MICROPALEONTOLOGICAL ANALYSIS AND FACIES EVOLUTION ACROSS THE TOURNAISIAN – VISEAN BOUNDARY IN ALADAĞ UNIT (CENTRAL TAURIDES, TURKEY)

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Approval of the Graduate School of Natural and Applied Sciences.

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

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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

MICROPALEONTOLOGICAL ANALYSIS AND FACIES EVOLUTION ACROSS THE TOURNAISIAN – VISEAN BOUNDARY IN ALADAĞ UNIT (CENTRAL TAURIDES, TURKEY)

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This study aims to enlighten microfacies evolution and micropaleontological properties of the Tournaisian – Visean boundary in Aladağ Unit (Central Taurides, Turkey). Two sections comprising dark shale and dark limestone alternations, including a fairly dolomitized part towards their top are measured. The microfacies analysis suggests a subtidal depositional environment.

Foraminiferal assemblages were distinguished at Section AP and biozonation was documented. The biozonation separates the measured section into three zones, described as A, B and C. Zone A is scarce foraminifera fauna, and mainly contains *Earlandia* sp. Zone B is defined by appearance of a diversified foraminifera fauna and the first appearance of *Lugtonia monilis* (Malakhova, 1955) with *Eoparastaffella* sp. (morphotype 1). Zone C is defined according to the first appearance of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) and foraminifers *Laxaendothyra* ex. gr. *laxa.* Tournaisian – Visean boundary is defined at the 60th sample, due to appearance of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2).

Seven microfacies types in section AP, and six microfacies types in section PA are identified and, the intensely sampled part of the measured section AP is separated into 13 shallowing upward meter-scale cycles. These cycles, showing subtidal character are detected by both repetitions of microfacies and changes in abundance of foraminifers.

A contrasting evaluation of the Tournaisian – Visean boundary of Taurides with Guangxi, South China and Dinant, Belgium is presented. The Chinese stratotype contains a diverse, more complete fauna of Tournaisian - Visean foraminifera, while the Belgium and Turkish sections are scarcer and most probably facies controlled.

Keywords: Tournaisian – Visean, Carboniferous, Carbonate Platform, Taurides, Foraminifera

ÖZ

ALADAĞ BİRİMİNİN TURNEZİYEN – VİZEYEN SINIRI BOYUNCA MİKROPALEONTOLOJİK ANALİZİ VE FASİYES EVRİMİ (ORTA TOROSLAR, TÜRKİYE)

Peynircioğlu, Ali Ahmet
Yüksek Lisans, Jeoloji Mühendisliği Bölümü
Tez Yöneticisi : Prof. Dr. Demir Altıner

Kasım 2005, 76 sayfa

Bu çalışma Orta Toroslar, Aladağ Birimi'nin Turneziyen – Vizeyen sınırındaki mikrofasiyes evrimini ve mikropaleontolojisini aydınlatmayı amaçlamıştır. Bu çalışmada ölçülen iki adet kesit, koyu renkli şeyller ile koyu renkli kireçtaşı ardalanmalarından ve yukarı doğru dolomitleşmiş bir kısımdan oluşur. Kesitler boyunca incelenen mikrofasiyesler gelgit-altı ortamının hakim olduğunu göstermektedir.

Çalışılmış olan AP kesitinde, foraminifer toplulukları belirlenmiş ve ölçülen kesitin biyozonasyonu belgelenmiştir. PA kesitinde foraminiferlere ender rastlandığından dolayı, benzer bir çalışma yapılmamıştır. Biyozonasyon, ölçülmüş AP kesitini A, B ve C zonları olmak üzere, üç parçaya ayırır. A Zonu foraminiferlerin ender gözlemlendiği bir zondur ve *Earlandia* sp. içerir. B zonu *Lugtonia monilis* (Malakhova, 1955) ve *Eoparastaffella* sp. (morfotip 1) in ilk ortaya çıkışı ve ayrıca daha çeşitlilik gösteren bir fauna ile tanımlanır. C zonu ise *Eoparastaffella simplex* (Vdovenko, 1964) (morfotip 2) ve *Laxaendothyra* ex. gr. *laxa*'nın ilk ortaya çıkışı ile belirlenir. Turneziyen – Vizeyen sınırı 60. örnekte

tanımlanmıştır, zira *Eoparastaffella simplex* (Vdovenko, 1964) (morfotip 2) bu sınırda ilk defa ortaya çıkar.

AP kesitinde yedi, PA kesitinde altı adet ana mikrofasiyes tipi tanımlanmış, ve AP kesiti'nin sıkça örneklenmiş üst kısmı, 13 adet yukarı doğru sığlaşan metre ölçeğinde devirlere ayrılmıştır. Bu devirler, gelgit-altı karakterdedir ve tekrar eden mikrofasiyes değişimleri ile foraminifer bolluğuna göre belirlenmiştir.

Bu araştırmada çalışılan Turneziyen – Vizeyen sınırı ile Guangzi, Güney Çin ve Dinant, Belçika Turneziyen – Vizeyen sınırları karşılaştırılmış, Güney Çin'deki stratotipin daha çeşitlilik gösteren ve bütünsellik içeren bir foraminifer topluluğu barındırdığı, büyük ihtimalle fasiyes kontrollü Belçika ve Türkiye kesitlerinin ise daha ender fosil topluluklarını içerdiği görülmüştür.

Anahtar Kelimeler: Turneziyen – Vizeyen, Karbonifer, Karbonat Platformu, Toroslar, Foraminifer

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CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

This study presents the benthic foraminiferal micropaleontology, and microfacies of the Tournaisian – Visean boundary at the carbonate deposits of the Aladağ Unit, Central Taurides. The purpose of the research is to delineate the Tournaisian – Visean boundary using the evolutionary pattern of benthic foraminifer, *Eoparastaffella* sp., and to distinguish the cyclic, and sequence stratigraphic evolution in the investigated section AP, crossing the Tournaisian – Visean boundary.

Central Taurides includes a Paleozoic carbonate sequence, which proves to be very suitable for defining Paleozoic stages. The foraminiferida, because of their small size, great abundance, and readily preserved diagnostic shells, are unsurpassed as stratigraphic and paleoecologic tools. They are the most widely used fossil organisms for biostratigraphy, age dating and correlation of sediments (Loeblich and Tappan, 1964). The criterion, for definition of Tournaisian – Visean boundary using benthic foraminifers, was recently modified. Previously the first appearance of the foraminifer *Eoparastaffella* sp. without any mention of the species was widely used as a stratigraphic marker for the base of Visean (Hance, 1997). However, since the biostratigraphic boundary at the Dinant Bastion type section was found to be ecologically controlled (Conil *et. al*., 1989), a refinement was found to be necessary. Hance et. al., (1997) redefined Tournaisian – Visean boundary, introducing a new evolutionary criteria on the genus *Eoparastaffella*.

This study aims to deliniate the Tournaisian – Visean boundary at a 26.74 m section, section AP, measured across Çityayla and Mantar Tepe Members, in Yarıcak Formation of Aladağ Unit, according to this new biostratigraphic criteria. To further understand the environmental conditions and fauna, microfacies analyses of the studied sections AP and PA is presented. In section AP, which is relatively rich in benthic foraminifers, sea-level changes and meter scale cyclicity is analysed and cycles were constructed according to the response of benthic foraminifera and microfacies changes.

In the process of defining Tournaisian – Visean boundary, benthic foraminiferal micropaleontological content and microfacies is critically examined on 145 samples. Although very scarce in section PA, in section AP, 42 samples contained benthic foraminifera, thus using benthic foraminiferal groups, the measured section was divided into three biozones, and this biozonation was then compared with the Belgium Dinant Bastion type section and Tournaisian – Visean transitional strata in South China (Guangxi). The associations are demonstrated on a foraminiferal range chart.

Furthermore, columnar sections are presented, showing microfacies texture, meter scale cycles and sequence stratigraphic interpretation. Microphotographs of the selected, well-preserved benthic foraminifera are illustrated in Appendix A. For the delineation of Tournaisian – Visean boundary, the dimensions of *Eoparastaffella* sp. are measured and presented on Appendix II.

1.2. Geographic Setting

The study area is located at 20 km southwest of Hadim town of Konya city (Figure 1.1). Two sections were measured along a road cut branching from the Hadim – Alanya highway (Figure 1.2).

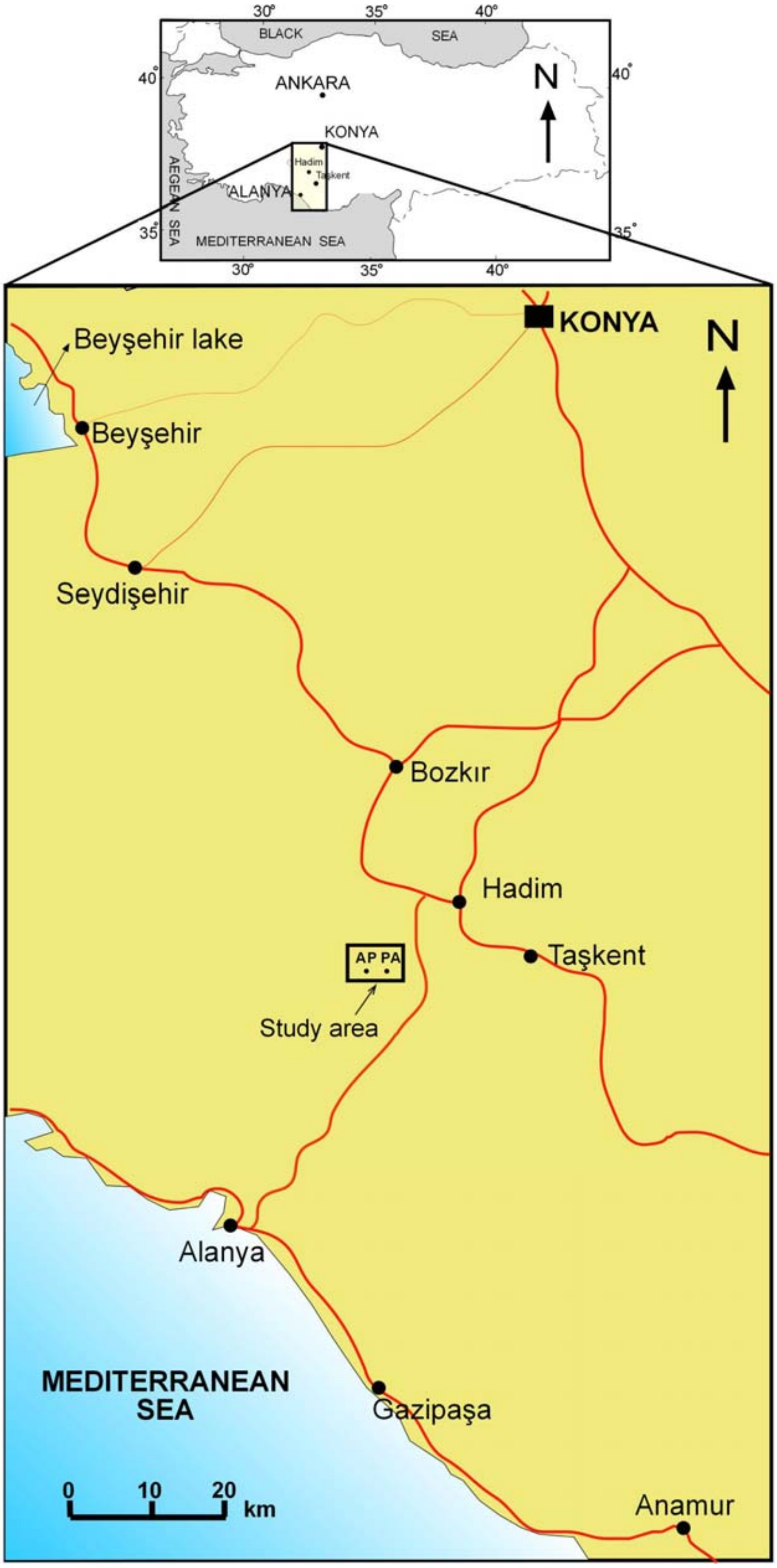

Figure 1.1: Geographic setting of the study area and the locations of the measured sections AP and PA.

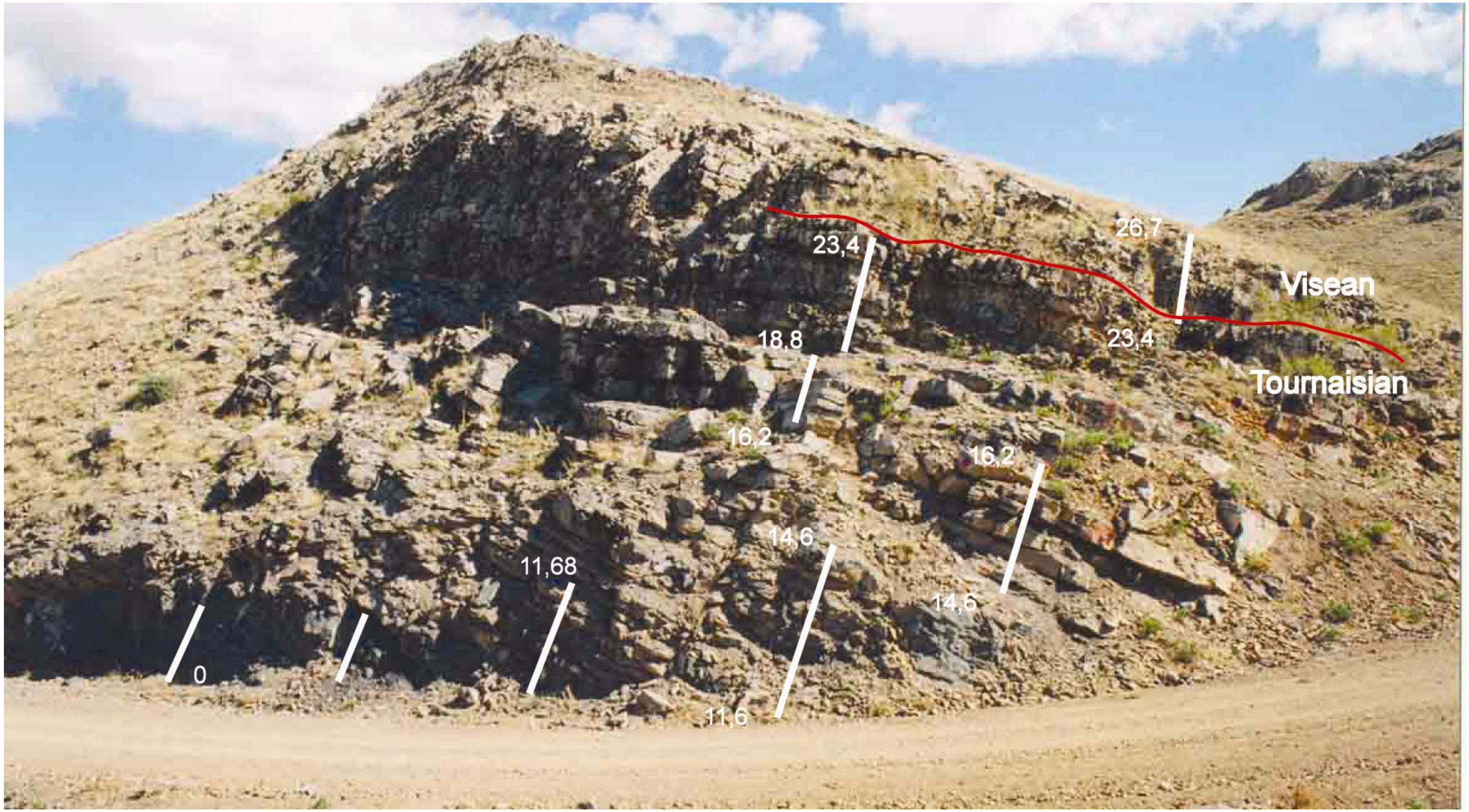

Figure 1.2: Location of the Tournaisian – Visean boundary and measured section AP. Numbers indicate meters.

1.3. Method of Study

This study consists of field and laboratory work. In the fieldwork, each bed is analyzed in terms of their lithologies and faunal contents. For the laboratory, work, thin sections of the samples were prepared in order to investigate the benthic foraminiferal content and microfacies evolution.

Two stratigraphic sections, namely Section AP and Section PA, were measured in the field, and a total of 145 hand samples were collected. The Section AP measures 26.74 m and cuts across the Tournaisian – Visean boundary. 73 samples were collected from this section. Towards the upper part of the section, across the boundary, samples were taken from both top and bottom of each layer. In thick beds, sampling was even more frequent to be able to maintain the accuracy needed to define the Tournaisian – Visean boundary. Section PA on the other hand measures 19.98 m and was sampled bed by bed towards the Tournaisian – Visean boundary. In this section, a few multilocular foraminifers are encountered at the very top, dolomitized zone present in this section. Therefore, cyclicity and sequence stratigraphic analyses were not carried out in this section. 72 samples were collected from this section and their microfacies analysis was carried out.

The biostratigraphic data is used for determine the Tournaisian – Visean boundary. Paleontological analysis, which is critical for the definition of Tournaisian – Visean boundary was carried out by Prof. Dr. Demir Altıner. In the measured section AP, benthic foraminifer *Eoparastaffella* sp. with axial sections is documented, and measured to define Tournaisian – Visean boundary, according to the criteria proposed by Hance *et. al*. (1997).

Vertical microfacies changes, and changes in benthic foraminiferal population is used for cyclo-stratigraphic and sequence stratigraphic analysis. In this study 42 samples, taken from section AP, containing benthic foraminifers were critically investigated and counted, their abundance relation to microfacies repetitions, and sea-level changes were observed.

1.4. Previous Works

The previous works related to this study is described according to three sub categories. These are the previous works related to general geology of the taurides, stuides on meter scale cyclicty and sequence stratigraphy of the Taurides, and the studies concerning the Tournaisian – Visean boundary in the global sense.

The Taurides has been studied over the years by both foreign and native researchers. Blumenthal (1944, 1947, 1951 and 1956) made the earliest studies, defining the basic geologic and geomorphologic features of the Western Taurides, presenting maps illustrating the general tectonic structure. Blumenthal (1944) studied the exposures of the Aladağ Unit around Beyşehir – Bozkır and northern Alanya regions and named these as Hadim Nappe. Brunn *et. al*. (1971) and Gutnic *et. al*. (1979) described the detailed geology and stratigraphy of Taurides. Monod (1967, 1977), Monod and Akay (1984) studied the evolution of Tauride Carbonate Platform, including stratigraphy, structural geology and evolution of Aladağ Unit in Western Taurides.

Several biostratigraphic studies on the Carboniferous, Permian and Triassic rocks were carried out in the Tauride belt by Altıner (1981, 1984), where micropaleontological and stratigraphic studies at Eastern Taurides and Upper Permian stratigraphy in localities of the Taurus Belt was invertigated. In Altıner *et. al*., (2000), Late Permian foraminiferal biofacies belts is discussed. The complete succession of the Upper Paleozoic of the Aladağ Unit cropping out between Silifke and Anamur regions was studied by Demirtaşlı (1984). In Demirtaşlı, (1982) a summary of the Paleozoic stratigraphy and Variscan events is discussed.

Concerning the stratigraphy, and geodynamic evolution of Aladağ Unit, important studies were published in different papers of Özgül (1971, 1976, 1984, 1997), Özgül and Gedik (1973), and Özgül *et. al*. (1991). In Özgül 1997, Aladağ unit was divided into six formations; Gölboğazı Formation (Devonian), Yarıncak Formation (Carboniferous), Çekiç Dağı Formation (Permian), Gevne

Formation (Triassic), Çambaşı Formation (Jurrassic – Cretaceous) and Zekeriya Formation (Maastrichtian).

Cyclostratigraphic and Sequence stratigrapic studies in Central Taurides were carried out by Altıner *et. al.*, (1999) who presented upper Jurassic, - upper Cretaceous sequence stratigraphic correlation in peritidal carbonates. Following studies are of, Ünal *et. al.*, (2003), Yılmaz *et. al.*, (2004). Ünal (2002) described the carbonate succession of the Permian – Triassic boundary in terms of cyclicty and established the sequence stratigraphic framework for the studied section. Pötürgeli (2002) studied the Middle Permian (Midian) carbonates in terms of cyclicity and discussed the nature of meter-scale shallowing-upward cycles in subtidal carbonates. Meter scale cycles of Middle Carboniferous (Moscovian) Carbonates were described by Şen (2002). In his work, biofacies, lithofacies and responses of fusulinacean foraminifers to sedimentary cyclicity were investigated.

Tournaisian – Visean boundary and foraminiferal biostratigraphy is extensively studied by numerous authors. Raphael Conil defined the previous stratotype section for Tournaisian – Visean Boundary (Subcommission on Carboniferous Stratigraphy, 1969), Conil and Lys (1968) studied the Dinantian foraminifers in Belgium, Conil and Lys (1977), studied and documented the effect of transgressions to Dinantian foraminifers. Conil *et. al*. (1969, 1977, 1988, 1989, 1991) studied Tournaisian – Visean boundary, and documented the foraminifers in Dinant basin. Hance *(*1988) and Hance *et. al*. (1994) studied Moliniacien in Belgium Dinant. Hance (1997) studied evolutionary pattern of *Eoparastaffella.* In Hance *et. al*. (1997), Tournaisian – Visean transitional strata was defiend according to evolutionary stage of *Eoparastaffella* in South China, Guangxi Autonomous Region.

