STAGE BOUNDARIES IN THE MISSISSIPIAN OF TAURIDES BASED ON CONODONT DATA: STATISTICAL ANALYSIS TAXONOMY AND BIOSTRATIGRAPHY

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ABSTRACT

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Conodonts are important biostratigraphic tools for the delineation and calibration of the geochronological boundaries within the Carboniferous and used generally as stage-boundary markers for the Lower Carboniferous (Mississippian). The studied successions in the Central and Eastern Taurides were mainly deposited in a shallow marine environment during the Carboniferous time and they comprise less abundant and diversified conodont fauna. The conodont fauna represented by twenty-four species belonging to ten genera have been described from the studied sections (AS; AAO; BSE and HB) in the Taurides (Turkey). Regarding the first occurrences and last occurrences of biostratigraphically significant species within these sections, the following zones have been established across the Lower Carboniferous successions: (1) *Polygnathus inornatus* Zone (Hastarian-Lower Tournaisian); (2) *Gnathodus cuneiformis – Polygnathus communis communis* Zone (Ivorian-Upper Tournaisian); (3) *Polygnathus mehli mehli* Zone (Ivorian-Upper Tournaisian); (4) *Gnathodus girtyi girtyi* Zone (Brigantian-Upper Visean); (5) *Gnathodus girtyi simplex* Zone (Pendelian-Lower Serpukhovian); (6) *Rhachistognathus muricatus* Zone (Zapaltyubinsky-Upper Serpukhovian) and (7) *Declinognathodus inaequalis - Declinognathodus noduliferus* Zone (Bogdanovsky-Lower Bashkirian). Based on the recovered conodont assemblages, Visean - Serpukhovian boundary has been recognized by the first occurrence of *Gnathodus girtyi simplex* and the Mid-Carboniferous boundary is delineated by the first occurrence of *Declinognathodus inaequalis,* which is an index taxon for the basal part of the Bashkirian. Based on the microfacies studies it can be concluded that conodont elements essentially obtained from the crinoidal bioclastic packstone-grainstone, crinoidal packstone-grainstone, coated bioclastic grainstone, intraclastic grainstone and spiculite packstone facies in the studied sections. It can be concluded that the occurrence of abundant crinoids are indicative criteria for the presence of conodonts. Additionally, geometric morphometric analyses of biostratigraphically important genus, *Gnathodus,* on the basis of data available in the literature emphasize the importance of numerical taxonomy and reveal that taxonomic revision of this genus is needed.

Keywords: Taurides, conodonts, Lower Carboniferous, biostraigraphy, geometric morphometrics

ÖZ

KONODONTLAR İLE TOROSLARDA MISSISSIPIYEN KAT SINIRLARI : İSTATİSTİKSEL ANALİZ, TAKSONOMY VE BİYOSTRATİGRAFİ

Özdemir, Ayşe
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Konodontlar Karbonifer'e ait kat sınırlarının tanımlanmasında ve belirlenmesinde önemli bir rol oynamakta ve genellikle Alt Karbonifer (Missisipiyen) Kat sınırlarında belirleyici olarak kullanılmaktadır. Orta ve Doğu Toroslarda çalışılan istifler Karbonifer zamanında genellikle sığ denizel ortamlarda çökelmiştir ve az sayıda ve çeşitlilikte konodont faunası içermektedir. Çalışılan kesitlerde (AS; AAO; BSE ve HB) 10 konodont cinsine ait 24 tür belirlenmiştir. Bu türlerin kesitlerde ilk ortaya çıkış ve yok oluşlarına göre, Alt Karbonifer istiflerinde yedi biyozon belirlenmiştir; (1) *Polygnathus inornatus* Zonu (Hastariyen-Alt Turneziyen); (2) *Gnathodus cuneiformis - Polygnathus communis communis* Zonu (İvoriyen-Üst Turneziyen); (3) *Polygnathus mehli mehli* Zonu (İvoriyen-Üst Turneziyen); (4) *Gnathodus girtyi girtyi* Zonu

(Brigantiyen-Üst Vizeyen); (5) *Gnathodus girtyi simplex* Zonu (Pendeliyen-Alt Serpukhoviyen); (6) *Rhachistognathus muricatus* Zone (Zapaltyubinski-Üst Serpukhoviyen) ve (7) *Declinognathodus inaequalis - Declinognathodus noduliferus* Zonu (Bogdanovski-Alt Başkiriyen). Elde edilen konodont topluluklarına dayanılarak, Vizeyen – Serpukhoviyen sınırı *Gnathodus girtyi simplex* türünün, orta Karbonifer sınırı ise Başkiriyen'in tabanı için indeks olan *Declinognathodus inaequalis* türünün ilk ortaya çıkışı ile belirlenmiştir. Mikrofasiyes çalışmaları sonucunda, konodont elementlerinin çoğunlukla krinoidal biyoklastik istiftaşı-tanetaşı, krinoidal istiftaşı-tanetaşı, sarılımlı biyoklastik tanetaşı, intraklastik tanetaşı and spikülitik istiftaşı fasiyeslerinden elde edildiği ortaya konulmuş ve krinoid bolluğunun konodont varlığı için önemli bir gösterge olduğu belirlenmiştir. Ayrıca, biyostratigrafik olarak önemli olan *Gnathodus* cinsinin literatür verileri kullanılarak uygulanan geometrik morphometrik analizleri sayısal sınıflandırmanın önemini vurgulamış ve bu cins için bir taksonomik revizyonun gerekliliğini ortaya koymuştur.

Anahtar Kelimeler: Toroslar, konodont, Alt Karbonifer, biyostratigrafi, geometrik morfometri

To my father

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INTRODUCTION

1.1 Purpose and Scope

Today, most of the multidisciplinary studies in an international platform have been carried out on the delineation of stage boundaries. Typically, a stage is defined by a consistent set of fossils in the rock (biostratigraphy). Different fossil groups primarily index microfossils that are abundant, geographically widespread, easily recognized, and having short stratigraphic range are studied to construct the biostratigraphic framework. Subcommission on Carboniferous Stratigraphy (SCCS) task groups are actively concentrating on different biostratigraphic schemes useful for delineating stage boundaries of the Carboniferous System. Conodonts are one of the most important fossil groups for biostratigraphic studies in Paleozoic and Triassic marine deposits. They are resistant microfossils owing to their small size and calcium phosphate composition.

In the same manner, the primary objective of this study is to delinate the Lower Carboniferous stage boundaries. In order to achieve the main aim, multidisciplinary approach has been necessary. Conodonts are the main tool used in this study for delinating the boundaries. A detailed taxonomical analysis including morphometric, microfacies and geochemical analysis have been carried out through samples collected from the Lower Carboniferous carbonates in Taurides, Turkey. Since the Aladağ Unit and the Geyik Dağı Unit include a continuous Paleozoic carbonate sequence and the best preserved Lower Carboniferous boundary succession is exposed in the Hadim, Bademli (Central Taurides), Melikgazi (Pınarbaşı) and Sarız (Eastern Taurides) regions, ten stratigraphic sections have been measured and sampled from these units.

Evaluation of the conodont fauna provided a basis for defining the boundaries between the Kinderhookian and Osagean, Visean and Serpukhovian, Serpukhovian and Bashkirian in Taurides. Moreover, this study aims to correlate the established zonation with previously published ones from the other localities in the world and to improve biostratigraphic resolution for Lower Carboniferous stage boundaries.

The biologic content of the rocks varied throughout time as the presence and absence of specific taxa in deposits. The presence-absence data are used to provide information about the paleoenvironmental conditions and the relationships between the forms as well. Conodont faunal variations in Paleozoic to Triassic marine deposits are generally environmentally controlled. Some conodonts were limited to shallow water environments, others to deep waters, and some forms occur in both environments. Within the context of paleoenvironmental interpretations, different microfacies types could be determined by microfacies criteria reflecting patterns of the depositional environments. The types of microfacies and their environmental interpretations can provide a framework for conodont paleoecology. Other objectives of this study are to display types of microfacies, the depositional environments and discuss the relationship between the species of conodont taxa and microfacies types. The conodont-microfacies relationships are discussed in terms of facies and their conodont contents.

Recently, there has been a growing amount of interest in statistical analysis such as morphometric and cladistic that defines the phylogenetic relationships have major significance in the delineation of the stage boundaries (Murphy and Cebecioglu, 1987; Croll et al., 1982, Klapper and Foster, 1986, 1993; Renaud and Girard, 1999; Sloan 2000, Girard et al., 2004; Jones and Purnell, 2007; Jones, 2009). Conodonts are already well-known as paramount tool for biostratigraphic analysis, but the application of new analytical methods should yield significant scientific rewards as, at present, poorly understood cryptic variations in Lower Carboniferous taxa blurs taxonomic boundaries and obscures variations that may have biostratigraphic significance. Quantitative techniques have potential to overcome these problems. The results have also potential to reveal new information regarding conodont evolutionary history. The one of the purposes of this study is to carry out outline-based geometric morphometric analysis in order to define size distributions and taxonomy and species recognition of biostratigraphically important conodont taxa, *Gnathodus* widely distributed in the successions of the Mississippian age. P_1 element of *Gnathodus* illustrates different morphological features, so it is very suitable for quantitative analysis.

In addition to the biostratigraphic, microfacies and morphometric analysis, geochemical studies are carried out for the determination of paleoenvironmental changes across the stage boundaries. Paleoenvironmental interpretations can be done by the results of the stable isotopes; $\delta^{13}C$, $\delta^{18}O$ and radiogenic; $^{87}Sr/^{86}Sr$ isotope ratios. The final objective of this study is to interpret the results of geochemical analysis of the Lower Carboniferous stage boundaries in Taurides, Turkey and to make a global correlation of these results.

Furthermore, in this study a broad taxonomical work including morphological descriptions, stratigraphical distributions and abundances of conodont elements is also presented. Concisely, this study sheds new light to the understanding of the paleogeographical and stratigraphical configuration of the studied areas for the Early Carboniferous Epoch.

1.2 Geographic Setting

This study has been carried out in four different regions located in the Central and Eastern Taurides including characteristic features of Tauride belt and comprising continuous and largely exposed Lower Carboniferous limestone deposits (Figure 1.1). A total of ten stratigraphic sections have been measured and sampled from these regions. Two studied areas are located in the Hadim and Bademli regions in the Central Taurides. The first studied area is placed in the southwest of the town of Hadim, Konya (Figure 1.1). Two stratigraphic sections (AN- and AAO-sections) from Tournaisian deposits have been measured and sampled in the Hadim region. Additionally, AP-section (Tournaisian - Visean) previously studied by Peynircioğlu (2005) and Özkan-Altıner et al. (2007) and HB-section (Mid-Carboniferous) studied by Atakul (2006) have been resampled for conodont biostratigraphy. The sections in the Hadim region are situated in the topographic map of Alanya O 28-b2 of 1:25.000 scales. The AN, AAO and AP sections are located along the road cut in the Hadim - Alanya highway. The HB section is situated at about 10 km southwest of the town of Hadim. The second studied area is in the Bademli region. Previously studied BT section (Özkan-Altıner et al. 2007) has been resampled for conodont biostratigraphy and two new stratigraphic (BS and BSE) sections have been measured to delineate the Visean - Serpukhovian boundary. These sections are located in the Konya N27-a3 of 1:25.000 scales.

Figure 1.1. Location map of the study areas (Red rectangles indicate the study areas).

The third and fourth studied areas are in the Eastern Taurides, located in the Melikgazi and Sarız regions. The Melikgazi region is located at approximately 20 km northwest of Pınarbaşı, one of the towns of the city of Kayseri. The sections of MT (Tournaisian - Visean) and SC (Visean - Serpukhovian) studied previously by Özkan-Altıner et al. (2007) and Demirel (2012) respectively in the Melikgazi region are situated in the topographic map of Elbistan K36-d2 of 1:25.000 scales. The last section, AS, was measured in the Sarız region in order to identify the conodont assemblages and to completely describe the conodont fauna of Upper Tournaisian. This section is located in the topographic map of Elbistan K36-c3 of 1:25.000 scales. All detailed information on the stratigraphic sections including GPS coordinates, thicknesses, numbers of samples are given in Table 1.1.

Table 1.1. GPS coordinates of the starting and ending points of the all stratigraphic sections.

Section	**Locality**	**Topographic Map (1/25.000)**	**Starting Position**	**Ending Position**
AN	Hadim	Alanya O28-b2	446675 E 4085698 N	446586 E 4085668 N
AAO	Hadim		446586 E 4085670 N	446568E 4085662 N
AP	Hadim		446550 E 4085656 N	446554 E 4085630 N
HB	Hadim		445144 E 4085730 N	445160 E 4085675 N
BT	Bademli	Konya N27-a3	387607 E 4129246 N	387608 E 4129329 N
BS	Bademli		387278 E 4129024 N	387265 E 4129040 N
BSE	Bademli		387346 E 4129171 N	387334 E 4129285 N
MT	Melikgazi	Elbistan K36-d2	256790 E 4291586 N	256807 E 4291564 N
SC	Melikgazi		256922 E 4291666 N	257386 E 4291768 N
AS	Sarız	Elbistan K36-c3	277211 E 4264540 N	277127 E 4264592 N

1.3 Methods of Study

The methods that are utilized in this thesis are grouped into three parts: detailed literature survey, field and laboratory studies. In order to interpret biostratigraphical, microfacies, morphometric and geochemical outcomes across the Lower Carboniferous stage boundaries, all the published and unpublished works related to the subject have been compiled. Moreover, detailed literature review has been carried out on the taxonomy, biostratigraphy and paleoecology of conodonts.

Field studies have been performed in order to delineate and interpret the environmental changes across the Lower Carboniferous boundaries in Taurides, Turkey. A total of ten sections have been measured and resampled. During the fieldwork, the microfacies and faunal content of each sample were described by a hand-lens in order to detect and control the facies changes. The stratigraphic sections have been measured and sampled in Carboniferous deposits of the Aladağ Unit in Yarıcak Yayla (Hadim-Taşkent), Bademli (Akseki) in the Central Taurides and Melikgazi (Pınarbaşı) and Sarız in the Eastern Taurides. To delineate Tournaisian - Visean boundary and document the conodont assemblages of Late Tournaisian, six stratigraphic sections have been sampled in Taurides. Three of these sections (AP, BT and MT) were studied previously by Peynircioğlu (2005) and Özkan-Altıner et al. (2007) and were resampled for conodont biostratigraphy. Three new sections (AN, AAO and AS) have been measured and sampled in this study. Additionally, for Visean - Serpukhovian boundary, three sections (BS, BSE and SC) have been measured in the Bademli and Melikgazi (Pınarbaşı) regions. Moreover, during this study a previously studied Mid-Carboniferous boundary section (HB) has been resampled for conodont biostratigraphy. A total of 144 samples were collected for microfacies and microplaeontological studies from all these sections. Each sample weighs approximately 2 to 3 kg.

During the laboratory studies, detailed microfacies and microplaeontological studies were carried out and thin sections were prepared from each sample for petrographic and paleontological analysis. Different microfacies types have been determined by the analysis of bioclastic components, and sedimentological features observed in thin sections based on Flügel (2004).

In order to extract conodont elements from the samples, the different processing techniques have been tested. The samples were broken into small pieces and approximately 1-2 kg of each sample was used to extract conodont elements. Number and preservation of isolated conodont elements gathered from the samples are strongly influenced by the extraction method; particularly, the acid type, percentage of acid solution, duration of process and choice of buffering (Jeppsson et al., 1999). Consequently, different techniques have been applied to samples and all these extraction techniques and their results are discussed in Micropaleontology Chapter (Chapter 7).

Additionally, conodonts have an important role to clarify the base of the vertebrate clade so utilizing conodont taxonomy is very critical and necessary. However, it is often challenging since species are defined just based on partial skeletal elements displaying wide-ranging morphological variation. This problem necessitates the application of morphometric analysis. Two outline-based geometric morphometric methods (Elliptical Fourier Analysis and Eigenshape Analysis) have been applied to analyse the taxonomy of biostratigraphically important conodont genus *Gnathodus*. The images of the specimens were obtained from the literature and their outlines have been digitized by using tps-util software (Rohlf 2004). Then, the obtained coordinates have been used to carry out outline-based morphometric analysis. In detail, morphometric methods and their results are discussed in Morphometrics Chapter (Chapter 5).

Besides all these laboratory studies, in order to detect the geochemical changes across the Lower Carboniferous stage boundaries geochemical analysis ($\delta^{13}C$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$) have been performed in the laboratories of Earth and Ocean Sciences of University of British Columbia (PCIGR). Their results are discussed in Geochemistry Chapter (Chapter 6).

1.4 Previous Works

1.4.1 Previous Works about the Tauride Belt

Considered as an important branch of the Alpine-Himalayan Orogenic Belt (Şengör and Yılmaz, 1981), the Taurides in Turkey has been examined by many researchers in various geological studies for different purposes over the last century.

The earliest studies concerning the geology of the Tauride Belt have been performed by Blumenthal (1944, 1947, 1951 and 1956). These earliest studies were about the general geologic and geomorphologic structures of Seydişehir - Beyşehir region and the Aladağ Unit exposed around Beyşehir - Bozkır and northern Alanya region in western Taurides. Following the studies of Blumenthal, numerous geological studies regarding the geodynamic evolution, geology and stratigraphy of the Tauride Belt have been carried out (e.g., Brunn et al., 1971, Özgül, 1971, 1976, 1984, 1997; Özgül et al., 1973, 1991; Özgül and Gedik, 1973, Monod, 1977, Gutnic et al., 1979, Monod and Akay, 1984, Özgül and Turşucu, 1984). Brunn et al. (1971), Monod (1977), Gutnic et al. (1979) and Monod and Akay (1984) studied the detailed geology, stratigraphy of Taurides and the evolution of Tauride Carbonate Platform. Brunn et al. (1971) concentrated mainly on the geology of the

Western Taurides and described also the Eastern Lycian Nappes around the Korkuteli region.

The Tauride Belt comprises several tectono-stratigraphic units (Blumenthal, 1947, 1951; Özgül, 1976, 1984, 1997; Şengör and Yılmaz, 1981; Göncüoğlu, 1997; Şenel, 1999; Mackintosh and Robertson, 2012). Most detailed classification of these units was suggested by Özgül (1976, 1984). These are Geyik Dağı (autochthonous-parautochthonous unit), Aladağ, Bolkar Dağı, Bozkır, Antalya and Alanya Units (allochthonous units) (Özgül 1984). Some researchers considered allochthonous units as “nappes” (Blumenthal, 1944, Brunn et al., 1971, Monod, 1977, Gutnic et al., 1979). The Aladağ Unit of Özgül (1984) had been named as Hadim Nappe in Blumenthal (1944). Şenel (1999) defined different autochthonous-parautochthonous and allochthonous units in Taurides. The autochthonous units are named as Beydağları autochthon, Anamas-Akseki autochthon and Southeast Anatolian autochthon. The allochthonous units are called as the Lycian Nappes, Antalya Nappes, Alanya Nappe, Beyşehir-Hoyran-Hadim-Bolkar Nappes, Yahyalı-Munzur Nappes and Bitlis-Pötürge-Malatya Nappes.

Within these tectonostratigraphic units, the Aladağ and Geyik Dağı Units are the main concern of this study since they contain in their stratigraphy well-developed Paleozoic carbonate sequences.

Regarding the stratigraphy and geodynamic evolution of Aladağ Unit in Central Taurides, main crucial studies were carried out by Özgül (1971, 1976, 1984, 1997), Özgül and Gedik (1973), Monod (1977), Gutnic et al. (1979), Tekeli (1980), Demirtaşlı (1984), Özgül et. al. (1991), Altıner and Özgül (2001), Göncüoğlu et al. (2007) and Mackintosh and Robertson (2012). Özgül (1971) performed very detailed study concerning the structural evolution of the Central Taurides. Two autocthonous (Hadim and Geyikdağı) and two allochthonous (South Central Anatolia and Central Taurus) units have been described in this study. Later, Özgül (1976) described different tectonostratigraphic units in the Tauride Belt. He defined the Aladağ Unit including the Upper Devonian - Upper Cretaceous shelf type clastics and carbonates. This study has become principle guide for other researchers. Monod (1977) and Gutnic et al. (1979) described the Paleozoic mainly Carboniferous units of Bademli region. Monod (1977) named the Paleozoic - Mesozoic rock units of Beyşehir Hoyran Nappes as “Bademli-Cevizli Unit” and thoroughly mapped the Bademli region. In this study, Carboniferous deposits of this unit were described as limestone and quartz arenitic sandstone intercalations and dolomites. According to Gutnic et al. (1979), Carboniferous units are composed of shales at the base and continue with carbonate deposits towards the upper part. Like Monod (1977), this study also defined the Visean - Namurian deposits as alternations of carbonates and quartz arenitic sandstones and dolomites. Tekeli (1980) studied the structural evolution of Aladağ Mountains in the Taurus Belt in detail. Özgül (1984) described the Carboniferous deposits of the Aladağ Unit in terms of the stratigraphy and tectonic evolution of the Central Taurides. Demirtaşlı (1984) presented the Paleozoic stratigraphy and tectonics of the Hadim Nappe (Aladağ Unit) in the Central Taurides. Özgül (1997) described the main tectonic units exposed in the Hadim-Taşkent region (Central Taurides) and presented the details of the formations within the Aladağ Unit. The distinguished formations from bottom to top are Gölboğazı Formation (Devonian), Yarıcak Formation (Carboniferous), Çekiç Dağı Formation (Permian), Gevne Formation (Triassic), Çambaşı Formation (Jurassic – Cretaceous) and Zekeriya Formation (Maastricthian). The Carboniferous Yarıcak Formation which is the main interest in this study has been divided into two members, Çityayla Member and Mantar Tepe Member. Göncüoğlu et al. (2007) examined the Missippian deposits in Central and Eastern Taurides. He described the Aladağ Unit in the

Hadim region as quartzarenitic sandstone and limestone alternations indicating coastal to shallow marine environments. Mackintosh and Robertson (2012) focused on Late Devonian - Late Triassic sedimentary development of the Central Taurides. Aladağ Unit of Özgül (1976) was described as Hadim Nappe in this study. Mackintosh and Robertson (2012) thoroughly examined the Carboniferous deposits of Hadim Nappe in Bademli and Hadim regions. The studied succession in Bademli region was characterized by Tournaisian - Visean age Bademli Shales comprising dark shales with locally interbeds of quartzarenitic sandstone and limestones, Late Visean - Early Serpukhovian Bademli Limestone including bioclastic grainstones packstones to mictitic limestones interbedded with the oolitic limestones and quartzarenitic sandstones and Serpukhovian - Bashkirian Dolomite Unit represented by thick bedded crystalline dolomites (Mackintosh and Robertson, 2012). The succession in Hadim region begins with Tournaisian age shale with interbeds of limestone and quartzarenitic sandstones and continues with Visean age shale, limestone, sandy limestone and sandstone interclations and the Serpukhovian to Moscovian age quartzarenitic sandstone and limestones (Mackintosh and Robertson, 2012).

The geology, stratigraphy and petroleum potential of the Paleozoic successions in the Eastern Taurides were the subject of numerous studies. Demirtaşlı (1967), Özgül et al. (1973), Metin et al. (1982), Metin (1983), Tutkun (1984) and Göncüoğlu et al. (2004a) studied and described the stratigraphic units in Pınarbaşı - Sarız - Tufanbeyli - Saimbeyli regions and classified them based on the geological and structural features. Altıner (1981) studied the geology, stratigraphy and biostratigraphy of the vicinity of Aygörmez Dağı, Pınarbaşı, Kayseri. He mapped the area and depicted three units namely parautocthonous Aygörmez Dağı Unit, allochthonous Ophiolitic Unit and Kocagedik Unit and the sedimentary unit covering the allochthonous deposits. Altıner

(1981) described Visean - Gzhelian aged Aziziye Gediği and Oruçoğlu formations comprising limestones and sandstones. Tekeli et al. (1984) described the Upper Paleozoic rocks composed of shallow marine platform carbonates and terrigenous clastics of the Aladağ Unit in Eastern Taurides. They defined the Lower Carboniferous deposits in Yahyalı Group, Siyah Aladağ Formation and Nohutluk Formation by the presence of foraminifers, brachiopods and algae. Bozkaya and Yalçın (1998) also investigated the Paleozoic successions of autochthonous and allochthonous units in the area around Tufanbeyli, Saimbeyli, Feke and Göksun regions.

