limited to shelf margin. It is also subaerially exposed and meteoric diagenesis dominates. Sequence VI has a

Figure 4.4 : Especially in reefal facies, composition sensitive diagenesis is common. Since corals are made of generally aragonite, it is the first mineral to dissolve (Pencil length 15 cm.) Picture is taken at eastern slope of Sosun Dere .

wider distribution and is characterized by an important truncation along the margin indicating subaerial exposure and erosion. Large caves are developed (Figure 4.5). Due to high cliff face, it was not possible to examine the caves and karstic feature in detail. Top of the sequence has a karst and caliche development and siliciclastic input marking the exposure and leaching of the surface as a result of subaerial exposure (Figures 4.6 and 4.7).

The diagenetic features observed in sequence I indicate that during the lowstand time, most of the ramp must have been exposed and saturated with fresh water. The syntaxial overgrowth is characteristic of fresh water phraetic zone (Choquette and Pray, 1970). Hence, the area must have been exposed to meteoric water. Today, water table is too low. However, fill of pore spaces with calcite cement and increase of crystal size toward pore center indicate phreatic diagenesis. In other words, features are not recent. Diagenesis mostly affected the sediments with an initial porosity and permeability and compo-

Figure 4.5: Large caves developed due to subaerial exposure in sequence VI. Due to high cliffs, it was not possible to make detailed analysis. Photo is taken from westen slope of Sosun Dere looking east.

Figure 4.6: At Çömelek section, sequence boundary is marked by the development of karstic feature and red clay.

Figure 4.7: At Çömelek section, there is coarse siliciclastic material indicating that there was some input from the land areas. Red to pink color indicates oxidizing which is evidence of subaerial exposure.

sition of grains which are made up of aragonite and high magnesium calcite that are more susceptible to dissolution when subjected to meteoric water.

Deep marine deposition allowed Sequence II to be cemented with micritic calcite cement. On Sequence III iron oxide staining indicates circulation of meteoric water rich in iron oxide. On sequences IV, V and VI the development of large caves show that the shelf areas were exposed and meteoric diagenesis dominated.

Just below and around the karstic surface extensive dolomitization developed (Figure 4.8). This dolomitization postdates early diagenesis and therefore is interpreted as late diagenetic event (Figure 4.9). There may be other dolomitized levels around sequence boundaries especially where erosion occurs, suggesting a considerable sea level fall. This falling event must have controlled the input of fresh water into the diagenetic environment. In the upper part of the meteoric zone, aragonite and high magnesium calcite are

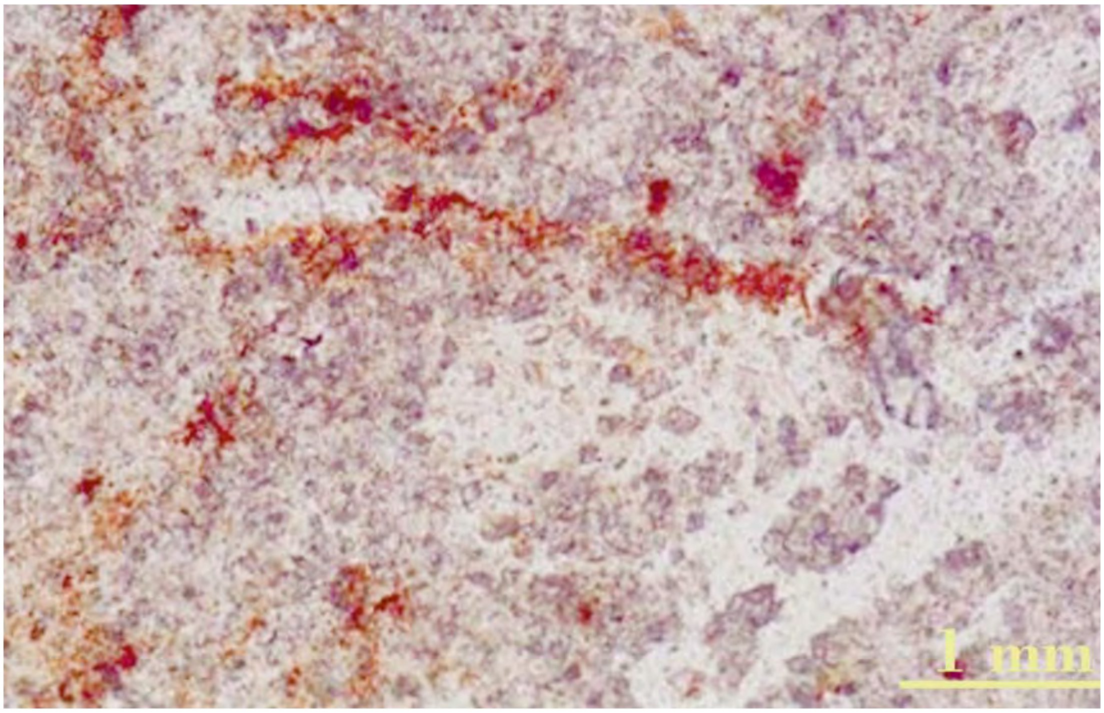


Figure 4.8: At the Çömelek section, just below the upper sequence boundary of Sequence V, extensive dolomitization and red iron staining present. Dolomitization may be developed due to iron rich meteoric water. Sample number 25 (Plane light, x2.5).