In Turkey, Dil (1975) studied a succession of foraminiferal zones in Famennian and Dinantian of the Zonguldak Basin and correlated the associations with Russia and Western Europe. In Dil (1976), Frasnian to upper Visean foraminifera assemblages from the Zonguldak Basin are illustrated and correlated with reference sections of Western Europe and North America.

1.5. Regional Geology

The study area is located within the Carboniferous of Aladağ Unit (Özgül, 1976) and is well exposed in Central Taurides in Hadim Region (Figure 1.3). Geographically defined as the area between two major strike slip faults, central

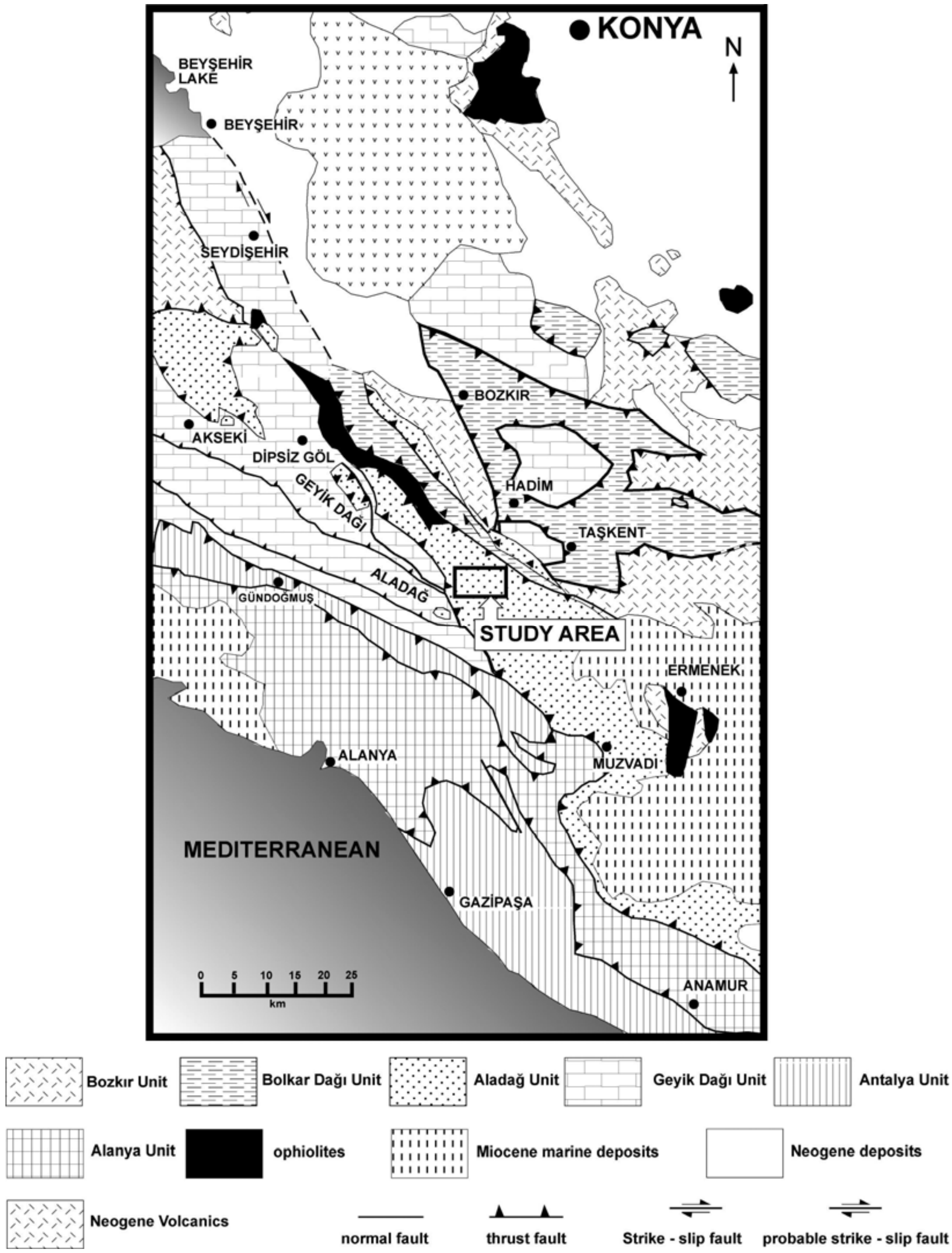

Figure 1.3: Tectono-stratigraphic map of the study area (modified from Altıner & Özgül, 2001).

Taurides lies within the area inside Kırkkavak Fault in the west and Ecemiş Fault in the East (Figure 1.4). Central Taurides shows most of the characteristic features of the Tauride Belt, consisting of tectono-stratigraphic units with distinctive stratigraphical, structural and metamorphic features. These rock units have been thrust on top of each other during the extensive Senonian and Lutetian movements giving rise to the complex nappe structure of the Taurides (Özgül, 1984).

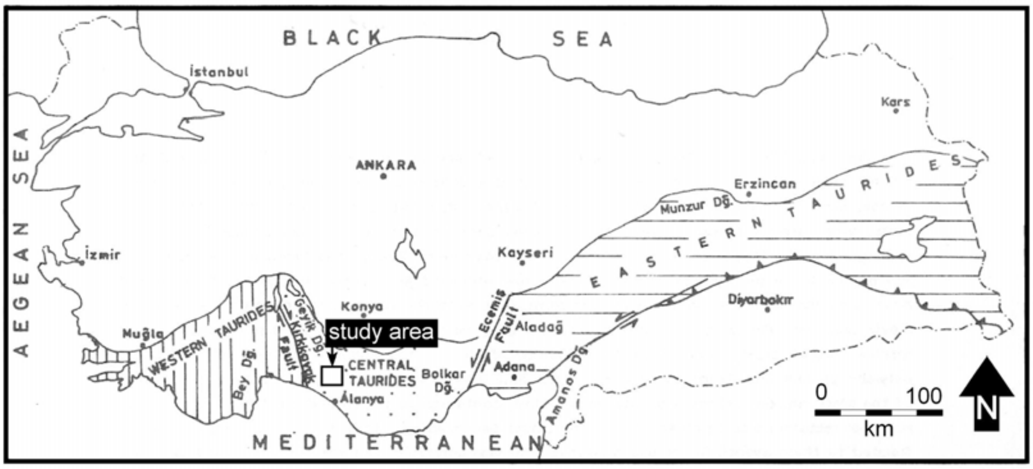

Figure 1.4: Geographical subdivision of the Tauride Belt (modified from Özgül, 1984).

The close lithological, faunal and chronological similarities between the Paleozoic sequences of the tectono-stratigraphic units of the central Taurides and the Anatolia indicate that during the Paleozoic, all of the tectono-stratigraphic units of the central Taurides formed the northern part of a huge platform, contiguous to the Gondwana land (Özgül, 1984).

Although the Paleozoic sequence is virtually continuous in the southeastern part of the central Taurides, in the Eastern Taurides, and in Southern Anatolia, upper Paleozoic is missing in some units of the central Taurides. For example, rocks of Silurian to Early Triassic age do not occur in Geyik Dağı Unit, and rocks of Silurian – Early Permian age are missing in Antalya Unit. The absence of Upper Paleozoic boulders in the Triassic and Lias basal conglomerates which are transgressive over the Cambrian – Ordovician rocks of Geyik Dağı Unit suggests that over a large area represented by Geyik Dağı Unit terrestrial conditions existed during most of the Silurian – Permian interval. During the Paleozoic, there were, to the north and South of Geyik Dağı Unit, two epicontinental seas represented by Bolkar – Aladağ and Antalya Alanya Units, respectively (Figure 1.5).

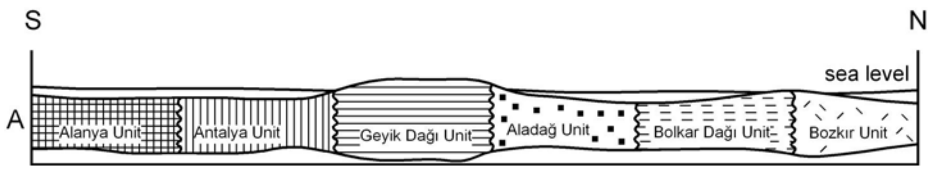

Figure 1.5: Isopic zones of Taurides (modified from Özgül, 1984).

CHAPTER 2

STRATIGRAPHY

2.1. Lithostratigraphy

The study area is located on Aladağ Unit which is one of the allochtonous units of Central Taurides. Aladağ Unit was deposited during Late Devonian – Late Cretaceous, and composed of shelf type carbonates and clastics. It is named after the mountain range "Aladağlar", located in Eastern Taurides where it has common outcrops (Özgül, 1997). Aladağ Unit is divided into Gölboğazı Formation (Devonian), Yarıcak Formation (Carboniferous), Çekiç Dağı Formation, (Permian), Gevne Formation (Triassic), Çambaşı Formation (Jurassic Cretaceous) and Zekeriya Formation (Maastrichtian) (Özgül, 1997). Since the sections are gathered from the Yarıcak Formation, it is discussed in detail in the following sections (Figure 2.1 and 2.2).

2.1.1. Yarıcak Formation

The Yarıcak Formation is characterized by shallow water limestones intercalated with quartzarenitic sandstone layers. In its base, it encompasses dark colored shale layers. The formation lies conformable at the top of Gölboğazı Formation, and is overlain by an angular unconformity to Çekiç Dağı Formation. The thickness is measured 860 m in the type section and 600 m in the reference section (Özgül, 1997). Due to limestone – sandstone intercalations, and erosional or non-depositional conditions within the formation, in certain surfaces, the thickness of the formation varies frequently. In some places, especially at the outcrops located in the southern parts, the thickness drops down to several hundred meters (Özgül, 1997).

The type section is located at 9–10 km southwest of Hadim, near "Çit" plateau, which will be termed as "Çityayla" hereafter. The formation is mainly limestone with lesser amount of sandstone. In its base, includes one of the key surfaces, a thin limestone layer, and intercalated with shales. The formation is divided into two successive members as "Çityayla Limestone Member", and "Mantar Tepe Member" respectively (Özgül, 1997).

2.1.1.1. Çityayla Member

The dark colored fossilliferous shale unit, with thin limestone – sandstone intercalations, forming the base of Yarıcak Formation is termed Çityayla Member. Type locality measures 107 m and reference section measures 50 m. Çityayla Member's dark colored shales suggest a low energy shelf environment in the subtidal zone (Özgül, 1997). The two sections presented in this study comprise the top of the Çityayla Member.

2.1.1.2. Mantar Tepe Member

Mantar Tepe Member forms the major part of the Yarıcak Formation. It is mainly composed of limestones intercalated with quartzarenite sandstone layers. The two sections presented in this study comprise the base of the Mantar Tepe Member.

2.2. Biostratigraphy

The studied sections are situated at Yarıcak Formation, across the Çityayla and Mantar Tepe Members. For biostratigraphy, only section AP was studied, since section PA was devoid of foraminifers and largely dolomitized towards the top. The studied part of the section AP is composed of 43 layers and measures 13 m. 57 samples were examined for biostratigraphical analyses. In this work, Özgül's boundary for the Çityayla and Mantar Tepe Members is drawn from top of last observed layer of shale – limestone alternation (Figure 2.3).

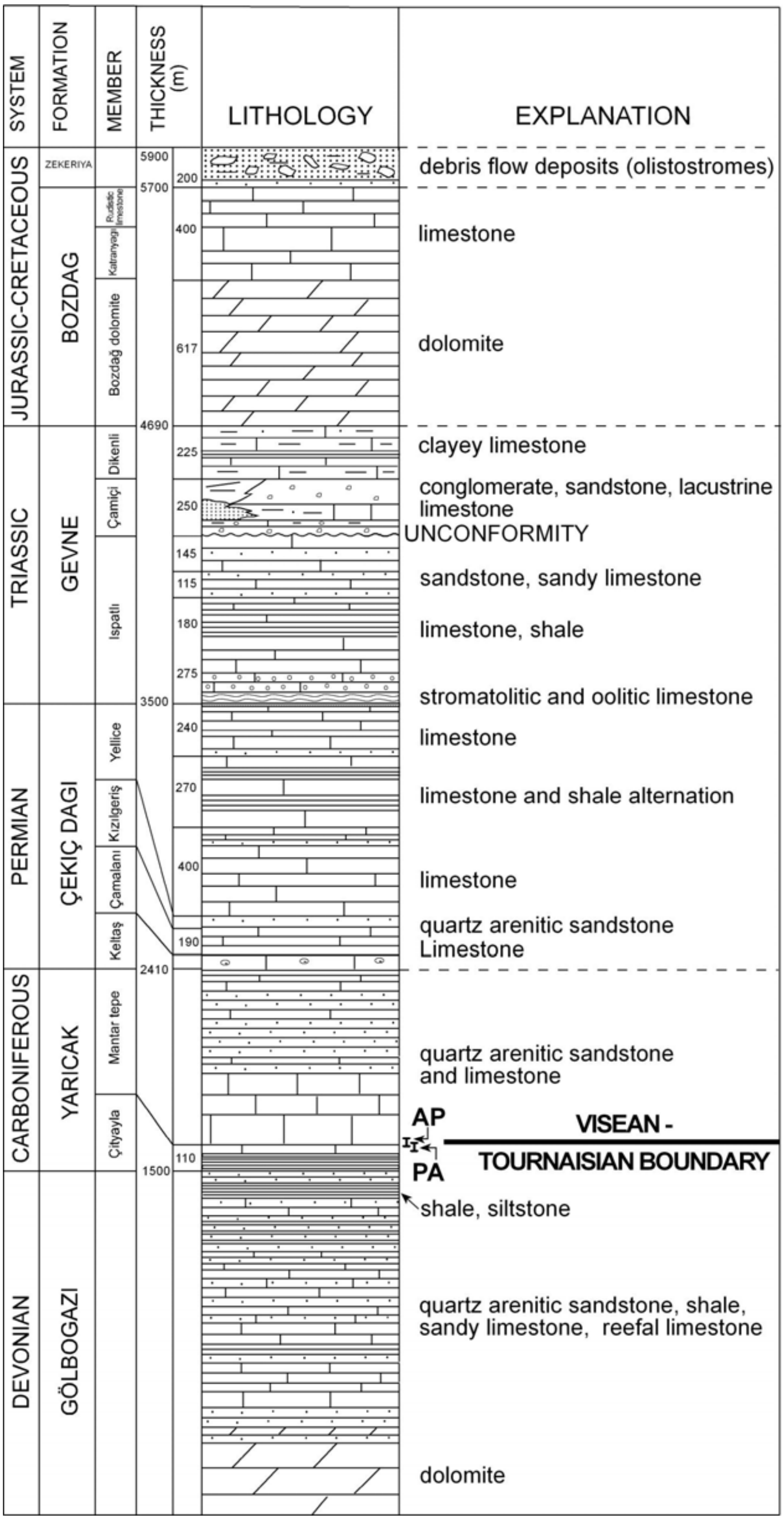

Figure 2.1: Generalized columnar section of the Aladağ Unit in the Hadim-Taşkent area (modified from Özgül, 1977). The position of measured sections (AP, PA) are shown by two dark bars situated in the column.

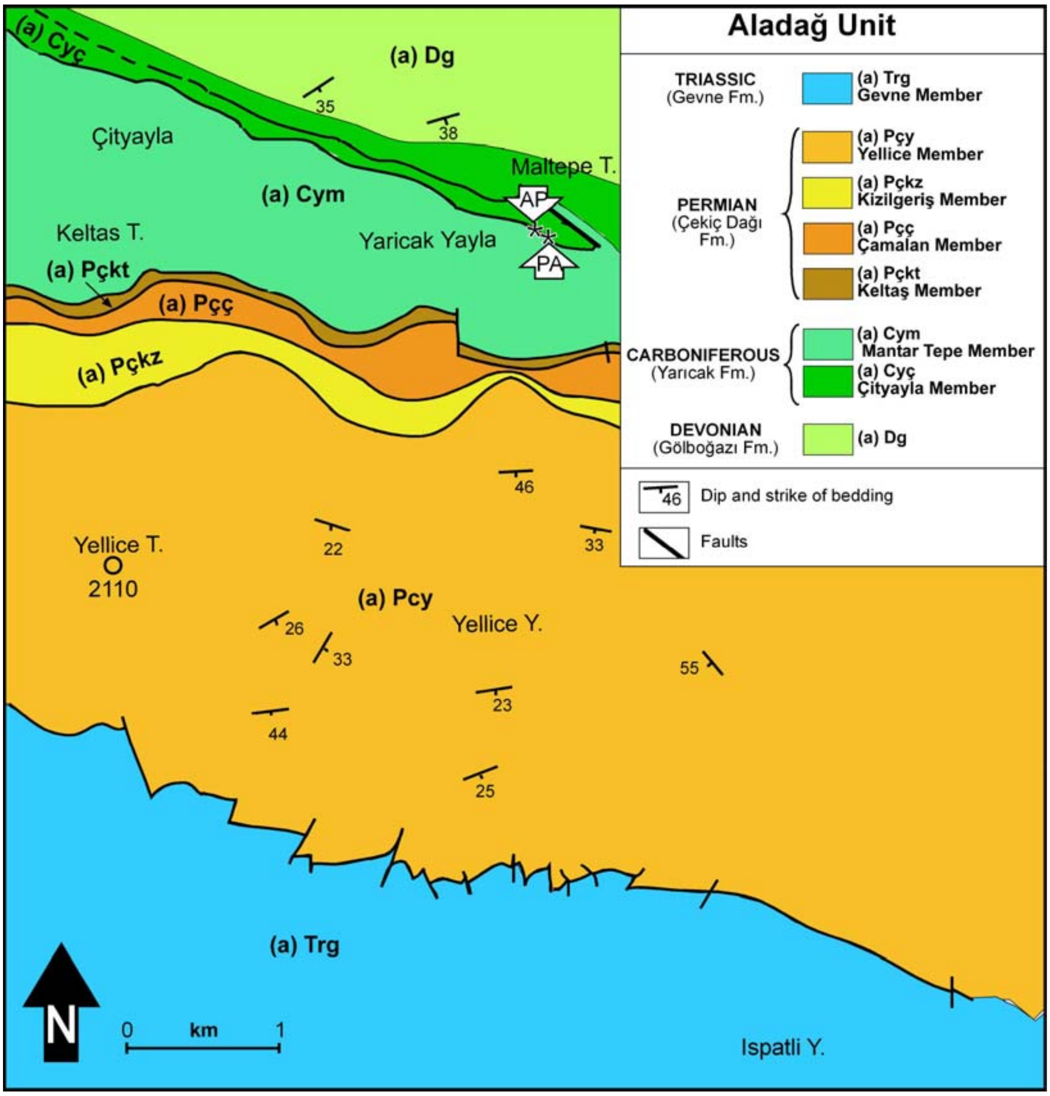

Figure 2.2: Geological map of the study area (from Altıner and Özgül, 2001).

According to Özgül (1997), macrofossil content of the Çityayla Member includes a brachiopod fauna comprising *Productus productus*, *Tomiproductus vaughani*, *Ripidomella michelini*, *Spirifer tornacensis*, *Marginifera* sp. identifying the Tournaisian. Mantar Tepe Member on the other hand, includes *Siphonophyllia cylindrica* bearing limestone at its base which forms the interval separating the upper Tournaisian – Lower Visean (Özgül, 1997).

For the measured section AP, the chronostratigraphic and biostratigraphic study and the biozonation of benthic foraminifera is recorded by Prof. Dr. Demir Altıner.

The measured and intensely sampled section of 13 m in Section AP is divided into three zones (A, B and C) by foraminiferal groups (Figure 2.3). Because of its very scarce and rare fauna, beds containing the samples 1-18 are not presented in figure 2.3, while only selected genus and species of importance is given at the figure.

2.2.1. Zone A

From the bottom of the measured section the samples 1-29 define the Zone A and comprise *Earlandia* sp. (Pl. 1, Fig. 8), calcispherids, *Diplosphaerina inaequalis* (Derville, 1931), *Spirorbis* sp. and appearance of *Granuliferella* sp.(Pl. 1, Fig. 1) and *Laxoseptabrunsiina.* Ranges of the selected foraminifera are presented in Figure 2.3.