A recent review of the statigraphy of the Geyik Dağı Unit in Eastern Taurides was given by Göncüoğlu and Kozlu (2000) and Göncüoğlu et al. (2004a). Göncüoğlu and Kozlu (2000) carried out an essential study about the early Paleozoic evolution of northwest of Gondwana based on the geologic data produced from the southern part of Turkey. On the basis of field observations, published and unpublished studies a revised stratigraphy of the Geyik Dağı Unit in the Eastern Taurides has been given by Göncüoğlu et al. (2004a). They described the Devonian - Carboniferous boundary within the black shales of Ziyarettepe formation. In the Eastern Taurides mainly four tectono-stratigraphic units, Geyikdağı, Aladağ, Görbiyes and Bozkır Units, have been differentiated by Özgül and Kozlu (2002). They described dolomites, neritic limestones and shales within the Geyik Dağı unit around the Kozan, Feke, Saimbeyli, Tufanbeyli, Develi and Pınarbaşı regions in the Eastern Taurides. Özgül and Kozlu (2002) described the Lower Carboniferous Ziyarettepe formation represented by shales and interbeds of sandstone and sandy limestone.

In addition to the geological and stratigraphical studies, the petroleum and hydrocarbon potential of Paleozoic units in the Eastern Taurides has been studied by several researchers (İlleez et al.,1994; Demirel et al., 1996; Demirel and Kozlu, 1997; Demirel, 2004). İlleez et al. (1994) reported that Cambrian, Ordovician and Silurian deposits lost their hydrocarbon properties due to the metamorphism however Gümüşali, Ziyarettepe and Yığılıtepe formations have a good source-rock potential. Similarly, Demirel et al. (1996) and Demirel (2004) suggested that the Lower Carboniferous Ziyarettepe formation within the Geyik Dağı Unit is the best source rock in Eastern Taurides. Demirel and Kozlu (1997) suggested that the Upper Paleozoic shale and limestone succesions in the Eastern Taurides are rich in organic matter and they have oil and gas potential.

1.4.2 Previous Works on Lower Carboniferous stage boundaries

In the Central Taurides, foraminiferal groups are intensely used in the stratigraphy of Lower Carboniferous successions (Altıner, 1981; Işık, 1981; Özgül, 1997; Altıner and Özgül, 2001; Peynircioğlu, 2005; Okuyucu and Vachard, 2006; Atakul, 2006; Özkan-Altıner et al., 2007, Dzhenchuraeva and Okuyucu, 2007; Atakul-Özdemir et al., 2011). Altıner and Özgül (2001) described the Carboniferous and Permian foraminiferal assemblages in the Hadim region. They identified several biozones in the Carboniferous and Permian deposits. The studies concerning the delineation of Lower Carboniferous stage boundaries by using foraminiferal biostratigraphy and determination of meter-scale cyclicity across the boundaries have been reported by Peynircioğlu (2005), Atakul (2006), Özkan-Altıner et al. (2007), Dinç (2009) and Atakul-Özdemir et al. (2011). The Tournaisian-Visean boundary in Aladağ Unit within the Central Taurides has been delineated by Peynircioğlu (2005) and Özkan-Altıner et al. (2007). Regarding the foraminiferal evolution across the Mid-Carboniferous boundary, Atakul (2006) and Atakul-Özdemir et al. (2011) carried out a detailed biostratigraphic and sequence stratigraphic study. Moreover, Kobayashi and Altıner (2008) described the Late Carboniferous and

Early Permian Fusulinoideans in the Hadim region (Central Taurides). Dinç (2009) provided information about the Upper Tournaisian carbonate deposits of the Aladağ Unit in the Hadim region (Central Taurides) based on benthic foraminifers and defined the sequence stratigraphic evolution of the carbonate deposits.

Several biostratigraphic studies on the Paleozoic deposits were performed in the Eastern Taurides by Altıner (1981, 1984), Özkan-Altıner et al. (2007) and Demirel (2012). Late Paleozoic stratigraphy and biostratigraphy of the Pınarbaşı area (Kayseri) was investigated by Altıner (1981) in his Ph.D. thesis. He performed detailed taxonomical studies on the Late Paleozoic foraminifera. Özkan-Altıner et al. (2007) have defined the Tournaisian-Visean stage boundary in the Central and Eastern Taurides by using foraminiferal biostratigraphy and sequence stratigraphy. Demirel (2012) carried out a detailed biostratigraphic and sequence stratigraphic studies across the Visean - Serpukhovian boundary succession.

In Taurides, besides the foraminiferal biostratigraphical studies, there are few studies regarding the conodont biostratigraphy in the literature (Özgül and Gedik, 1973; Gedik, 1977; Ekmekçi and Kozur, 1999). Conodont studies in Turkey mainly include Upper Cambrian (Özgül and Gedik, 1973), Ordovician (Özgül and Gedik, 1973; Gedik, 1977; Kozlu et al., 2002), Silurian (Gedik, 1977; Kozlu et al., 2002; Boncheva et al., 2009), Devonian (Gedik , 1977, 1988; Çapkınoğlu, 1991, 1997, 2000, 2005a, 2005b; Çapkınoğlu and Bektaş 1998), Carboniferous (Gedik, 1977; Gedik and Çapkınoğlu, 1984; Ekmekçi and Kozur, 1999; Göncüoğlu et al. 2004a,b; Atakul-Özdemir et al., 2012a), Permian (Gedik 1977) and Triassic (Gedik 1975, 1977; Önder 1984a, b; Önder and Göncüoğlu 1989) units. Özgül and Gedik (1973) studied the stratigraphy and the conodont faunas of Lower Paleozoic Çaltepe Limestone and Seydişehir Formation in Central Taurides. Gedik (1977) studied the conodont fauna from Cambrian to Triassic in Central Taurides. Ekmekçi and Kozur (1999) reported the Moscovian conodonts of the Kongul Formation (Bolkardağı Unit) in the northwest of Hadim region. Atakul-Özdemir et al. (2012a) reported the conodont biostratigraphy across the Mid-Carboniferous boundary beds in Central Taurides. The studies deal with the delineation of Lower Carboniferous stage boundaries using conodont biostratigraphy have been performed by Belka (1990), Webster and Groessens (1990), Wang (1990), Yuping and Zhihao (2005) and Sanz-Lopez et al. (2007). There are also some studies concerning the determination of stage boundaries only using foraminifera (Reitlinger, 1950; Rauser-Chernoussova et al., 1951; Ginkel, 1965; Brazhnikova et al., 1967; Ainsenverg et al., 1968; Bozorgnia, 1973; Lys, 1977; Mamet, 1976; Armstrong and Mamet, 1974; Monod, 1977; Massa and Vachard, 1979; Conil et al., 1976, 1979; Vachard, 1980, Zhao et al., 1984; Altıner, 1981, Altıner and Özgül, 2001; Metcalfe, 1985; Minato, 1985; Weyant et al., 1985; Rocha Campos and Archangelsky, 1985; Yang Shihpu et al., 1985; Ross and Ross, 1987; Wu Wangshi et al., 1987; Groves et al., 1994; Ross and Ross, 1995; Villa, 1995; Gallagher, 1996; Özgül, 1997; Brenckle and Milkin , 2003). There are also few studies regarding the stage boundaries of Lower Carboniferous based on conodont and foraminifera biostratigraphy. Brenckle (1990), Bogush and Yuferev (1990) and Kulagina et al. (2003) described the micropaleontological basis for determination of the Lower Carboniferous stage boundaries based on both conodonts and foraminifers.

Although there are several studies which dealt with the conodont biostratigraphy in the Taurides, these studies were not related with the delineation of Lower Carboniferous stage boundaries. This PhD study, however, has focused on the conodont biostratigraphy in order to delineate the Lower Carboniferous stage boundaries in the Central and Eastern Taurides, Turkey.

1.5 Regional Geology

The Tauride belt situated on the Alpine-Himalian Orogenic Belt is one of the main tectonic units of Turkey. The Taurides has been divided into three structurally distinct units as Western Taurides, Central Taurides and Eastern Taurides (Figure 1.2) (Özgül, 1976, 1984).

Within this belt, several tectono-stratigraphic units representing different depositional environments from Cambrian to Tertiary have been differentiated. These units were thrusted over each other during the closure of Neotethyan oceanic branches attaining a complex nappe structure in the Tauride Belt (Özgül, 1976, 1984, 1997, 2009; Göncüoğlu, 1997; Altıner and Özgül, 2001) (Figure 1.3). A thorough classification of the units has been defined by Özgül (1976, 1984). These are Bolkar Dağı, Aladağ, Geyik Dağı, Alanya, Bozkır, Antalya and Görbiyes Dağı Units (Özgül, 1976, 1984; Özgül and Kozlu, 2002). Within these units, solely the Geyik Dağı Unit is described as an autochthonous or parautochthonous while the others are defined as allochthonous units (Özgül, 1976, 1984). The Bolkar Dağı, Aladağ, Geyik Dağı and Alanya units comprise shelf type carbonates and clastic rocks. Conversely, the Bozkır and Alanya units encompass deep sea sediments, ultrabasic rocks and submarine volcanic rocks (Özgül, 1976, 1984). Additionally, the Görbiyes Dağı Unit includes carbonate rocks from Jurassic to Late Cretaceous and displays a low grade regional metamorphism. The studied sections are placed within the Lower Carboniferous deposits of the Aladağ (Hadim, Bademli and Melikgazi sections) and Geyik Dağı (Sarız Section) Units.

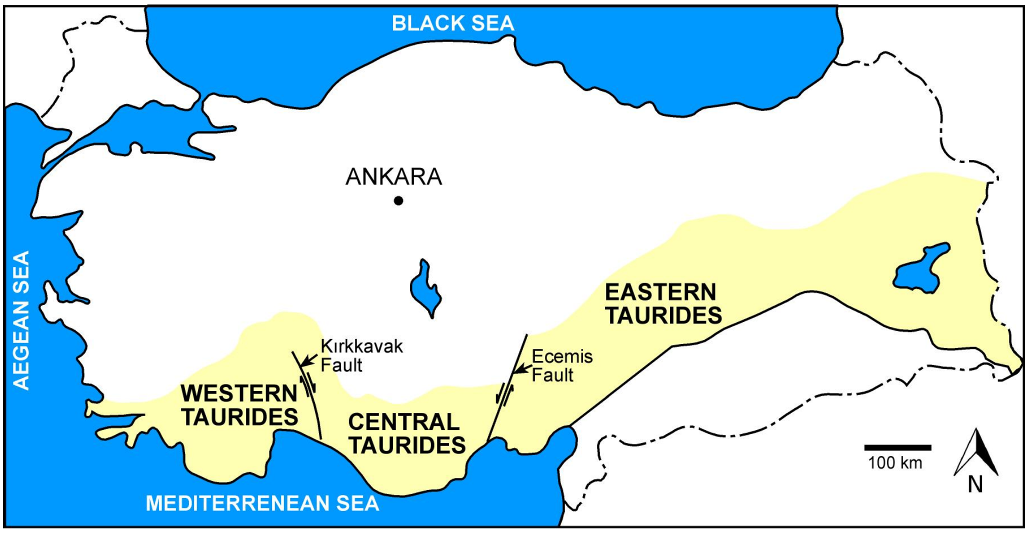


Figure 1.2. The broad geographical subdivision of the Tauride Belt (Özgül, 1984).

The Aladağ Unit is characterized by shelf type carbonate and clastic deposits of Late Devonian - Late Cretaceous (Özgül, 1976, 1984, 1997; Monod, 1977; Altıner, 1981; Altıner ve Özgül, 2001) (Figure 1.4). The lowest part of the unit comprises the Upper Devonian Gölboğazı Formation including quartz arenitic sandstone, shale and reefal limestones. The Carboniferous Yarıcak Formation of the Aladağ Unit is characterized by mainly quartzarenitic sandstone and limestone intercalations and dark colored shales. This formation is correlated with the Ekşimenlik, Aziziye Gediği and Oruçoğlu Formations in the Eastern Taurides (Altıner, 1981). The overlying Permian Çekiç Dağı Formation embraces foraminiferal and algal limestones. Triassic Gevne Formation of this unit starts with algal limestone overlying the stromatolitic limestone of Upper Permian. It passes upward to shallow marine limestone and sandstone deposits. Jurassic - Cretaceous Çambaşı Formation is represented by thick carbonate deposits containing dolomites and shallow marine limestones and the Maastrichtian Zekeriya Formation involves olistoliths and olistrostroms derived from the allochthonous Bozkır Unit (Özgül, 1976, 1984, 1997).

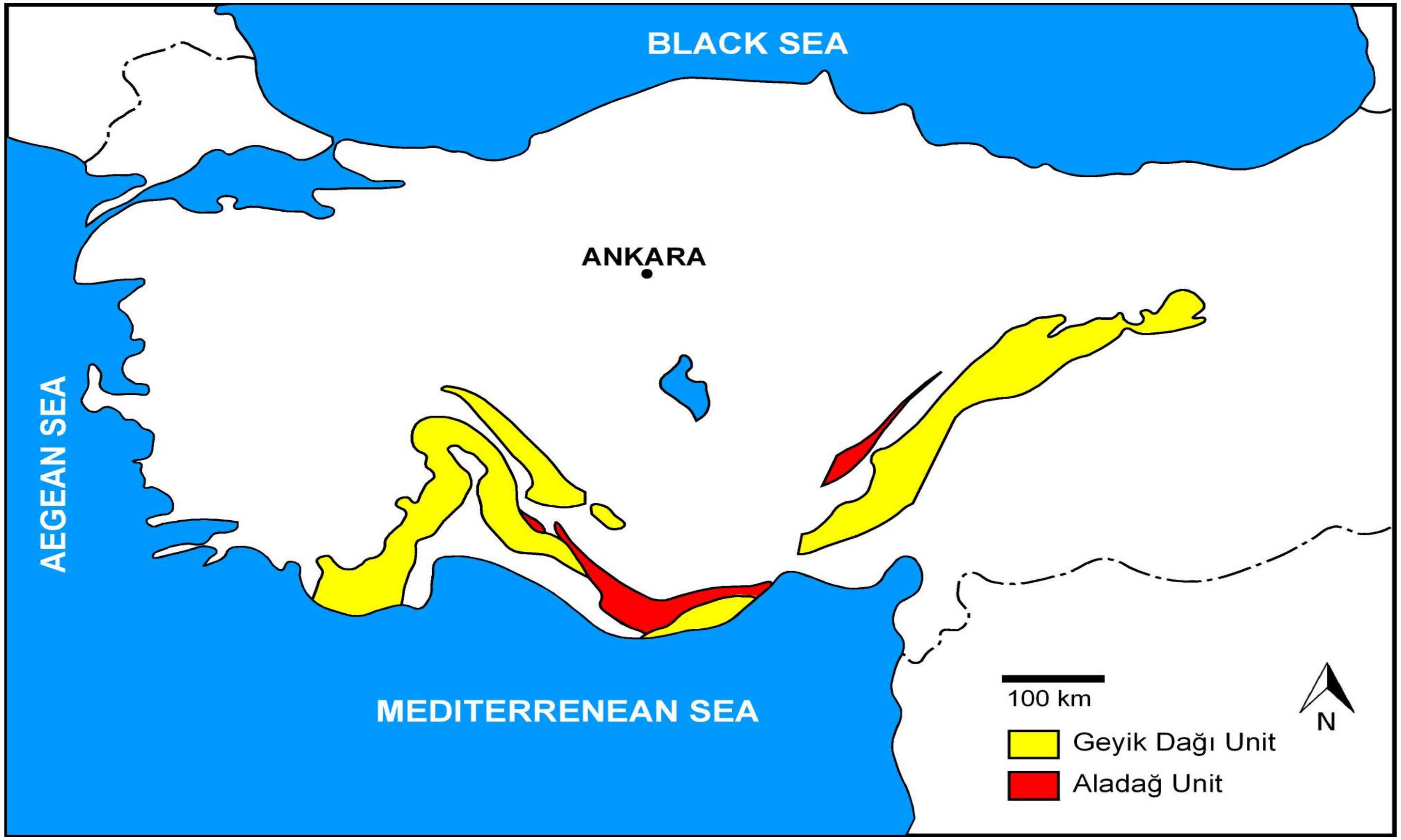


Figure 1.3. Distribution of tectono-stratigraphic units in Tauride Belt (Özgül, 1976).

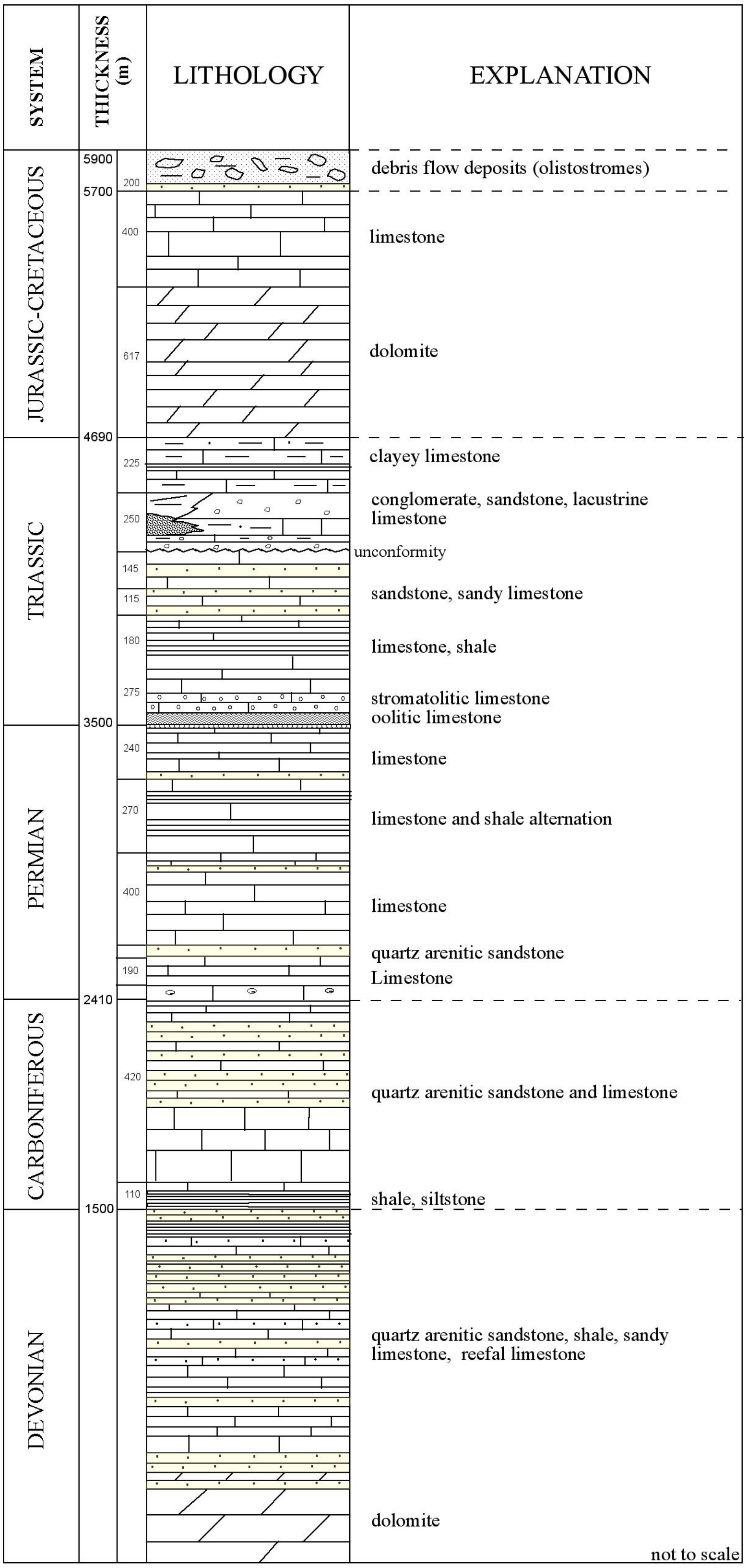


Figure 1.4. Generalized columnar section of the Aladağ Unit (modified from Özgül, 1997).

The Geyik Dağı Unit, the autochthonous-parautochthonous unit of the Taurides lies at the base of other units (Özgül, 1976, 1984, 1997). It is composed of platform type sediments starting with a Paleozoic basement comprising Cambrian and Ordovician rocks and a transgressive Upper Mesozoic - Lower Tertiary rocks in Central Taurides (Özgül, 1984). The most prominent and continous Paleozoic sequence of Geyik Dağı Unit is mostly observed in Eastern Taurides (Figure 1.5). Precambrian age Emirgazi Formation occur throughout the Tauride Belt (Özgül and Kozlu, 2002; Göncüoğ lu et al. ,2004a). Three members were defined in the formation as *Oruçlu Member* represented by low grade metamorphic siliciclastic rocks, *İçme Tepe Member* characterized by stramatolitic and cherty limestones and dolomite and *Koçyazı Member* consisting of mainly quartz arenitic sandstone (Özgül and Kozlu, 2002; Göncüoğlu et al., 2004a). The Koçyazı Member was named as Feke Quartzite by Göncüoğlu et al. (2004a). The overlying Değirmentaş Formation is composed of mainly limestone and dolomitic limestone passing upward into nodular limestone. This formation is described as Çal Tepe Formation by Dean and Monod (1990) and Göncüoğlu et al. (2004a). The Armutlu Dere Formation includes intercalation of shale and sandstone and overlying Sabova formation is characterized by mixed siliciclastic and carbonate rocks. These formations named as Seydişehir Formation by Dean and Monod (1990) and Göncüoğlu et al. (2004a). The Halit Yaylası Formation comprises mostly conglomerates and sandstones. Puscu Tepe Shale Formation is conformably overlies the Halit Yaylası Formation and characterized by graptolite-bearing black shales. The overlying Yukarı Yayla Formation is represented by limestone shale alternations and is rich in nautiloids. The Lower Devonian Ayı Tepesi Formation includes shallow marine quartz arenites. The Safak Tepe Formation consists of neritic carbonates mainly limestones and dolomites and is overlain by the Gümüşali Formation which is composed of alternations of limestones, shales and sandstones.