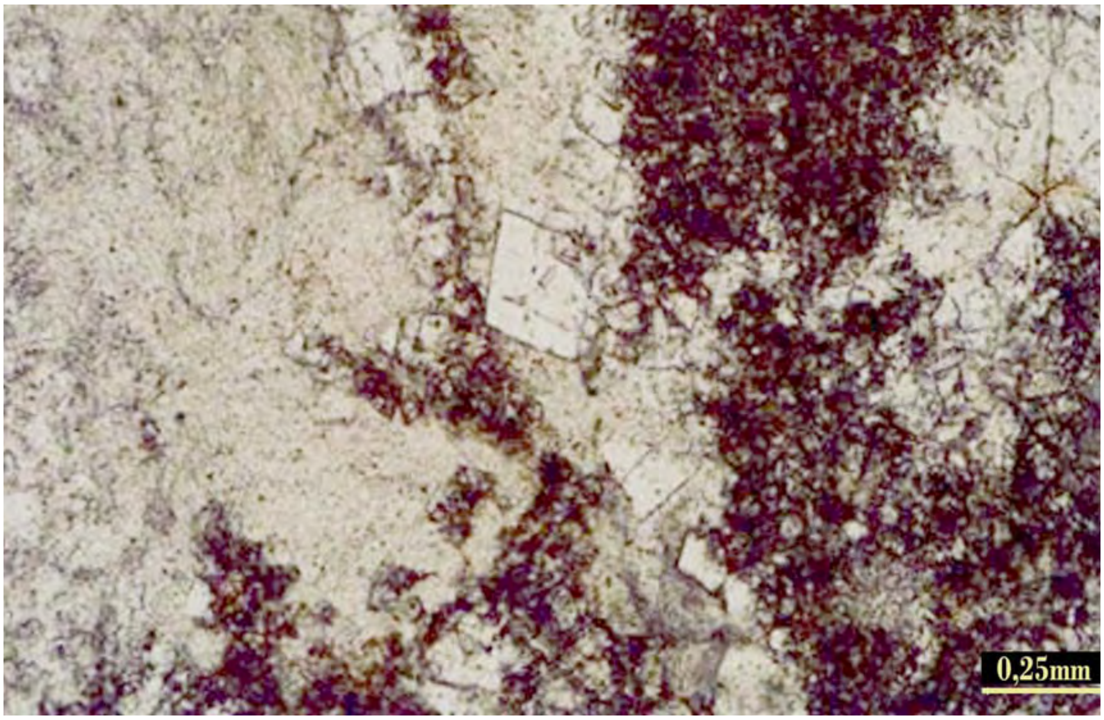


Figure 4.9: At the Çömelek section, dolomite rhombs indicate that dolomitization was a late diagenetic event. Note that dolomite rhomb is growing on calcite crystal postdating early fresh water diagenesis. Sample number 24. (Cross polars, x10).

easily dissolved and transported downward supplying excess Mg for dolomitization.

Karst can develop under all climatic conditions; caliche is attributable to generally semi-arid climatic conditions. Many subaerial exposure surfaces may not contain any diagenetic features, so the absence of such features in the rock record does not necessarily mean that the limestone was never subaerially exposed. Climatic effect is also important but it is the beyond of the limit of this thesis, so it will not be discussed here. Rate of water flow within the limestone (pore space) is the most important single diagenetic rate factor with flow rates probably depending on climate, topography and differential permeability (Bricker, 1971). Therefore limited cementation and diagenetic imprint in the sediments may be attributable to the muddy nature of the carbonate which delimits the flow of water within the environment and lack of high porosity within the sediment.

Mineralogically selective dissolution is common in the shallow marine limestone especially red algae, and some bivalve shell fragments are selectively dissolved and porosity was created.

CHAPTER 5

CORRELATION OF SECTIONS

Measured sections within the study area and surface exposures have been correlated with each other in order to construct the sequence stratigraphic framework of the Miocene carbonate sediments in the area. In correlating the sequences, field observations, thin section studies and tracing of beds along surface exposures are used (Figure 5.1). Erosional unconformities are very clear as indicated by removal of sediments along the margin (Figure 5.2) and by onlapping relations of the beds (Figure 5.3). Top of each shallowing upward cycle, as well as an erosion surface, is interpreted to represent a sequence boundary and marked as an "unconformity surface" on the marginal areas. Shallowing upward cycles, debris flows (Figure 5.4) and sudden deepening have been used to define correlatable surfaces to define sequence boundaries and systems tract in the slope or basinal areas. Such surfaces are then followed along the exposure faces to tie them to the measured sections. All sections are tied in a N-S direction. Studies are concentrated on two areas:

1- Relatively deeper water areas, where the effect of sea level fall can be distinguished by microfacies analysis (through thin section studies) or observation of large scale features like development of megabreccia beds and siliciclastic interbeds, as observed between Aracasivrisi Hill and Kaşbağı Hill (Figure 2.3). Development of megabreccias and siliciclastic material are the product of sea level fall that causes siliclastic material bypass the shelf and be deposited in the basinal areas (Handford and Loucks, 1993). The material may be so fine grained that they can only be defined by studying thin sections. Saytepe and Dereköy sections are located in relatively deeper marine areas (Figure 2.3).

2- Shallow water and/or lagoon, where effect of sea level changes is more pronounced and is reflected by the facies types developed. Stratal geometries can be best observed in areas from shore to shelf margin. Especially shelf margin erosional features can be used for defining sequence

Figure 5.1: Along Sosun Dere bedsets can be traced from Toskaba Hill to reefal margin in the south of Çömelek, which allowed correlation of sequences. Picture is taken from the west of Toskaba Hill looking toward NE.

boundaries. Çömelek section is located near paleoshoreline, representing shallow marine setting (Figure 2.3).Lowest sequence in the study area is recognised as a transgressive conglomeratic bed over Mesozoic carbonates forming the basement. This first sequence is exposed north of Dereköy village; lithologic details are not recorded due to difficulty in reaching the cliff face. Lateral extension of this sequence is exposed at the base of Sosun Dere. There is no shelf margin or break in slope developed during Sequence I. Highstand Systems Tract of Sequence I is overlain by Transgressive Systems Tract of Sequence II (Figure 5.5). This sequence boundary is

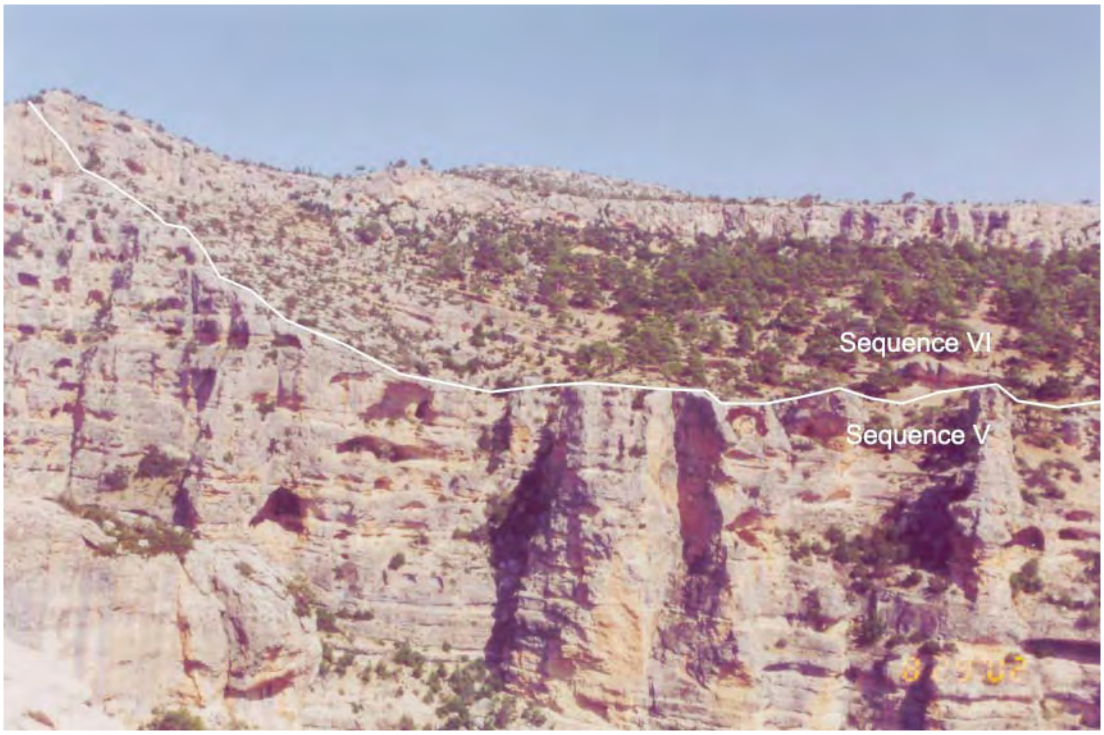


Figure 5.2: Erosional features are used to define sequence boundaries along the reefal margin.Picture is taken from about 2 km south of Çömelek village, looking E.