2.2.2. Zone B

Overlying Zone A is Zone B, comprising samples 30 – 59, is defined by the first appearance of *Eoparastafella* sp. (morphotype 1, Hance *et. al.*, 1997) (Pl. 2, Fig 1-9) and *Lugtonia monilis* (Malakhova, 1955) (Pl. 1, Fig. 9-12). This zone is further characterized by its diversity of foraminifers (see Figure 2.3). These foraminifers are *Elevenella?* sp., *Eotextularia diversa* (N. Tchernysheva, 1948) (Pl. 3, Fig. 8-12), *Paleospirıplectammina* sp., *Endospiraoplectammina* sp., *Endospiroplectammina venusta* (Vdovenko, 1954) (Pl. 5, Fig. 9), *Eoforschia moelleri* (Malakhova, 1953) (Pl. 5, Fig. 3-5), *Tournayella* sp. (Pl. 6, Fig. 6), *Septatournayella* sp., *Pseudolituotubella* sp., *Condrustella modavica* (Conil & Lys, 1967), *Condrustella* ? sp., *Granuliferella* sp. (Pl. 1, Fig. 1), *Latiendothyranopsis* sp. (Pl. 4, Fig. 1-10; Pl. 5, Fig. 1, 2), *Endothyaranopsis* sp. (Pl. 6, Fig. 5), *Plectogyranopsis* sp. (Pl. 6, Fig. 8), *Inflatoendothyra inflata* (Lipina, 1955) (Pl. 3, Fig. 1-3), *Inflatoendothyra* sp. (Pl. 2, Fig. 15-21), *Spinoendothyra* ? sp., *Endothyra* sp. (Pl. 1, Fig. 2-7), *Omphalotis* sp. (Pl. 5, Fig. 6, 7), *Bessiella* sp. (Pl. 6, Fig. 3), *Laxoendothyra* ex. gr. *Laxa* (Conil & Lys, 1964) (Pl. 6, Fig. 1, 2), *Laxoendothyra* ? sp. (Pl. 5, Fig. 10, 11), *Septabrunsiina* sp. (Pl. 3, Fig. 13), *Eoparastafella subglobosa ?* (Pl. 2, Fig. 10) and *Mediocris* ? sp. (Pl. 5, Fig.

8). The upper boundary for this zone is defined by the first apperance of *Eoparastafella simplex* (Morphotype 2) (Vdovenko, 1964) (Pl. 2, Fig. 11-14).

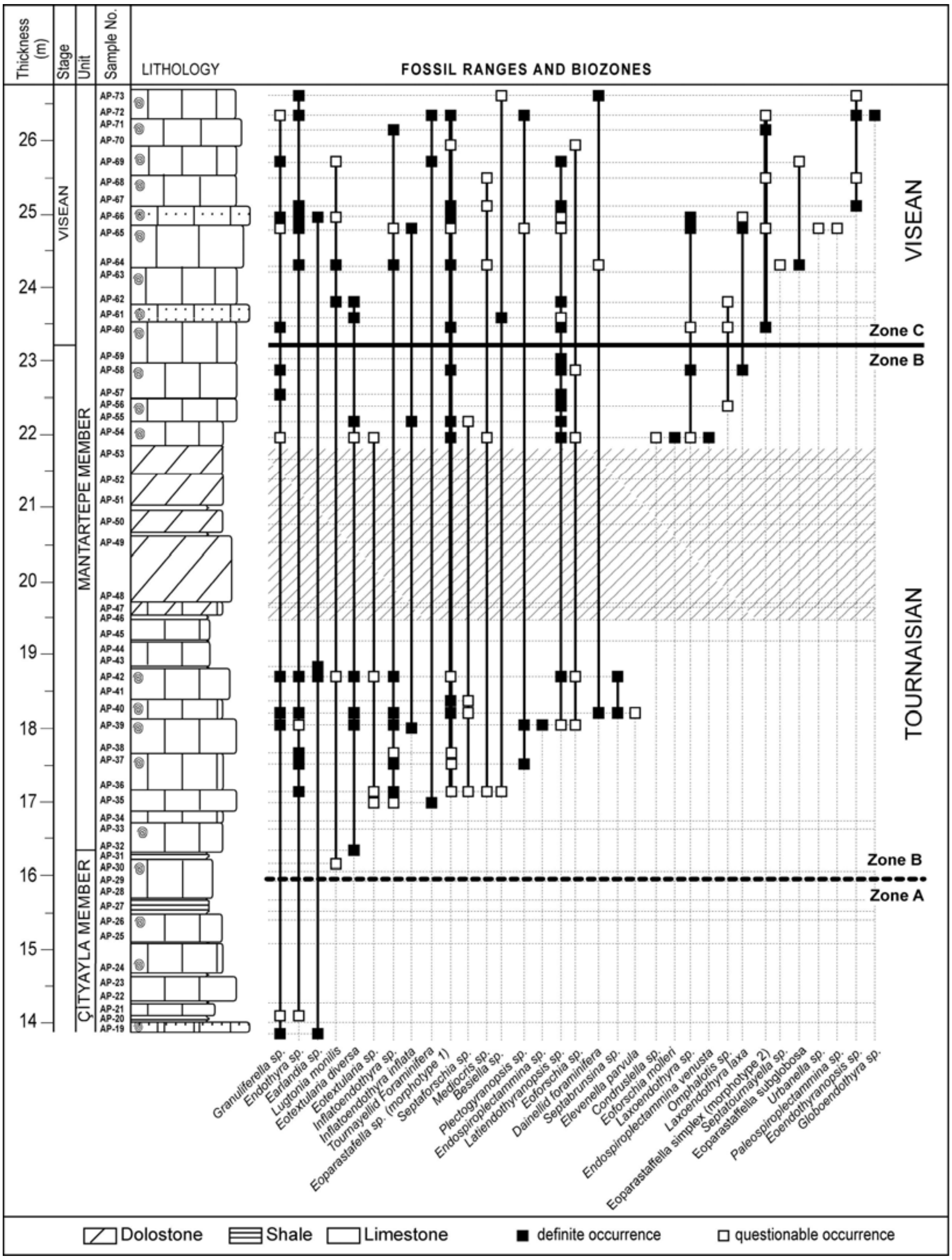

Figure 2.3: Biostratigraphic ranges of the selected documented foraminifera showing biozones (from section AP).

2.2.3. Zone C

This zone is comprises the samples 60 – 73, and characterized by the first appereance of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2, Hance *et. al.*, 1997) (Pl.2, Fig 11-14) in its base. Moreover, in this zone, foraminifers *Latiendothyranopsis* sp. (Pl. 4, Fig. 1-10; Pl. 5, Fig. 1, 2), *Endothyranopsis* sp. (Pl. 6, Fig. 5), *Globoendothyra* sp. (Pl. 6, Fig. 7), *Endothyra* sp. (Pl. 1, Fig. 2-7), *Bessiella* sp. (Pl. 6, Fig. 3), *Laxaendothyra* ex gr. *laxa* (Pl. 6, Fig. 1, 2), *Lysella* ? sp., *Dainella staffelloides* ? (Pl. 3, Fig. 7), *Eoparastaffella* sp. (morphotype 1) (Pl. 2, Fig. 1-9), *Eoparastaffella subglobosa* (Pl. 2, Fig. 10) are present (Figure 2.3).

The line separating the Zones B and C is also the Tournaisian – Visean boundary, drawn according to the evolutionary lineage of *Eoparastaffella* morphotypes (Hance *et. al*. 1997) (Figure 2.3).

2.3. Tournaisian-Visean Boundary

In 1967, The 6th International Carboniferous Congress adopted Conil's proposal for defining the lower boundary of the Visean in the Dinant Bastion section in the Southern Belgium, at the first black limestone intercalation within the Leffe Facies (Subcomission on Carboniferous Stratigraphy, 1969). This level coincided with the first occurrence of the calcareous foraminifera genus *Eoparastaffella* (Conil *et. al.*, 1969). Thus *Eoparastaffella,* without any species defined, was used for identifing the Visean.

However, it was later understood that, due to restricted environmental conditions, the distribution of the principal fossil guides in the T-V transitional strata of the Dinant Bastion section was ecologically controlled. (Conil *et. al.*, 1989). The stratigraphically significant taxa occurred in a few grainstone beds whose constituents were found to be derived from surrounding shallow water areas (Lees, 1997). Consequently, the successive entries of fossils do not occur in an evolutionary lineage. (Hance, 1988; Hance *et. al.,* 1994; Kalvoda, 1994; Riley, 1995) Moreover, the most primitive species of *Eoparastaffella* (Vdovenko, 1964) is not found in the Dinant area, further implying selective environmental controls (Conil and Lys, 1968; Conil *et. al*., 1980)

It was also discovered, the base of the Moliniacien Stage at its type section along Route de Salet does not coincide with the base of the Visean Series at the Bastion stratotype as originally thought. (Conil *et. al*., 1977; Conil *et. al*., 1989). The correlation was based on appearance of black limestones in both areas (Hance *et. al*., 1997). Micropaleontological studies later showed that *Eoparastaffella* at the Route de Salet first occurs above the Moliniacien stratotype, and it is this entry, which correlates to the basal Visean at Bastion. This discrepancy made earliest Visean Stage (Moliniacien) correlate with partly with the latest Tournaisian, which lead to confusion.

Because of these inconsistencies, Tournaisian – Visean boundary had to be re-established with new criteria introduced. Hance *et. al*., (1997), introduced the following criterion to calibrate the evolution of *Eoparastaffella* (Figure 2.4). The coefficient (e) is defined as the elevation of the outer, subangular periphery. Its ratio to the radius (r) of the largest interior circle is then calculated. The ratio ranges between 0 in primitive specimens to 0.8 for evolved *Eoparastaffella* (Hance *et. al*., 1997). The *Eoparastaffella* that have an e/r ratio <0.5 are termed as morphotype 1 species (Hance et al., 1997), where as specimens that have an e/r ratio >0.5 are termed as morphotype 2 species (Hance et al., 1997). The base of the Visean is recognized by *Eoparastaffella* specimens exhibiting an e/r value >0.5 which separates morphotypes 1 and 2. Hance *et. al*., (1997). (see Figure 2.4)

In this study selected *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) was used to assess the Tournaisian – Visean boundary in measured section AP. Photographs of axial sections were measured (see Appendix II), and their e/r ratios were calculated (Figure 2.5). Due to scarce occurence of the *Eoparastaffella* sp. in the measured section AP, dimensions of seven samples, the ones with good axial sections were measured. According to the ratios derived from calculated measurements, the base of the Visean starts from 60th sample, with the introduction of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2), (Figure 2.5). Four individuals belonging to *Eoparastaffella* sp. (morphotype 1) which have an e/r ratio smaller than 0.5, and three individuals of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) which have an e/r ratio larger than

0.5 is shown in figure 2.5. It can be seen from the presented figure, that although the *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) appears at the 60th sample, the morphotype 1 still exists in the fauna (at the upper right corner, above the Tournaisian – Visean boundary).

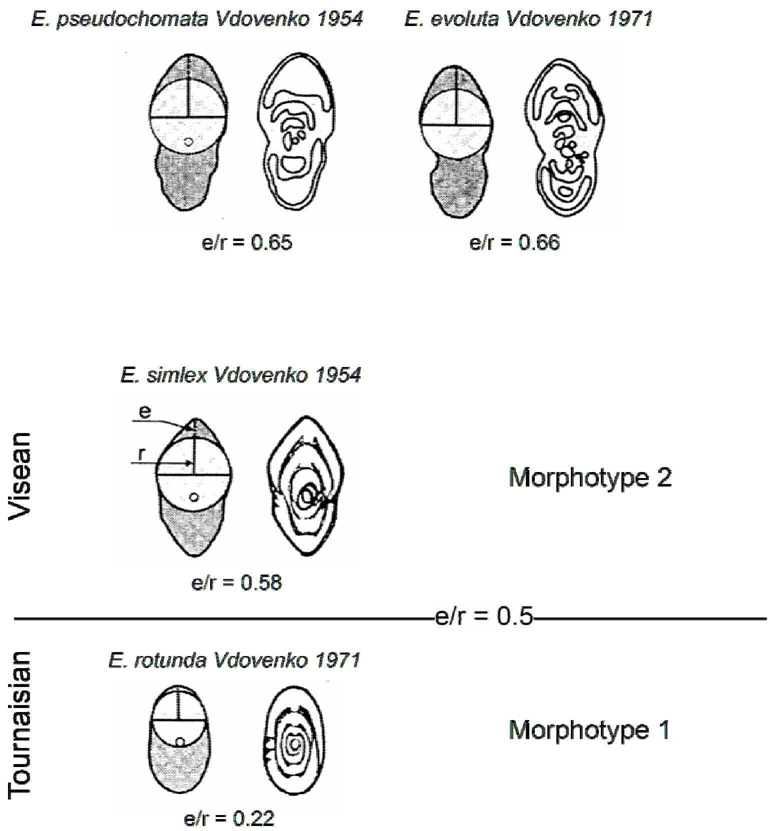

Figure 2.4: Criteria for defining the *Eoparastaffella* morphotypes critical for the definition of Tournaisian - Visean boundary (modified from Hance *et. al.*, 1997).

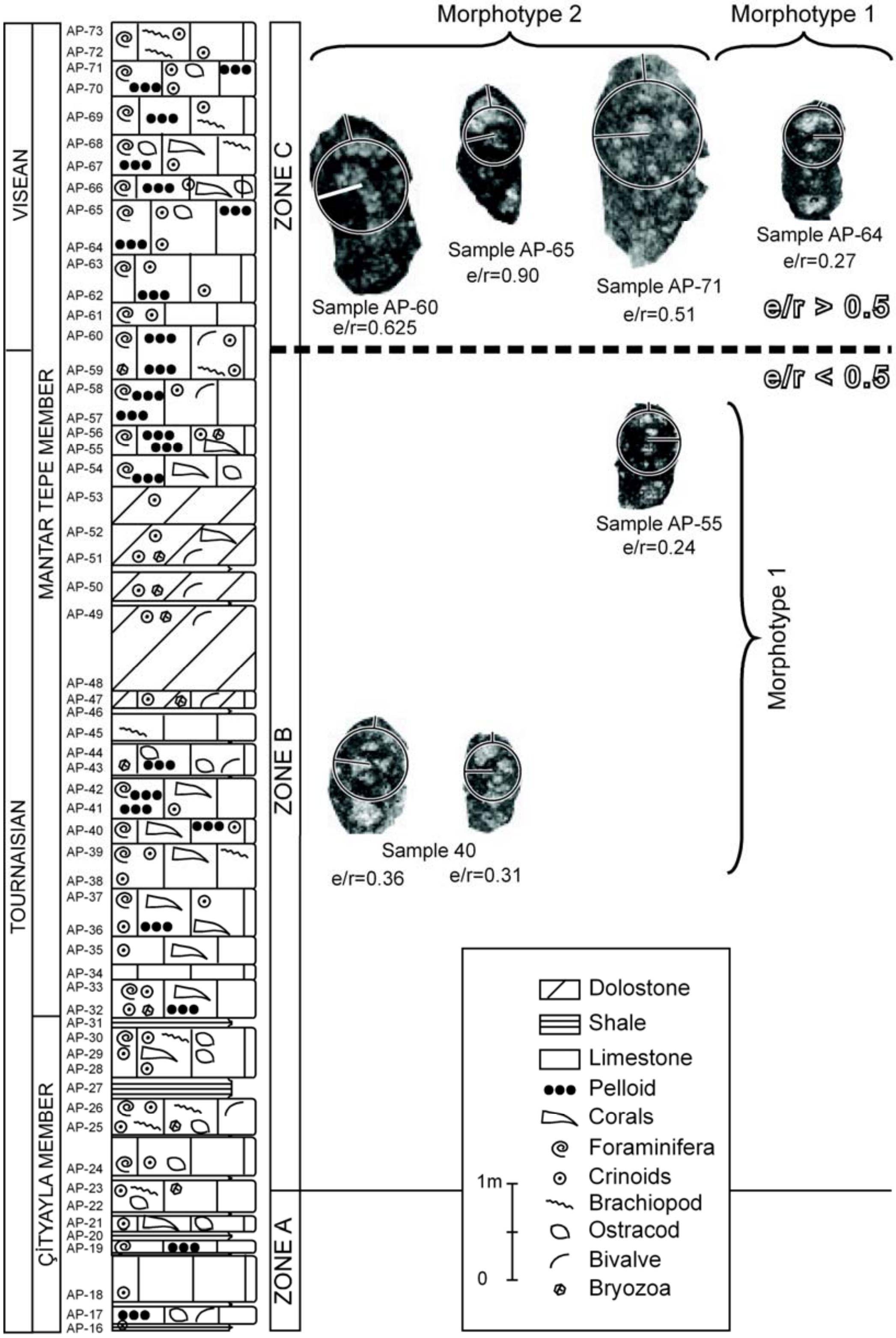

Figure 2.5: Tournaisian-Visean boundary deduced from *Eoparastaffella* e/r ratio in Section AP. (for dimensions of *Eoparastaffella* sp., see Appendix II)

2.4. Sequence Stratigraphy and Meter-scale Cycles

Meter-scale cycles of the study area is based on microfacies types, abundances of benthic foraminifera, and their mutual relationships. Each microfacies type encountered during this study and their stacking patterns are presented and discussed in the next sections.

2.4.1. Microfacies Types

In order to fully appreciate the nature of facies, and depositional environment changes, in order to construct a sequence stratigraphic framework, and ensure the facies control on biostratigraphy, microfacies studies has to be carried out.

In the studied section of Hadim, shallow subtidal carbonates intercalated with shales are present. Predominantly, sections AP (Figure 2.6) and PA (Figure 2.7) are divided into 4 main microfacies types, and 3 specific microfacies types are also presented. (Figures 2.6 and 2.7)

2.4.1.1. Sandy Peloidal Mudstone – Wackestone Facies

This facies type is present at the base of the measured section AP, in samples 5-15, and towards the middle parts of the section PA, in samples 38-46 and 54-57 (see figure 2.6 and 2.7) these microfacies consist of peloids and dark clasts and although very rarely, echinoid fragments, crinoid stem fragments, bryozoan fragments and ostracod shells are present in a few beds. Mud content of some samples is greater than others, and a distinct mud-supported vs. grain supported fabric is distinguishable. Small amount of subhedral to anhedral quartz grains is present in all the samples, and minor stylolization is observed. Although not common, *Earlandia* foraminifers are also observed (Figure 2.8). These facies can be considered as the protected lagoon, or below wave-base facies.

2.4.1.2. Micritic Sandstone Facies

This facies overlies the sandy peloidal wackestone facies, and includes poorly sorted, subrounded to subangular quartz grains, and rare crinoid stem and echinoid fragments. (Figure 2.9)

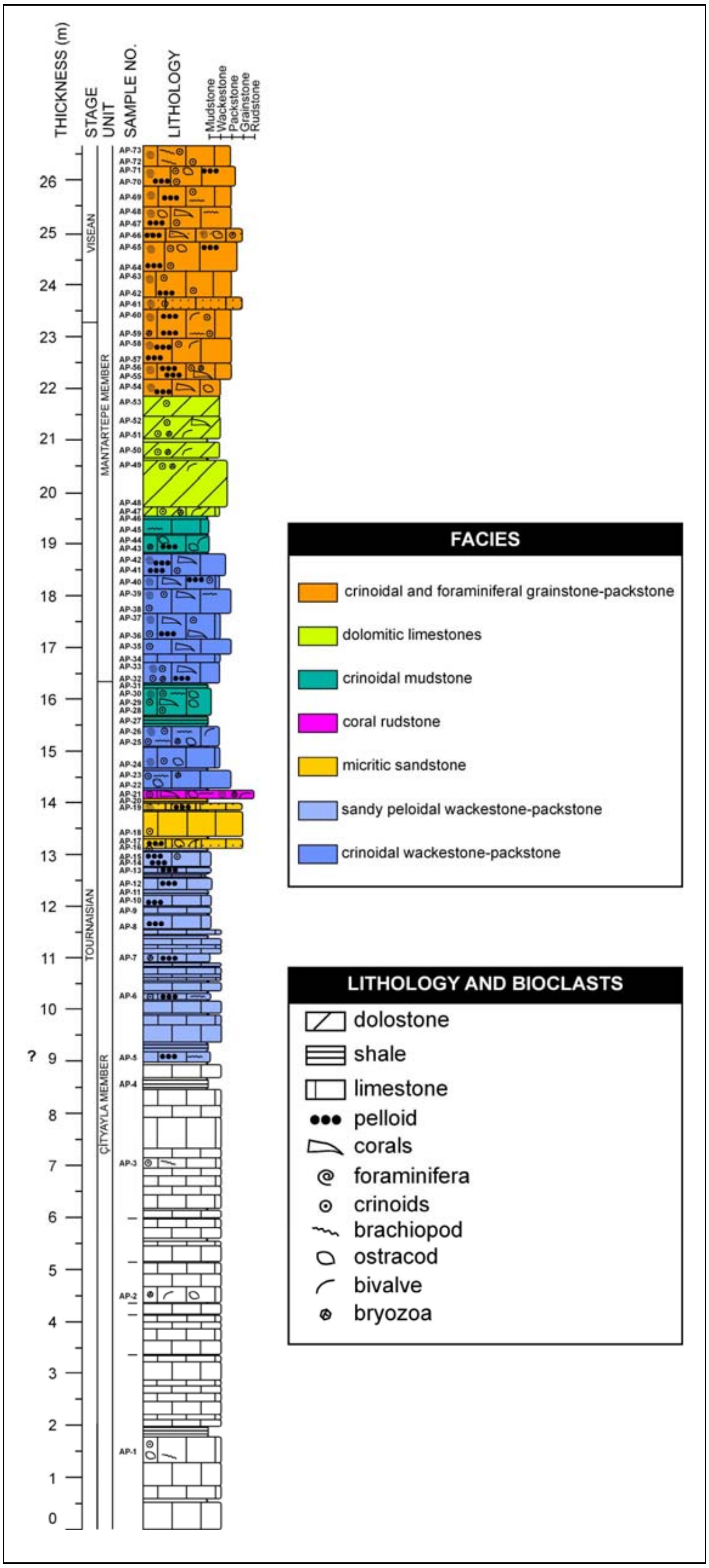

Figure 2.6: Section AP depicting lithology, biological constituents and corresponding facies types.