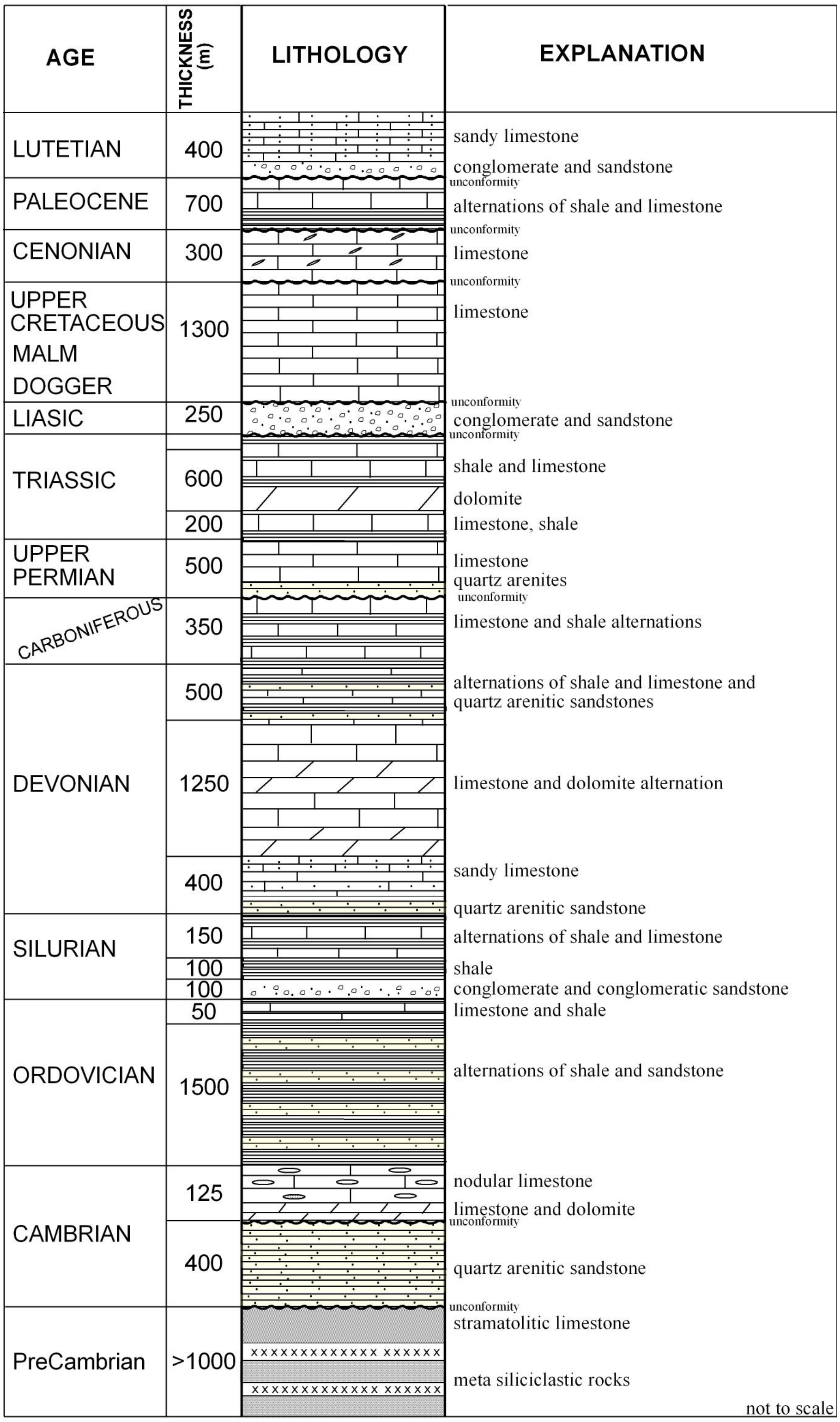


Figure 1.5. Generalized columnar section of the Geyik Dağı Unit in Eastern Taurides (modified from Özgül and Kozlu, 2002).

The conformably overlying Ziyarettepe Formation is represented by black shales at the bottom and passes upward into shale and limestone alternations. This formation is unconformably overlain by the Middle - Upper Permian Yığılı Tepe Formation which is characterized by shelf-type carbonate deposits.

1.6 Structure of Thesis

This PhD thesis is divided into 8 chapters. Following this introductory chapter:

Chapter 2 deals with the lithostratigraphy and summarizes details of studied sequences of the Central and Eastern Taurides, Turkey.

Chapter 3 discusses the Lower Carboniferous conodont biozones recognized in the Taurides. This chapter also explains the delineation of the Lower Carboniferous stage boundaries, Kinderhookian - Osagean, Visean-Serpukhovian and mid-Carboniferous, in Turkey based on the bioevents (first apperances / last apperances) of biostratigraphically significant species within the measured sections and their correlation with the studies around the world. A part of this chapter has been published as a paper entitled **“Conodont distribution across the Mid-Carboniferous boundary in the Central Taurides, Turkey”** in Rivista Italiana di Paleontologia e Stratigraphia. The co-authors on this publication are: Demir Altıner and Sevinç Özkan-Altıner, Department of Geological Engineering, Middle East Technical University, 06531, Ankara, Turkey.

Chapter 4 documents microfacies types throughout the measured sections to interpret paleoenvironmental conditions. Furthermore, this chapter focuses on the distribution of conodonts and their relations with microfacies types and depositional environments.

Chapter 5 gives brief information about morphometric analyses, the application and the results of geometric morphometric analyses (Eliptical Fourier Analysis and Eigen Shape Analysis) on biostratigraphically important conodont species of *Gnathodus.*

Chapter 6 is dealing with the stable (carbon and oxygen) and radiogenic (strontium) isotope geochemistry across the Lower Carboniferous boundaries and their global correlation.

Chapter 7 provides brief introduction about the conodonts, their morphology and internal structure, functions, classifications and processing methods. Moreover, this chapter consists of descriptions of the forms, the remarks explaining the main identification criteria and a synonym list comprising the most recent studies.

Chapter 8 presents discussions on the conodont assemblages and delineation of Lower Carboniferous stage boundaries and their worldwide correlation, and finally overall conclusions of this thesis.

CHAPTER 2

LITHOSTRATIGRAPHY

This research included the study of ten stratigraphic sections within the time interval from the Tournasian to the Bashkirian (Figure 2.1). This study focused on five measured stratigraphic sections (AN, AAO, AS, BS, and BSE) and five previously studied Lower Carboniferous reference successions (AP, BT, MT, SC, and HB) within the Aladağ Unit and the Geyik Dağı Unit. While seven of the studied sections were measured in the Hadim and the Bademli regions of the Central Taurides, three of them were sampled in the Sarız and the Melikgazi (Pınarbaşı) regions of the Eastern Taurides. The Lower Carboniferous sequence of the Aladağ Unit is widely exposed in the Hadim, Bademli and Melikgazi (Pınarbaşı) regions. Whereas, the Lower Carboniferous succession of the Geyik Dağı Unit is well exposed in the Sarız region (Figure 2.1).

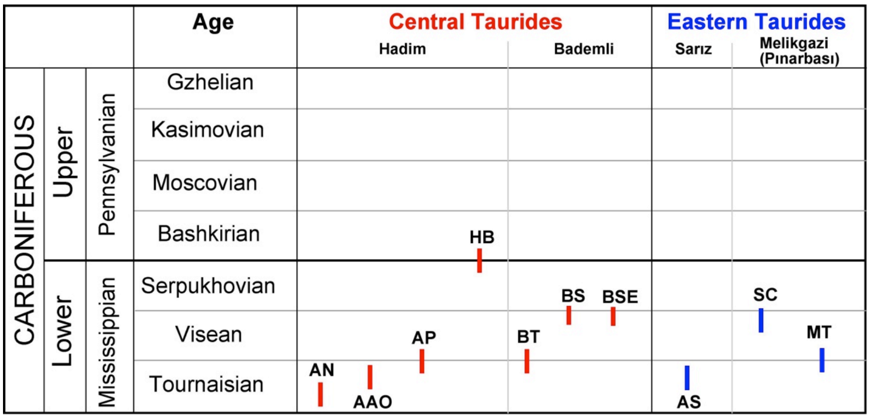


Figure 2.1. Stratigraphical distributions of the studied sections.

2.1 Lithostratigraphy in the Central Taurides

2.1.1 Bademli Region

The Paleozoic units widely exposed around the Bademli village were first studied by Ziegler (1939) and Blumenthal (1951). Paleozoic of the Bademli area was defined later within the Aladağ Unit of Özgül (1976). Monod (1977) described these rocks including the Mesozoic succession in the area as the Bademli Unit within the Beyşehir-Hoyran Nappe and mapped the Bademli region in detail (Figure 2.2).

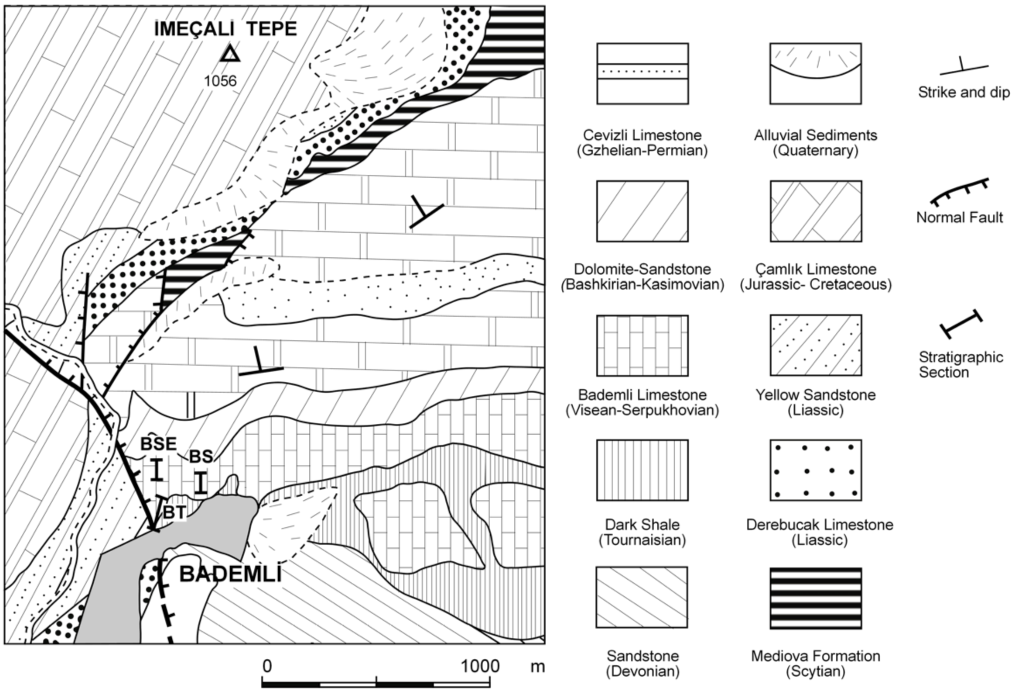


Figure 2.2. Geological map of the Bademli region (modified from Monod 1977 and Özkan-Altıner et al., 2007). BT, BS and BSE are the measured sections.

The Carboniferous deposits of the Bademli Unit overlying Devonian age sandstones have been divided into four units. They start with Tournaisian dark colored shale with clayey limestone intercalations and pass upward into Visean - Serpukhovian Bademli Limestone dominated by carbonate rocks. Towards the upper part, Bashkirian - Kasimovian dolomites and sandstones dominate and they are overlain by Gzhelian - Permian limestone and sandstone deposits named as the Cevizli Formation (Figure 2.2). Within these units, previously measured and studied BT section (Özkan-Altıner et al., 2007) crossing the Tournaisian - Visean boundary has been resampled for conodont biostratigraphy and two more sections, BS and BSE, have been measured in the Bademli Unit in order to delineate the Visean - Serpukhovian boundary.

BT Section:

According to Özkan-Altıner et al. (2007), BT section comprises intercalations of two main lithologies, shale and limestone. Shales are dominant at the bottom of the section and towards the upper part limestones become dominant (Figure 2.3, 2.4). The succession begins with the alternations of calcareous shales and marls covered by fine grained crinoidal packstones (between samples BT-95 and BT-84) and towards the upper part of the section shale and marl alternations are overlain by more proximal packstone facies comprising abundant brachiopods, crinoids and corals fragments (between samples BT-83 and BT-69) (Özkan-Altıner et al., 2007). The middle part of the measured section comprises mainly alternations of foraminiferal packstones and bioclastic packstones with brachiopods, crinoids and corals (between samples BT-68 and BT-44) (Özkan-Altıner et al., 2007). The upper part of the section is characterized by limestone deposits (between samples BT-43 and BT-39) and more proximal packstone facies (between samples BT-38 and BT-1) (Özkan-Altıner et al., 2007). Tournaisian - Visean boundary is located based on foraminifera between the samples BT-18 and BT-19 (Özkan-Altıner et al., 2007). Nineteen samples for conodont biostratigraphy were collected from the limestone facies within the studied section (Figure 2.3). No conodont elements have been recorded from these samples.

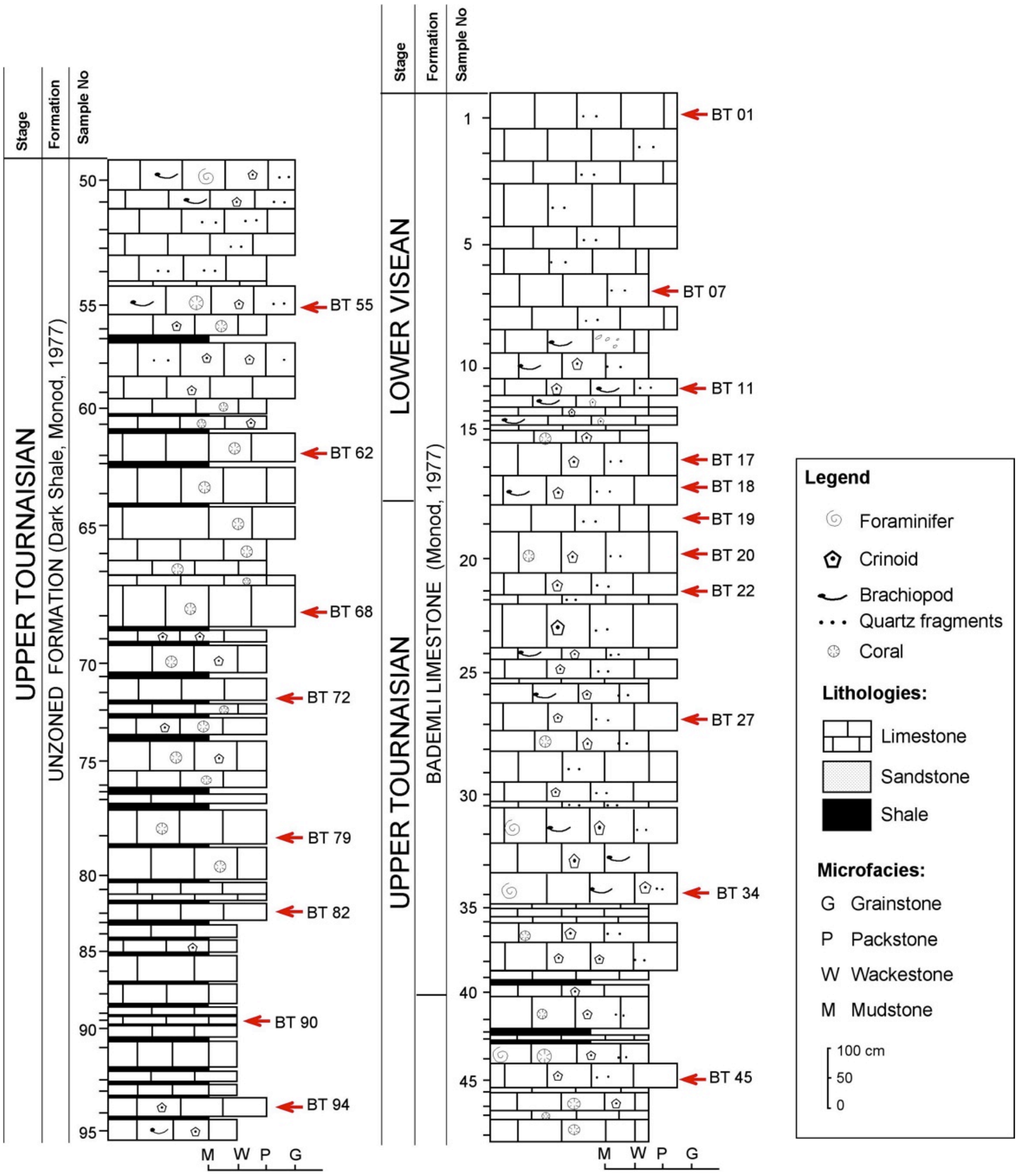


Figure 2.3. Columnar section of the BT section in the Bademli region, Central Taurides (Özkan-Altıner et al., 2007). The sampled conodont levels are indicated by red arrows.

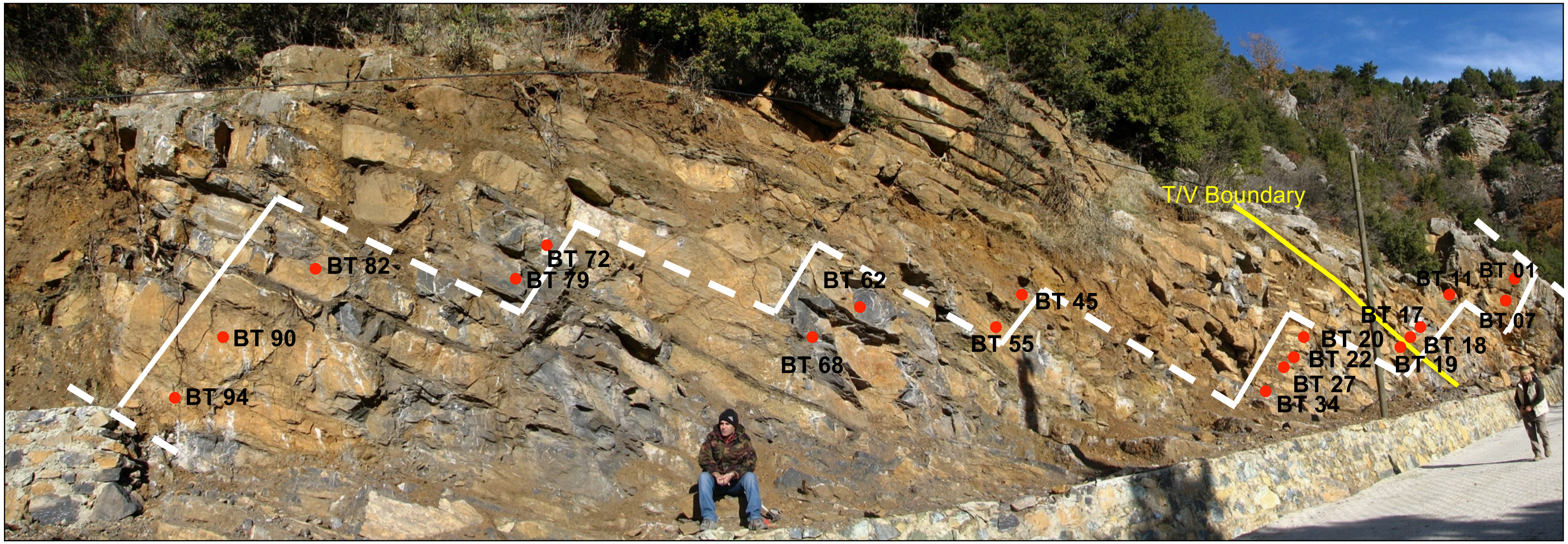


Figure 2.4. Location of the Tournaisian – Visean boundary beds and the BT section (Bademli, Central Taurides), red dots indicate the conodont sampling points.

BS Section:

The studied succession predominantly consists of limestones interbedded with quartz arenitic sandstones (Figure 2.5, 2.6A). The lower part of the succession is characterized by bioclastic grainstones and sandy oolitic grainstones (between samples BS-1 and BS-9). The succession continues upward into an alternation of quartz arenitic sandstones, quartz peloidal grainstones and sandy oolitic grainstones containing abundant ooids (between samples BS-10 and BS-17). The upper part of the succession consists of bioclastic grainstones and crinoidal bioclastic packstones (between samples BS-18 nd BS-21). To locate the Visean - Serpukhovian boundary, seven samples have been collected through the BS-section (Figure 2.5) and no conodont elements have been recorded from this section.

BSE Section:

The sequence measured through the BSE section is mainly composed of continuous carbonate deposition including quartz arenitic sandstone intercalations (Figure 2.6B, 2.7). The lower part of the succession comprises mainly quartz arenitic sandstone and sandy limestone intercalations and in the upper part of the section limestones become dominant (Figure 2.7). The succession starts with quartz arenitic sandstone and interbedded with quartz peloidal grainstones (between samples BSE-1 and BSE-11). This alternation is overlain by the bioclastic grainstones and sandy oolitic grainstones (between samples BSE-12 and BSE-24). The upper part of the succession is mainly characterized by crinoidal bioclastic packstones (between samples BSE-25 and BSE-31). In order to delineate the Visean - Serpukhovian boundary, eight samples have been collected through the BSE-section (Figure 2.7) and conodont elements from these samples will be discussed in detail in the Biostratigraphy Chapter.

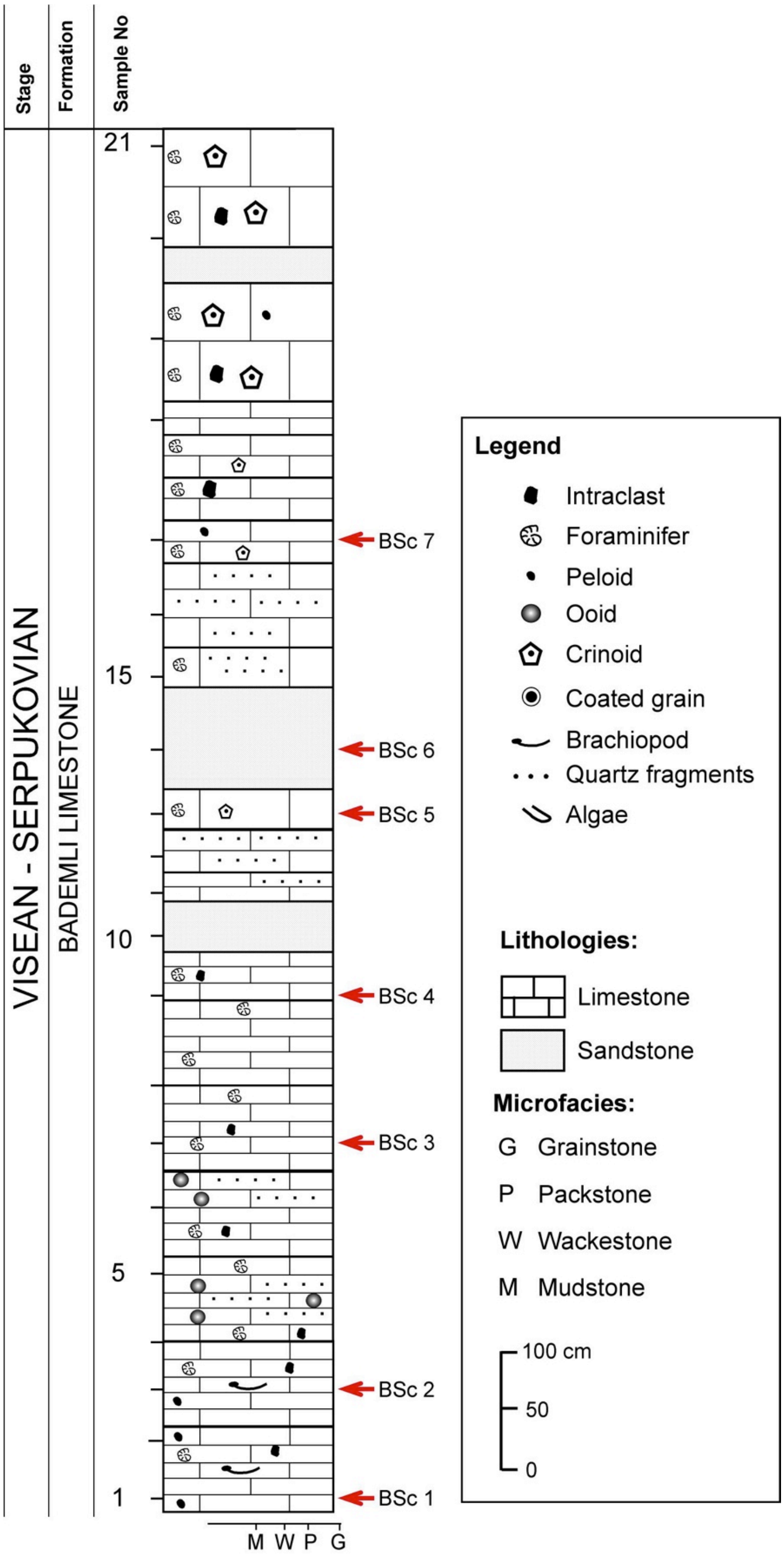
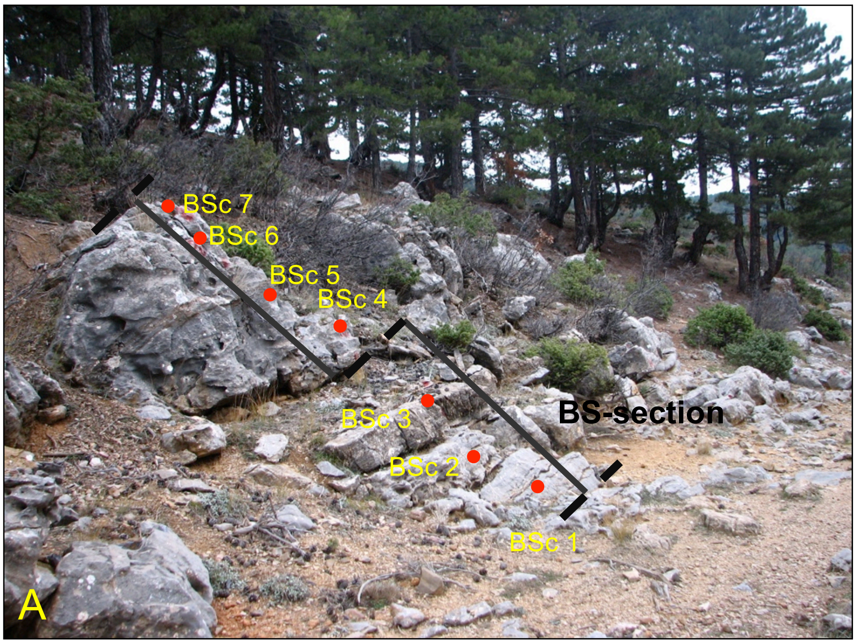


Figure 2.5. Columnar section of the BS section in the Bademli region Central Taurides, the red arrows indicate the conodont sampling points.