Figure 5.3: Along the reefal margin, onlapping relations are also used to define sequence boundaries. Note truncation of beds. Picture is taken from the eastern slope of Sosun Dere looking toward NW.

Figure 5.4: Debris flows are used in both defining lowstand sequences and correlating sequences within the study area. Picture is taken from eastern slope of Sosun Dere. Bottle is about 15 cm long.

marked with a sharp contact between shallow marine carbonates and overlying marls (Figure 5.7). Sequence I in Değirmenönü section can be correlated with Sequence I of Saytepe section (Figure 5.6).

Sequence II is topped by an oyster rich bed (Figure 5.8), probably forming top of the Highstand Systems Tract. Oyster bed wedges out in the basinal direction marking the limit of the sea level fall. This surface is also distinguishable at the exposure surface along the margin. Here a basinward dipping bed is overlain by a prograding set of beds indicating highstand systems tract (Figure 5.5). Above this surface is a sequence boundary which is followed by a transgressive surface. This transgressive surface is the beginning of Sequence III.

Sequence III begins with a deepening upward lower part (Transgressive Systems Tract) and ends with a shallowing upward carbonates that was truncated at the shelf edge (Figures 3.3 and 5.5). Base of

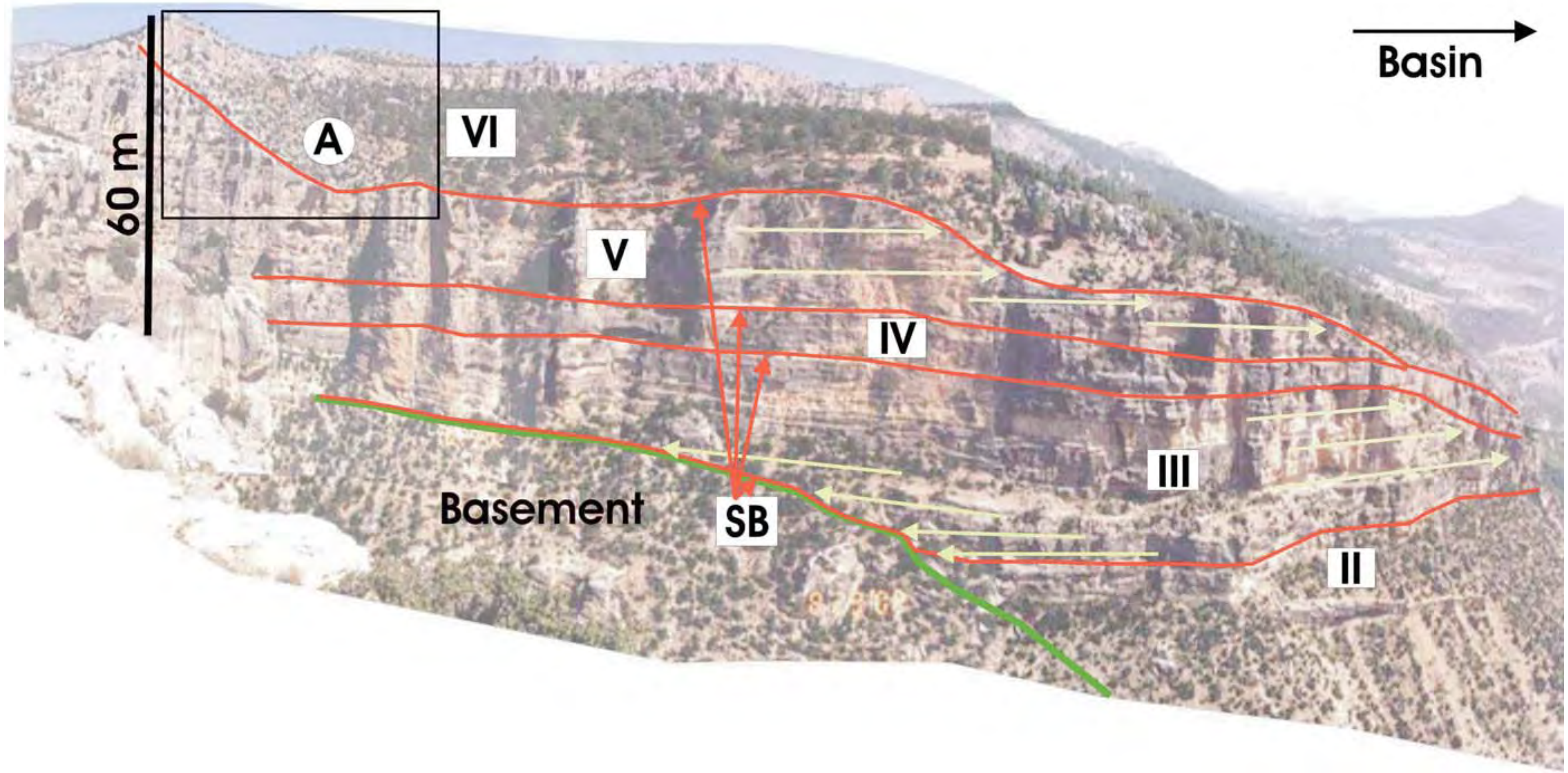


Figure 5.5: Relation of sequences are best observed along the reefal margin in the southeast of Çömelek village along Sosun Dere. Red lines indicate sequence boundaries, green line indicate top of basement and yellow arrows indicate truncated beds or onlapping beds. A refers to Figure 5.11.