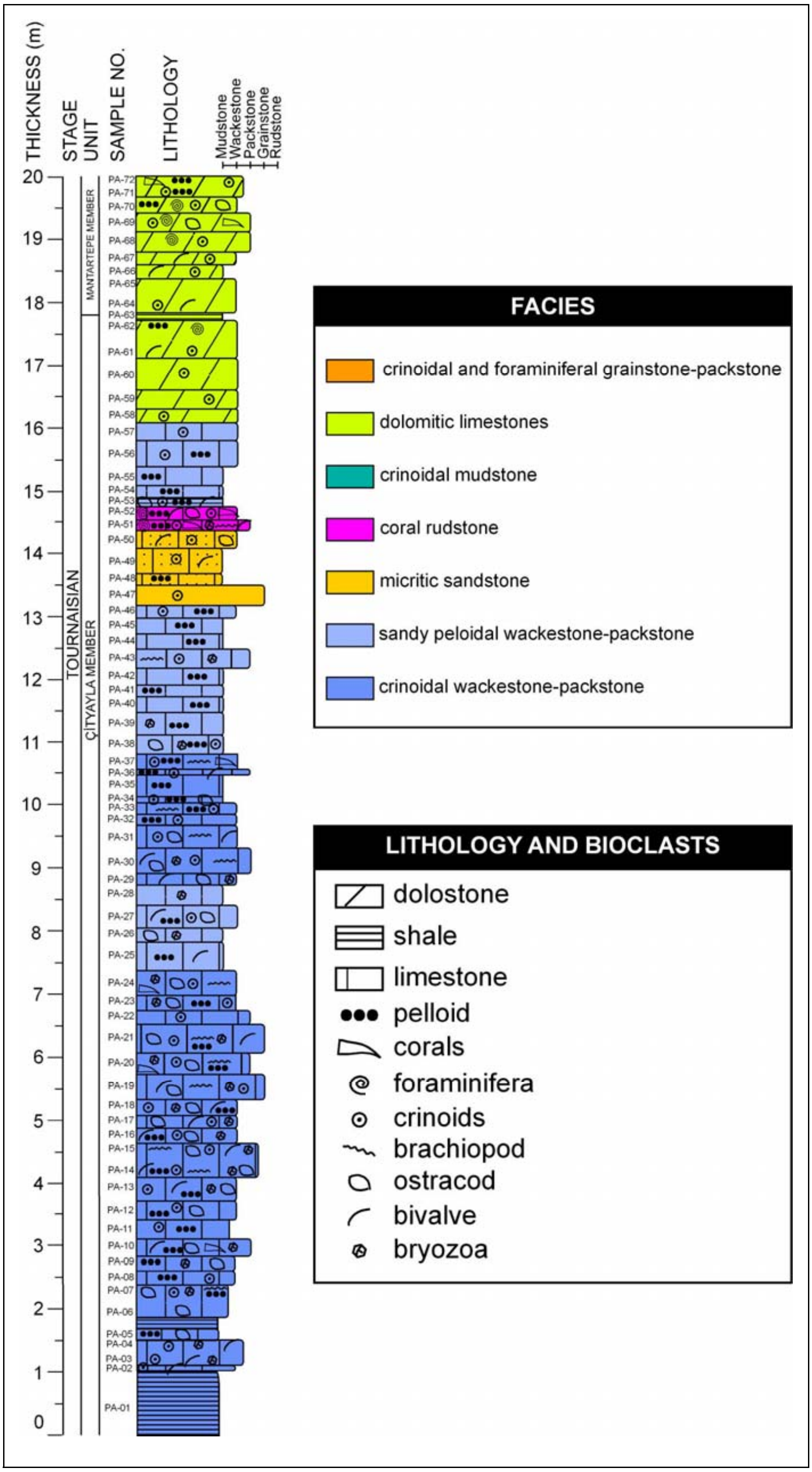

Figure 2.7: Section PA depicting lithology, biological constituents and corresponding facies types.

The distinctive character of these facies enabled the local correlation of the two measured sections AP and PA. This facies is present in the samples 17-19 in section AP and 47-50 in section PA. (Figures 2.6 and 2.7)

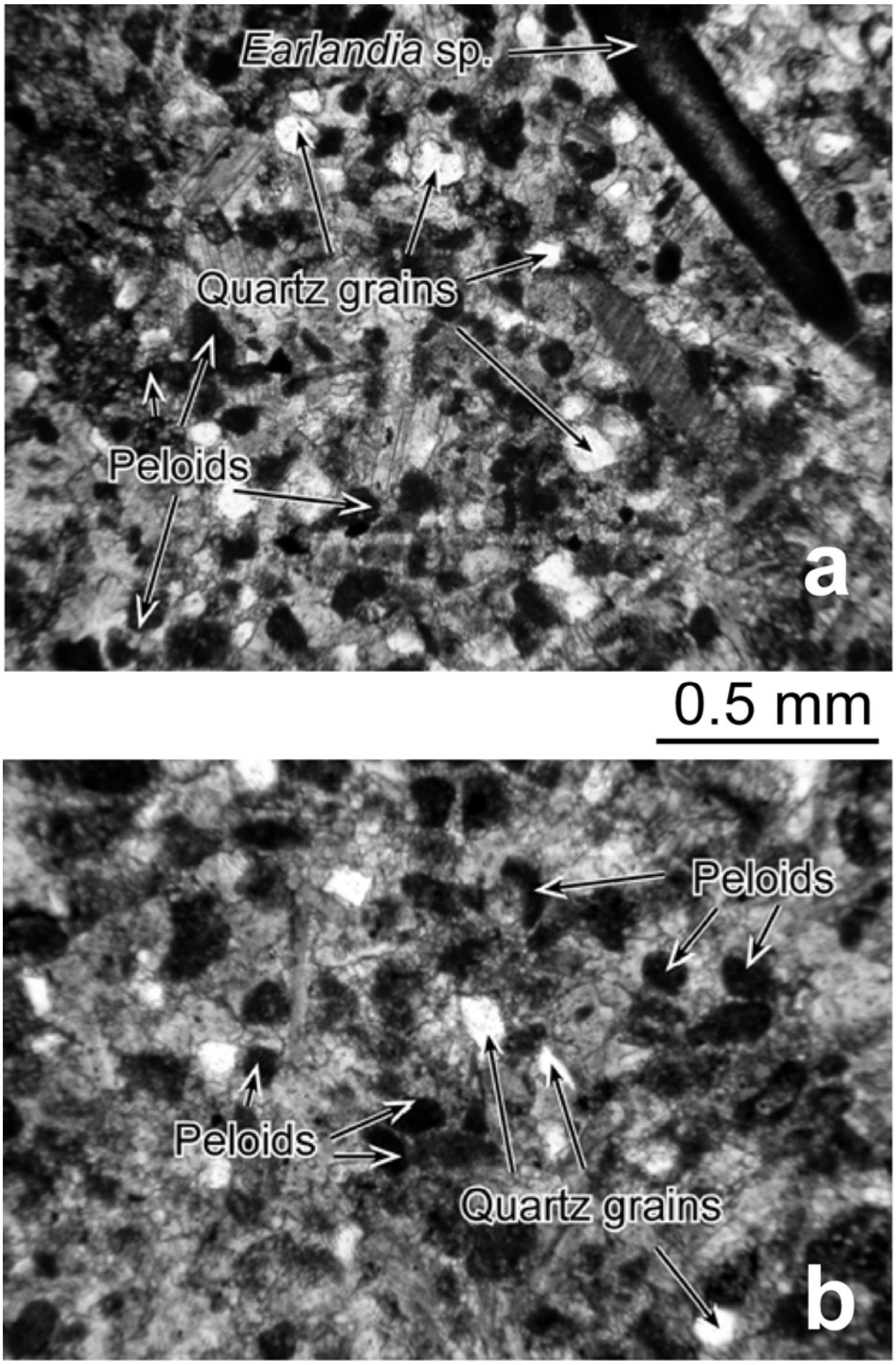

Figure 2.8: Photomicrographs of sandy peloidal mudstone – wackestone facies. Section AP; A: Sample AP-5, B: Sample AP-8.

2.4.1.3. Coral Rudstone Facies

The facies consists of large coral cross-sections, ostracod shells, crinoid stem fragments and bivalve shells and brachiopod shells in between. Small foraminifera is present in between corals in the Section AP, however, Section PA lacks any foraminifers in this level. Detrital quartz grains, subangular to subrounded is present. The sides of the corals are touching each other is stylolized, and sutured. (Figure 2.10)

This facies is sampled at AP-21 at Section AP, and PA- 51 at Section PA. (Figure 2.6 and 2.7). Thus it was used as a "marker microfacies", to correlate the two sections, together with the micritic sandstone facies (discussed in Section 2.4.2.)

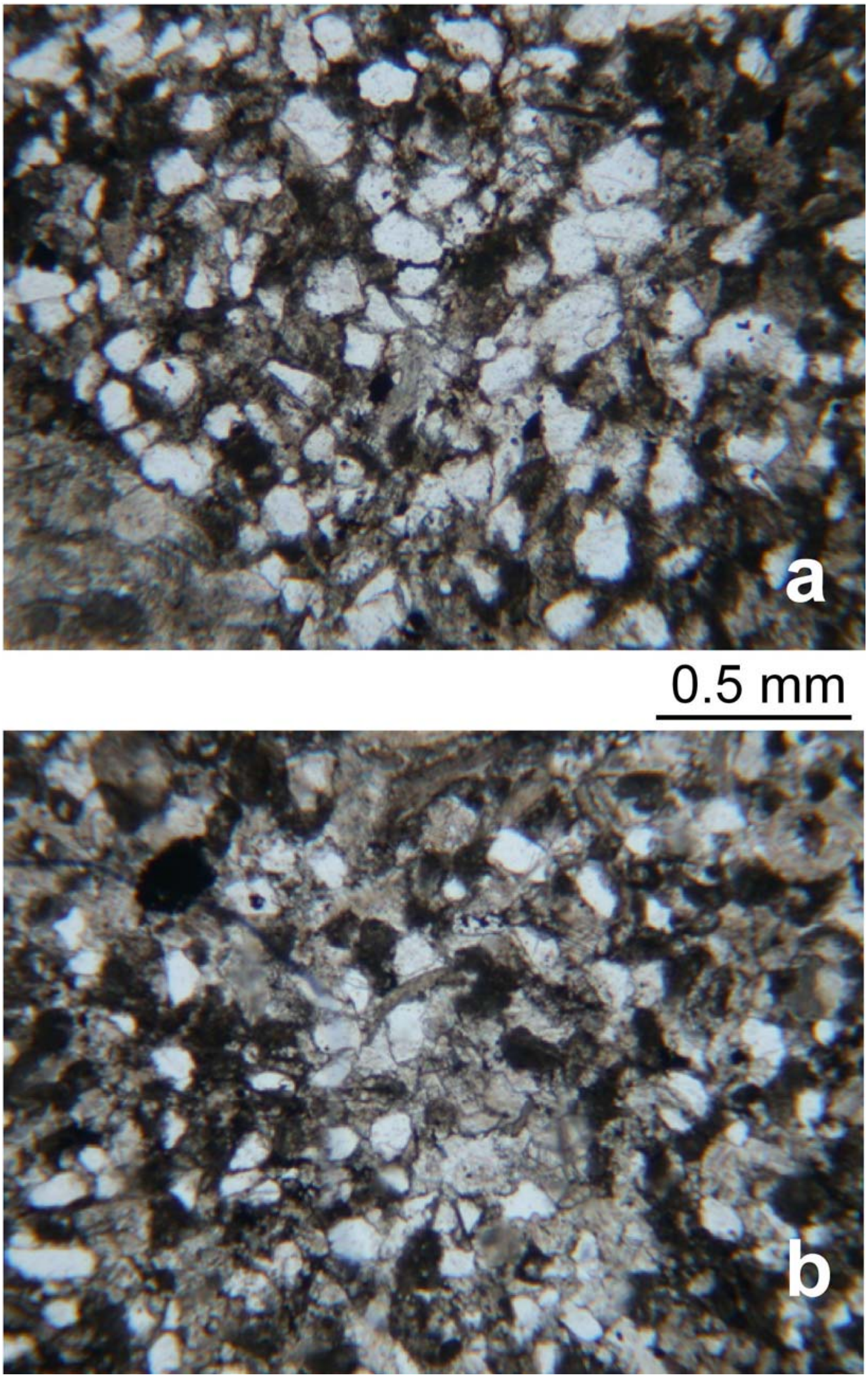

Figure 2.9: Photomicrograph of micritic sandstone facies, abundant quartz grains in micritic matrix. Section AP, A: Sample AP-18; B: Sample AP-19.

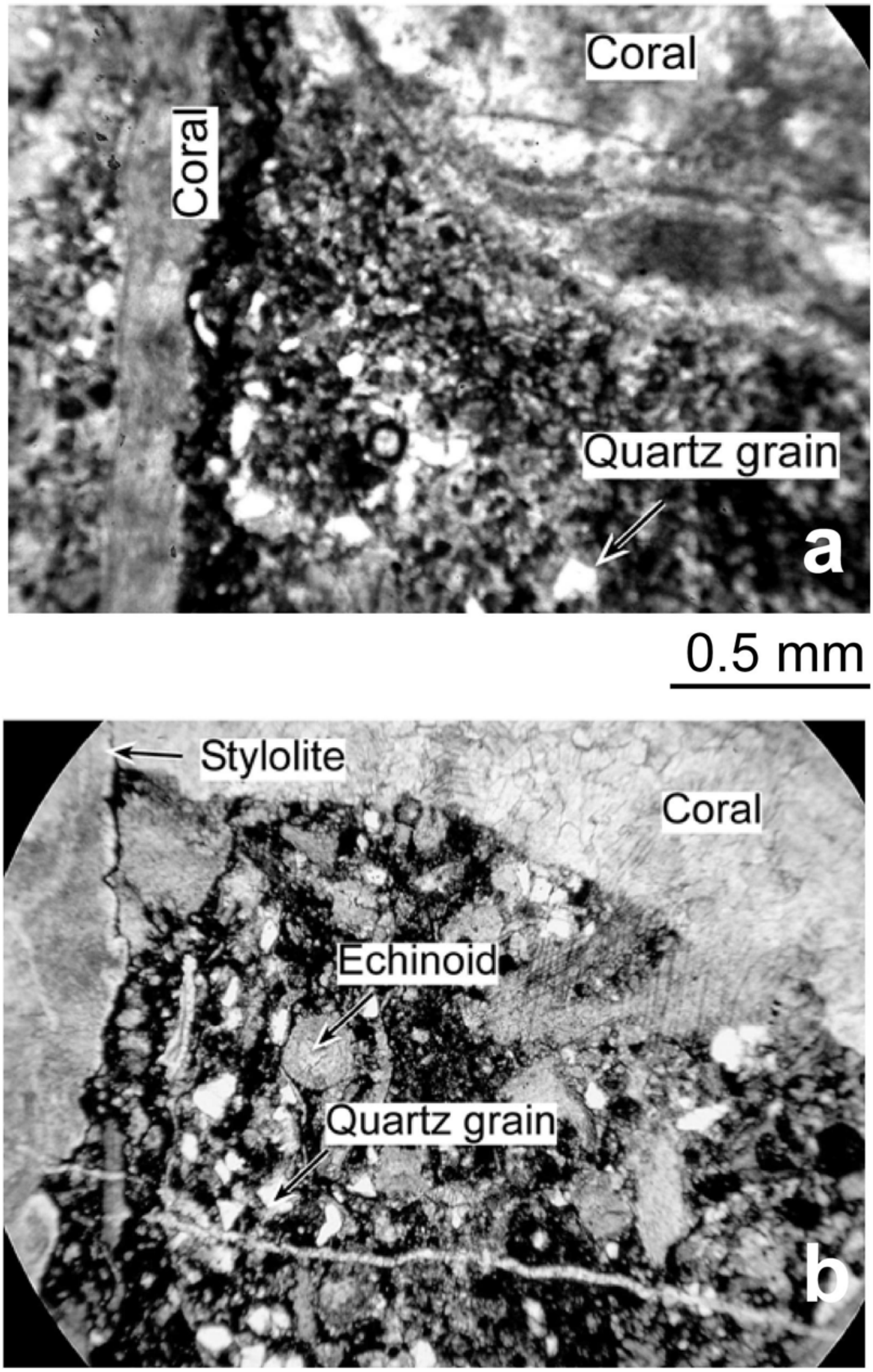

Figure 2.10: Photomicrograph of coral rudstone facies, Section AP, A and B: Sample AP-21.

2.4.1.4. Crinodal and Foraminiferal Grainstone – Packstone Facies.

This facies is dominant through the upper part of Section AP (samples 55-73), it commonly consists of peloids and crinoid stem and echinoderm fragments. Towards the top, brachiopod shells, bivalve shells, and rarely bryozoa fragments are present. Foraminifers are relatively abundant in this facies, compared to the rest of the section. Angular to subangular quartz grains is present (Figure 2.11, 2.12 and 2.13).

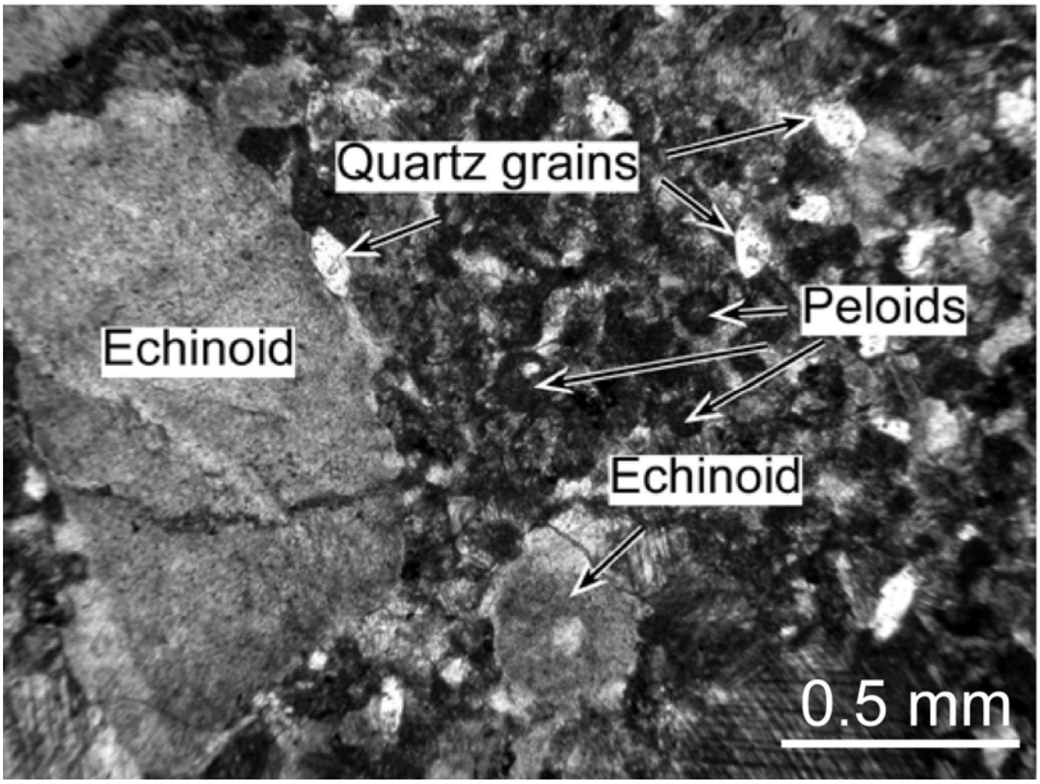

Figure 2.11: Photomicrograph of Crinodal and foraminiferal grainstone – packstone. Echinoid fragments and peloids are seen. Section AP, Sample AP- 59.