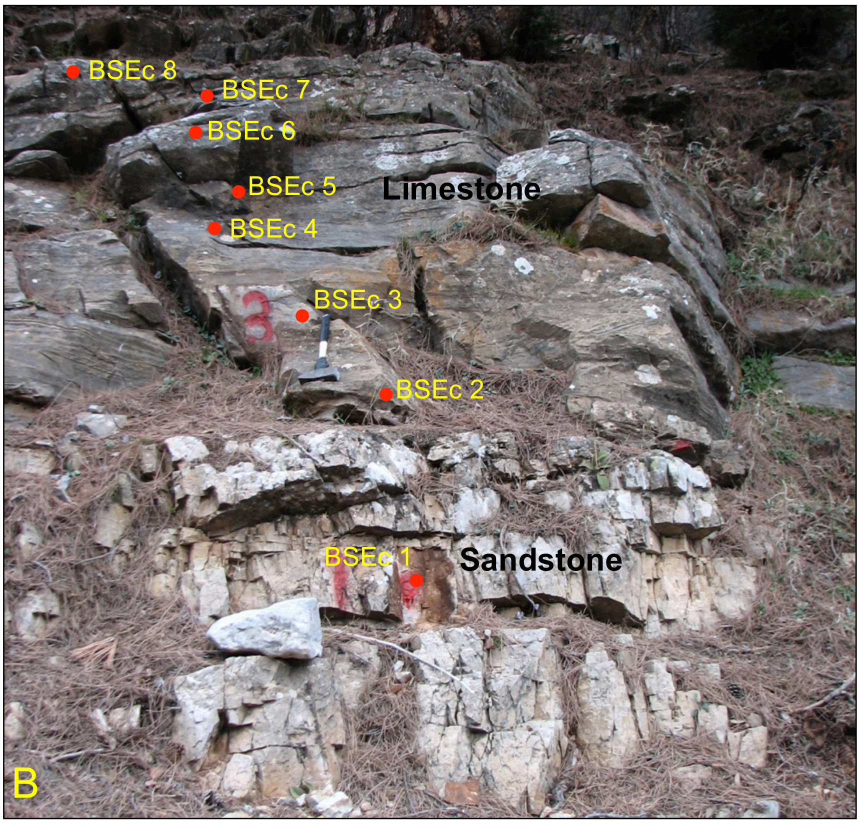


Figure 2.6. Locations of the BS-section (A) and part of the BSE-section (B) (Bademli, Central Taurides), red dots indicate the conodont sampling points.

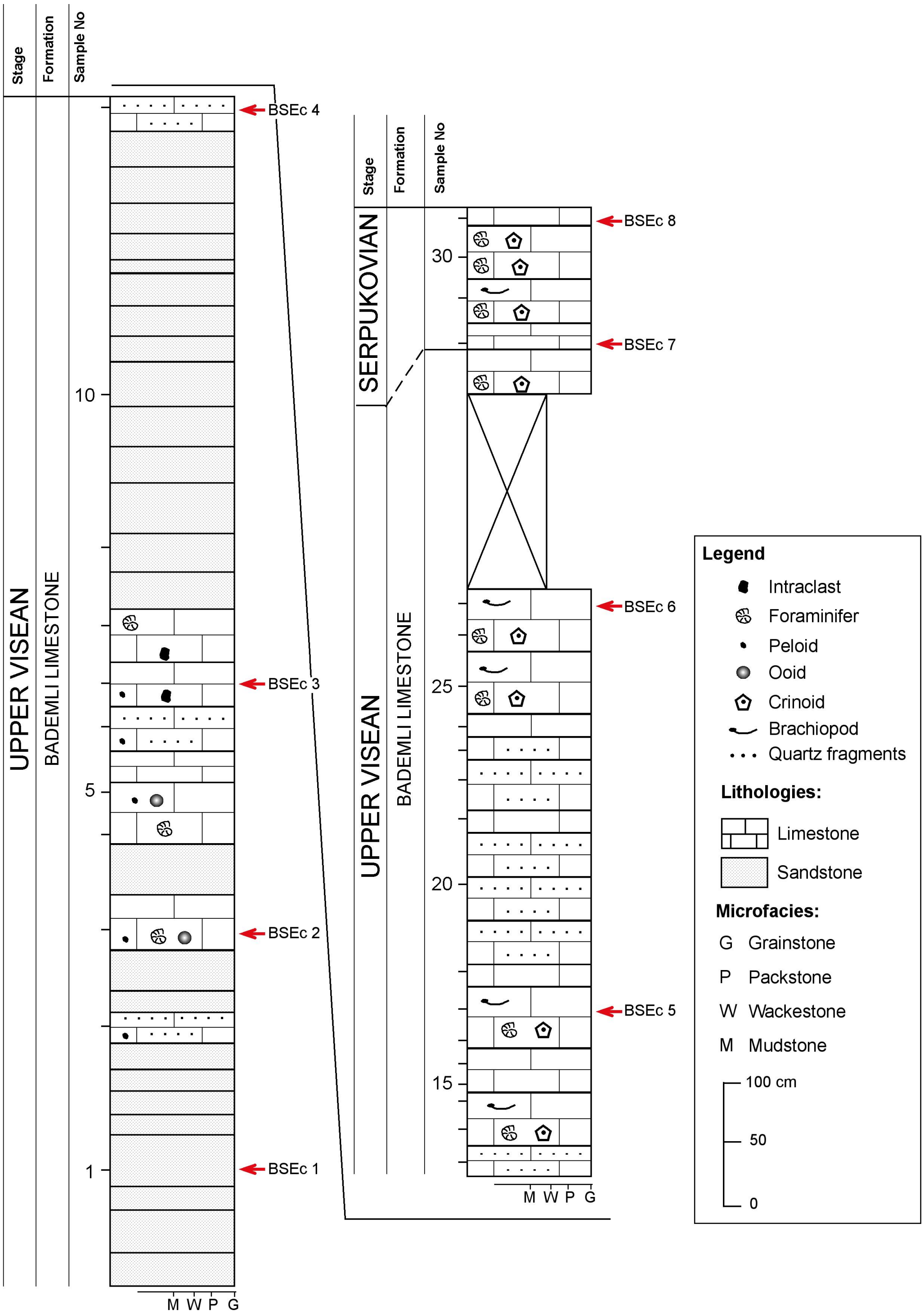


Figure 2.7. Columnar section of the BSE section in the Bademli region, the red arrows indicate the conodont sampling points.

2.1.2 Hadim Region

The study area comprises mainly Paleozoic carbonate deposits of the Aladağ Unit (Figure 2.8, Altıner and Özgül, 2001). These carbonate deposits starts at its base with Devonian quartz arenitic sandstones, shales, sandy limestones and reefal limestones (Gölboğazı Formation) and continues with Carboniferous shales, quartz arenitic sandstones and limestones (Yarıcak Formation) (Figure 2.9). They are conformably overlain by Permian quartz arenitic sandstones and limestones (Çekiç Dağı Formation). This formation is paraconformably overlain by the Triassic stromatolitic, oolitic and sandy limestones (Gevne Formation) (Figure 2.9).

The Yarıcak Formation is characterized by mainly shelf type limestones with dark colored shale layers at the base and quartz arenitic sandstone intercalations at the top (Figure 2.9). The formation conformably overlies Devonian age Gölboğazı Formation and is overlain by Permian Çekiç Dağı Formation (Figure 2.9). The Yarıcak formation is subdivided into two members, the Çityayla Member and the Mantar Tepe Member (Özgül, 1997). The Çityayla Member comprises dark colored shales interbedded with thin limestone beds. This member includes Tournasian brachiopods, crinoids, bryozoa and rarely trilobites and few microfossils (Özgül, 1997). This member was probably deposited in low energy shelf conditions below the wave base level due to the presence of dark shale deposits. The Mantar Tepe Member is mainly composed of bioclastic, oolitic and micritic limestones in the lower part and quartz arenitic sandstones intercalated with fusulininid foraminifers-rich limestone levels in the upper part (Altıner and Özgül, 2001). It also includes siliceous-iron cemented conglomerate lenses with quartz and flintstone fragments (Özgül, 1997). Based on foraminiferal and algal zones, Özgül (1997) recognized Visean, Serpukhovian, Bashkirian, Moscovian stages in the succession.

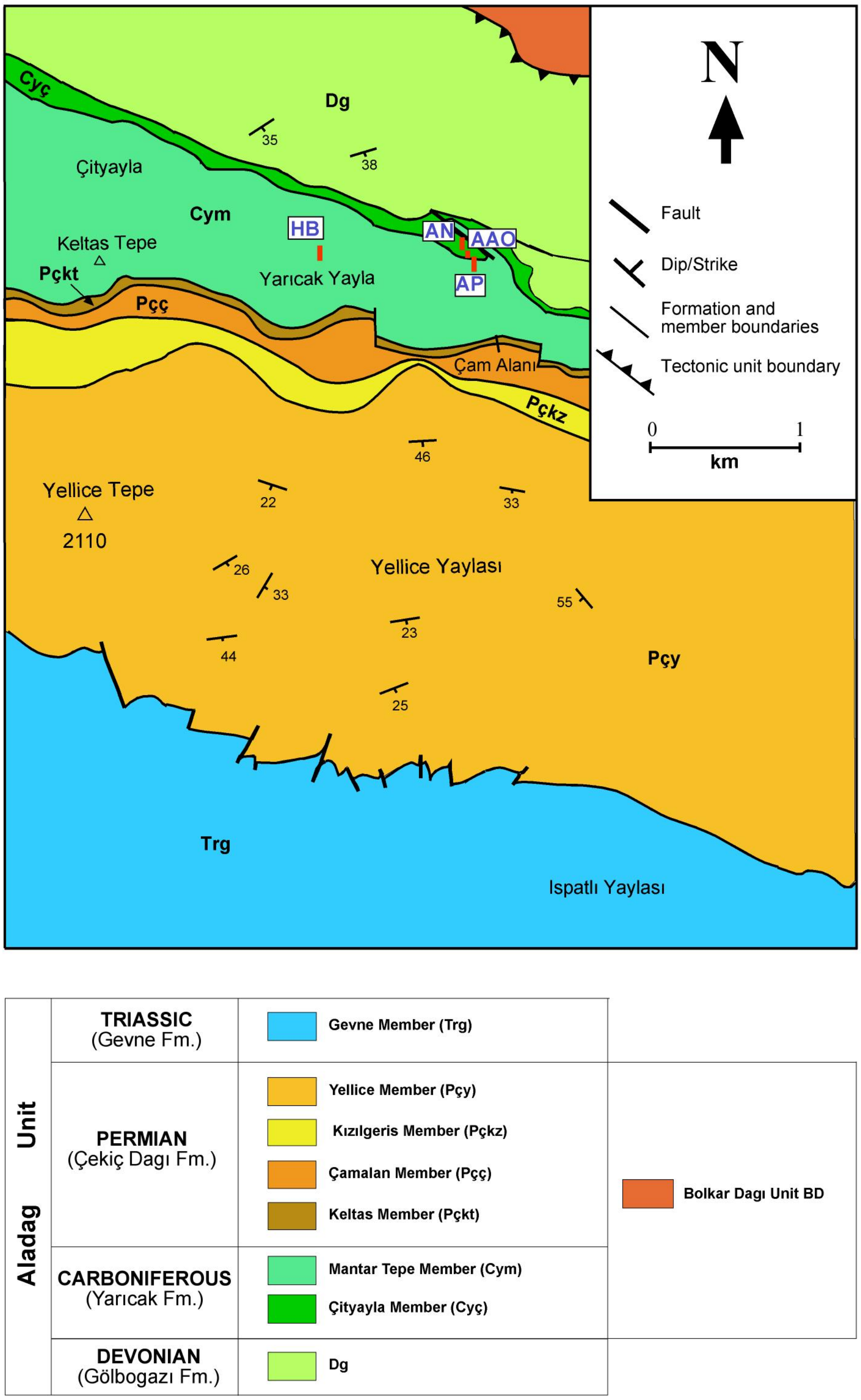


Figure 2.8. Geologic map of the study area in the Hadim region, Central Taurides (Altıner and Özgül, 2001).

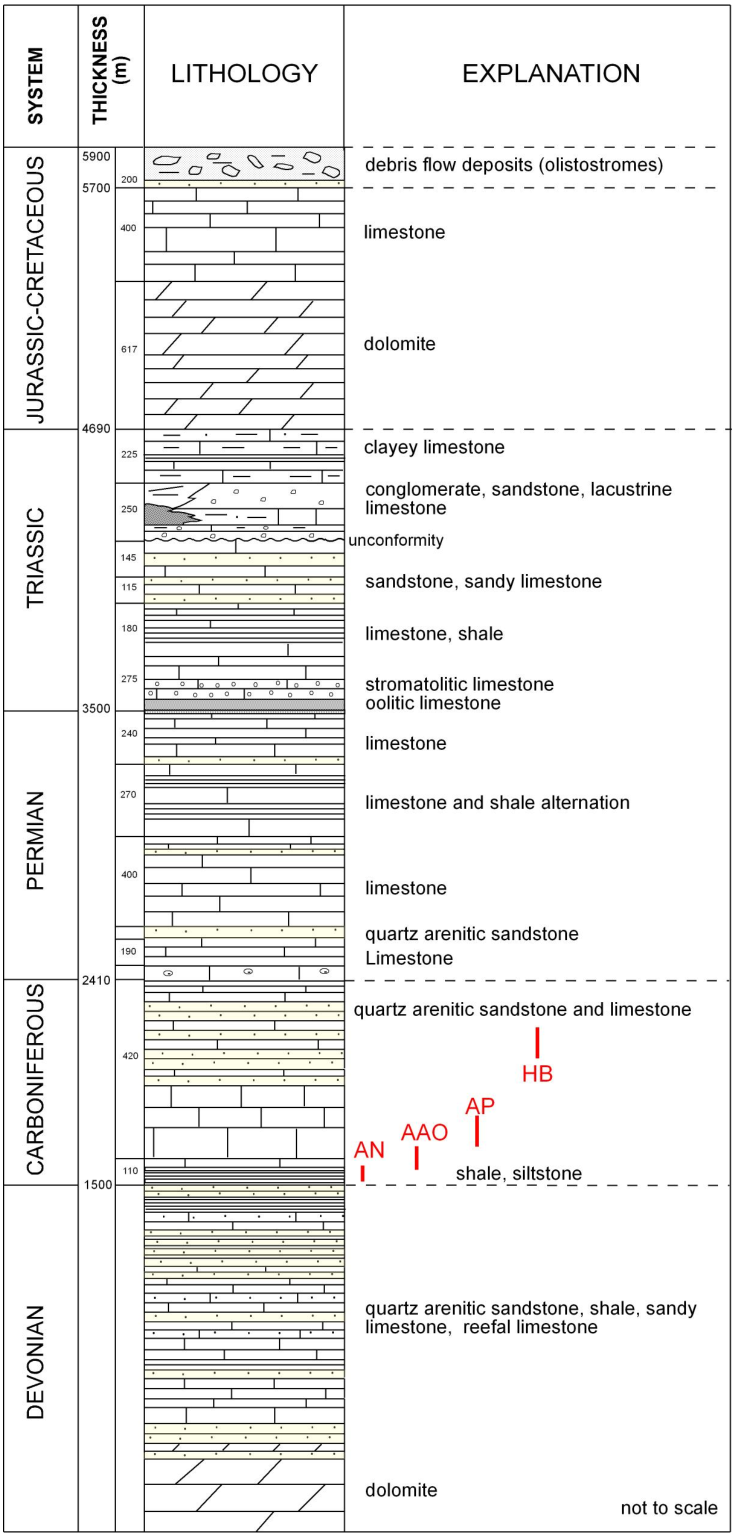


Figure 2.9. Generalized columnar section of the Aladağ Unit in the Hadim-Taşkent region, Central Taurides (simplified from Özgül, 1997). The measured sections are shown by bars.

More recently, Altıner and Özgül (2001) have divided the Carboniferous into several foraminiferal biozones. The Mantar Tepe Member with its sandy, pelloidal, oolitic, crossed bedded, bioturbated grainstones and packstones with abundant microfossils and macrofossils was deposited in a relatively high energy environment of a shallow shelf receiving high amount of sediment influx from the land.

Among the Paleozoic carbonate deposits of the Aladağ Unit in the Hadim region, previously studied AP section encompassing Tournaisian - Visean boundary (Özkan-Altıner et al., 2007; Peynircioğlu, 2005) and HB section covering Mid-Carboniferous boundary (Atakul, 2006; Atakul-Özdemir et al., 2011) were resampled and two stratigraphic sections (AN and AAO) were measured and sampled for conodont biostratigraphy through the Yarıcak Formation.

AN Section:

Tournaisian AN section comprising the Çityayla Member predominantly consists of dark colored shales with thin bedded limestone intercalations (Figure 2.10, Figure 2.11). The lower part of the succession is dominated by thick bedded shales and includes peloidal packstone-grainstone interbeds (between samples AN-1 and AN-8). The succession continues with the alternations of shales and peloidal packstone-grainstones (between samples AN-9 and AN-11). Towards the upper part of the section, the thickness of shale deposits increases and this part is composed of an alternation of shale and crinoidal packstone-grainstone facies (between samples AN-12 and AN-17). Seventeen samples have been collected from the section in order to construct the conodont biostratigraphy but the samples are barren of conodonts.

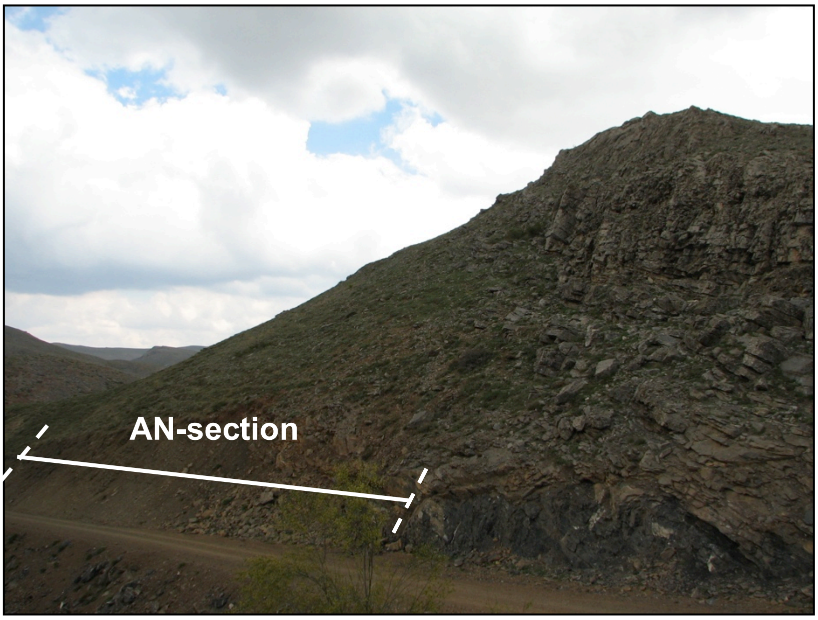


Figure 2.10. Location of the AN section (Hadim, Central Taurides).

AAO Section:

The measured AAO section representing the Çityayla Member is chiefly composed of limestones throughout the succession partly interbedded with thin shale deposits (Figure 2.12). The succession starts with peloidal packstone-grainstones intercalated with shales (between samples AAO-11 and AAO-9). The middle part of the section is mainly characterized by crinoidal packstone-grainstone facies and includes shale intercalations (between samples AAO-8 and AAO-4). Towards the upper part of the succession peloidal packstone-grainstones become dominant with shale intercalations (between samples AAO-3 and AAO-1). Eleven samples have been collected from the AAO-section (Figure 2.13) and the obtained conodonts will be discussed in the Biostratigraphy Chapter.

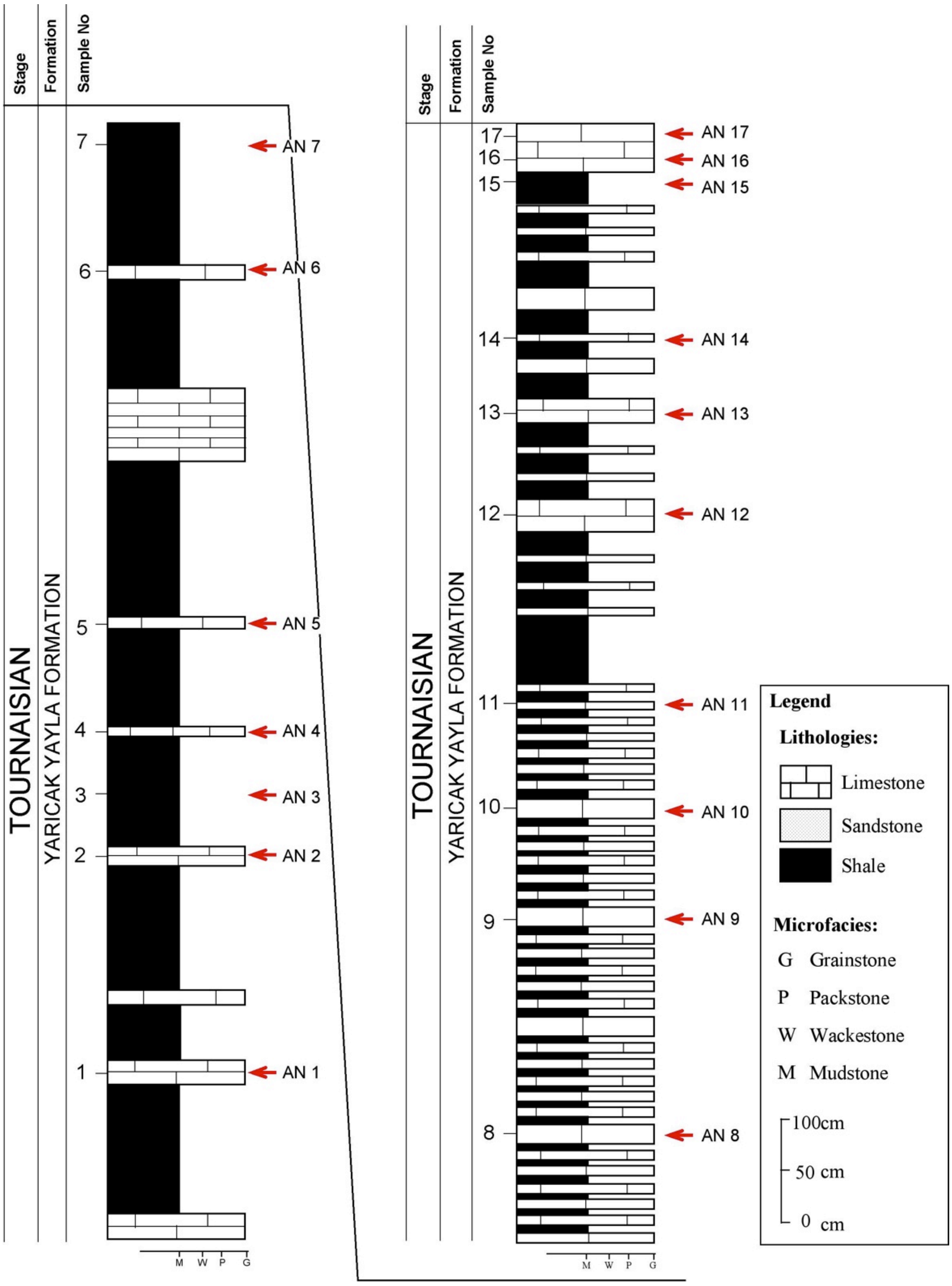


Figure 2.11. Columnar section of the AN section (Hadim, Central Taurides), the red arrows indicate the conodont sampling points.