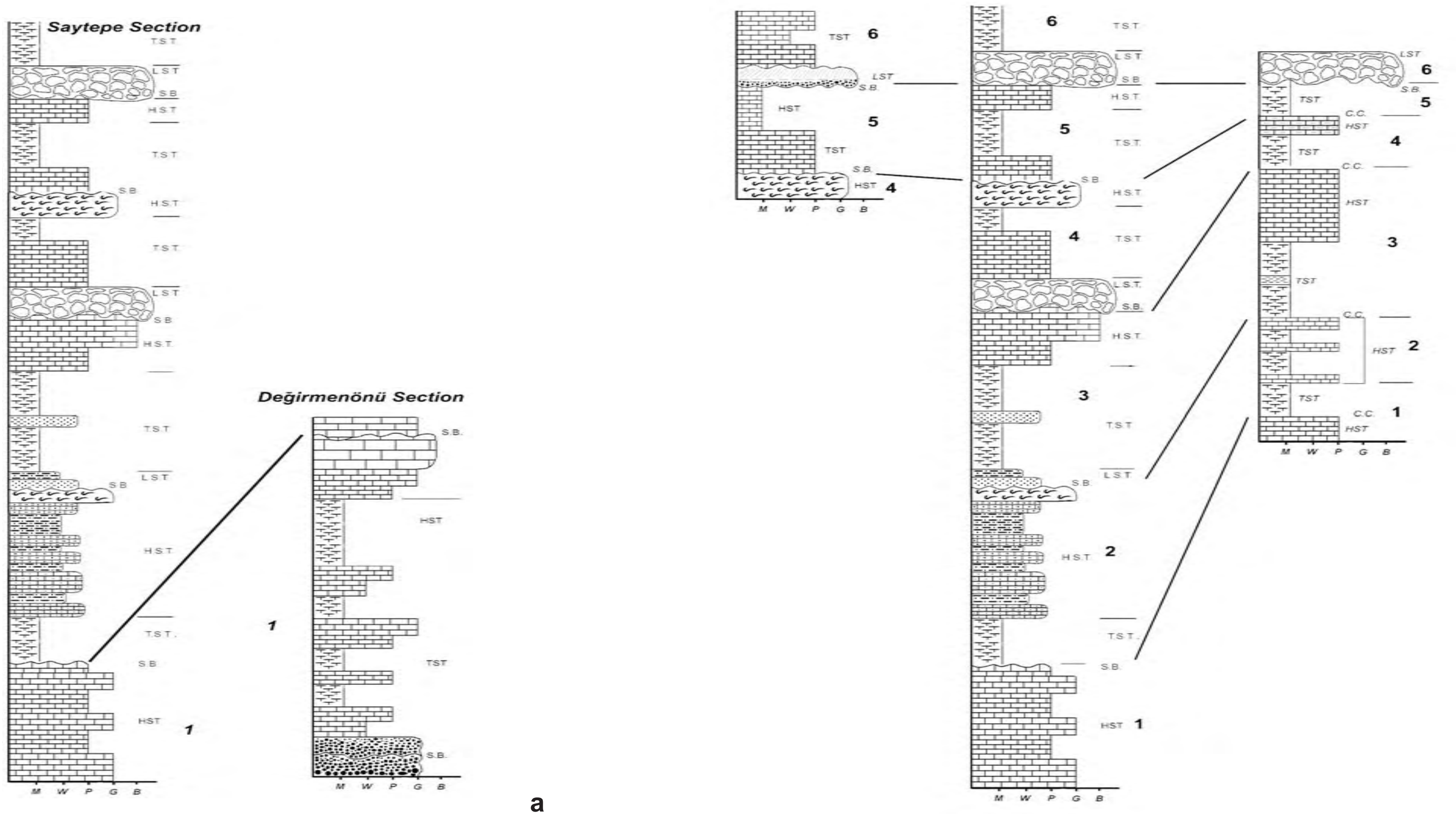


Figure 5.6: Correlation of a) Saytepe and Değirmenönü sections, b) Çömelek, Saytepe and Dereköy sections

Figure 5.7: Top of the Sequence II (red line) is exposed in Sosun Dere. Picture is taken from Sosun Dere looking toward west.

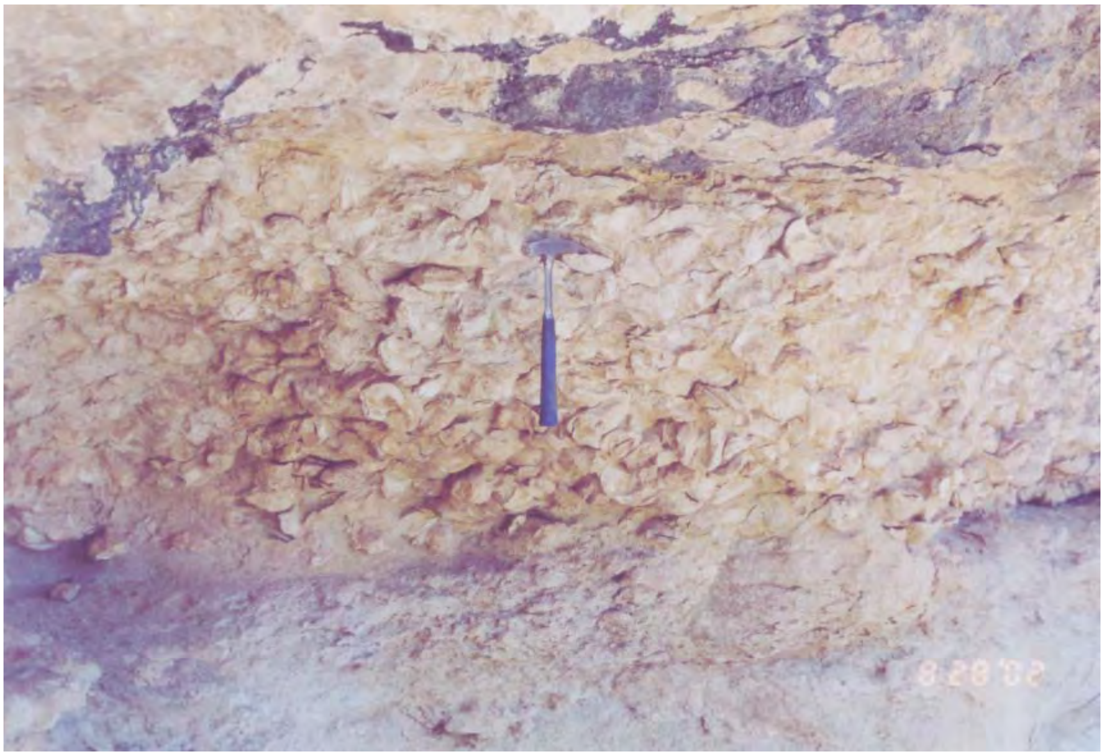


Figure 5.8: Oyster bed that can be used as a key level is used to tie sequence boundary from Saytepe section to Çömelek section.

Sequence III is marked with a coarse breccia bed at the slope and by a basinward sloping bed at the margin. Transgressive Systems Tract is very thin and followed by a thick Highstand Systems Tract (Figures 3.3 and 5.5).

Sequence IV begins with transgressive beds in the marginal areas, but begins with a breccia bed in the slope to basinal areas (Figure 5.9). Highstand of the same sequence is characterized by downlapping beds (Figure 5.10). This sequence is correlated in three areas. In Çömelek section upper part of the sequence (dominated by oysters) representing Highstand Systems Tract can be correlated with Sequence IV (Figures 5.6 and 5.8). Between these two sections the same surface is traced along exposure paralleling to basin margin and represent a sequence boundary with a well defined unconformity surface (Figure 5.5).

Sequence V begins with a transgressive bed overlying about 2 metres thick Oyster bed in Çömelek section. The same surface is marked by an erosional surface without much sediment and following highstand systems tract is indicated by downlapping bed on the same erosional surface (Figure 5.11). In Saytepe section it is marked with a packstone overlying Oyster bed indicating deepening of environment and rise in sea level. Sequence VI is marked with a transgressive surface overlying a karstic surface in between Çömelek and Saytepe section by a breccia bed and the same breccia bed is traced on the exposure downslope and along the slope to Saytepe section. Each sequence boundary shows different characteristics depending on the location that the section was measured. This is due to the nature of the sediment characteristics in the area where the measured section is located.