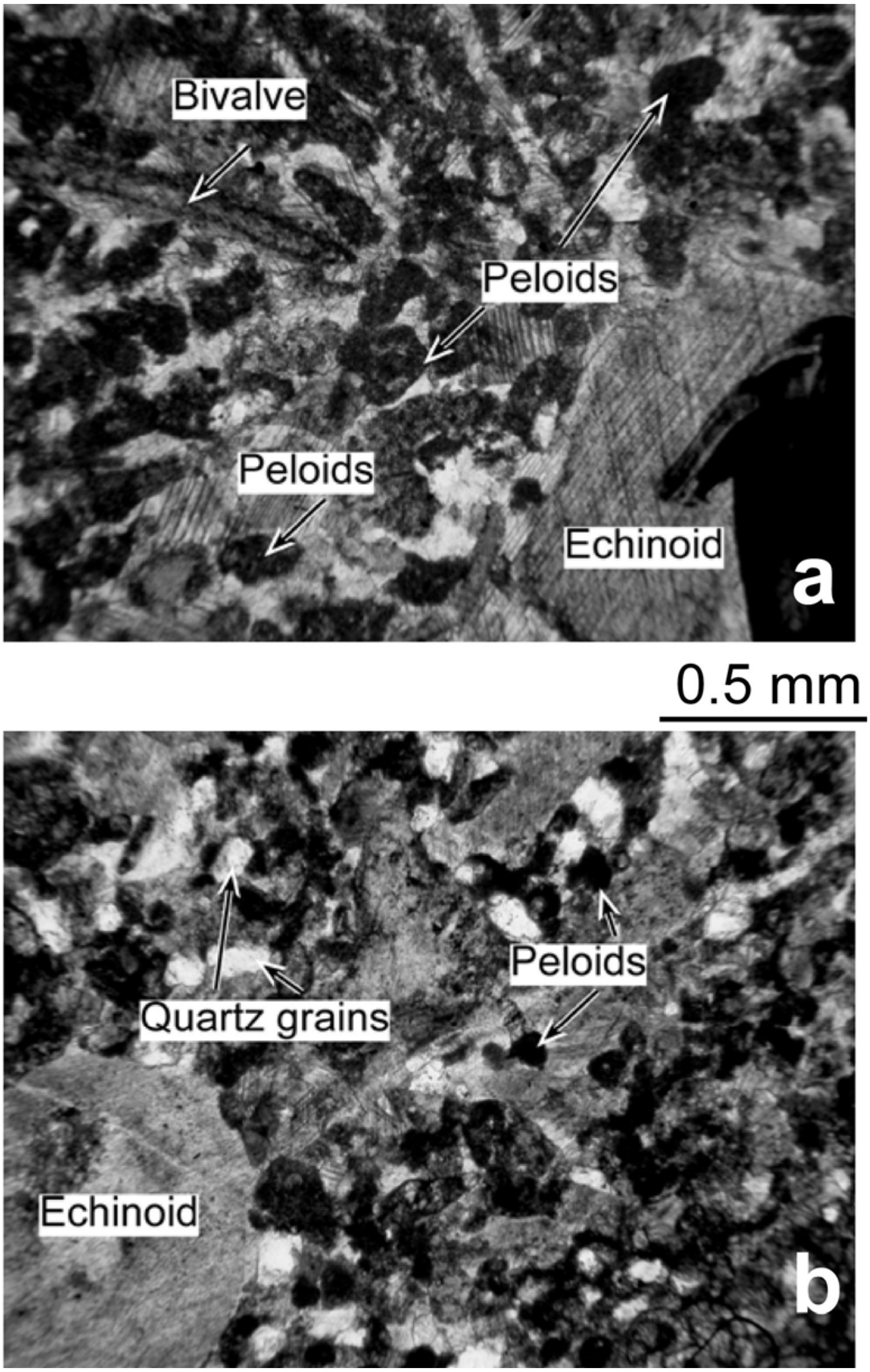

Figure 2.12: Photomicrograph of crinodal grainstone facies with peloids. A and B: Section AP, Sample AP-64.

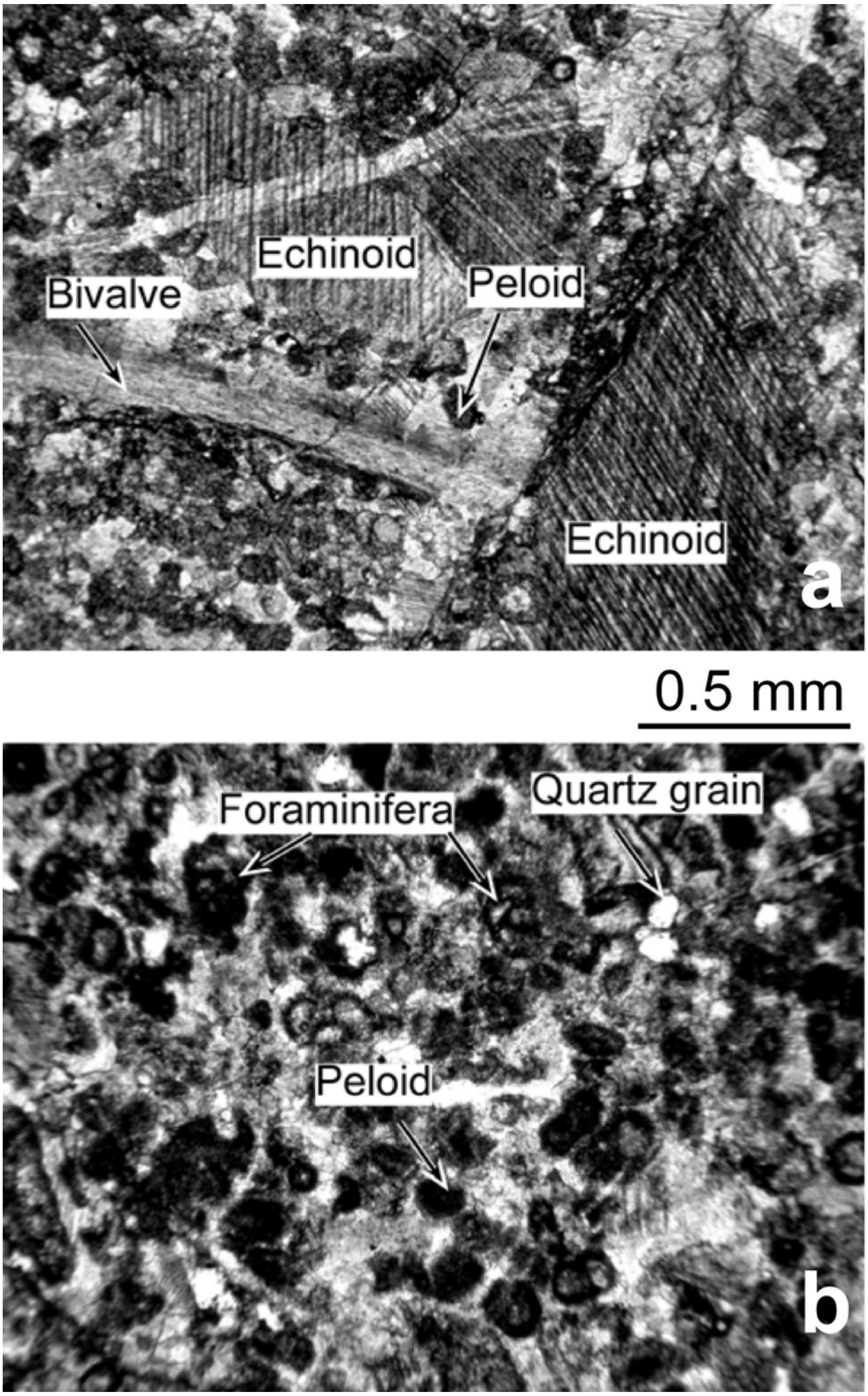

Figure 2.13: Photomicrograph of crinodal and foraminiferal grainstone – packstone with abundant peloids and foraminifera. Section AP, A: Sample AP-60; B: Sample AP-71.

2.4.1.5. Crinodal Wackestone – Packstone Facies

Dominant through the middle part of the section AP, below the dolomitized part, this microfacies serves as a bridge and connects the sandy peloidal wackestone – packstone facies to crinoidal foraminiferal grainstone – packstone facies. This facies occurs at sample intervals 22-26 and 32-42 in section AP, and it is the dominant facies from bottom to sample 37, in section PA (figure 2.6 and 2.7). This facies contains a substansial amount of lime-mud, as well as crinoid fragments, echinoid fragments, and rarely bryozoa fragments. Peloids are common, and rarely pelecypod, brachiopod shells are present (Figure 2.14 and 2.15).

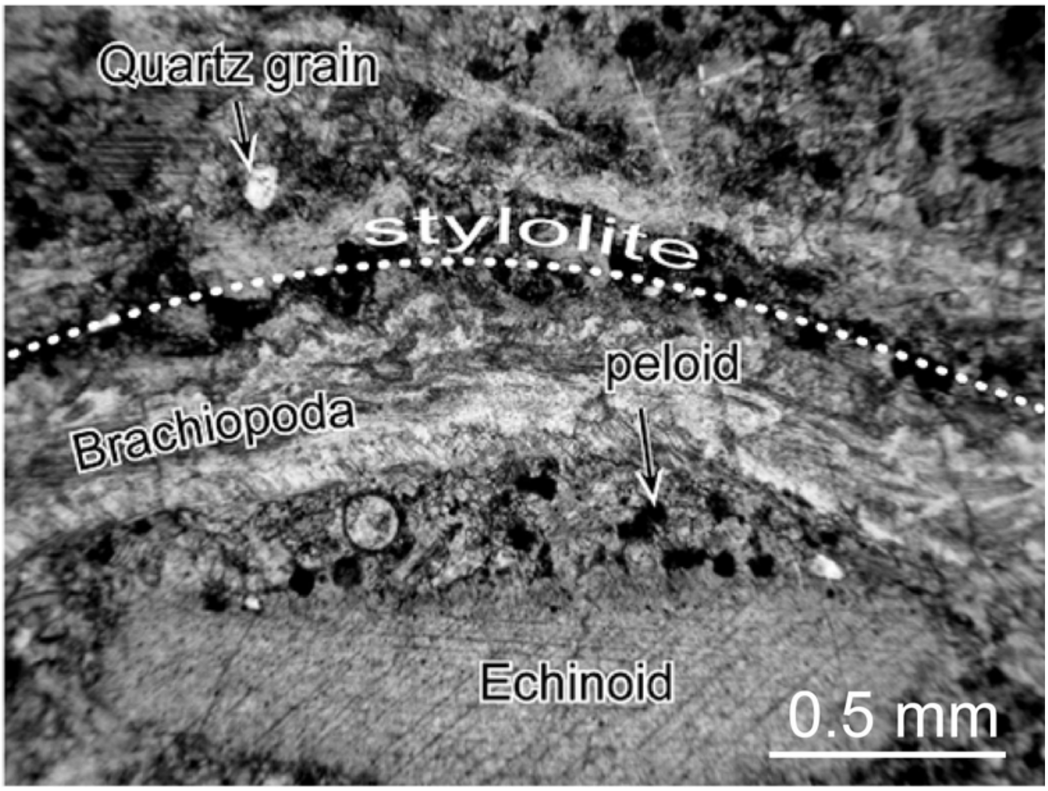

Figure 2.14: Photomicrograph of crinodal wackestone – packstone facies with stylolite Section AP, Sample AP-36.

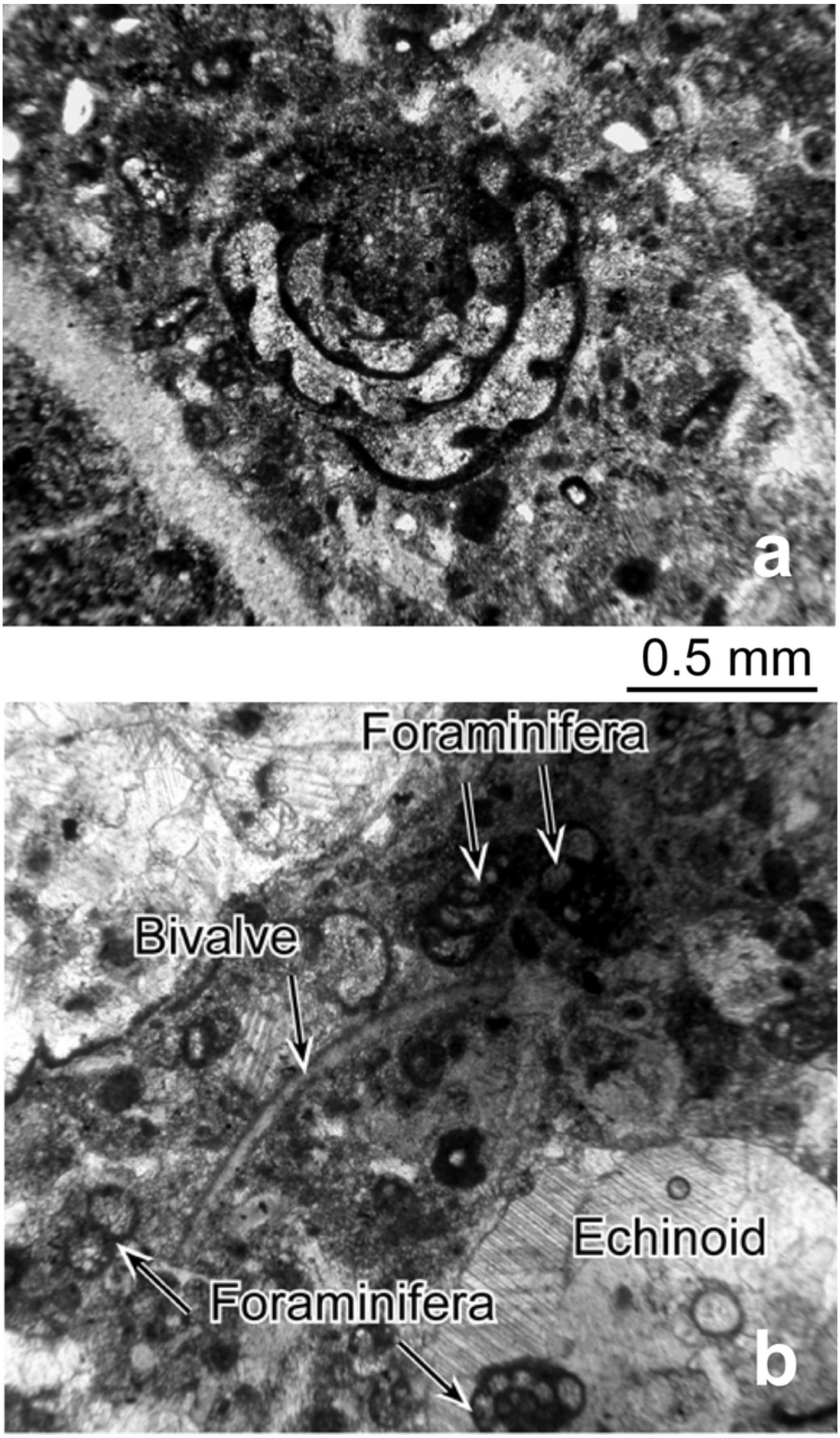

Figure 2.15: Photomicrograph of crinoidal wackestone – packstone facies with dominant echinoid and bivalve fragments. A and B: Section AP, Sample AP-36.

2.4.1.7. Crinoidal Mudstone Facies

This microfacies is matrix supported and composed of high amount of lime mud, with small amount of detrital quartz. Bivalve fragments are present, and crinoids fragments are relatively dominant (Figure 2.16).

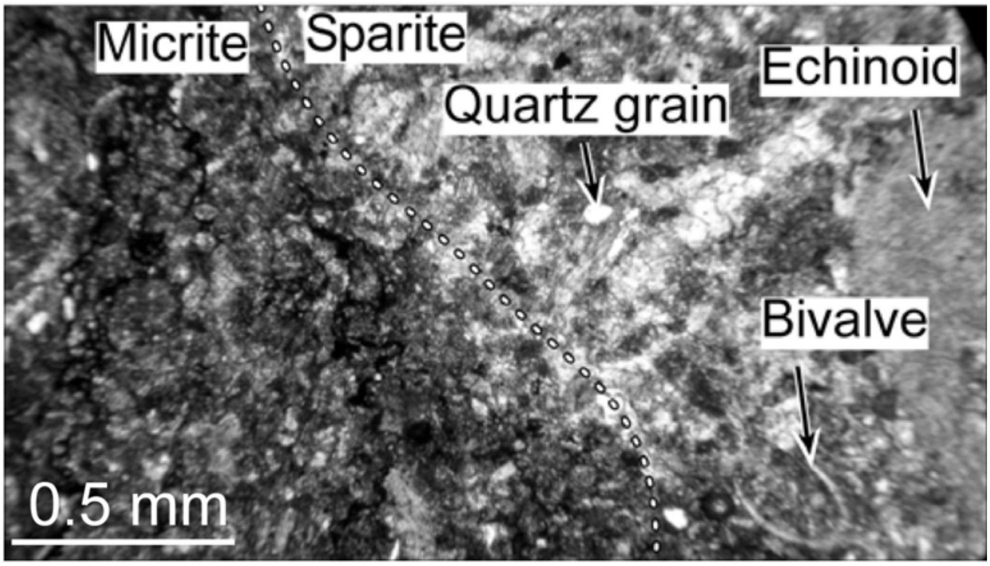

Figure 2.16: Photomicrograph of crinoidal mudstone facies. Section AP; Sample AP-44

2.4.1.8. Dolomitic Limestones

In the measured sections, both sections AP and PA contain a dolomitized zone towards their top. The interval sample 46-53 of AP and 58-72 of PA is dolomitized (Figure 2.6 and 2.7). Dolomites were described according to the nomenclature proposed by Randazzo and Zachos (1983).

- AP-47 equigranular dolomite, medium to fine grained crystals euhedral to subhedral.
- AP-48 inequigranular fogged mosaic dolomite, coarse to very fine euhedral to subhedral crystals, includes, peloids, echinoids and crinoid fragments that are dissolved in micritic matrix, grain supported quartz grains are visible.

- AP-49 equigranular fogged mosaic dolomite, medium to fine, euhedral to subhedral crystals, echinoid crinoid stems.
- AP-50 inequigranular fogged mosaic dolomite, coarse to fine grained, euhedral to subhedral crystalls.
- AP-51 inequigranular sutured mosaic dolomite, coarse to fine, euhedral to subhedral crystals.
- AP-52 inequigranular, spotted mosaic dolomite, medium to fine, euhedral to subhedral crystalls. echinoid spines (Figure 2.17)
- AP-53 inequigranular, medium to very fine grained, tightly packed, euhedral to unhedral dolomite crystals.
- AP-56 equigranular, sutured mosaic dolomite, medium to coarse crystalline, euhedral to subhedral crystals. In this sample, crinoid stem fragments, with small amount of quartz is present. Corals and bryozoa fragments are abundant. (Figure 2.18)
- AP-57 equigranular, fine, peloidal, floating, euhedral, rhombohedral dolomite crystals.

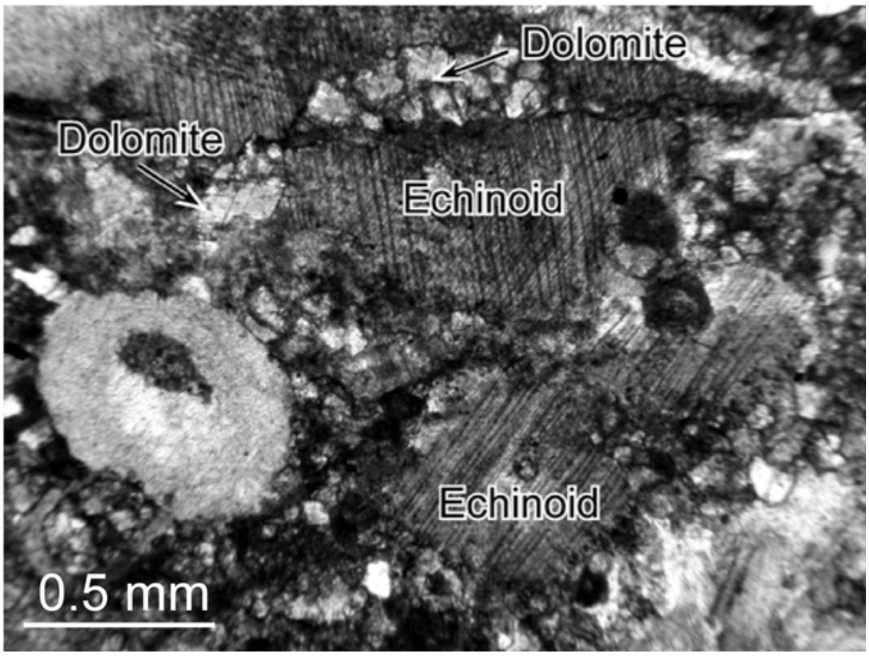

Figure 2.17: Photomicrograph of dolomite fabric with echinoids. Section AP, AP-52.