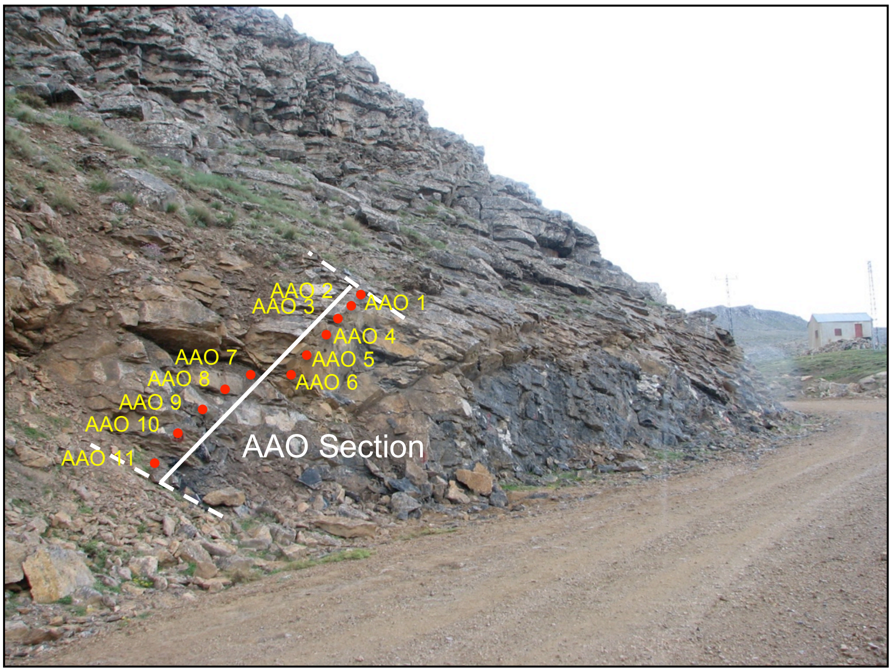


Figure 2.12. Location of the AAO section (Hadim, Central Taurides).

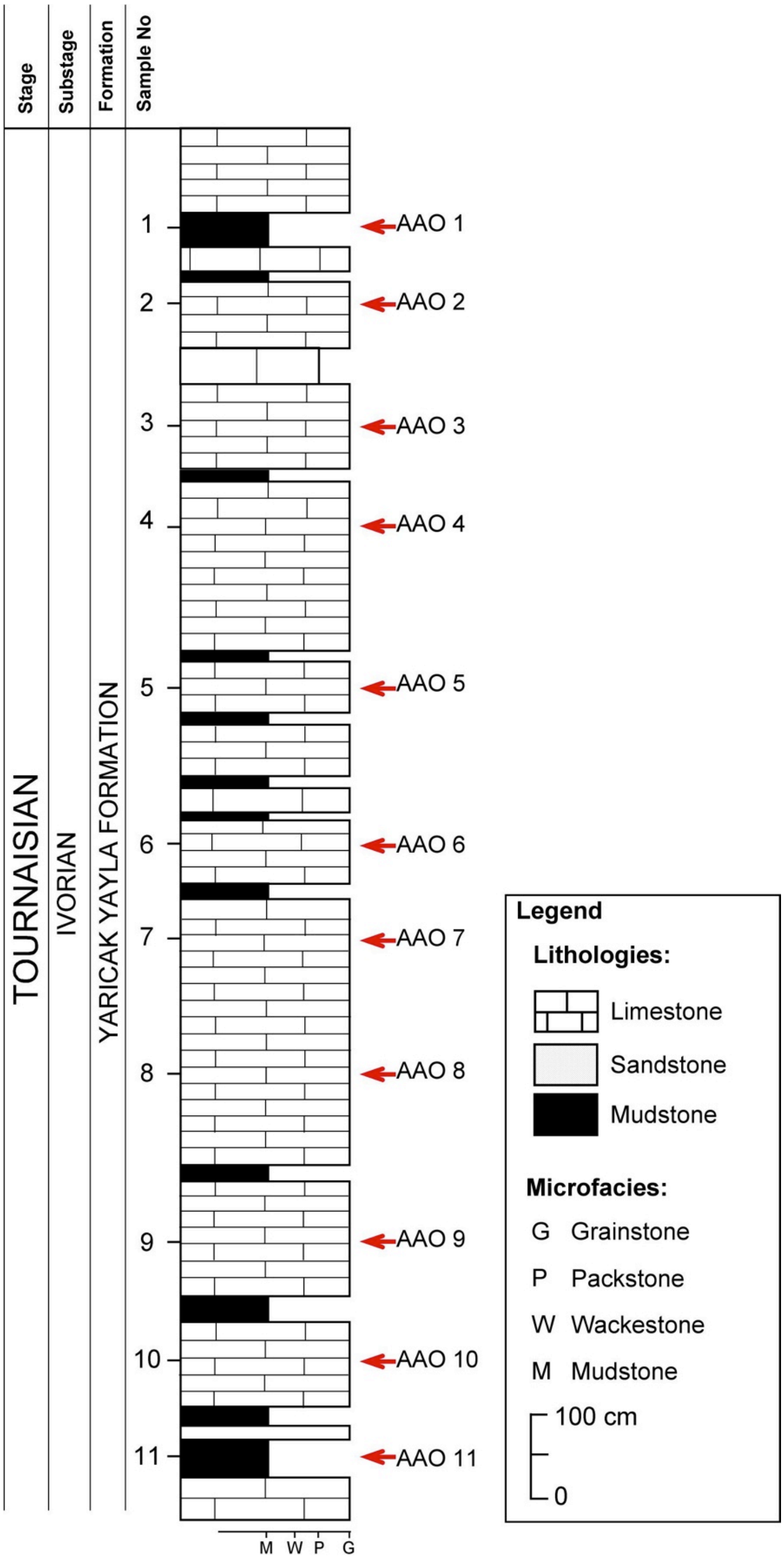


Figure 2.13. Columnar section of the AAO section (Hadim, Central Taurides), the red arrows indicate the conodont sampling points.

AP Section:

This section was measured and studied earlier by Peynircioğlu (2005) and Özkan-Altıner et al. (2007)based on foraminifers. AP section covering Tournaisian - Visean boundary beds encompass the Çityayla and the Mantar Tepe members (Figure 2.14, Figure 2.15). Özkan-Altıner et al. (2007)stated that the lithologies defined in the Bademli region are very similar to those described in Hadim region. He recommended that lithostratigraphic nomenclature in these two areas should be reviewed throughout the Tauride Belt. Based on Özkan-Altıner et al. (2007), the succession starts with the intercalations of calcareous shales, marls and crinoidal packstone-wackestone facies (between samples AP-1 and AP-12) and continues towards the upper part mainly with alternations of crinoidal packstone-wackestone and bioclastic packstone including brachiopods, crinoids and corals (between samples AP-13 and AP-26). It passes upward into a sequence composed of an alternation of bioclastic packstone and foraminiferal packstone facies (between samples AP-27 and AP-35) (Özkan-Altıner et al., 2007). This interval is overlain by calcareous shales, marls and crinoidal packstones (between samples AP-36 and AP-39) (Özkan-Altıner et al., 2007). Towards the upper part of the section, bioclastic packstones with brachiopods, crinoids and corals become dominant (between samples AP-40 and AP-46) and the succession ends with alternations of bioclastic packstone and foraminiferal packstone facies (between samples AP-47 and AP-66) (Özkan-Altıner et al., 2007). Based on foraminiferal biostratigraphy, Tournaisian - Visean boundary was positioned at the base of sample AP-58 (Özkan-Altıner et al., 2007). Twenty-six conodont samples have been collected mainly from the packstone facies (Figure 2.15). No elements have been found from these samples.

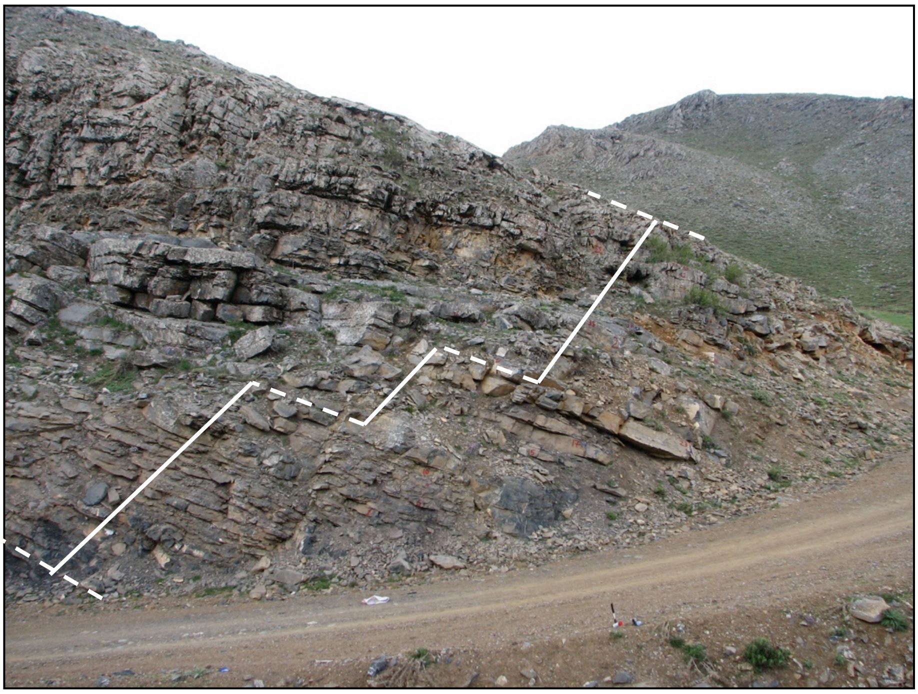


Figure 2.14. Location of the AP section (Hadim, Central Taurides).

HB Section:

HB section was also studied previously by Atakul (2006) and Atakul-Özdemir et al. (2011). This section comprising Mid-Carboniferous boundary embraces the Mantar Tepe member. The succession is mainly characterized by limestone and sandstone intercalations (Figure 2.16, 2.17). The succession starts with quartz arenitic sandstones at the base and continues upward with peloidal grainstones rich in quartz grains intercalated with quartz arenitic sandstones (samples between HB-64 and HB-53) (Atakul, 2006 and Atakul-Özdemir et al., 2011). It passes upward into bioclastic and oolitic grainstones containing abundant microfossils and ooids (samples between HB-52 and HB-21) (Atakul, 2006 and Atakul-Özdemir et al., 2011). The middle of this interval (sample HB-34) includes a prominent dark calcareous mudstone facies (Figure 2.17).

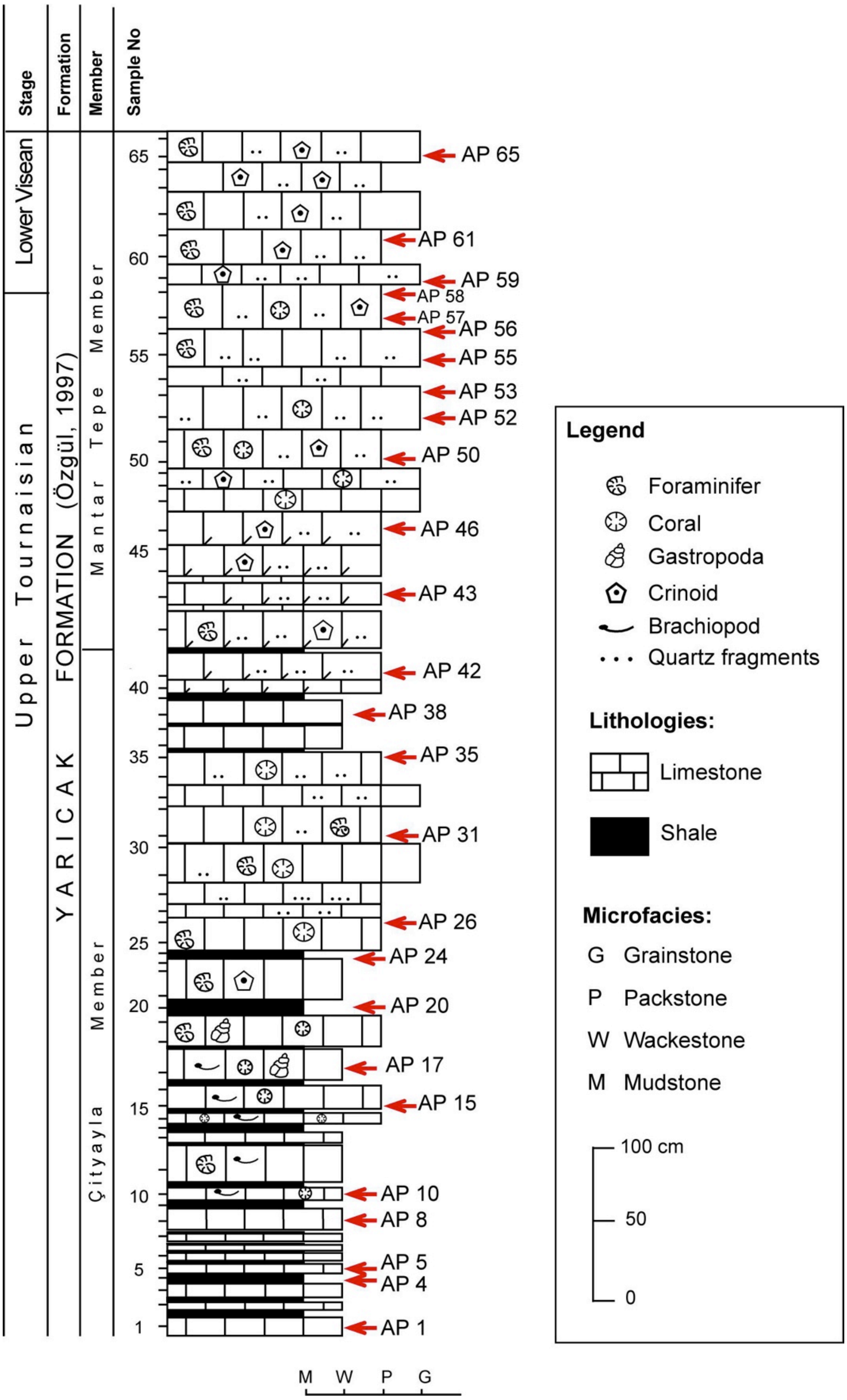


Figure 2.15. Columnar section of the AP section (Hadim, Central Taurides), the red arrows indicate the conodont sampling points (Özkan-Altıner et al., 2007).

Towards the upper part of the section, oolitic grainstones with quartz grains and quartz arenitic sandstones become dominant (samples between HB-20 and HB-12) (Atakul, 2006 and Atakul-Özdemir et al., 2011). This interval is overlain by oolitic and bioclastic grainstones including mudstone level in the upper part (samples between HB-12a and HB-1) (Atakul, 2006 and Atakul-Özdemir et al., 2011). Mid-Carboniferous boundary was placed between the samples HB-28 and HB-27 by foraminifera (Atakul, 2006; Özkan-Altıner et al., 2007; Atakul-Özdemir et al., 2011). Twenty samples for conodont biostratigraphy have been collected through HB-section and the faunal content of these samples will be discussed in detail in the Biostratigraphy Chapter.

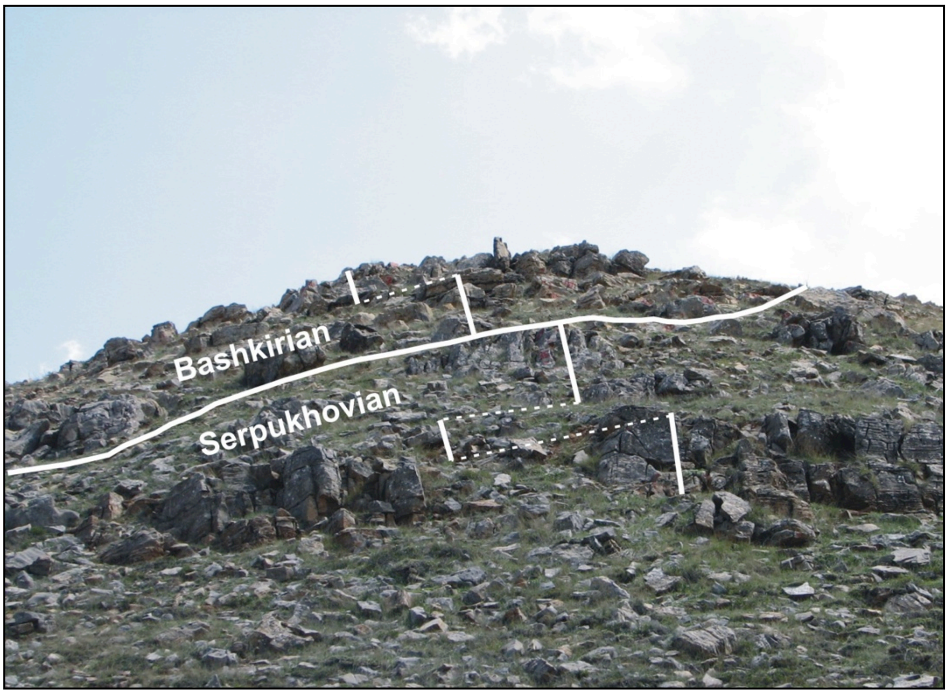


Figure 2.16. Location of the HB section (Hadim, Central Taurides) (Atakul-Özdemir et al., 2011).

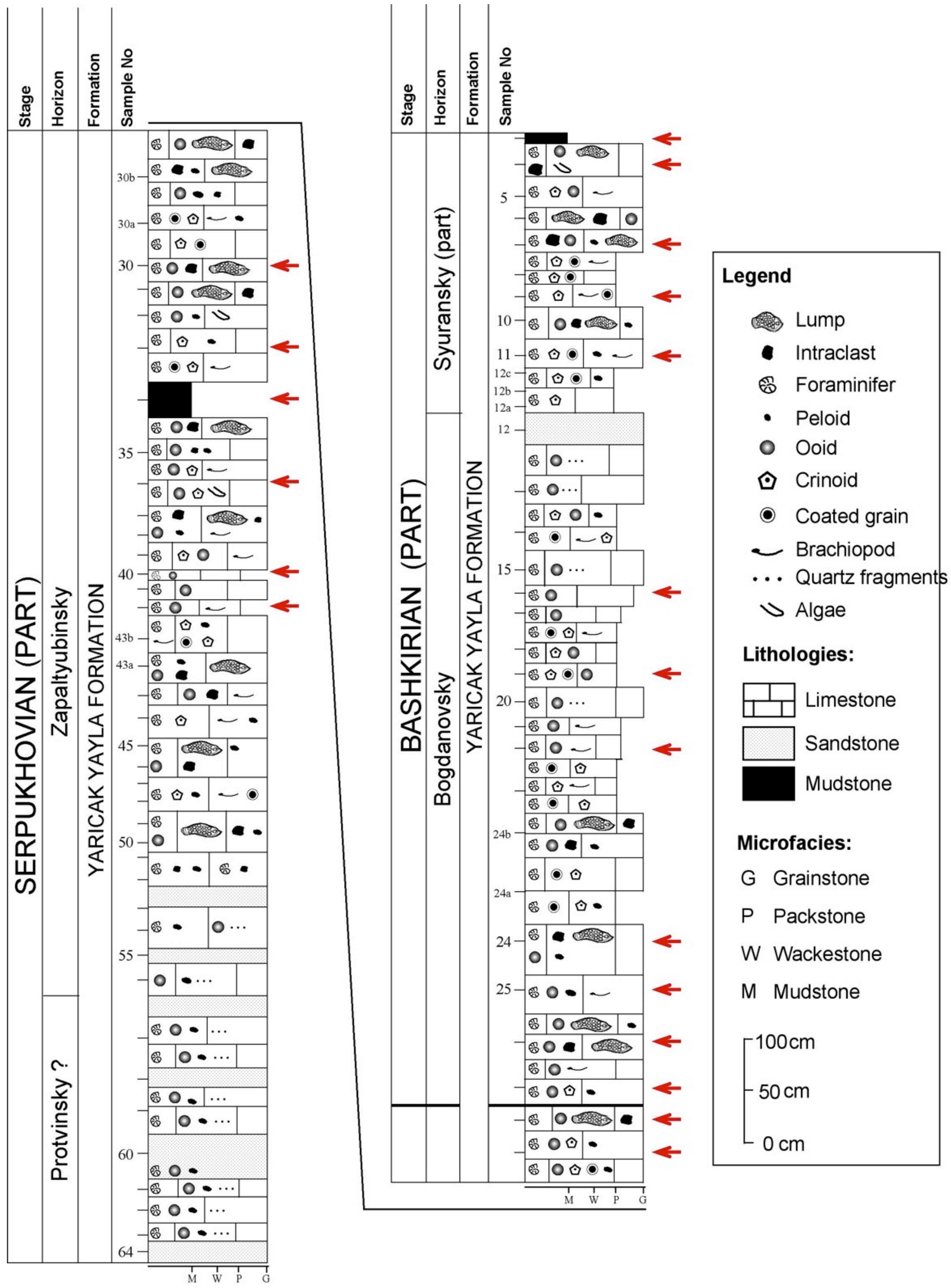


Figure 2.17. Columnar section of the HB section (Hadim, Central Taurides), the red arrows indicate the conodont sampling points (Atakul-Özdemir et al., 2011).

2.2 Lithostratigraphy in the Eastern Taurides

2.2.1 Melikgazi (Pınarbaşı) Region

The study area is located on the Aladağ Unit, which is exposed around the Melikgazi village, Pınarbaşı in the Eastern Taurides (Figure 2.18). The detailed geological map of the study area was made by Altıner (1981). Based on Altıner (1981) and Özkan-Altıner et al. (2007), four principal rock units have been differentiated in the Melikgazi region. The first unit comprises Jurassic - Cretaceous ultrabasic rocks, the second one is Cretaceous volcano-sedimentary sequences including thin clastics and pillow lava alternations and the other one is Ladinian? - Norian age reefal limestone named as the Kocagedik Unit (Özkan-Altıner et al., 2007). The Aladağ Unit, fourth unit in the region, is characterized by the Paleozoic and Mesozoic deposits. Within the Aladağ Unit, the oldest unit in the study area is the Devonian coralline limestone. This unit is overlain by the Famenian - Tournaisian Ekşimenlik Formation including shale, sandstone and clayey limestone alternations. The overlying Upper Tournaisian - Visean Aziziye Gediği Formation consists of limestones. It is conformably overlain by Upper Visean - Gzhelian Oruçoğlu Formation comprising alternations of limestone and sandstone lithologies. In the study area, Permian is subdivided into two units, Asselian - Artinskian Taşlıgüney Sırtı Formation consisting of oncoidal limestones and sandstones and the Wordian - Changhsingian Sarpkaya Tepe Formation characterized by sandstones at the base and algal and foraminiferal limestones at the top.