In the slope and basinal areas, the change is reflected by a more deeper water facies overlying a level which contain siliciclastic input level depending on the degree of the sea level fall.

On a reefal margin a transgression is marked by a bed overlying a truncated bed, an erosional surface or an onlapping relation (Figure 5.5). On the more landward side of the system. It is marked by either an erosional surface, a karst feature and/or more marine facies over lagoonal or a more restricted facies. Since these unconformity surfaces can be traced along the eastern

Figure 5.9: Megabreccia bed marks the lowstand systems tract which is deposited when sea level drops below shelf margin and bottom of which shows sequence boundary. Picture is taken from Sosun Dere.

Figure 5.10: Above Sequence III, prograding and basinward sloping beds of Sequence IV, are seen resting on shale sediments near right end. Yellow lines indicate downlapping beds. Picture is taken from Sosun Dere.

Figure 5.12: Siliciclastic sediments also mark the lowstand sediments in the basinal areas, indicating that sediment bypassed the shelf during lowstand time. Picture is taken from Sosun Dere.

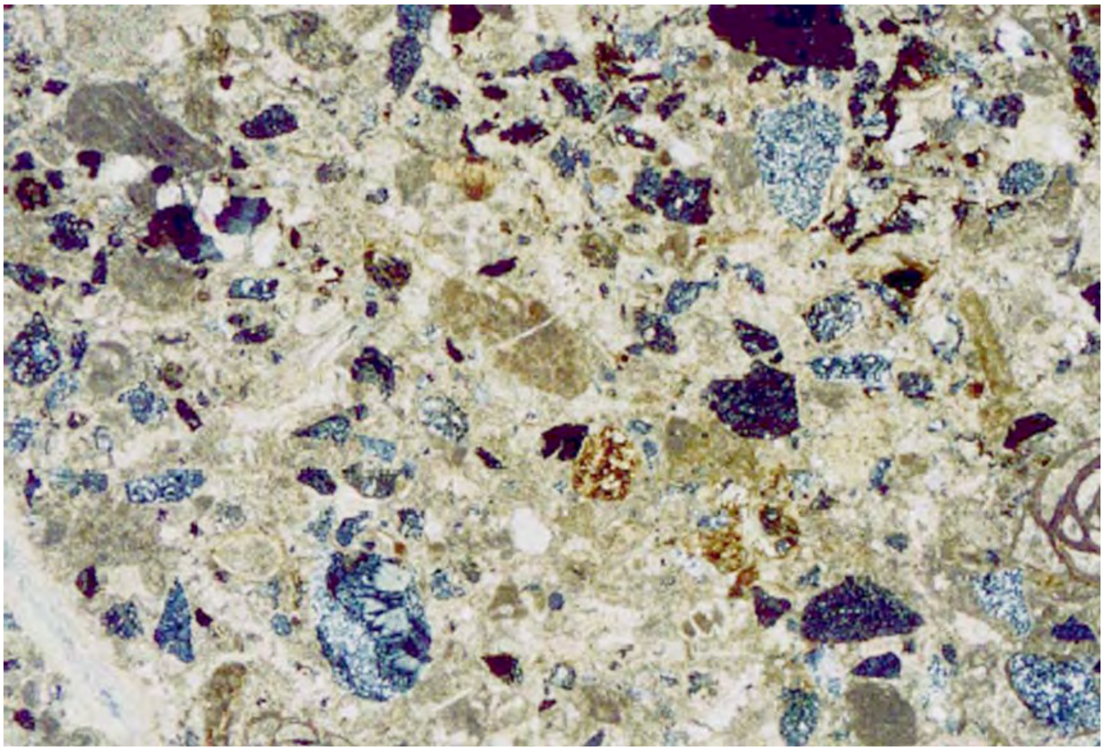


Figure 5.13: Thin section of the carbonate shows that land driven material (chert in this case) is present, indicating sea level drop and siliciclastic bypass.

Figure 5.11: Photograph showing the erosional truncation of the upper boundary of Sequence V. Yellow lines indicate lateral termination of beds and downlapping beds. Above red line prograding beds of next sequence are seen.

margin of Sosun Dere it was possible to tie the sections of Çömelek, Saytepe and Toskaba hills. The first level of Toskaba hill can be correlated with the first carbonate level in the Saytepe section and onlaps the slope of the carbonates of the basement. Second level is also onlapping to the slope of the basement in the same area. Third level steps back toward the north and overlies the second level in this area. Lowstand systems tract is marked either a thick and chaotic breccia bed in the basinal side of the system (Figure 5.9) or indicated by input of fine grained siliciclastic sediments (Figures 5.12 and 5.13). Figure 5.14 illustrates the depositional model proposed from the correlation of measured sections.