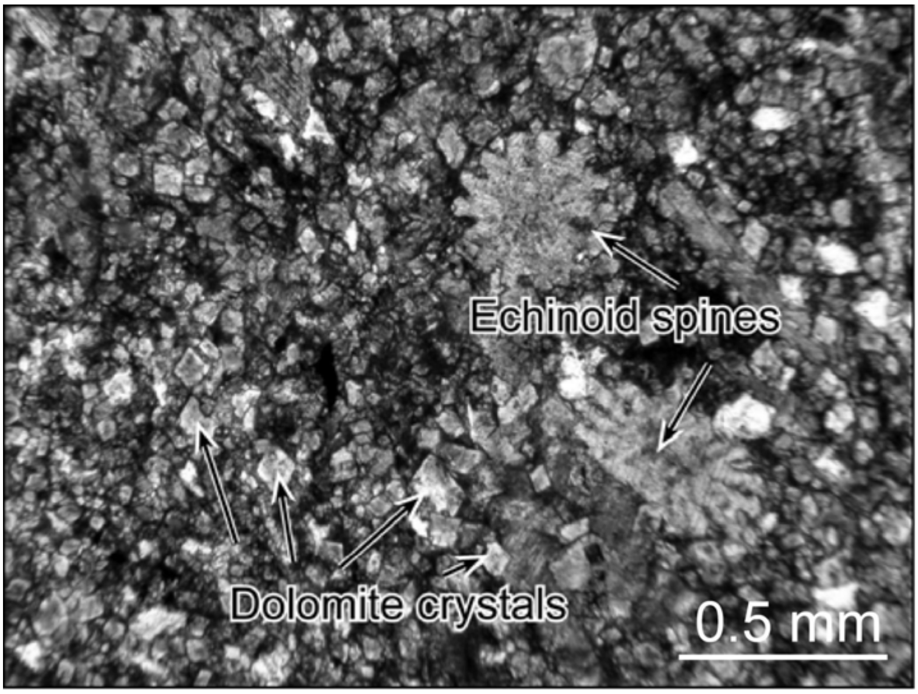

Figure 2.18: Photomicrograph of dolomite with echinoid spines. Section AP, AP-56

2.4.2. Correlation of Local Sections

The two measured sections, section AP and PA were correlated according to their microfacies types, since the foraminifers were highly deformed, and rare due to neomorphism recognized in the dolomitized top of the second section, Section PA.

Both sections were correlated according to the occurrence of sandy micritic limestone beds and occurrence of coral rudstone facies. Both facies are very distinctive under microscope, and are successfully used for correlation. The tie point in the correlation of the section is coral rudstone facies observed around the sample numbers 51 and 52 in the Section PA while it is observed around sample number 21 in the Section AP (see Figure 2.19). In both of the sections the micritic sandstone facies underlying the key horizon is very apparent. In addition to these, sandy peloidal mudstone wackestone facies underlies the micritic sandstone facies.

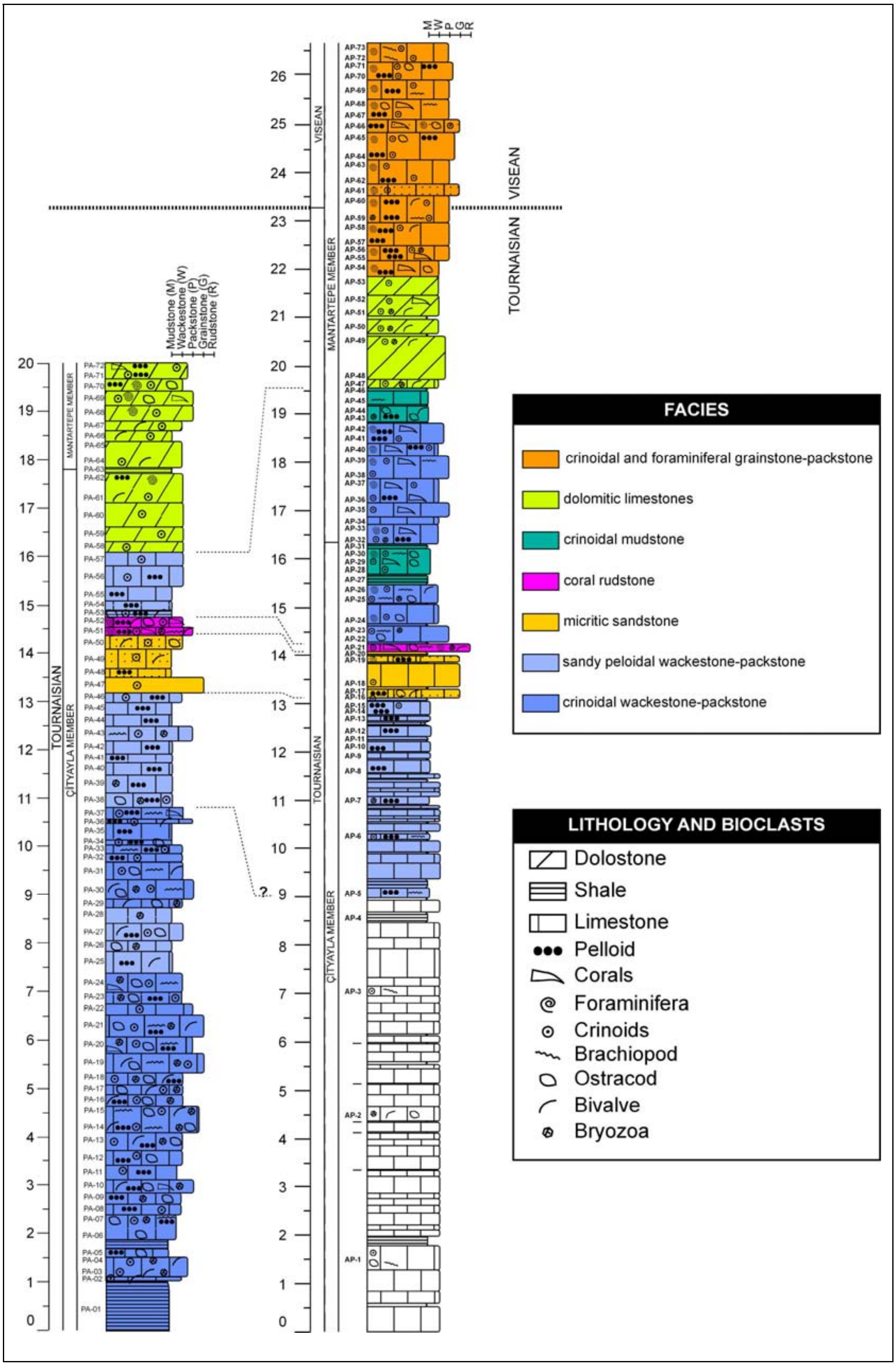

Figure 2.19: Correlation of Section AP and PA based on microfacies.

2.4.3. Meter Scale Cycles Across the Tournaisian – Visean Boundary

This study is based on the results obtained from 57 samples collected from Section AP, since stratigraphic section is relatively abundant in foraminifers, a critical criteria to define shallowing upward cycles. This section contains the Tournaisian – Visean boundary and consists of 48 beds, which are classified according to their textural propeties of limestone, such as mudstone, wackestone, packstone and grainstone. (Figure 2.20).

Section AP is composed of three major types of limestone; in its base, it contains dominantly, sandy peloidal mudstone - wackestone, and towards its top, it contains crinoidal foraminiferal grainstone – packstone. In between, crinoidal wackestone – packstone facies is dominant, right under the dolomitized part. The section is relatively rich and contains abundant benthic foraminifera in some grainstone beds. The middle part of the measured section is dolomitized (samples 48-53), therefore since the microfacies record is majorly altered, and no foraminifers are present in this part of the section, this part is not covered during cyclostratigrapy and sequence stratigraphy studies.

The cycles are defined according to two main criteria; the number of individual benthic foraminifera, and microfacies evolution. Benthic foraminifers are organisms that react to environmental changes, and together used with microfacies interpretations, they are good indicators of shallowing upward cycles. This approach was found to be very successful to distinguish the shallowing upward cycles of Şen (2002).

The measured section contains 13 shallowing upward cycles. This cycle pattern is the result of both foraminiferal abundance peaks and variations of shale with mudstone, wackestone, packstone and grainstone microfacies. Generally these cycles can be characterized by relatively low energy micritic, peloidal mud or wackestones at bottom to relatively high energy, crinoidal wackestone, packstone or grainstones at the top.

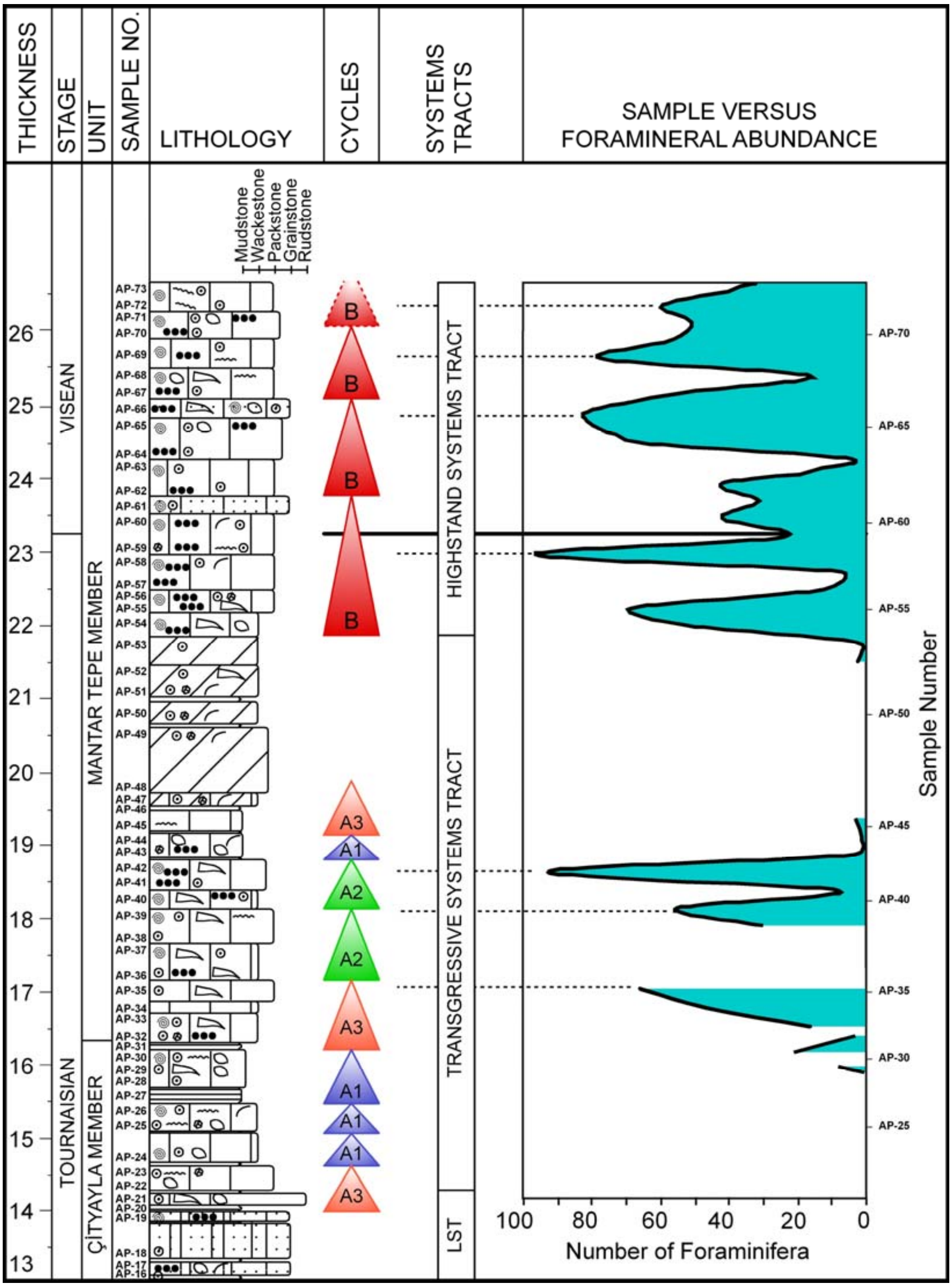

Figure 2.20. Figure 2.19. Meter-scale cycles derived from benthic foraminiferal abundance and microfacies analysis in the section (see Appendix B for details).

The observed cyclic pattern is further analyzed in terms of its microfacies stacking pattern and two main types of cycles are observed and classified according to their microfacies texture. A type cycles are presented by lower energy facies, and B type cycles consist of higher energy facies (Figure 2.21). Towards the top of the studied area, in Figure 2.20 the relation between abundance of foraminifers and shallowing upward cycles is clearly seen.

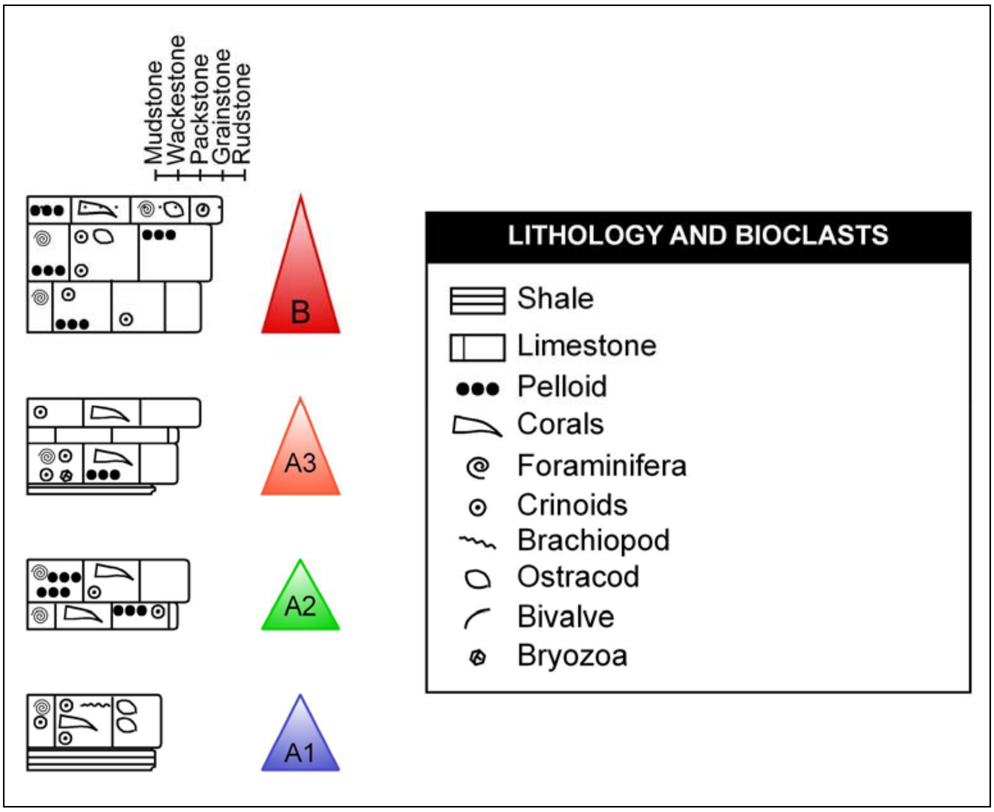

Figure 2.21: Types of cycles based on microfacies stacking patterns.

2.4.3.1 A Type Cycles

A type cycles consist of relatively low energy facies of the measured section. These cycles are observed at the middle part of the measured section AP, through samples, 20 – 47 (Figure 2.20). A type cycles consist of different stacked beds of shale with mudstone, wackestone and packstone facies. Crinoidal wackestone – packstone facies, crinoidal mudstone facies, are the building blocks for these cycles. This facies are grouped into 3 subcategories according to their occurrence as A1, A2 and A3 (Figures 2.20 & 2.21).

A1 type cycles are composed of shale and mudstone alternations. In the studied section four A1 type cycles are defined, with shales at the bottom of the cycles and mudstones, showing rare occurence of ostracod, brachiopod and bivalve shells, with occasional crinoid stem fragments and corals at the top. In these cycles, foraminifers are present, but occur very rare and their abundance does not correlate with the cyclic phenomena, in cycles generated from these facies. It can be assumed that due to environmental controls.

A2 type cycles are composed of wackestone and packstone alternations. In the stuied section, two A2 type cycles are presented, with crinoidal wackestone facies defining the bottom of the cycles and crinoidal packstone facies defining the top of these cycles. The microfacies consist of, peloids, brachiopods and crinoid, echinoid fragments, with corals present. In these cycles, foraminifers are giving good correlation in terms of abundance, as the cycle tops are defined by populated, abundant foraminiferal faunas, while cycle bottoms are rare in foraminiferal population (Figure 2.20 and Appendix B).

A3 type cycles comprimise a shallowing upward stacking pattern, which consist of shales to mudstones and/or wackestones to packstones. In the studied section, three A3 type cycles is present, with variations among them. The bottom of these cycles are shales, generaly overlain by crinoidal mudstone facies or crinoidal wackstone facies, and the cycle tops are crinoidal packstone facies. In the figure, there is one A3 cycle that gives a good correlation with foraminiferal abundance, while the other cycles would not give the same relation, either because the foraminifers simply doesn't exist there (at the bottom of the section) or they're not recognizable due to dolomitization (A3 cycle right under the dolomitized part).

2.4.3.2 B Type Cycles

B type cycles are made up of relatively high energy facies compared to the rest of the section. These cycles are observed at the upper part of the section AP, through samples 55 – 73, Figure 2.20. These cycles are constructed by stacking of crinoidal and foraminiferal packstones at the bottom and crinoidal and foraminiferal grainstones at the top. These facies, rich in bioclasts, commonly consist of peloids and crinoid stem fragments, with occasionaly ostracod, bivalve and brachiopod shells, corals and foraminifers. In the studied section, the repeating microfacies change is seen 4 times, whilst the last cycle is incomplete since the measured section ends before the cycle. This cyclic pattern, correlated with the benthic foraminiferal abundance, gives also sound conclusions: Foraminifers make abundance peaks at the cycle tops, while the cycle bottoms consist of considerably scarcer benthic foraminiferal population.

2.4.4 Sequence Stratigraphic Interpretation.

A sequence stratigraphic interpretation is put forward based on the character of meterscale cycles and microfacies. Because of the subtidal character of the depositional facies, no exposure surfaces, or erosional boundary is present in the measured section. Moreover, working with only one section has its own difficulties, since the relations of transgression – regression and shallowing – deepening is very hard to distinguish without the aid of proving sedimentary structures (Strasser, *et. al.,* 1999).

However, general evolution of vertical facies can give birth to a sensible model. In the applied section, micritic sandstone, which lies over sandy peloidal mudstone – wackestone facies may indicate a correlative conformity of an erosional boundary. Coral rudstone facies supports this assumption, since the low relative rise of sea-level would create a small accommodation place, creating a packed dense lag deposit in the subtidal area. After this, alternations of A1, A2 and A3 cycles are interpreted as transgressive systems tract, since the vertical evolution of these cycles implies progradation to higher energy microfacies. The dolomitized zone masks the middle part of the studied section, which B type higher energy cycles dominate afterwards. B type cycles compromise a diverser benthic foraminifer fauna with gentle oscillations of packstone – grainstone facies, and are interpreted as the highstand systems tract, where the environment has changed to higher energy conditions, and there are abundant foraminifers since the environment is suitable for these organisms to florish.

This interpretation is given as an initial approach to investigate the sequence stratigraphy of the area. More sections, measured behind and front as well as side would greatly enhance this frame model.

CHAPTER 3

COMPARISONS WITH WELL-KNOWN TOURNAISIAN-VISEAN SECTIONS OF THE WORLD

3.1. South China (Guangxi)

In a recent study conducted by Hance et al. (1997) Tournaisian – Visean transitional strata in South China was investigated, and biostratigraphy with sedimentological evolution was determined. Six foraminiferal associations were distinguished, allowing correlation between the shallow and deep water deposits. Furthermore in this study, Tournaisian – Visean boundary was defined according to the evolutionary stage of foraminifer *Eoparastaffella* providing an accurate criterion for the boundary. For last, sequence stratigraphy of the T-V strata was constructed by combining biostratigraphical and sedimentological data.

During the Early Carboniferous, South China was located in a subequatorial position on the northern border of the Paleotethys. The Late Tournaisian and Early Visean sedimentation took place on a complex carbonate platform , bordered to the north by the Yangtze Old Land and southeastwards by the Zengcheng-Leiqiong Old Land. The platform carbonates, covering a large area, were deposited along a narrow intraplatform basin. According to Liao and Li (1996) the platforms were probably shelves possessing a notable brake of slope.

Four sections passing through the Tournaisian – Visean boundary were measured, namely Huaqiao Farm, the Mopanshan, the Yajiao River and the Pengchong sections.

Six foraminiferal associations were distinguished in the Tournaisian – Visean transitional strata, and these associations are reffered to as local assemblage zones.

Association A is formed of typical late Tournaisian foraminifers coexisting with a suite of foraminifers of Visean affinity, referring to the type area in Belgium (Conil *et. al.* 1991). The common elements are *Tetrataxis, Pseudotaxis, Latiendothyranopsis, Granuliferella, Priscella, Spinoendothyra, Tuberendothyra, Condrustella, Eoforschia* and abundant Tournayellinae. Moreover, colonization of 'transitional' foraminifers took place in successive steps. From base to up the following trend of first occurrences has been observed:

- *Bessiella, Florennella, dainellids,*
- *Brunsia, Globoendothyra, Endospiroplectammina,*
- *Plectogyranopsis, Endothyranopsis,*
- *Pseudolituotubella, Pseudolituotuba.*

Association B differs from association A by the contemporaneous first occurence of *Laxoendothyra* ex gr. *laxa, Loeblicha (?)* ex gr. *fragilis* and *Eoparastaffella* morphotype 1, followed by the appearance of *Mediocris*.