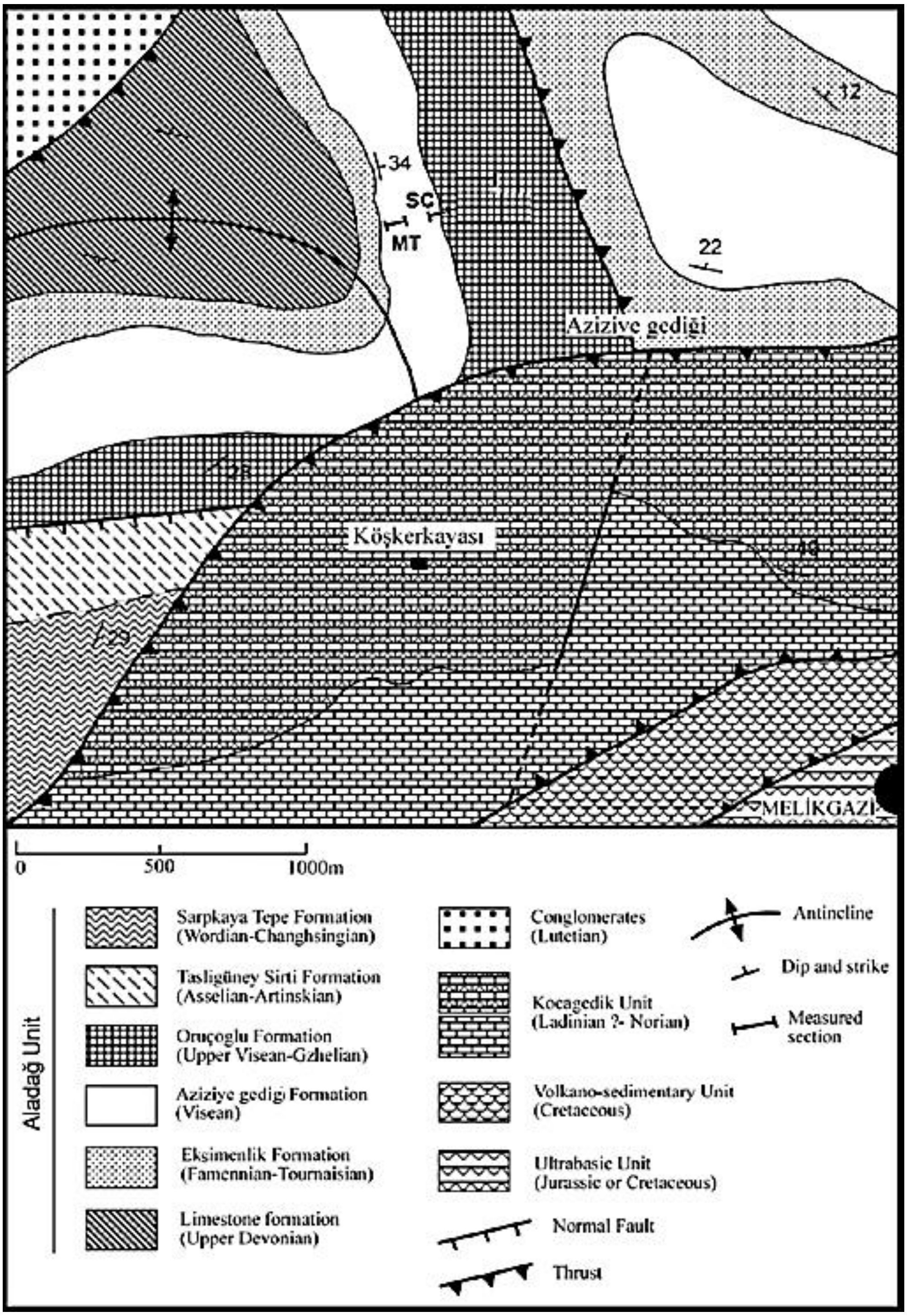


Figure 2.18. Geologic map of the Melikgazi region in Pınarbaşı, Eastern Taurides (Altıner 1981 and Özkan-Altıner et al. 2007).

Among the Paleozoic carbonate deposits of the Aladağ Unit in the Hadim region, previously studied AP section encompassing Tournaisian - Visean boundary (Özkan-Altıner et al., 2007; Peynircioğlu, 2005) and HB section covering Mid-Carboniferous boundary (Atakul, 2006; Atakul-Özdemir et al., 2011) were resampled and two stratigraphic sections (AN and AAO) were measured and sampled for conodont biostratigraphy through the Yarıcak Formation.

Within this generalized stratigraphic framework, the previously studied MT-section covering Tournaisian - Visean boundary (Özkan-Altıner et al., 2007) was resampled for conodont biostratigraphy. Additionally, conodont samples have been collected from the previously studied Visean - Serpukhovian SC-section (Demirel, 2012).

MT Section:

The MT section covering Tournaisian - Visean boundary beds was measured and studied earlier by Özkan-Altıner et al. (2007)(Figure 2.19). According to Özkan-Altıner et al. (2007), the succession begins with dolomites representing the uppermost unit of the Ekşimenlik Formation (samples MT-1, MT-2). It passes upward into bioclastic limestones with ostracodes, crinoids and brachiopods interbedded with sandy oolitic and oncoidal limestones (between samples MT-3 and MT-19) (Özkan-Altıner et al., 2007). The upper part of the section comprises the intercalations of wackestone-packstone and grainstone facies (between samples MT-20 and MT-50) (Özkan-Altıner et al., 2007). This interval is also characterized by the interbeds of packstone-grainstone facies with dark clasts (Özkan-Altıner et al., 2007). Thirteen samples have been collected from this succession for conodont biostratigraphy (Figure 2.20) but they are barren of conodonts.

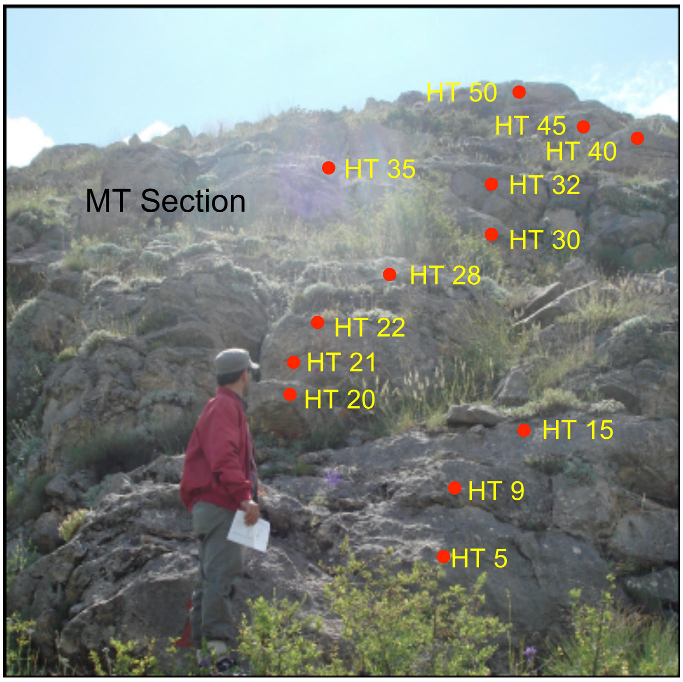


Figure 2.19. Location of the MT section (Melikgazi, Eastern Taurides), the red dots indicate the conodont sampling points.

SC Section:

The SC-section representing the Upper Visean and Lower Serpukhovian deposits of Aziziye Gediği and Oruçoğlu Formations was measured and studied by Demirel (2012) (Figure 2.21). Demirel (2012) stated that the succession starts with the alternations of dark grey bioclastic packstone and grainstone facies (between samples SC-1 and SC-15) and continues upward with grainstone facies with abundant macrofossils (samples SC-16, SC-17 and SC-18). This interval is overlain by grainstone and packstone alternations (between samples SC-19 and SC-27) (Demirel, 2012). Wackestone facies is also observed from the samples SC-28 and SC-29 and this facies is overlain by grainstone facies (samples between SC-30 and SC-37) (Demirel, 2012). The succession continues with fossiliferous wackestone and mudstone facies from samples SC-40, SC-41 and passes upward into intercalations of grainstone and packstone facies (samples between

SC-42 and SC-72) (Demirel, 2012).

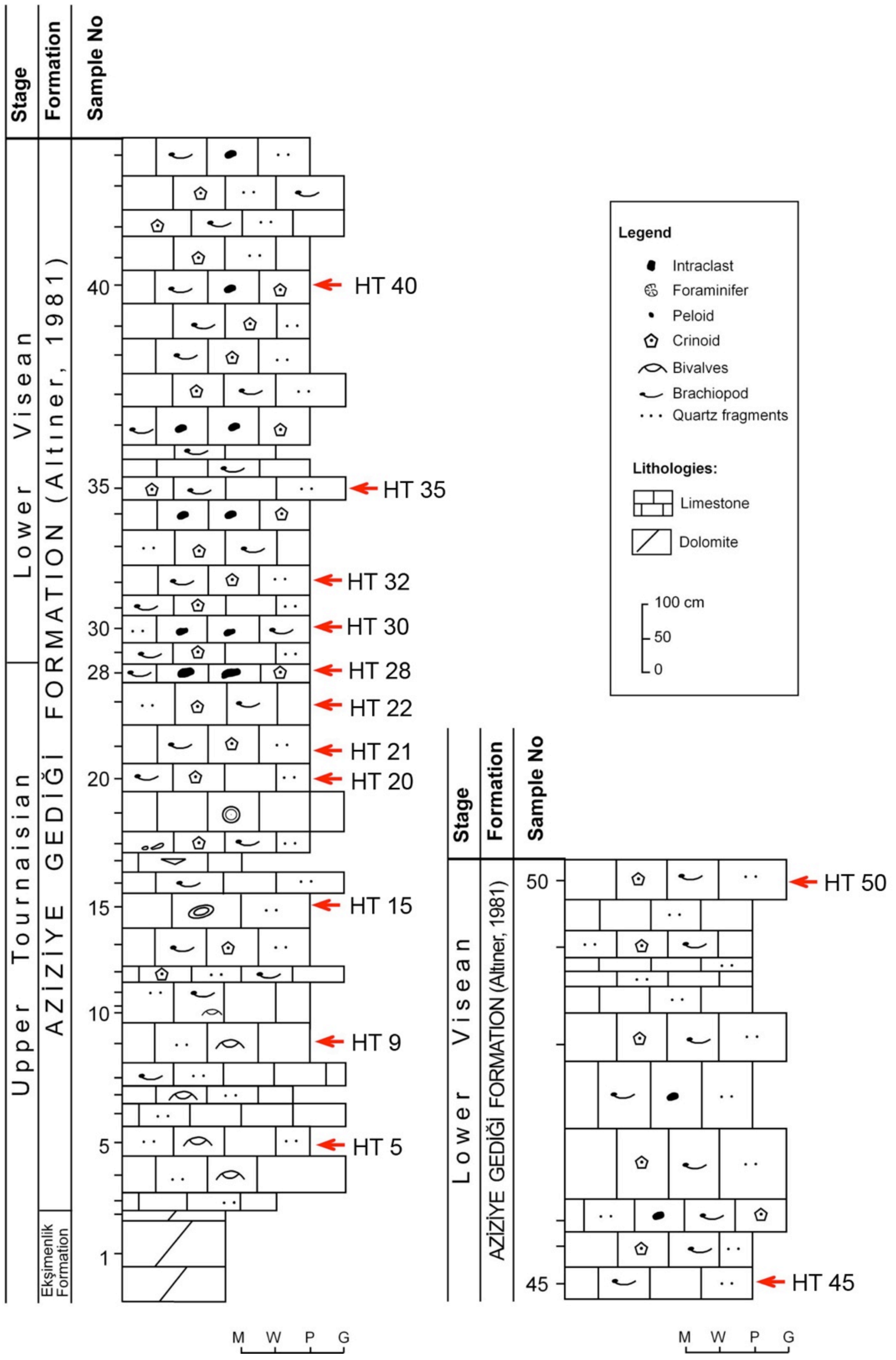


Figure 2.20.Columnar section of the MT section (Melikgazi (Pınarbaşı), Eastern Taurides), the red arrows indicate the conodont sampling points (Özkan-Altıner et al., 2007).

Oruçoğlu Formation overlying the Aziziye Gediği Formation starts at the sample SC-73 (Demirel, 2012). This formation starts with limestones (between samples SC-73 and SC-74) and continues with dark colored, fossiliferous wackestone facies (sample SC-75). This interval is overlain by the quartzarenitic sandstones (samples SC-75A and SC-79), fenestral mudstone (sample SC-80) and shale (sample SC-81). Towards the upper part of the section, packstone and grainstone alternations become dominant (between samples SC-82 and SC-92) (Demirel, 2012). Tournaisian - Visean boundary was located between the samples SC-81 and SC-82 by foraminiferal biostratigraphy (Demirel, 2012). Ten samples for conodont biostratigraphy have been collected through SC-section (Figure 2.22) and no conodont elements have been obtained from these samples.

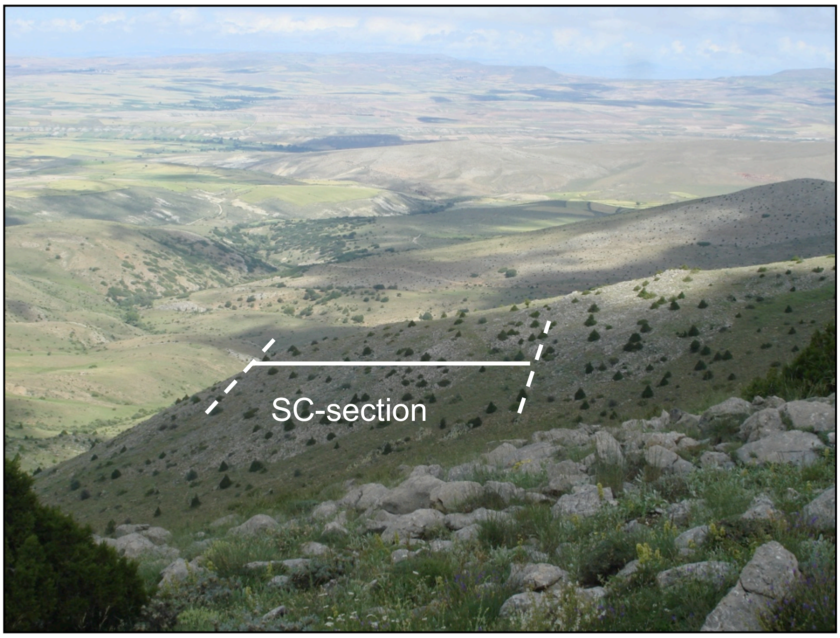


Figure 2.21. Location of the SC section (Melikgazi, Eastern Taurides).

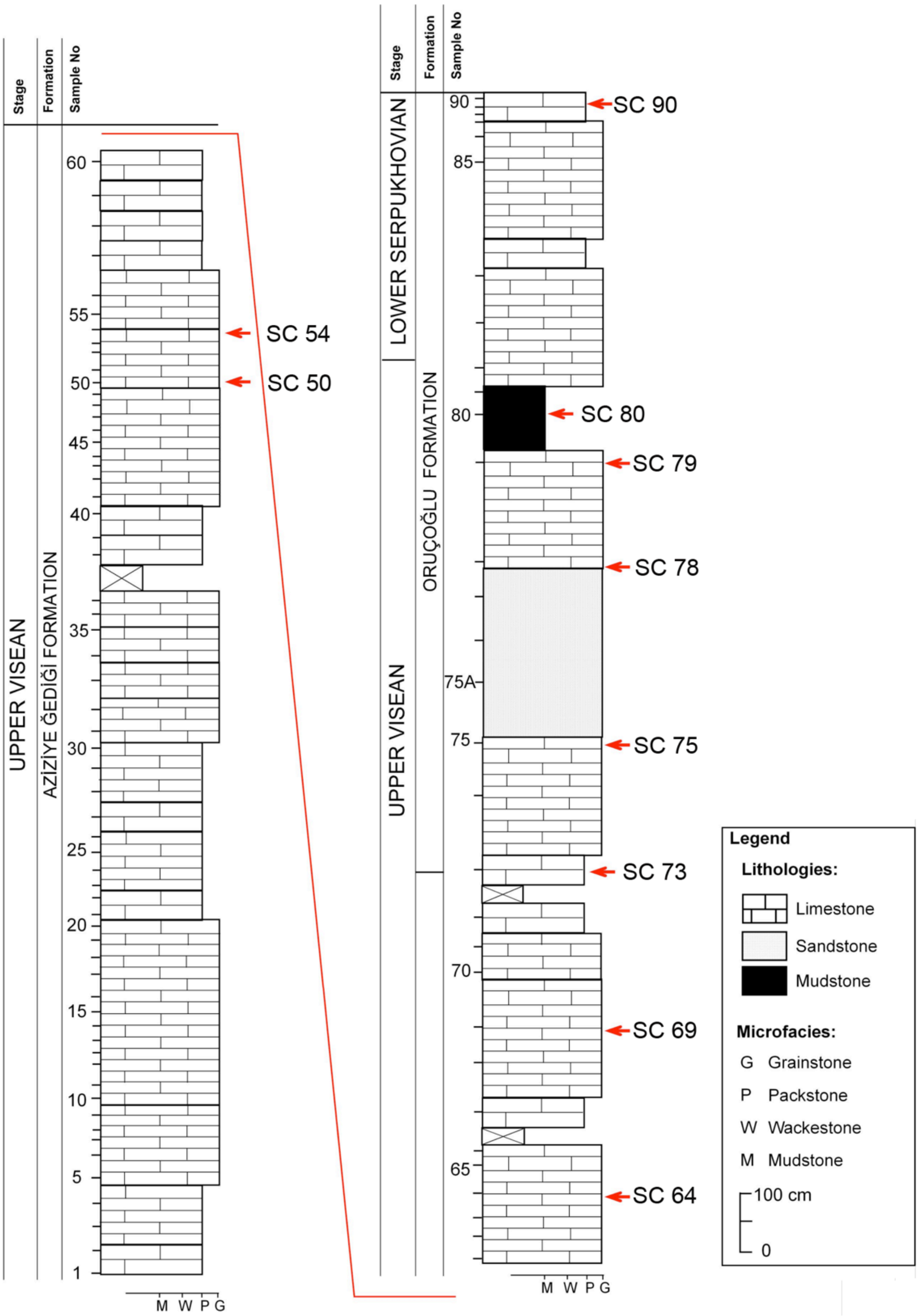


Figure 2.22. Columnar section of the SC section (Melikgazi (Pınarbaşı), Eastern Taurides), the red arrows indicate the conodont sampling points (Demirel, 2012).

2.2.2 Sarız Region

In the study area, Sarız region, Middle and Upper Devonian, Carboniferous, Upper Permian, Jurassic-Cretaceous, Eocene and post-Eocene deposits of the Geyik Dağı Unit are widely exposed (Figure 2.23). Middle Devonian Safak Tepe Formation of the Geyik Dağı Unit comprises neritic carbonates mainly made up of limestones and dolomites. The overlying Upper Devonian Gümüşali Formation is composed of an alternation of limestones, shales and sandstones. The conformably overlying Lower Carboniferous Ziyarettepe Formation is represented by black shales at the bottom and passes upward into shale and limestone alternations. The Middle - Upper Permian Yığılı Tepe Formation overlying unconformably the Ziyarettepe Formation is characterized by shelf carbonate deposits. Among these formations, AS-section was measured within the Lower Carboniferous Ziyarettepe Formation around the Sarız region, in Eastern Taurides.

AS Section:

AS section representing part of the Tournaisian deposits of the Ziyarettepe Formation is characterized by the two main lithologic units, shale and limestone (Figure 2.24). The lower part of the succession includes mainly clayey limestone and shale intercalations and towards the upper part of the section limestone lithology become more dominant (Figure 2.24). The studied succession begins with the spiculite packstone microfacies with abundant sponge spicules interbedded with shales (samples AS-1 and AS-2). This alternation is overlain by the micritic sandstone with abundant quartz grains (sample AS-3). It passes upward into spiculitic packstones and crinoidal bioclastic packstone-grainstones intercalated with shales (between samples AS-4 and AS-7). This interval is overlain by the bioclastic grainstones with abundant ostracodes (sample AS-8). Towards the upper part of the section, micritic sandstones and shales become dominant (samples AS-9 and AS-10). The succession continues with the ostracodal bioclastic grainstones, crinoidal bioclastic packstone-grainstones and shales (between samples AS-11 and AS-13). In order to carry out conodont biostratigraphy, thirteen samples have been collected through the AS-section and the faunal content of these samples will be discussed in detail in the Biostratigraphy Chapter.

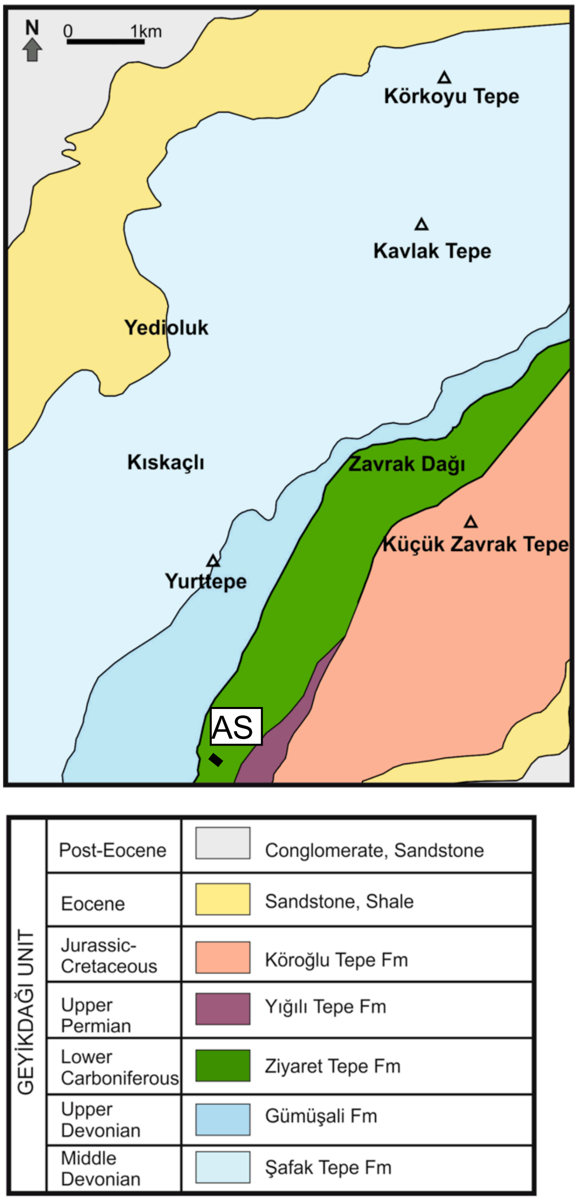


Figure 2.23. Geologic map of the Sarız region in Eastern Taurides (modified from MTA, 2002).