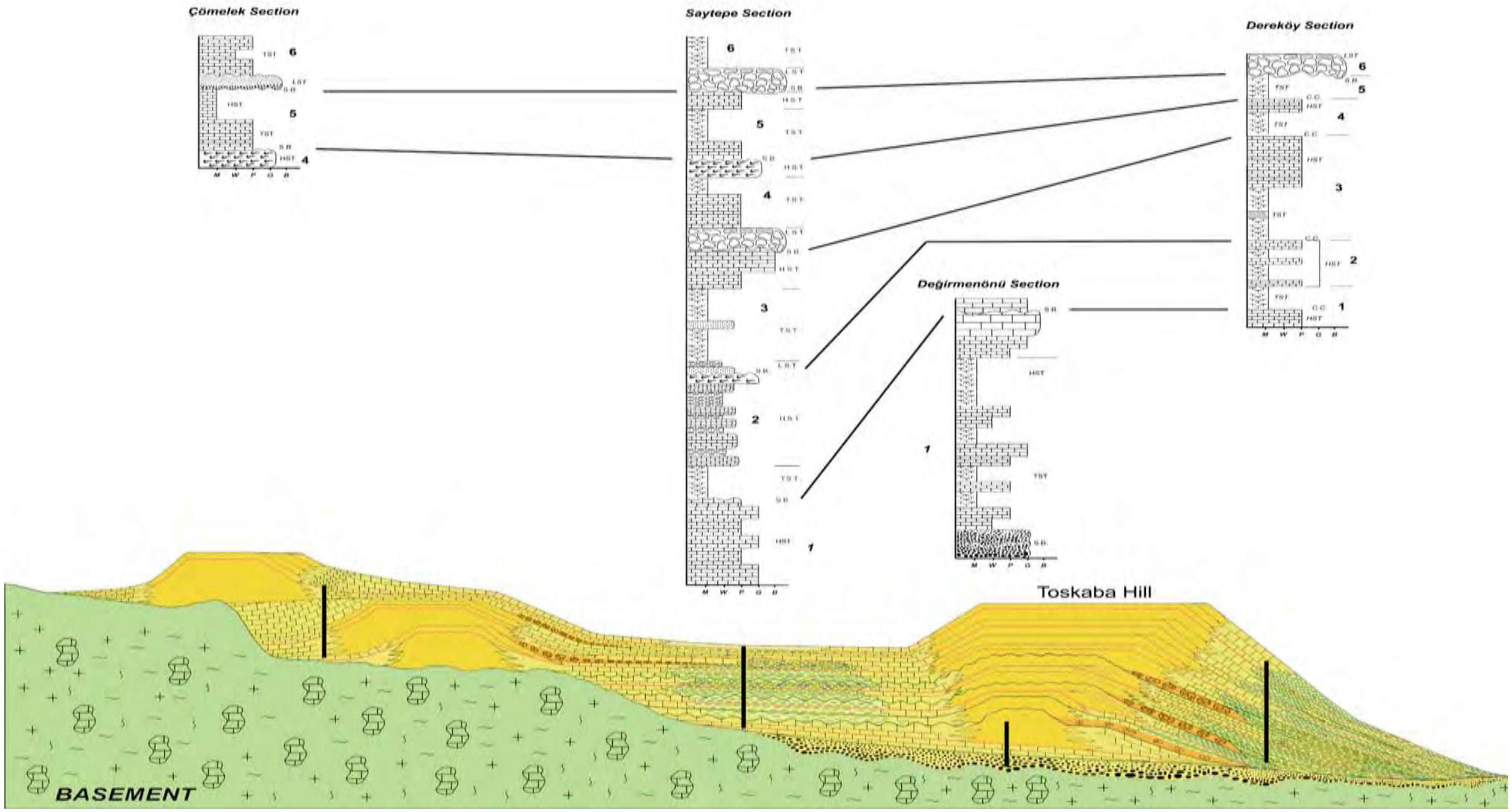


Figure 5.14: A schematic diagram showing correlation of sections. Figures refer to sequences identified in the study area. Vertical black lines on the sketch cross section show the approximate positions of the 4 measured sections.

CHAPTER 6

DISCUSSION

6.1 Definition of the sequences in the study area

Sequence I has been identified as a ramp sequence, mainly because of the lack of distinct break in the slope and development of reefal margin (Figure 6.1). This type of carbonate sequence may develop either in areas where conditions are not suitable for reef building organism or in areas where paleotopography is controlled by subsidence that is flexural and gradients are slight over large areas (Burchette and Wright, 1992). I favor the second alternative for the development of ramp since reef building organism (coral and algae) are abundantly present in the area. Progradation indicating a sea level drop is not observed. This may be due to the low lying slope angle which is the characteristic feature of the ramp. On ramp when sea level drops no progradation is observed due to the absence of the reefal margin, but shift of facies occur instead (Burchette and Wright, 1992). The stratal relationships of the first sequence do not exhibit any downlap surface. Thus, it must be deposited on a ramp setting, because the ramp geometry does not allow significant downlapping beds as in platform carbonates (Handford and Loucks, 1993).

Sequence II advances landward and laps on the "basement" rocks (Figure 5.5). Dominance of marls and absence of shallow water carbonates along the basement in the east of Çömelek indicate either a steep slope or increase in accomodation space. The existence of a steep topography seems to be valid since onlapping relations of beds make such interpretation more realistic. On Toskaba Hill the development of shallow water carbonates and gradation into marls in a short distance (~1 km) also suggest that the area around Toskaba Hill was shallow enough to allow shallow water carbonate production. These data suggest that irregular topography controlled the carbonate facies types during sea level rise. When sea level began to drop, shallow water carbonates began deposition and advanced toward basin due to loss of accomodation space in the east of Çömelek. Toskaba Hill area, however, must have subaerially exposed and leaching developed (Figure 3.4).

Sequence III is marked by a sea level rise as indicated by onlapping relation of the strata of the new sequence and the basement (Figure 5.5). This time, however, shallow water carbonate deposition dominates the marginal areas. This has two implications. The first implication is that the area remained shallow water areas to allow carbonate deposition (Sarg, 1988), hence growth of coral and algae to form reefal facies. The second implication is that carbonate deposition must have kept up with the sea level rise (Sarg, 1988). If carbonate production had not kept up with sea level rise, carbonate deposition would have been drowned and more pelagic facies would have been dominated. The similarity of facies between the area southeast of Çömelek (Figure 5.5) and Toskaba Hill area (Figure 3.3) indicates that both areas were dominated by shallow water carbonate deposition and bathymetry were similar. In Toskaba hill area carbonate deposition must have recovered sea level rise. During early stage, features in the east of Çömelek village indicate that following sea level drop have caused shallow water areas to subaerially exposed and eroded. This erosion can be explained in two ways: First an earthquake might have trigerred the collapse of the margin. In this case, the erosion would have been much more extensive than the area limited to the southeast of Çömelek. No erosional feature or surface is observed in the Toskaba Hill. This rule out the possible cause of collapse. Second, sea level drop and progradation of facies basinward may cause overloading shallow water facies over marly facies and collapse occur. This type of collapse are much common in carbonate depositional areas which controlled by sea level fluctuations (Handford and Loucks, 1993). If we consider sea level was 5 metres above the uppermost bed (approximate depositional depth for the carbonates) and since each truncated bed is about 4-6 metres, sea level must have dropped more than 30 metres. Of course this is an approximation of the value but gives a figure to understand the scale. Since an erosional surface is developed and the sea level dropped below the shelf margin, this sequence boundary must represent type I sequence boundary.

Sequence IV seems to be a single carbonate sand bed (3-4 m. thick) and follows and rests on the underlying erosional surface (Figure 5.5). The thickness of the sequence compared with underlying sequence suggests that accomodation was limited. During transgressive phase flooding of the erosional surface must have created a shallow and high energy environment. Therefore, shallow water sands have been deposited. Gently inclined beds indicate original paleotopographic control of depositional surface. Otherwise underlying and overlying beds would have been deformed and inclined. All these relation indicate that erosional topography controlled the deposition. Downlapping relations of the beds limited to the southern part of the same margin indicate that sea level dropped and remained stationary for a certain period of time. Constant rate of accomodation must have resulted in the progradation of carbonate in a narrow zone. Another alternative explanation is that an erosional event could have removed some sediments and amount of erosion is much higher in the landward direction than in seaward direction. The oyster bed in this sequence may represent lagoonal deposits that indicated migration or shift of facies basinward indicating a drop in sea level. This relation also indicates that sea level dropped below shelf edge and type I unconformity surface developed.

Sequence V advanced further landward than Sequence IV. This is indicated by the onlapping beds of sequence V on both sequence IV and the basement (Figure 5.5 and Figure 6.1). This relation indicates that during transgressive phase much accomodation was created and carbonate production kept up with sea level rise.

Absence of progradation in the upper part of the sequence can be

Figure 6.1: Sequence V onlaps to the basement near Çömelek looking toward NE.

explained in two different ways. First, sea level might have dropped suddenly and destruction of accomodation space did not allow progradation of carbonate deposition. Second, sea level dropped slowly and limited progradation might have been developed. However, following erosion might have removed the sedimentary record that we do not observe today. Topographic expression of the exposure suggest that the greatest sea level drop have occurred during this period and considerable amount of shallow water carbonate material have been eroded and transported to the basinal areas (Figure 5.9). Amount of erosion imply that about 100 m. of sea level drop occurred following sequence V.