Association C only occurs in the carbonate-rich Penchong Member and is characterized by more abundant Loeblichiidae and *Eoparastaffella* with more evolved specimens designated as morphotype 2.

The lower part of the Huaqiao Farm section consists of dolomites and bioclastic and sometimes peloidal packstones. The main bioclasts in the limestones are crinoids, moravammininds and foraminifers. A major part of the strata is composed of cycles, several meters thick of peloidal and/or bioclastic pack- to grainstones. Tabulate and rarely rugosa corals and brachiopods have been observed in the field. In thin section, bioclasts mainly include foraminifers, moravamminids, crinoids, calcispeheres, shells, algae and ostracods. The uppermost part of the Yingtang Formation is irregularly dolomitized, with a hummocky and pitted surface.

The packstones with an open marine fauna in the lower part of the Huaqiao section is interpreted to be deposited near or below wave-base. The peloidal and/or bioclastic wackestones that characterize the lower part of the cycles, in the uppermost part of the Yingtang Formation, also formed below normal wave-base whereas the pack to grainstones in the upper part of the cycles are considered to have been deposited above wave-base in an open marine environment. The presence of lithoclasts suggests a continuous reworking of the freshly deposited carbonate by currents and or waves. Such wacke to grain stone cycle usually represents a shallowing upward depositional setting.

3.2. Moscow Syneclise (Russian Platform)

Alekseev et al. (1996) characterize The Russian or East-European Platform as one of the largest Precambrian cratons of the world. It is described to have a relatively low intraplate tectonic activity and a thick sedimentary cover which stores information about the evolution of this craton and surrounding fold belts as well as global events. Devonian and Carboniferous shallow-marine carbonate sequences, including several subordinate terrigenous intervals, comprise the main part of the sedimentary platform cover.

The Moscow Syneclise is a vast sedimentary basin located in the centre of the East European Platform. In a recent paper by Alekseev et al. (1996), relative Devonian – Carboniferous sea-level curves and chronostratigraphic / lithostratigraphic figures for the Moscow Syneclise were presented. Carboniferous sea-level changes were previously described for the Donets Basin, the Voronezh Anteclise, the Moscow Syneclise and the Volga – Ural Region by Aisenverg et al., (1985, 1986).

According to Alekseev *et. al*., (1996), an Early Tournaisian transgression covered almost the entire Moscow Syncleise with normal marine waters. A prominent Early and Middle Visean regression induced prolonged erosion and then accumulations of coal-bearing floodplain sediments deposited in the southern and western parts of the area. At the same time, the Tokomovo Uplift was arched up and subjected to intense erosion of Tournaisian and older rocks (Gubareva *et. al*., 1983).

During Early Visean, the Moscow Syneclise was uplifted and Tournaisian rocks were eroded by numerous river systems. However, the Tokomovo uplift, to the east of Moscow Syneclise, shows more intensive growth and increased depth of erosion. In the Early Visean, the Dniepr-Donets Basin Depression and the Donets Basin subsided relative to the Voronezh Anteclise and the Moscow Syneclise and filled mainly with marine carbonates.

According to Alekseev *et. al*. (1996), Late Tournaisian – Early Visean sedimentation didn't take place at the first place, due to prolonged subaerial exposure. According to charts, while most of Karakubian, Cherepetian (Middle Tournaisian) was eroded, Iselin, Covina (Upper Tournasian) and Radovan Barbican (Early Visean) deposition did not occur in the first place.

A foraminiferal zonation was proposed for the first time by Lipina (1965) for the Tournaisian and by Rauser (1948) for the Visean in Central Russia. It was modified by several subsequent workers and summarized by Vdovenko et al. (1985) and Makhlina (1993). The main sources of this zonation are the Moscow Syneclise and the Donets Basin sequences which are complementary to each other.

3.3. Comparison of Taurides with other Tournaisian-Visean Transitional Strata

The association A of Hance et al. (1997), preceding the entry of the Ozawainellidae and Loeblichiidae is of Late Tournaisian age. This zone corresponds to the conodont Cc3 Zone which is time-equivalent to the Carboniferous foraminiferal Cf3 Zone (Conil et al. 1991).

In Belgium this zone contains very few taxa and is largely dominated by *Tetrataxis*, *Pseudotaxis* and *Eotextularia diversaı* (N. Tchernysheva, 1948).

In China Guangxi section, the fauna seems to be excitingly diverse, as *Tetrataxis, Pseudotaxis, Latiendothyranopsis, Granuliferella, Priscella, Spinoendothyra,* *Tubeendothyra, Condustella, Eoforschia* and *Tournayellidinae* are common as Late Tournaisian elements. Also successive incomings of *Besiella* sp., *Florennella* sp., dainellids, followed by *Brunsia* sp., Loeblichidae, *Globoendothyra* sp., *Endospiroplectammina* sp., *Endothyranopsis* sp., *Plectogyranopsis* sp., *Pseudolituotubella* sp., *Pseudolituotuba* sp.

In Turkey, Central Taurides, this zone includes *Earlandia* spp. calcispherid, *Diplosphaerina inaequalis* (Derville, 1931), *Spirorbis* sp., and *Granuliferella* sp. and *Laxoseptabrunsiina.*

The similarities with China are the presence of *Granuliferella*, however, it can be clearly stated that Chinese foraminiferal fauna is much diverse than both Belgium and Turkey. The *Eotextularia diversa* (N. Tchernysheva, 1948) present in Tournaisian (Ivorian) in China is present in Association A of Taurides. No occurence of *Tetrataxis* or *Pseudotaxis* was spotted in the study area.

Association B is characterized by *Eoparastafella* sp. (morphotype 1), coexists with conodont *Scaliognathus anchoralis europensis.* It can be concluded that, this zone is older than the Cf4a2 subzone, referring to Belgium (Belka and Grossens 1986; Conil et al. 1991; Hance et al. 1994) and is likely to have Cf4a1 age (Hance et al. 1997).

In Belgium, this zone is charcterized by *Valvulinella* sp., *Pseudolituotuba* sp., *Omphalotis* sp., *Endospiraoplectammina* sp., *Loeblichia (?)* ex gr. *fragilis,* and then appearance of dainellids, *Laxaendothyra* ex. gr. *laxa* and *Brunsia* sp.

In China *Eoparastaffella* sp. (morphotype 1) and cf. *Mediocris*, *Loeblichia (?)* ex. gr.. *fragilis and Laxaoendothyra* ex. gr. *laxa* are present.

In Turkey, this zone contains *Eotextularia diversa* (N. Tchernysheva, 1948), *Paleospirıplectammina* sp., *Endospiraoplectammina* sp., *Endospiroplectammina venusta* (Vdovenko, 1954), *Eoforschia moelleri* (Malakhova, 1953), *Tournayella* sp., *Septatournayella* sp., *Pseudolituotubella* sp., *Condrustella modavica* (Conil & Lys, 1967), *Condrustella ?* sp., *Granuliferella* sp., *Latiendothyranopsis* sp., *Endothyranopsis* sp., *Plectogyranopsis* sp., *Inflatoendothyra inflata* (Lipina, 1955), *Inflatoendothyra* sp., *Spinoendothyra ? sp.*, *Endothyra* sp., *Omphalotis* sp., *Bessiella* sp., *Laxoendothyra* ex. gr. *laxa, Laxoendothyra* ? sp., *Septabrunsiina* sp., *Eoparastaffella subglobosa* and *Mediocris* ? sp.

It can be noticed that, *Laxoendothyra* ex. gr. *laxa*, is common in all stratotypes, while the *Bessiella* sp., *Endospiroplectammina* sp. which was at association A in China, appears in Association B in Turkey. Moreover, dainellids, and *Endospiroplectammina* sp. are also appearing in Belgium in Association B, while they were already present in Association A of China.

Association C contains the first *Eoparastafella* sp. (morphotype 2) in its lower part. Specimens are similar with the oldest *Eoparastafella* of Belgium. In the latter area they are indicative of an Early Visean age (Cf4a2).

In all three strata, the Association C is represented by *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2), among the similarities, *Eoendothyranopsis* sp. is common in all three sections, *Globoendothyra* sp. found in Association A in South China appears first time in Association C in Turkey, whilst *Pseudolituotubella* sp. found in association A in South China appears first time in Association C in Belgium.

What is apparent from the following result is that, South China Guangxi platform hosts a diverse fauna with minimal environmental control. However, Belgium and Turkish sections are less diverse in their content. Nevertheless the fossil guide *Eoparastafella* is found in all three sections, and it's evolutionary characteristics are well suited for the definition of Tournaisian – Visean boundary.

CHAPTER 4

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

In this study, definition of Tournaisian – Visean boundary in the Central Taurides, Aladağ Unit, Hadim was aimed according to the criteria introduced by Hance *et. al.*, (1997). The cyclic nature, and sequence stratigraphic interpretation of the measured section was also investigated.

Detailed analyses of microfacies of the measured sections and exhaustive investigation of benthic foraminiferal associations in section AP across the Tournaisian – Visean strata led to following conclusions:

Two closely measured sections, Section AP cutting across the Tournaisian – Visean boundary, and Section PA, measured below the boundary were investigated according to their microfacies and correlated.

Section AP is characterized by sandy peloidal mudstone-wackestone, and crinodal wackestone-packstone facies. The section is relatively rich in foraminifers, and contains quite a large amount of bioclastics. (Crinoid, echinoids, ostracods, brachiopods etc.) The section is dolomitized towards the top, which is overlain by crinoidal and foraminiferal packstone – grainstone facies.

Section PA is dominantly composed of crinoidal wackestone – packstone facies overlain by sandy peloidal mudstone - wackestone facies. This section is nearly completely devoid of foraminifers, and its top most part is completely dolomitized.

Both sections include beds that contain distinctively different microfacies. These are coral rudstone facies and micritic sandstone facies. Both sections were correlated according to these `marker beds`.

Biozonation of the Section AP led to 3 different biozones. Among these, the Zone B is defined according to first appereance of *Lugtonia monilis* (Malakhova, 1955), and *Eoparastafella* sp. (morphotype 1). Zone C, which is also defined as the Tournaisian – Visean boundary is differentiated by the evolutionary change in the *Eoparastaffella* sp. The appereance of *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) is the criterion for both the biozone and the Tournaisian – Visean boundary in Taurides.

Cyclicity was investigated in the relatively foraminiferal rich section AP. The criteria used for the definition of shallowing upward sections are the abundance of benthic foraminifera and the microfacies evolution of the measured section. 13 shallowing upward cycles were detected in the studied area, and these cycles were grouped according to microfacies stacking patterns. Four A1, two A2, three A3, and four B type cycles were defined. In cycle types A2 and B, cycle tops are characterized by abundance of foraminifera, while cycle bottoms are usually devoid of these benthic organisms. In these cycle types abundance of benthic foraminifers shows a good correlation. A second criterion for the definition of cycles is the microfacies evolution. Alternations of grainstone and packstone facies and alternations of sandy peloidal wackestone and grainstone facies is used for describing the shallowing upward cycles. Grainstone facies, suggesting a higher energy of deposition and scarceness of lime-mud suggests a relatively high energy environment, while mud deposition and pelloidal wackestone deposits suggest a deepening, low energy environment.

Response of benthic foraminifers to sea-level changes was determined according to their abundance, and cycle tops inferred according to foraminifera abundance is correlative with the microfacies variations of low energy, high energy facies and thus, successful in defining shallowing upward cycles.

The measured section and documented foraminiferal genera and species were compared with Belgium and South China stratotypes. It can be concluded that South China with its diverse fauna sets a good example of foraminiferal richness. A later appearance of foraminifers, *Bessiella* sp. in Turkey and *Brunsia* sp. in Belgium suggests that Belgium and Turkish strata have environmental controls.

Both sections consist of a dolomitized part towards their top. In Section AP this dolomitized layer is about 1.5 m below the Tournaisian – Visean boundary. The reasons for the dolomitization is not clear, and it's relation with the global Tournaisian – Visean relative sea-level fall should be investigated.

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APPENDICES

APPENDIX A

PLATE I

Figures

1. *Granuliferella* sp. AP-19, X70, oblique section.

2. *Endothyra ?* sp. AP-21, X70, axial section.

3. *Endothyra ?* sp. AP-35, X70, axial section.

4. *Endothyra* sp. AP-36, X70, oblique section.

5. *Endothyra* sp. AP-36, X70, equatorial section.

6. *Endothyra* sp. AP-37, X70, axial section.

7. *Endothyra* sp. AP-42, X70, equatorial section.

8. *Earlandia* sp. AP-24, X70, axial section.

9. *Lugtonia monilis ?* (Malakhova, 1955) AP-31, X70, axial section.

10. *Lugtonia monilis* (Malakhova, 1955) AP-42, X70, axial section.

11. *Lugtonia monilis* (Malakhova, 1955) AP-62, X70, axial section.

12. *Lugtonia monilis* (Malakhova, 1955) AP-64, X70, axial section.

PLATE I

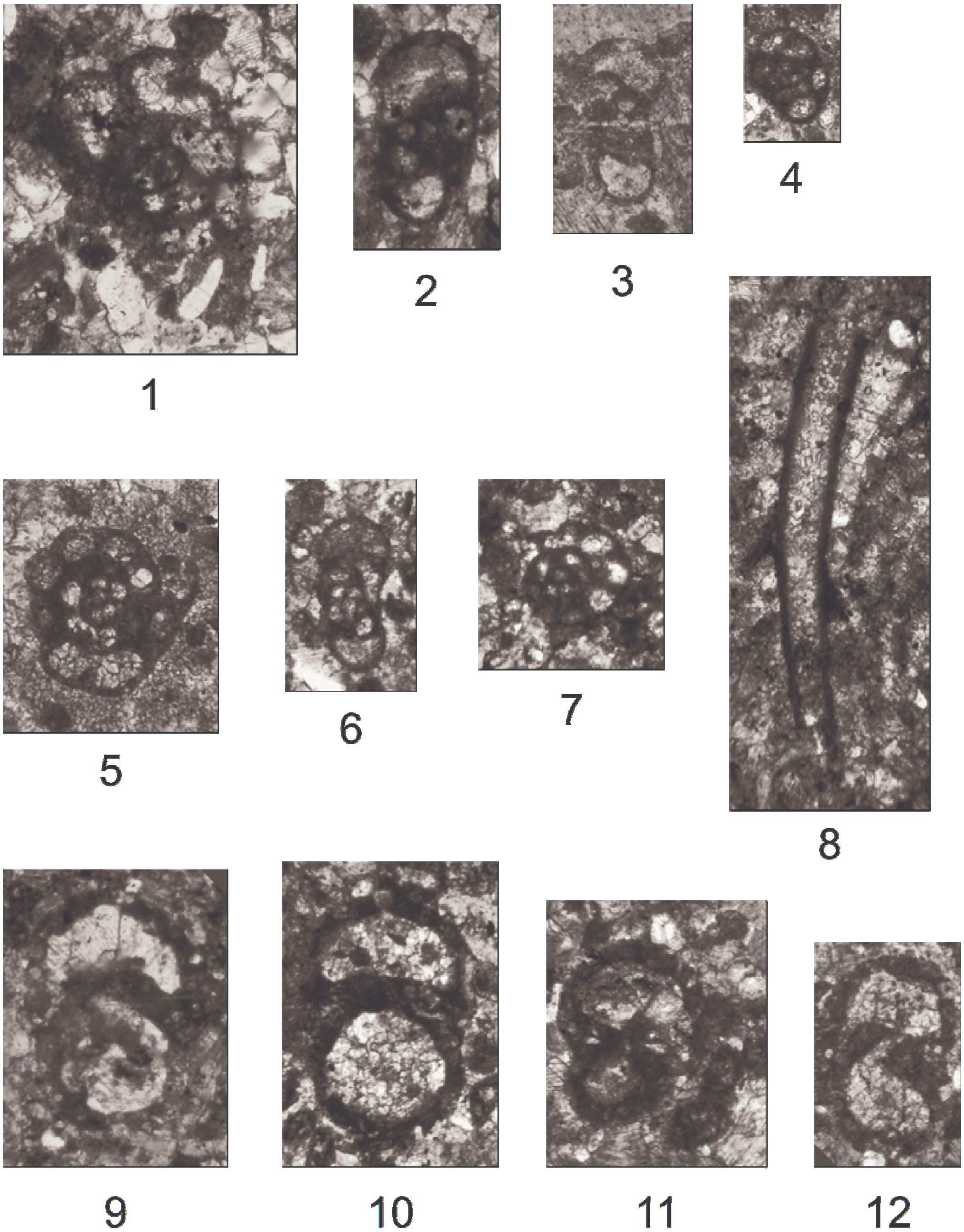


PLATE II

Figures

1. *Eoparastaffella* (morphotype 1) ? AP-36, X70, axial section.

2. *Eoparastaffella* (morphotype 1) sp. AP-40, X70, axial section.

3. *Eoparastaffella* (morphotype 1) sp. AP-40, X70, axial section.

4. *Eoparastaffella* (morphotype 1) sp. AP-54, X70, axial section.

5. *Eoparastaffella* (morphotype 1) sp. AP-55, X70, axial section.

6. *Eoparastaffella* (morphotype 1) sp. AP-55, X70, axial section.

7. *Eoparastaffella* (morphotype 1) sp. AP-64, X70, axial section.

8. *Eoparastaffella* (morphotype 1) sp. AP-64, X70, axial section.

9. *Eoparastaffella* (morphotype 1) sp. A-67, X70, axial section.

10. *Eoparastaffella subglobosa* ? AP-69, X70, axial section.

11. *Eoparastaffella simplex* (Vdovenko, 1964) (morphotype 2) AP-60, X70, axial sc.

12. *Eoparastafella simplex* ? (Vdovenko, 1964) AP-65, X70, axial section.

13. *Eoparastaffella simplex* ? (Vdovenko, 1964) AP-71, X70, axial section.

14. *Eoparastaffella simplex* ? (Vdovenko, 1964) AP-72, X70, axial section.

15. *Inflatoendothyra* sp. AP-36, X70, equatorial section.

16. *Inflatoendothyra* sp. AP-36, X70, equatorial section.

17. *Inflatoendothyra* sp. AP-37, X70, equatorial section.

18. *Inflatoendothyra* sp. AP-37, X70, axial section.

19. *Inflatoendothyra* sp. AP-40, X70, equatorial section.

20. *Inflatoendothyra* sp. AP-40, X70, equatorial section.

21. *Inflatoendothyra* sp. AP-64, X70, equatorial section.

PLATE II

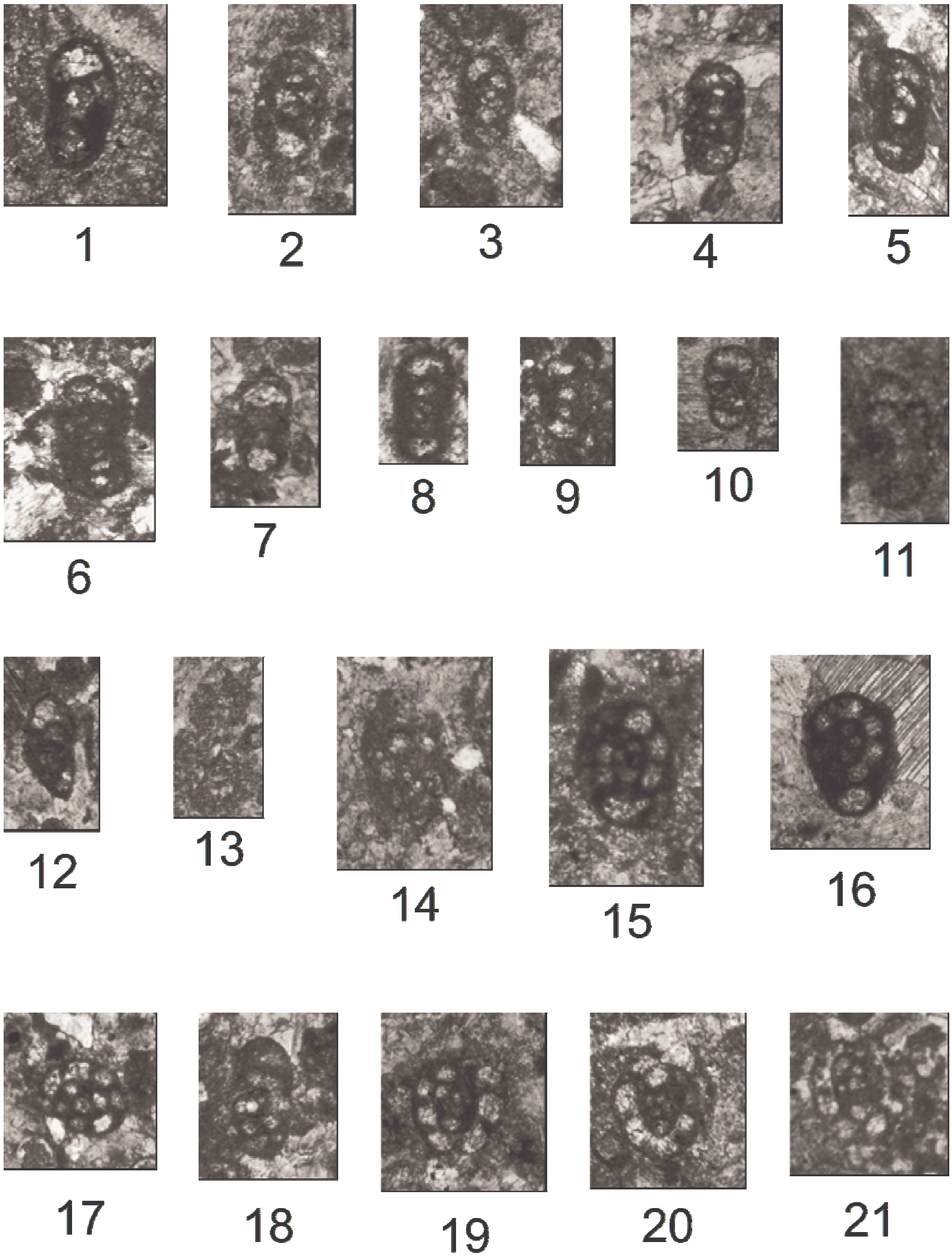


PLATE III

Figures

1. *Inflatoendothyra inflata* (Lipina, 1955) AP-39, X70, equatorial section.