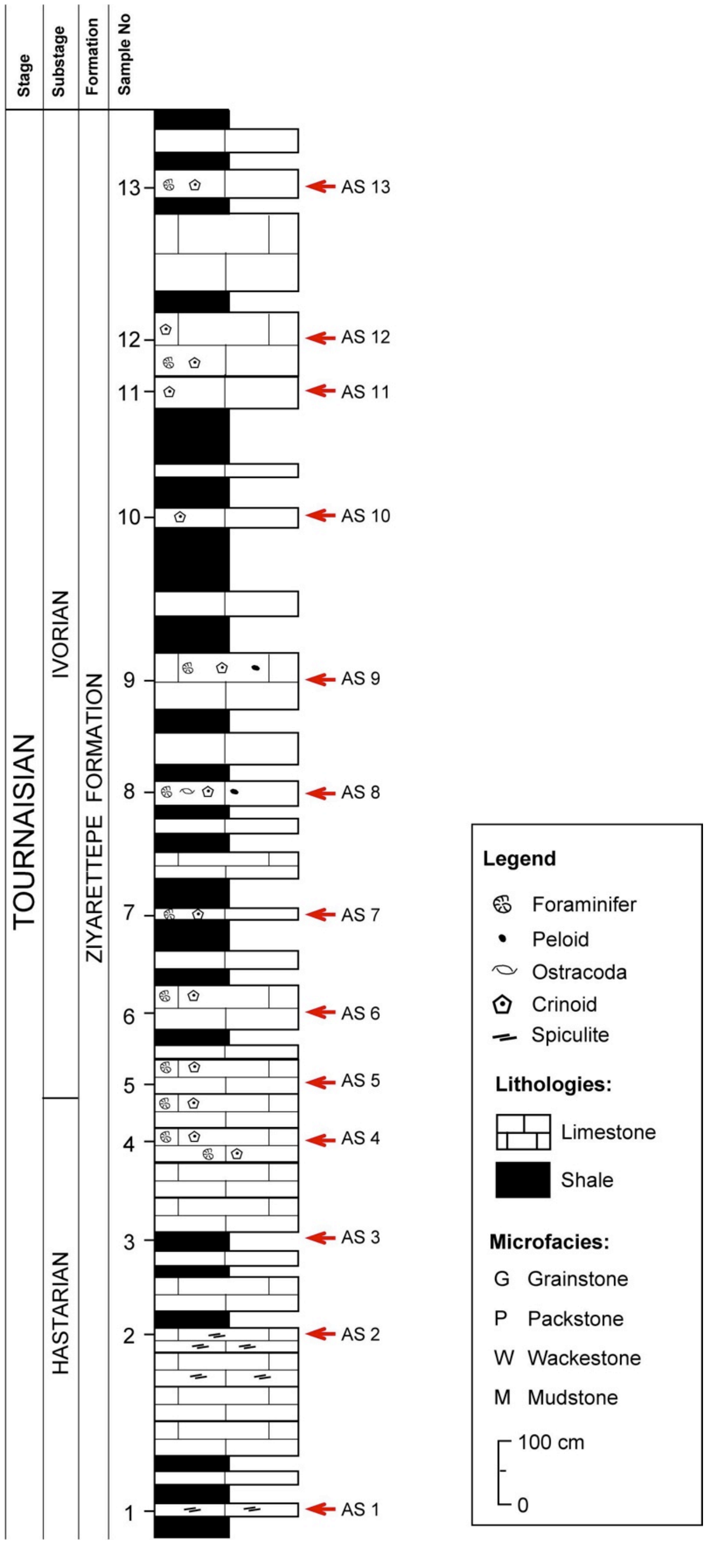


Figure 2.24. Columnar section of the AS section in the Sarız region, Central Taurides. Red arrows indicate the conodont sampling points.

CHAPTER 3

BIOSTRATIGRAPHY

Calcareous foraminifera and conodonts are the most important microfossil groups for the Lower Carboniferous biostratigraphy. Until recently, all Global Boundary Stratotype Sections and Points (GSSP) were defined by index fossils and global correlations achieved by biostratigraphy, other stratigraphic disciplines were seldomly employed. However, multiple stratigraphic methods including biostratigraphy, sequence stratigraphy, stable-isotope geochemistry, and magnetostratigraphy are increasingly being used to supplement biostratigraphy to establish a GSSP.

In this study biostratigraphic framework for the Lower Carboniferous in the Central and Eastern Taurides has been constructed by using conodonts.

3.1 Conodont Biostratigraphy

In addition to foraminifers, conodonts are, undoubtedly, important biostratigraphic tools in the Carboniferous time interval. The conodont succession, although least studied and also some degree proviancial, over the last three decades has become the most reliable tool for the calibration and geochronological boundary definition within the Carboniferous (Davydov et al. 2004 in Gradstein et al. 2004). Some conodont species are excellent index microfossils for the Lower

Carboniferous time period. These are mainly the platform elements (P elements), easily recognized and used generally as time-markers. Although some conodonts are restricted to particular areas, many of them have worldwide distributions.

Conodonts are one of the main microfossil groups used to date and correlate the Lower Carboniferous rocks. Though numerous conodont studies (Metcalfe 1981; Belka 1985; Varker and Sevastopulo 1985; Higgins 1985; Wang 1991; Perret 1993; Perret and Weyant 1994; Nemirovskaya et al. 1994; Skompski et al. 1995; Nemyrovska 2005; Nemyrovska et al. 2006) have been constructed for the Lower Carboniferous biostratigraphy, the zonations of Lower Carboniferous proposed by Lane et al. (1980) and Ziegler and Lane (1987) have been accepted as standard conodont zonation. The preliminary standard conodont zonation defined by Sandberg et al. (1978) is mainly established by the first appearances of *Siphonodella* species. Lane et al. (1980) described a standard zonation for Upper Tournaisian - Lower Visean interval, following the Tournaisian conodont zonation, which is mainly based on the *Siphonodella* zonation of Sandberg et al. (1978). These are generally applicable to open marine offshore deposits. It is difficult to use these zonations in shelf and shallow marine deposits since shallow marine conodonts are different from the open marine ones and they are less diverse and low in abundance. Therefore, different local zones have been suggested and these are correlated with the standard zonation (Groessens, 1974; Varker and Sevastopulo, 1985; Conil et al., 1990; Webster and Groessens, 1990; Matyja et al., 2000).

The zones established in the Mississippian and Pennsylvanian in North America and Europe (Dunn 1970; Lane et al. 1971, 1980; Higgins 1975; Barskov and Alekseev 1975; Sandberg et al. 1978; Barskov et al. 1980) are used world-wide and actively refined (Nemirovskaya and Alekseev

1994; Skompski et al. 1995; Brenckle et al. 1997; Heckel et al. 1998; Nemirovskaya 1999; Lambert et al. 2001; Chernykh 2002).

Several beds within the measured sections in Taurides are barren of conodonts, while others contain not very abundant, but quite differentiated taxa. The measured sections are not rich in conodonts but all important species including those of the Lower Carboniferous boundary conodonts, obtained in the samples. Among the ten studied sections, conodont elements have been gathered from only four of them and of the total 144 samples, only 28 samples yield conodonts. The conodont fauna recovered in the Taurides are less diversified and low in abundance.

Standard Carboniferous conodont zonations proposed by Lane et al. (1980) could not be readily applied to the Tournaisian sections since zonal markers are absent in the studied samples. Due to the absence of *Siphonodella* and other index species of the standard zonation, conodont zones in the studied sections can be correlated to the standard zonation by the presence of associated forms, *Gnathodus*, *Polygnathus* and *Bispathodus*. Of all the studied sections, Lower Carboniferous zonation has been estalished through the AS section cropping out in the Eastern Taurides and the AAO, BSE and HB sections in the Central Taurides. Based on the first appearance of biostratigraphically significant species within these sections, the following zones were established across the Lower Carboniferous time interval in the Taurides (Turkey).

3.1.1 *Polygnathus inornatus* Zone

Definition: The lower boundary of this zone is defined by the first appearance of *Polygnathus inornatus.* The upper boundary is marked by the fist appearance of *Gnathodus cuneiformis.* This zone is an interval zone and characterized by the presence of *Polygnathus inornatus.*

Remarks: The association is limited and the diversity of conodont fauna is very low and dominated by *Polygnathus inornatus* in this interval. The accompanied fauna includes *Hindeodus minutus, Hindeodus cristulus, Bispathodus stabilis, Polygnathus communis communis* and *Polygnathus longiposticus* (Table 3.1, Figure 3.1).

Lane et al. (1980) defined the *Siphonodella isosticha* - Upper *Siphonodella crenulata* standard conodont zone by the presence of important Kinderhookian conodont species. Huber (1986) stated that *Siphonodella isosticha*, *Siphonodella cooperi*, *Siphonodella crenulata, Polygnathus communis communis, Polygnathus inornatus, Polygnathus longiposticus* and *Bispathodus stabilis* are the most important conodont taxa in this zone. The species of *Siphonodella, Siphonodella isosticha*, *Siphonodella cooperi*, *Siphonodella crenulata,* have not been recorded in *Polygnathus inornatus* Zone in this study. However, the main latest Kinderhookian forms, *Polygnathus communis communis, Polygnathus inornatus, Polygnathus longiposticus* and *Bispathodus stabilis,* have been recognized in this zone. Consequently, *Polygnathus inornatus* Zone in this study corresponds to the *Siphonodella isosticha* - Upper *Siphonodella crenulata* standard conodont zone of Lane et al. (1980).

Polygnathus inornatus and *Polygnathus longiposticus* are dominant in the Lower Tournaisian, Latest Kinderhookian stages in North America and Hastarian substage in Europe (Huber, 1986, Bahrami et al., 2011).

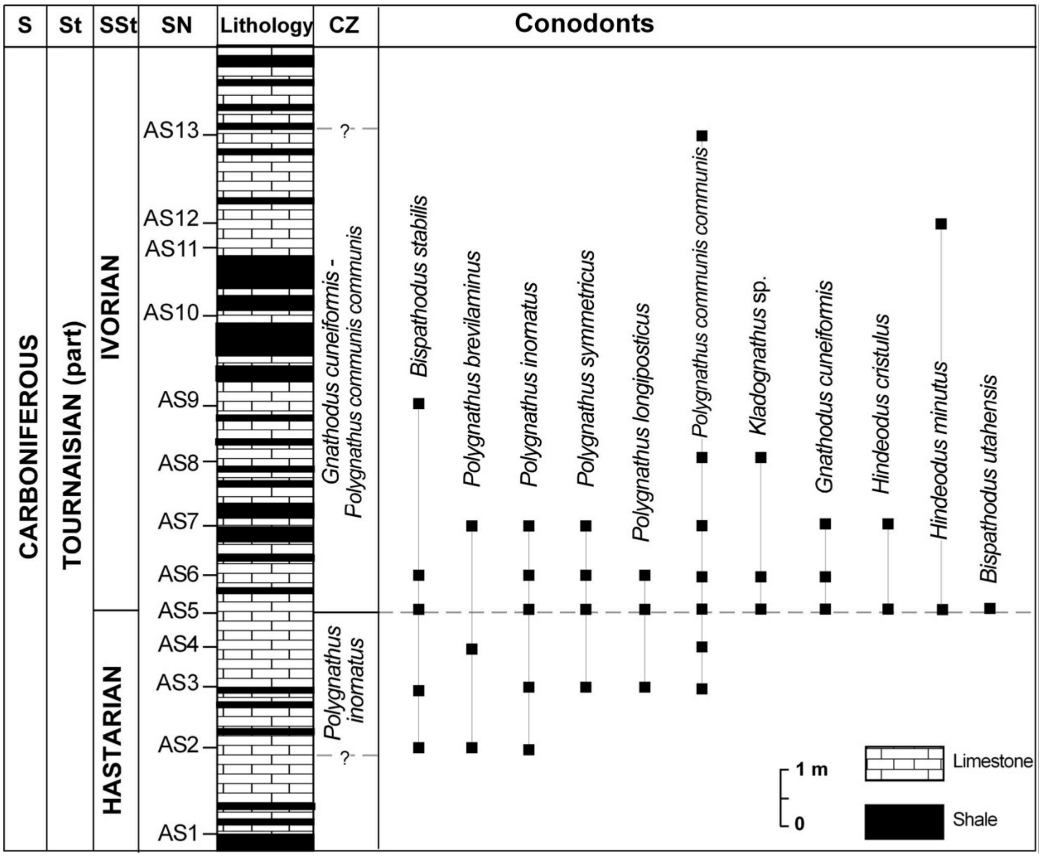


Figure 3.1. The Upper Tournaisian conodont zonation of the AS-section in the Bademli region (S:System, St: Stage, SSt: Substage, SN: Sample Number, CZ: Conodont Zones).

Table 3.1. Stratigraphic distribution and number of conodont elements recorded from the AS section in the Sarız region in the Eastern Taurides.

					Species											**Fragments**				
System	**Stage**	**Substage**	**Conodont Zones**	**Sample No**	*Bispathodus stabilis*	*Polygnathus brevilaminus*	*Polygnathus inornatus*	*Polygnathus symmetricus*	*Polygnathus longiposticus*	*Polygnathus communis communis*	*Kladognathus* sp.	*Gnathodus cuneiformis*	*Bispathodus utahensis*	*Hindeodus cristulus*	*Hindeodus minutus*	P_2 element fragments	M element fragments	S element fragments	Free Blade fragments	Undifferentiated fragments
CARBONIFEROUS	**Tournaisian (part)**	**Ivorian (part)**	*Gnathodus cuneiformis - Polygnathus communis communis*	AS13						1										
				AS12											2					
				AS11												1		2	2	1
				AS10																
				AS9	1													10	1	5
				AS8						7	4						1	28	1	8
				AS7		2	2	2		6		2		2		3	1	15		9
				AS6	2		3	1	3	8	2	1				2	8	53	5	17
				AS5	3		57	12	10	22	5	2	7	2	3	28	12	124	12	128
		Hastarian (part)	*Polygnathus inornatus*	AS4		1				2						2		7		5
				AS3	1		4	1	2	2								10	1	16
				AS2	2	1	1											4		1
			?	AS1																

The described *Polygnathus inornatus* Zone in this study can be correlated with the *Siphonodella isosticha* - Upper *Siphonodella crenulata* Zone of standard conodont zonation in North America (Lane et al., 1980) and in the Carnic Alps (Perri and Spattella, 1998); the *Mestognathus harmalai* Zone (von Bitter et al., 1986); the *Gnathodus delicatus* Zone in Polland (Belka, 1985); *Polygnathus inornatus* - *Gnathodus* Zones in Western Europe (Varker and Sevastopulo, 1985; Jones and Sommerville, 1996; Poty et al., 2006) and *Siphonodella* Zone in Belgium (Groessens, 1976) (Table 3.2).

Poty et al. (2006) described four Mississippian Foraminiferal Zones in Hastarian substage (MFZ1-MFZ4). They stated that the MFZ4 identified by the appearance of tuberculate endotyrids includes conodont *Siphonodella* species and *Polygnathus inornatus*. In the studied section in the Eastern Taurides, *Polygnathus inornatus* zone is defined by the presence of *Polygnathus inornatus* so this conodont zone corresponds to the MFZ4 (Mississippian Foraminiferal Zone) defined by Poty et al. (2006).

Stratigraphic distribution: From the sample AS-2 to the sample AS-4.

Age: Hastarian (Tournaisian).

Table 3.2. Comparision of Tournaisian conodont zonation schemes.

	Stage	**N.A. Stage**	**Substage**	**Turkey Central Taurides** (This Study)	**North America Standard Conodont Zonation** (Lane et al. 1980)	**Mestognathus based Conodont Zones** (von Bitter et al. 1986)	**Polland** (Belka 1985)	**Carnic Alps** (Perri & Spalletta 1998)	**Europe** (Riley 1995 Jones & Sommerville 1996 Poty et al. 2006)	**Belgium** (Groessens 1976)
Carboniferous (part)	**Tournaisian (part)**	**Osagean**	**Ivorian**	*G. cuneiformis*	Lower *G. typicus*	*M. harmalai*	*G. cuneiformis*	Lower *G. typicus*	*Ps. multistriatus*	*P. communis carina*
		Kinderhookian	***Hastarian***	*P. inornatus*	*S. isosticha – Upper S. crenulata*		*G. delicatus*	*S. isosticha – Upper S. crenulata*	*Gnathodus* *P.inornatus*	*Siphonodella*

3.1.2 *Gnathodus cuneiformis - Polygnathus communis communis* Zone

Definition: The first occurrence of *Gnathodus cuneiformis* defines the base of this zone. This zone is characterized by the presence of the marker species and *Polygnathus communis communis.* The upper boundary of this zone could not be recognized within the studied section.

Remarks: The associated fauna in this zone includes *Polygnathus communis communis, Polygnathus inornatus, Polygnathus longiposticus, Polygnathus symmetricus, Bispathodus stabilis, Bispathodus utahensis* and *Kladognathus* sp. (Figure 3.1, Table 3.1).

This zone is equivalent to lower *typicus* zone of Lane et al. (1980). Based on Lane et al. (1980) the lower *typicus* is defined by the first appearance of *Gnathodus typicus* morhotype 2. Additionally, they stated that the first occurrence of *Gnathodus cuneiformis* is one of the main events at the base of this zone.

Belka (1985) proposed a conodont zonation named as *cuneiformis* Zone to substitute the *typicus* Zone of Lane et al. (1980) because of the low frequency of the *Gnathodus typicus* in the Carboniferous of Europe. According to Belka (1985), the distribution of *Gnathodus cuneiformis* overlaps the stratigraphic distribution of *Gnathodus typicus* morphotype 2. Some authors reported that the first appearance of *Gnathodus cuneiformis* is rather above the first appearance of *Gnathodus typicus* morphotype 2. Belka (1985) stated that *Gnathodus cuneiformis* should be used as biozonal marker since it is well documented both in the European and in the North American rocks. In Carnic Alps *Gnathodus cuneiformis* occurs in high frequency so Perri and Spalletta (1998) recognized this zone by the first appearance of this species together with the disappearance of *Siphonodella*. Likewise, Haywa-Branch and Barrick (1990) defined the *typicus* zone of Lane et al. (1980) within Welden limestone in Southern Oklahoma by the first appearance of *Gnathodus cuneiformis* and *Gnathodus typicus* morphotype 2.

The base of this zone also corresponds to the boundary between Hastarian (Lower Tournaisian) and Ivorian (Upper Tournaisian) substages in Belgium; Ceherepetsky and Kiselovsky Horizons in Russian Platform and Kinderhookian and Osagean stages in North America. Chen et al. (1994) reported that the first appearance of *Polygnathus communis carina* and *Polygnathus multistriatus* defines the Kinderhookian - Osagean boundary. According to Collinson et al. (1962), Straka (1968) and Sandberg (1979) the last occurrence of *Siphonodella* is the boundary marker for the Kinderhookian – Osagean boundary. Groessens (1974, 1976) stated that the first appearance of *Polygnathus multistriatus* is also a potential boundary marker. Other proposals for the delineation of this boundary include the first occurrence of *Gnathodus typicus* (Webster and Groessens, 1990), *Gnathodus cuneiformis* (Belka, 1985 and 1991) and *Gnathodus semiglaber* (Wang, 1991). Moreover, at the Kinderhookian - Osagean boundary the genus *Siphonodella* became extinct (Groessens, 1976; Mory and Crane, 1982).

While the elements of *Gnathodus typicus, Polygnathus multistriatus* have not been recognized in our studied samples, those of *Gnathodus cuneiformis* have been recorded. Consequently, this zone in the Taurides is defined by the first appearance of *Gnathodus cuneiformis*.

The defined *Gnathodus cuneiformis – Polygnathus communis communis* zone in Taurides, Turkey can be comparable with the Lower *Gnathodus typicus* Zone of standard conodont zonation in North America (Lane et al., 1980) and in Carnic Alps (Perri and Spattella, 1998); the *Mestognathus harmalai* Zone (von Bitter et al., 1986); the *Gnathodus cuneiformis* Zone in Polland (Belka, 1985); *Polygnathus multistriatus* Zone in Western Europe (Varker and Sevastopulo, 1985; Jones and Sommerville, 1996; Poty et al., 2006) and *Polygnathus communis carina* Zone in Belgium (Groessens, 1976) (Table 3.2).

Poty et al. (2006) described four Mississippian Foraminiferal Zones in Ivorian substage (MFZ5-MFZ8). They stated that the MFZ5 corresponds to the *Polygnathus communis carina* Zone. In the studied section in the Eastern Taurides, *Gnathodus cuneiformis* Zone is equivalent to the *Polygnathus communis carina* Zone so it matches with the MFZ5 (Mississippian Foraminiferal Zone) defined by Poty et al. (2006).

Stratigraphic distribution: From the sample AS-5 to the sample AS-13.

Age: Ivorian (Late Tournaisian).

3.1.3 *Polygnathus mehli mehli* Zone

Definition: This zone defined by the occurrence of Upper Tournaisian conodont species, *Polygnathus mehli mehli*. The lower boundary of this zone was drawn by the first appearance of the marker taxon. The upper boundary was defined by the last appearance of *Polygnathus mehli mehli* and Polygnathus *communis communis.*

Remarks: The most significant coexisting conodont taxa are *Gnathodus cuneiformis, Hindeodus cristulus, Hindeodus minutus, Kladognathus* sp. and *Vogelgnathus campbelli* (Figure 3.2, Table 3.3).

Two coeval conodont assemblages have been documented in late Tournaisian; a deep-water outer shelf and basin assemblage characterized by (1) *Siphonodella;* (2) *Polygnathus communis carina* and (3) *Scaliognathus anchoralis* zones, and a shallow-water shelf assemblage including (1) *Polygnathus spicatus*; (2) *Polygnathus inornatus*; (3) *Pseudopolygnathus multistriatus* and (4) *Polygnathus mehli* zones (Somerville and Jones, 1985; Varker and Sevastopulo, 1985; Somerville et al., 1992; Jones and Somerville, 1996; Somerville, 2008). The distribution of the subspecies of *Polygnathus mehli* is restricted to Upper Tournaisian rocks.

The studied Upper Tournaisian in the Hadim region, the Central Taurides mainly consists of shallow water limestone facies so the deep-water conodont assemblages could not be recognized. Consequently, based on the shallow water conodont assemblages, the *Polygnathus mehli mehli* zone has been defined in the Taurides, Turkey.

Polygnathus mehli mehli zone is equivalent to the *Scaliognathus anchoralis - Doliognathus latus* Zone of standard conodont zonation in North America (Lane et al., 1980) and in Carnic Alps (Perri and Spattella, 1998); the *Mestognathus praebeckmani* Zone (von Bitter et al., 1986); the *Scaliognathus anchoralis* Zone in Polland (Belka, 1985) and in Belgium (Groessens, 1976); *Polygnathus mehli* Zone in Europe (Varker and Sevastopulo, 1985; Jones and Sommerville, 1996; Poty et al., 2006) (Table 3.4).

Poty et al. (2006) reported that MFZ6 coexists with the conodont species within the upper *Gnathodus typicus* Zone to lower *Siphonodella anchoralis* Zone and conodont assemblages of MFZ7 indicate the upper part of the *Siphonodella anchoralis* Zone. Consequently, *Polygnathus mehli mehli* zone corresponds to MFZ6 and MFZ7 foraminiferal zones of Poty et al. (2006).