Sequence VI begins with sediments overlying erosional surface of Sequence V. Absence or very thin development of transgressive deposits over erosional sequence boundary and direct downlap of overlying highstand deposits suggest that sea level rose abruptly and there was not enough time for shallow water carbonate deposition. Another alternative would be the drowning of carbonates caused by sudden sea level rise. This means greater accomodation space is created during the early phase of sequence VI. Following highstand created limited highstand deposits in these marginal areas. These highstand deposits are developed on the irregular topography of previous sequence.

6.2 Sea level oscillations

From the surface expression and the relations of the bedding within the sequences indicate that a number of sequences were developed (Figure 6.2). The stratigraphic significance of relative sea level change is that many are tied to eustatic events and so are predictable within a basin of deposition (Kendal and Schlager, 1981).

Most accurate measure of changes in sea level is the type of sediments, geometry and the diagenesis of the carbonate shelves and platforms. This is because carbonates frequently occur at or very near sea level and are usually less compacted than siliciclastics. Falls are accompanied by platform wide fresh water diagenesis. During relative sea level rises marine diagenesis is common in the subtidal portions of the shoaling upward carbonates, and fresh water diagenesis and dolomitization and sulfate deposition is common in the intertidal and supratidal portions (Kendala and Schlager, 1981).

Different thickness of deposits indicate that relative sea level falls and rises occurred at different magnitudes during Miocene. The existence of barrier reefs show that their deposition occurred on a platform type setting. In sequence stratigraphic concept lowstand is the time interval when vast amounts of siliciclastic material enter the depositional system. However, in the study area even in lowstand facies no major siliciclastic input is observed. The existence of minor siliciclastic input must be related to a sudden influx, which is related to small scale seasonal changes. The major fluvial system must be behind a barrier (a hill, a topographic high etc.) which prevented it from entering the Mediteranean Sea at this location.

6.3 Evolution of the sequences in the study area

Different models can be proposed to explain the evolution of sequences. First, carbonate depositional environment in the study area began as a ramp and then transformed to a barrier reef. Second, barrier reef existed from the beginning of deposition and it migrated landward with continuous transgression. The laterally discontinuous reefs of Sequence I make the first model more realistic. The discontinuity of reefs and their random distribution indicate that they were deposited as patch reefs. With continuous transgression some of these patch reefs have been drawn, but some other kept up with the sea level rise and converted into pinnacle reefs. The formation of barrier reef began with the deposition of Sequence II. The deposition occurred on marginal highs. Figure 6.2 is a schematic illustration showing evolution of sequences discussed in this study.

6.4 Recognition of abrasion surfaces in sequences

Diagenetic features identified within the study area are closely linked to the sequence boundaries. Red colored clay, leaching porosity and dolomitization are related to subaerial exposure. However, questions remain regarding whether carbonate platforms generally are exposed to subaerial conditions sufficiently long to develop karst topography prior to sea level. The amount of fall might be an important control together with climate, because it controls the development of fresh water input.

Biostratigraphic control has an important role in sequence stratigraphy. Unexpected low sample quality affected the control on sequence differentiation. Nevertheless, the sequences differentiated in the study area must be third order sequences, since they all occurred during Miocene.

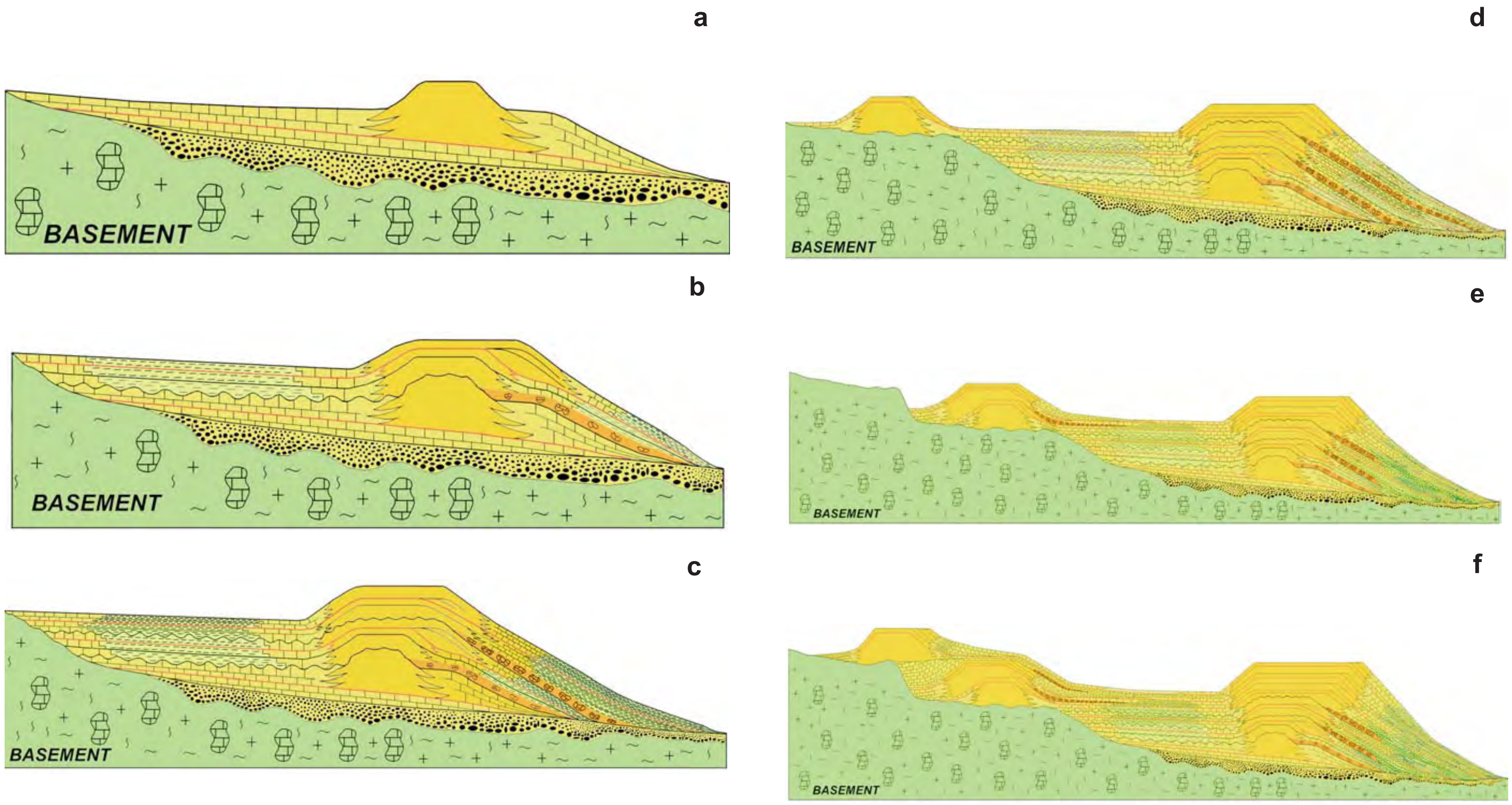


Figure 6.2: Sketch illustrating the evolution of six sequences differentiated in the study area. Early stage (a-c) represents the transition from ramp setting to reefal margin setting. Late stage (d-f) represents mature barrier reef environment.