2. *Inflatoendothyra inflata* (Lipina, 1955) AP-55, X70, nearly equatorial section.

3. *Inflatoendothyra inflata* (Lipina, 1955) AP-65, X70, nearly equatorial section.

4. *Septaforschia* ? sp. AP-36, X70, oblique section.

5. *Septaforschia* ? sp. AP-40, X70, oblique section.

6. Dainellid foraminifera AP-40, X70, oblique section.

7. *Dainella staffelloides* AP-73, X70, oblique section.

8. *Eotextularia diversa* (N. Tchernysheva, 1948) AP-40, X70, axial section.

9. *Eotextularia diversa* (N. Tchernysheva, 1948) AP-42, X70, axial section.

10. *Eotextularia diversa* (N. Tchernysheva, 1948) AP-42, X70, axial section.

11. *Eotextularia diversa* (N. Tchernysheva, 1948) AP-42, X70, axial section.

12. *Eotextularia diversa* (N. Tchernysheva, 1948) AP-55, X70, axial section.

13. *Septabrunsiina* sp. AP-42, X70, oblique section.

PLATE III

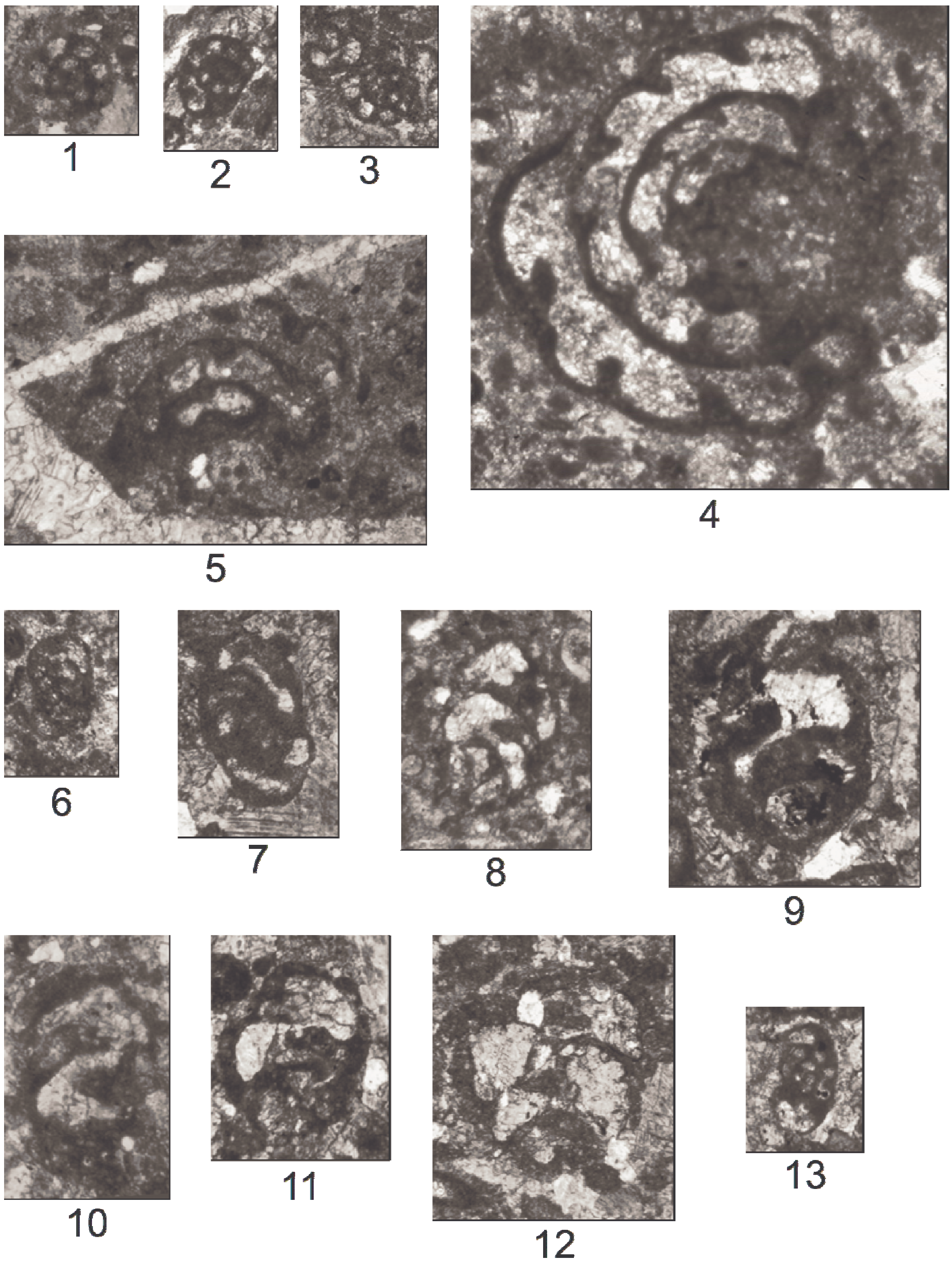


PLATE IV

Figures

1. *Latiendothyranopsis* sp. AP-42, X70, oblique section.

2. *Latiendothyranopsis* sp. AP-55, X70, axial section.

3. *Latiendothyranopsis* sp. AP-56, X70, oblique section.

4. *Latiendothyranopsis* sp. AP-58, X70, equatorial section.

5. *Latiendothyranopsis* sp. AP-59, X70, equatorial section.

6. *Latiendothyronopsis* sp. AP-60, X70, equatorial section.

7. *Latiendothyranopsis* sp. AP-60, X70, equatorial section.

8. *Latiendothyranopsis* sp AP-62, X70, axial section.

9. *Latiendothyranopsis* sp. AP-58, X70, oblique section.

10. *Latiendothyranopsis* sp. AP-62, X70, axial section.

PLATE IV

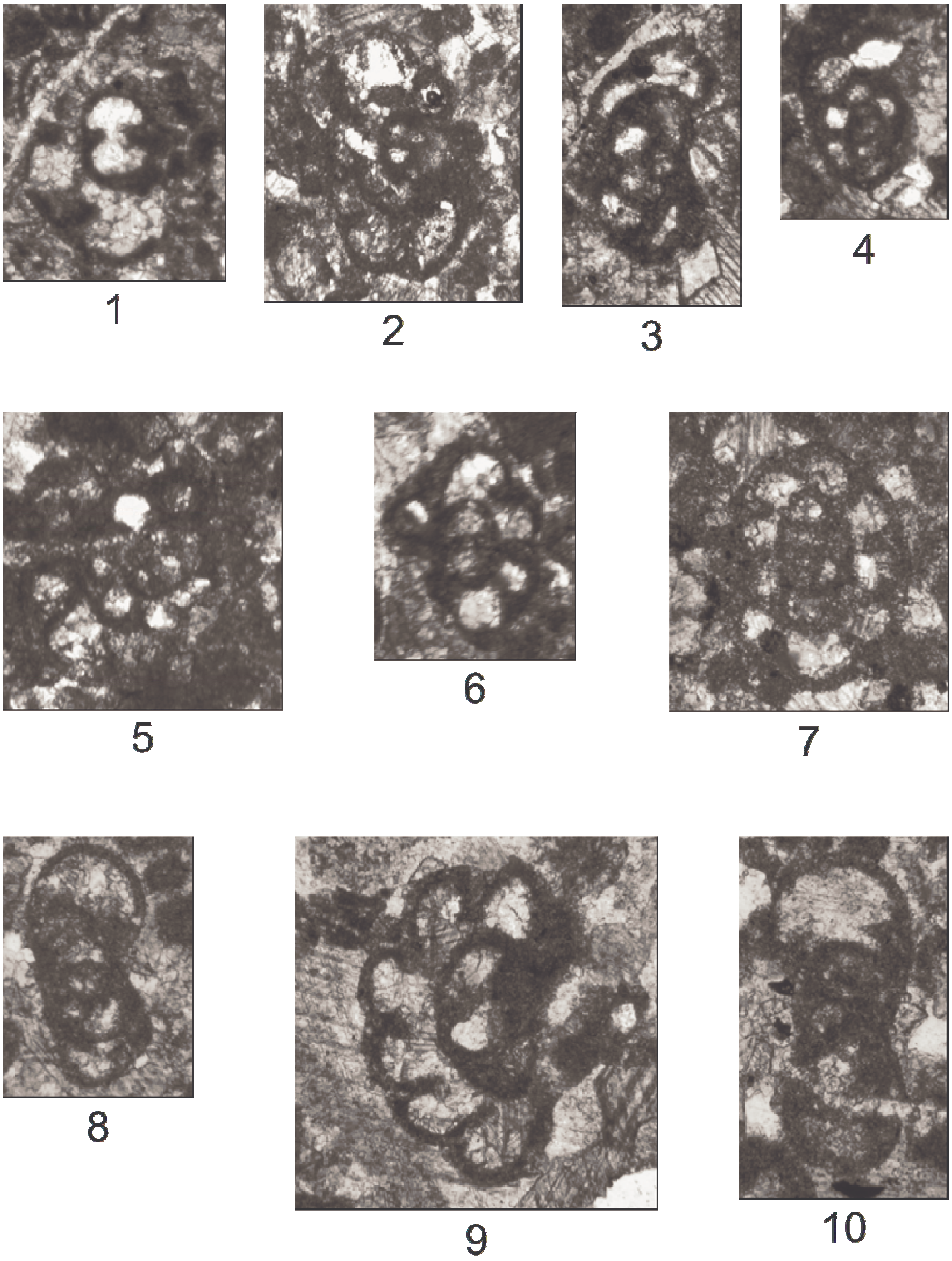


PLATE V

Figures

1. *Latiendothyranopsis* sp AP-62, X70, nearly axial section.

2. *Latiendothyranopsis* sp. AP-62, X70, nearly equatorial section.

3. *Eoforschia moelleri* (Malakhova, 1953) AP-54, X70, oblique section.

4. *Eoforschia moelleri* (Malakhova, 1953) AP- 54, X70, axial section.

5. *Eoforschia moelleri* (Malakhova, 1953) AP-54, X70, equatorial section.

6. *Omphalotis* ? sp. AP-56, X70, oblique section.

7. *Omphalotis* ? sp. AP-62, X70, nearly axial section.

8. *Mediocris* ? sp. AP-67, X70, axial section.

9. *Endospiroplectammina venusta* (Vdovenko, 1954) AP-54, X70, equatorial section.

10. *Laxoendothyra* sp. AP-58, X70, equatorial section.

11. *Laxaendothyra* ? sp. AP-60, X70, equatorial section.

PLATE V

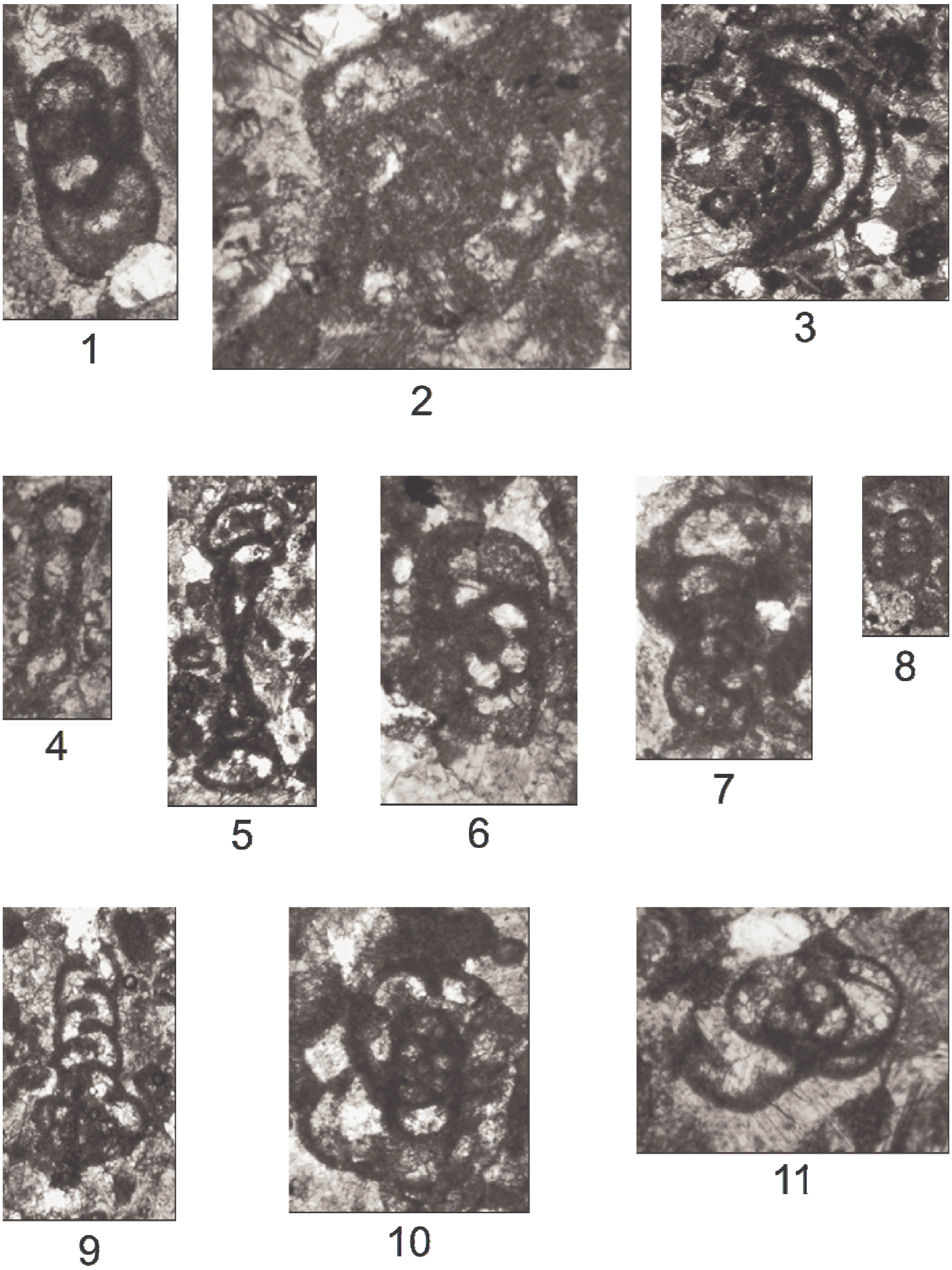


PLATE VI

Figures

1. *Laxaendothyra* ex. gr. *laxa* sp. AP-58, X70, axial section.

2. *Laxoendothyra* ex. gr. *laxa* sp. AP-65, X70, equatorial section.

3. *Bessiella* sp. AP-61, X70, nearly equatorial section.

4. *Urbanella* ? sp. AP-65, X70, axial section.

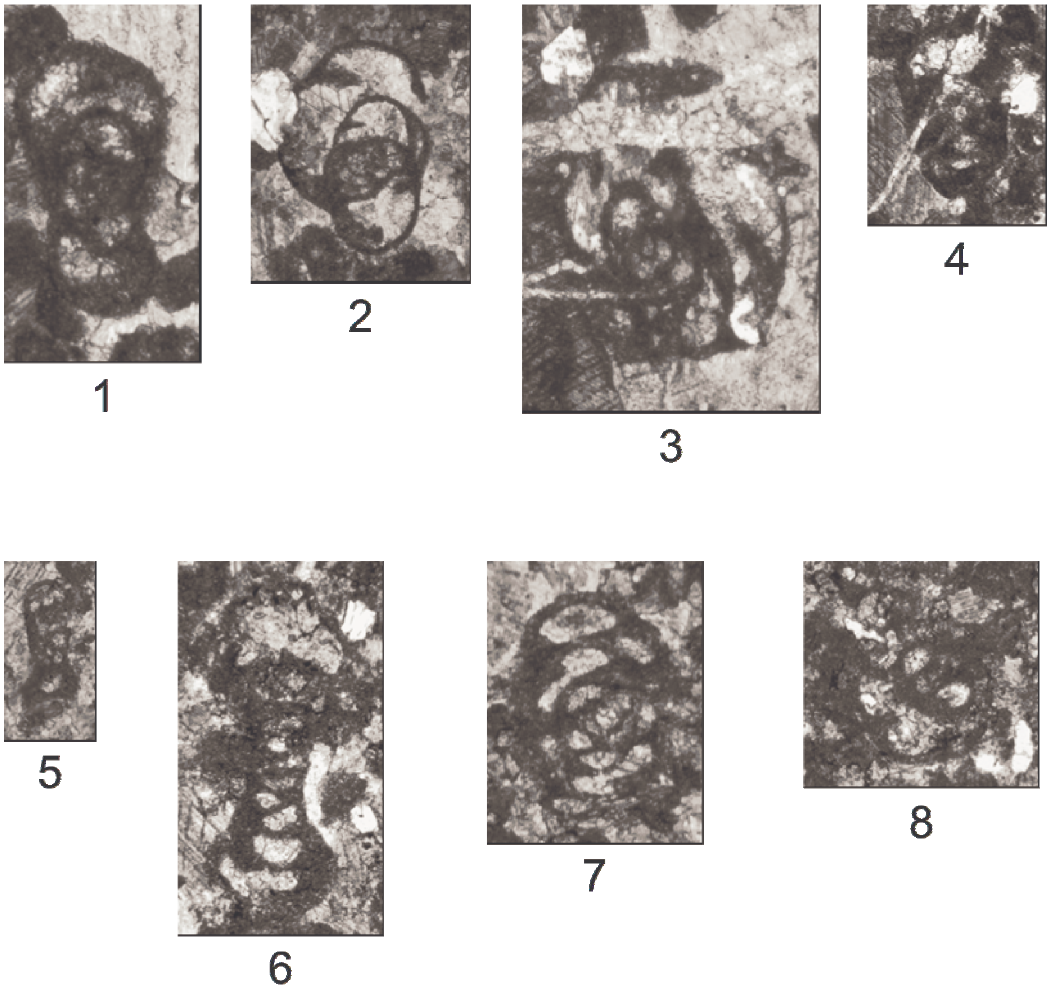
5. *Eoendothyranopsis* ? sp. AP-68, X70, axial section.

6. Tournayellid foraminifera AP-72, X70, axial section.

7. *Globoendothyra* sp. AP-72, X70, axial section.

8. *Plectogyranopsis* sp. AP-72, X70, oblique section.

PLATE VI



APPENDIX B

Number of Benthic Foraminifera counted in section AP

Sample No	Number of Foraminifera
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	1
20	0
21	5
22	0
23	0
24	2
25	0
26	3
27	0
28	0
29	0
30	12
31	0
32	21
33	3
34	0
35	16
36	47

Sample No	Number of Foraminifera
37	66
38	0
39	30
40	55
41	8
42	93
43	3
44	1
45	3
46	0
47	0
48	0
49	2
50	0
51	0
52	1
53	1
54	51
55	67
56	11
57	6
58	95
59	23
60	41
61	30
62	41
63	2
64	64
65	76
66	80
67	53
68	15
69	76
70	55
71	50
72	58
73	32

Dimensions and e/r ratio of selected *Eoparastaffella* sp.			
	e (µm)	r (µm)	e/r
Eoparastaffella sp. (morphotype 1) Sample 40	31	92	0.36
Eoparastaffella sp. (morphotype 1) Sample 40	23	71	0.31
Eoparastaffella sp. (morphotype 1) Sample 55	20	83	0.24
Eoparastaffella simplex (Vdovenko, 1964) (morphotype 2) Sample 60	75	120	0.625
Eoparastaffella sp. (morphotype 1) Sample 64	20	75	0.27
Eoparastaffella simplex (Vdovenko, 1964) (morphotype 2) Sample 65	55	76	0.71
Eoparastaffella simplex (Vdovenko, 1964) (morphotype 2) Sample 71	76	148	0.51