CHAPTER 7

CONCLUSION

7.1 Stratal Relationships

Clean vertical outcrops exposed along a river valley (Sosun Dere) almost perpendicular to the general trend of reef-platform orientation in the study area allowed observation and study of features related to the carbonate depositional system. By identifying different facies types (reefs, forereef and platform), Mut Formation was divided into sequences, bounded by unconformity surfaces in the marginal areas, while conformable in the basinal areas where lithology changes laterally from limestone to marl. Onlapping relations, offlapping surfaces and truncation of carbonates along the margin of a carbonate platform suggest that sea level changes have played an important role in the development of the stratal packages. These packages have been organized into six sequences, mainly the result of change in sea level.

Progradation/Aggradation ratio is different in each sequence due to the frequency of sea level falls or rises. The stratal relationships in the study area showed that the models proposed for siliciclastic depositional environments are not always valid for carbonate depositonal environments. Especially if the transgression is not long enough to form onlapping muddy facies the Transgressive Systems Tract deposits can occur as a thin bed which can be interpreted as the early highstand strata (as sequence IV, shown in Figure 5.5)

It is observed that Mut formation, which has been interpreted as a single carbonate body, includes important clues about the evolution of the basin. The stratal relationships of sequences in the study area show that carbonate deposition began on a ramp setting with patch reefs. Then the patch reef at Toskaba Hill transformed to a pinnacle reef. Later in the development of the basin, when the sea reached a higher level,a laterally continuous reefal margin developed.

7.2 Facies associations

In Mut Basin the paleotopography controlled the facies distribution and stratal relationships in several ways: First, reefal carbonate deposition is controlled by topographic highs, while the depressions in the landward side formed the lagoon of this carbonate environment. Second, the highs prevented siliciclastic material directly empty into the basin, so carbonate deposition was able to develop along the margin. Third, local highs controlled the deposition of local patch of pinnacle reefs. Fourth, since an irregular topography existed before the transgression, onlapping relations were developed as the basin has been filled. Fifth, irregular topography reflects any changes of sea level more than basinal areas as it controlls the deposition of the carbonates which is very sensitive to change in depth. Finally paleotopography controls the depth of the depositional environment which in turn controls the type of carbonate facies developed.

In the study area, parasequence set scale facies associations exhibit shallowing upward character. Such cycles can be best observed on shelf rather than slope and basin. This is related to the location of carbonate deposition. The shallowing upward cycles can also be differentiated in basinal or slope setting. In these deep marine (low energy) environments fauna content is a useful tool to determine such cycles. In cycles where homogenous facies are seen, increasing or decreasing fauna content is used as a criteria to define shallowing upward sequences. It is also observed that each systems tracts exhibits different facies associations. Thickness and facies change does not stay same. This might be related with internal and external factors controlling carbonate deposition, such as water depth, basin subsidence etc.

Each shallow water facies of Highstand Systems Tract are overlain by open marine marl indicating that surface of exposure is flooded suddenly, so that no shallow marine facies were developed. Dominance of marl and shale in the basinal areas and some siliciclastic material observed in the marl support the idea that a siliciclastic source existed somewhere around the basin and a barrier protected the basin from siliciclastic input.

7.3 Diagenetic Imprint

The diagenetic change showed that it is possible to use diagenetic texture to define sequence boundaries. Especially, phreatic diagenetic zone can be used to interpret sea level oscillations. Fresh water diagenesis, dolomitization and some karst development took place when sea level dropped below shelf edge. The degree of leaching and karst surfaces are related to the degree of sea level fall and/or duration of lowstand time.

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APPENDIX

GLOSSARY OF TERMS

Aggradational geometry: occur when the rate of deposition is equal to rate of accomodation (Van Wagoner et al., 1988).

Catch Up deposition : Catch up carbonate system display a relatively slow rate of accumulation . This response may result from the maintenance of water conditions throughout most of the highstand that are not conducive to rapid carbonate production. A catch up carbonate is characterized at the platform margins by extensive, early submarine cementation, and it may contain abundant mud rich parasequences.

Downlap : A base discordant relaton in which initially inclined strata terminate downdip against an initially horizontal or inclined surface (Mitchum, 1977).

Downlap Surafce/Maximum Flooding Surface (mfs) : 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 parasequence set and is the surface of maximum flooding (Van Wagoner et al., 1988).

Keep Up carbonate systems : Keep up carbonate systems display a relatively rapid rate of accumulation and is able to keep up with relative rises in sea level. A keep up carbonate is characterized at the platform margin by relatively small amounts of early submarine cement and is generally dominated by grain rich, mud poor parasequences. The keep up carbonate systems display a mounded/oblique geometry at the platform/bank margin and in places on the platform.

Onlap : A base discordant relation in which initially horizontal strata terminate progressively agaist an initially inclined surface, or in which initially inclined strata terminate progressively updip against a surface of greater initial inclination (Mitchum, 1977)

Parasequence : is a relatively conformable succession of genetically related beds or bedsets bounded by marine flooding surfaces and their correlative surfaces (Van Wagoner, 1985).

Parasequence set : is a succession of genetically related parasequences which form a disitinctive stacking pattern that is bounded, in many cases, by major flooding surfaces and their correlative surfaces (Van Wagoner, 1985).

Patch Reef : Isolated more or less circular area of organic frame constructed buildups. In modern seas patch reefs are mainly on shelves and rise into wave base and close to sea level (Wilson, 1975).

Pinnacle Reef : Conical or steep sided upward tapering mound or reef (Wilson, 1975).

Progradational geometry: occur when the rate of deposition exceeds the rate of accumulation (Van Wagoner et al.,1988).

Ramp : Huge carbonate bodies built away from positive areas and down gentle regional paleoslopes. No striking break in slope exists, and facies pattern are apt to be wide and irregular belts with the highest energy zone relatively close to the shore (Wilson, 1975).

Retrogradational geometry: occur when the rate of accumulation exceeds the rate of deposition (Van Wagoner et al., 1988).

Toplap : Termination of strata against an overlying surface mainly as a result of nondeposition (sedimentary bypassing) with perhaps only minor erosion. Each unit of strata laps out in a landward direction at the top of the unit, but the succesive terminations lie progressively seaward (Mitchum, 1977).

Transgressive Surface : The top of the lowstand wedge, coincident with the top of the lowstand systems tract, is a marine flooding surface called the transgressive surface (Van Wagoner et al., 1988).

Type 1 sequence boundary : is characterized by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation, a basinward shift of facies, a downward shift in coastal onlap, and onlap of overlying strata (Van Wagoner et al., 1988).

Type 2 sequence boundary: is marked by subaerial exposure and a downward shift in coastal onlap landward of the depositional shoreline break ; however, it lacks both subaerial erosion associated with stream rejuvenation and a basinward shift in facies.