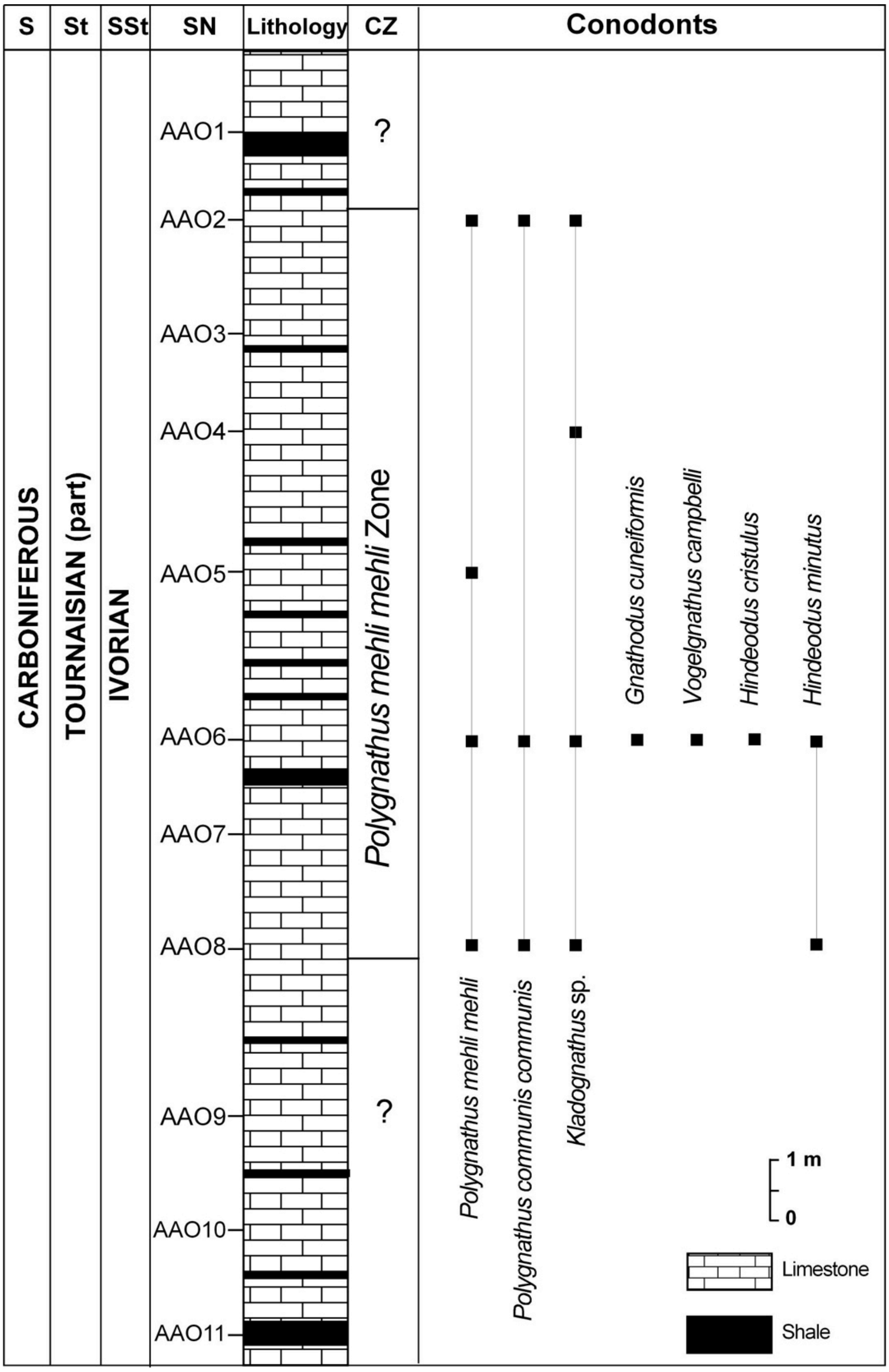


Figure 3.2. The Upper Tournaisian conodont zonation in the AAO section in the Hadim region (S:System, St: Stage, SSt: Substage, SN: Sample Number, CZ: Conodont Zones).

Table 3.3. Distribution and number of conodont elements recorded from the AAO section in the Hadim region in the Central Taurides.

					species							fragments				
System	**Stage**	**Substage**	**Conodont Zones**	**Sample No**	*Polygnathus mehli mehli*	*Kladognathus* sp.	*Polygnathus communis communis*	*Gnathodus cuneiformis*	*Vogelgnathus campbelli*	*Hindeodus cristulus*	*Hindeodus minutus*	P_2 element fragments	M element fragments	S element fragments	Free Blade fragments	Undifferentiated fragments
CARBONIFEROUS	**Tournaisian (part)**	**Ivorian (part)**	?	AAO 1												
			Polygnathus mehli mehli	AAO 2	2	1	2							1	1	
				AAO 3												
				AAO 4		1									1	
				AAO 5	7									1	2	4
				AAO 6	8	8	11	1	2	2	2	1	1	12	2	6
				AAO 7												
				AAO 8	1	12	6				1	1	6	10	3	9
			?	AAO 9												
				AAO 10												
				AAO 11												

Stratigraphic distribution: From the sample AAO-2 to the sample AAO-8.

Age: Ivorian (Late Tournaisian).

3.1.4 *Gnathodus girtyi girtyi* Zone

Definition: The lower boundary of this zone is defined by the first appearance of the *Gnathodus girtyi girtyi*. The top of this zone is marked by the first appearance of *Gnathodus girtyi simplex.*

Remarks: The defined *Gnathodus girtyi girtyi* Zone in the Taurides yields long ranging conodont taxa including *Gnathodus girtyi girtyi, Lochriea commutata* and *Kladognathus* sp. (Table 3.5, Figure 3.3).

Sweet (1988) stated that *Gnathodus girtyi* has a long stratigraphic range from earliest Visean to latest Namurian. Metcalfe (1981) reported the first occurrence of *Gnathodus girtyi girtyi* at the base of *Gnathodus bilineatus* Zone in the Asbian substage but Varker and Sevastopulo (1985) recorded this subspecies earlier, especially from Arundian stage. Skompski (1996) reported this taxon mainly in upper Visean rocks in the Lublin Basin (Poland). In this study the elements of *Gnathodus girtyi girtyi* have been described from Upper Visean to Lower Serpukhovian rocks.

Table 3.4. Comparision of Upper Tournaisian conodont zonation schemes.

	Stage	**N.A. Stage**	**Substage**	**Turkey Central Taurides** (This Study)	**North America Standard Conodont Zonation** (Lane et al. 1980)	**Mestognathus based Conodont Zones** (von Bitter et al. 1986)	**Polland** (Belka 1985)	**Carnic Alps** (Perri & Spalletta 1998)	**Europe** (Riley 1995 Jones & Sommerville 1996 Poty et al. 2006)		**Belgium** (Groessens 1976)
Carboniferous (part)	**Tournaisian (part)**	***Osagean***	***Ivorian***	*P. mehli mehli*	*Sc. anchoralis - D. latus*	*M. praebeckmani*	*Sc. anchoralis*	*Sc. anchoralis – D. latus*	*Sc. anchoralis* *D. latus* *D. bouckaerti* *P.mehli* *Ps. multistriatus*	*P.mehli*	*Sc. anchoralis*
										Ps. multistriatus	

Gnathodus girtyi girtyi zone is equivalent to the *Gnathodus girtyi collinsoni* in Great Britain and England (Higgins 1985); the *Lochriea nodosa* Zone in Southern Urals (Nikolaeva et al. 2009; Pazukhin et al., 2010), in Moscow Basin (Alekseev et al. 2004), in Spain (Nemyrovska 2005); in South China (Wang and Qi 2003) and in Northern Urals (Zhuravlev 2003) and the *Gnathodus girtyi girtyi* - *Paragnathus mononodus* Zone in the Donets Basin (Nemyrovska 1983, 1985, 1999) (Table 3.6).

The beds including the MFZ15 foraminiferal assemblages corresponding to the Upper Visean to Lowermost Serpukhovian, contain *Gnathodus girtyi, Lochriea commutata, Lochriea cruciformis* and *Cavusgnathus naviculus* conodont taxa (Bouckaert and Higgins, 1964; Higgins and Bouckaert, 1968; Poty et al. 2006). *Gnathodus girtyi girtyi* zone corresponds to the MFZ15 of Poty et al. (2006) due to the presence of conodont assemblages of *Gnathodus girtyi girtyi, Lochriea commutata* and *Kladognathodus* sp..

Stratigraphic distribution: From the sample BSEc-2 to the sample BSEc-6.

Age: Late Visean.

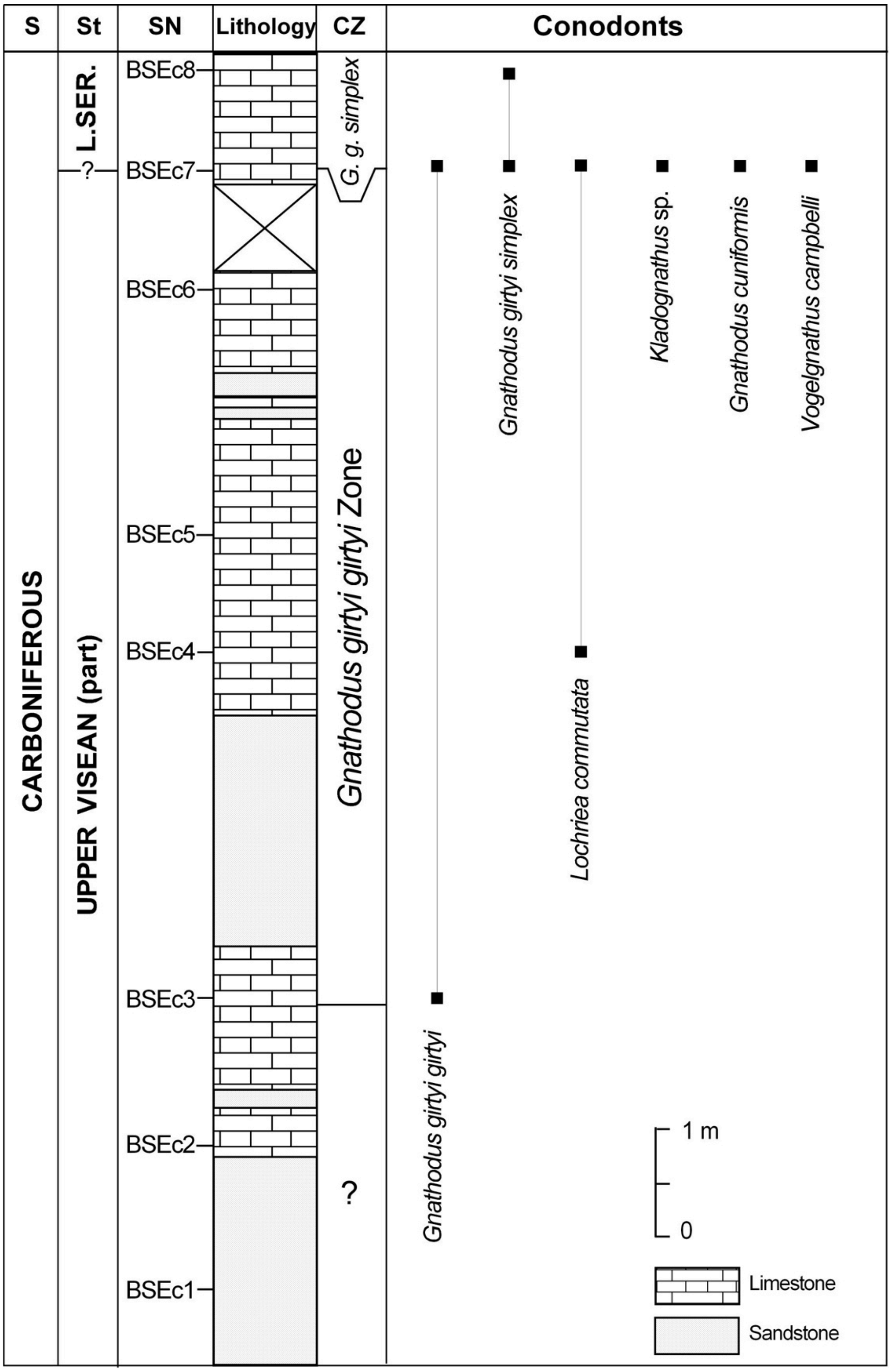


Figure 3.3. The Visean - Serpukhovian boundary conodont zonation in the BSE section in the Bademli region in the Central Taurides (S:System, St: Stage, SN: Sample Number, CZ: Conodont Zones).

Table 3.5. Distribution and number of conodont elements recorded from the BSE section in the Bademli region in the Central Taurides.

				species						fragments				
System	**Stage**	**Conodont Zones**	**Sample No**	*Gnathodus girtyi girtyi*	*Gnathodus girtyi simplex*	*Gnathodus cuneiformis*	*Kladognathus* sp.	*Lochriea commutata*	*Vogelgnathus campbelli*	P_2 element fragments	M element fragments	S element fragments	Free Blade fragments	Undifferentiated fragments
CARBONIFEROUS	**L. Ser. (part)**	*G. girtyi simplex*	BSEc 8		1								1	2
			BSEc 7	7	5	2	1	2	2	1	2	1	5	15
	Upper Visean (part)	*Gnathodus girtyi simplex*	BSEc 6											
			BSEc 5											
			BSEc 4					1			2		2	3
			BSEc 3									2	1	4
			BSEc 2	3								1		8
		?	BSEc 1											

3.1.5 *Gnathodus girtyi simplex* Zone

Definition: Only the lower boundary of *Gnathodus girtyi simplex* Zone can be defined in the studied section. The lower limit of this zone is marked by the first appearance of the index species.

Remarks: The accompanied conodont fauna contains *Lochriea commutata*, *Gnathodus girtyi girtyi, Gnathodus cuneiformis, Polygnathus mehli mehli, Vogelgnathus campbelli* and *Kladognathus* sp. (Table 3.5, Figure 3.3). This zone includes long ranging taxa like *Lochriea commutata* and *Kladognathus* sp.. The stratigraphic range of the former is Visean through Serpukhovian.

Table 3.6. Comparision of Visean-Serpukhovian boundary conodont zonation schemes.

System	Stage	**Turkey Central Taurides** (This Study)	**Great Britain & England** (Higgins 1985)	**Donets Basin** (Nemyrovska 1983, 1985, 1999)	**Moscow Basin** (Alekseev et al. 2004)	**Southern Urals** (Nikolaeva et al. 2009a,b, Pazukhin et al. 2010)	**Northern Urals** (Zhuravlev 2003)	**South China** (Wang and Qi 2003)	**Spain** (Nemyrovska 2005)
Carboniferous	**Serpukhovian (part)**	*Gnathodus girtyi simplex*	*Kladognathus - Gnathodus girtyi simplex*	*Gnathodus girtyi girtyi – Paragnathus mononodosus*	*Lochriea ziegleri*	*Lochriea ziegleri*	*Lochriea cruciformis*	*Lochriea ziegleri*	*Lochriea ziegleri*
	Visean (part)	*Gnathodus girtyi girtyi*	*Gnathodus girtyi collinsoni*		*Lochriea nodosa*	*Lochriea nodosa*	*Lochriea nodosa*	*Lochriea nodosa*	*Lochriea nodosa*

Gnathodus girtyi simplex is an important conodont taxon that became extinct at the Mid-Carboniferous boundary. This species originated at the bae of Serpukhovian and evolved from the *Gnathodus girtyi girtyi*. *Gnathodus girtyi simplex* has been described in the lowest Serpukhovian beds in the Cantabrian Mountains, Spain (Nemyrovska 2005) and in the Southern Urals (Pazukhin et al. 2010).

Gnathodus girtyi simplex zone is equivalent to the *Kladognathodus* sp. - *Gnathodus girtyi simplex* in Great Britain (Higgins 1985); the *Lochriea ziegleri* Zone in the Southern Urals (Nikolaeva et al. 2009; Pazukhin et al., 2010), in the Mocow Basin (Alekseev et al. 2004), in Spain (Nemyrovska 2005) and in South China (Wang and Qi 2003); the *Gnathodus girtyi girtyi - Paragnathus mononodus* Zone in the Donets Basin (Nemyrovska 1983, 1985, 1999) and the *Lochriea cruciformis* Zone in the Northern Urals (Zhuravlev 2003) (Table 3.6).

Poty et al. (2006) defined the foraminiferal zone MFZ15 by the apperance of *Janischewskina typica and* they reported *Gnathodus girtyi, Lochriea commutata* and *Cavusgnathus naviculus* as the coexisting conodont taxa. The beds corresponding to *Gnathodus girtyi simplex* zone is equal to MFZ15 of Poty et al. (2006).

Stratigraphic distribution: From the sample BSEc-7 to the sample BSEc-8.

Age: Serpukhovian.

3.1.6 *Rhachistognathus muricatus* Zone

Definition: This zone is characterized by the presence of *Rhachistognathus muricatus*. The top of the zone is marked by the first appearance of *Declinognathodus inaequalis*. The lower boundary cannot be defined because of the absence of conodonts in the underlying levels.

Remarks: Typical Mississippian taxa that occur within this zone include *Rhachistognathus minutus minutus, Rhachistognathus minutus declinatus, Gnathodus girtyi simplex, Declinognathodus bernesgae, Adetognathodus lautus* and *Kladognathus* sp. (Figure 3.4, Table 3.7). *Gnathodus girtyi simplex* has been reported together with *Declinognathodus noduliferus* in Nevada (Baesemann and Lane, 1985) however, in our section *Gnathodus girtyi simplex* recorded below the first appearance of *Declinognathodus noduliferus*. Previous studies (Baesemann and Lane 1985; Brenckle et al. 1997; Lane et al. 1999) indicated that mid-Carboniferous boundary has been defined by the first occurrence of *Declinognathodus* taxa however, recent studies (Sanz-Lopez et al. 2006; Sanz-Lopez and Blanco-Ferrera 2009; Nemyrovska et al. 2008; Nemyrovska 2009) suggested that *Declinognathodus noduliferus bernesgae* and *Declinognathodus praenoduliferus* appear below the first appearance of *Declinognathodus ineaqualis*. In our studied section, *Declinognathodus bernesgae* occur just below the mid-Carboniferous boundary, as well. Baesemann and Lane (1985) and Lane et al. (1999) defined this latest Mississippian zone at the Arrow Canyon by the appearance of the index species *Rhachistognathus muricatus, Gnathodus bilineatus* and *Cavusgnathus unicornis.*

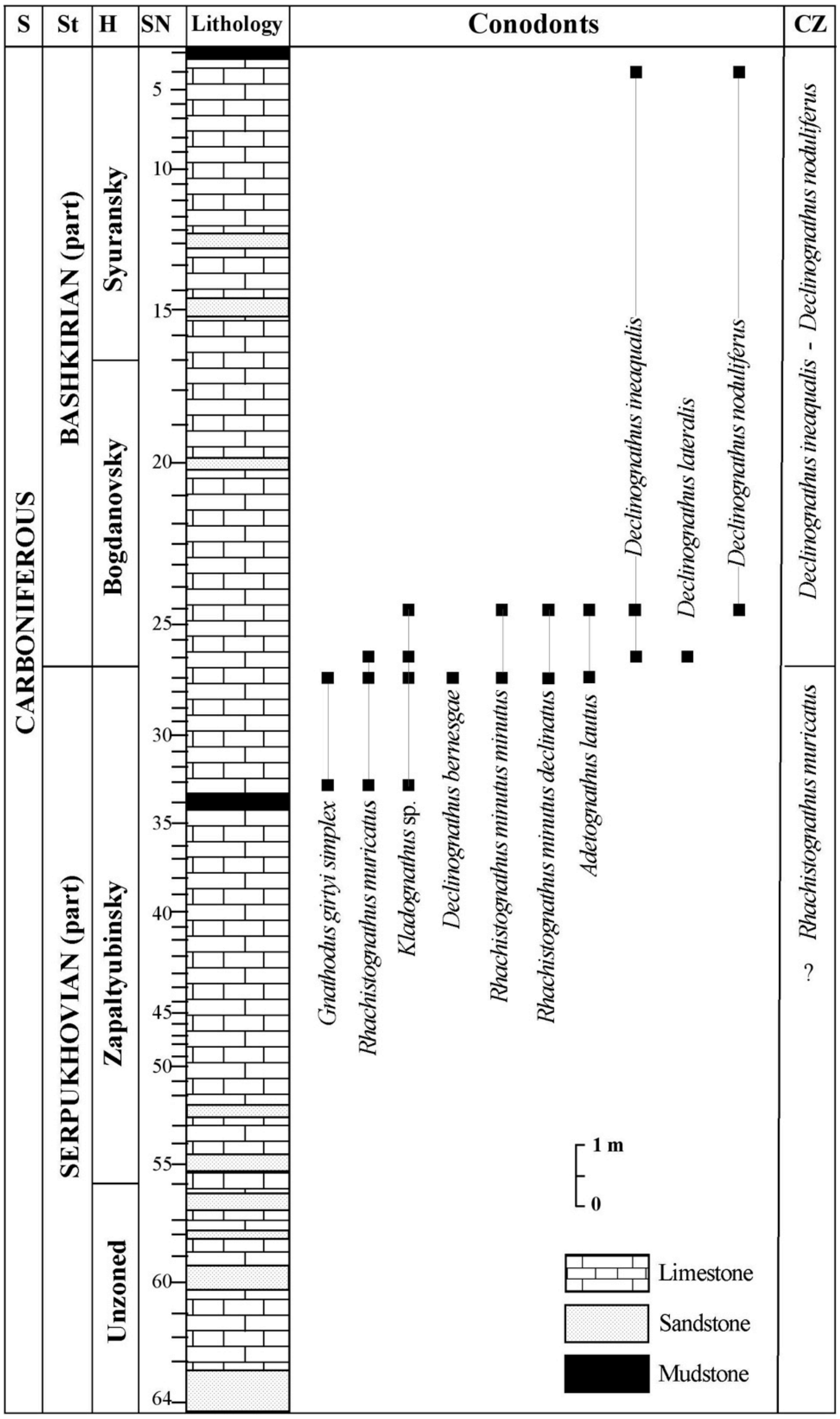


Figure 3.4. The Mid-Carboniferous boundary delineated by the conodont occurrences in the HB section in the Hadim region in the Central Taurides (S: System, St: Stage, H: Horizon, SN: Sample Number, CZ: Conodont Zones).

Table 3.7. Stratigraphic distribution and number of conodont elements recovered from the HB section in the Hadim region in the Central Taurides.

					species										**fragments**				
System	**Stage**	**Horizon**	**Conodont Zones**	**Sample No**	*Gnathodus girtyi simplex*	*Rhachistognathus muricatus*	*Kladognathus* sp.	*Declinognathodus bernesgae*	*Rhachistognathus minutus minutus*	*Rhachistognathus minutus declinatus*	*Adetognathus lautus*	*Declinognathodus inaequalis*	*Declinognathodus noduliferus*	*Declinognathodus lateralis*	P2 element fragments	M element fragments	S element fragments	Free Blade fragments	Undifferentiated fragments
Mid-Carboniferous	**Lower Bashkirian**	**Syuransky**	*Declinognathodus inaequalis - Declinognathodus noduliferus*	HB03															
				HB04								5	3					1	3
				HB07											1		1		12
				HB09															
				HB11															2
		Bogdanovsky		HB16															
				HB19															
				HB22															
				HB24			3		4	1	3	1	1	2			1	2	3
				HB25															
				HB26															
				HB27		2	1					11		4	1		1	3	6
	Upper Serpukhovian	**Zapaltyubinsky**	*Rhachistognathus muricatus*	HB28	3	6	1	7	10	1	3				1	1	4	3	33
				HB29															
				HB30															
				HB33	3	1	1										1		3
				HB34															
				HB36															
				HB40															
				HB42															

Gnathodus bilineatus, a common element in most uppermost Mississippian conodont zonation schemes is notably absent in the Mid-Carboniferous beds of the Taurides. Higgins (1975), Riley et al. (1987) and Varker et al. (1990) reported that the appearance of *Rhachistognathus minutus* is below that of *Declinognathodus noduliferus* s.l. and its first occurrence is within the Late Mississippian in England. Lane et al. (1999) reported the first appearance of *Rhachistognathus minutus* above the *noduliferus-primus* zone. Krumhardt et al. (1996) concluded that *Rhachistognathus minutus* appeared earlier in Europe than in North America.

Rhachistognathus muricatus zone of Taurides, Turkey can be correlated with the *Rhachistognathus muricatus* zones of the GSSP in the Arrow Canyon, Nevada (Lane et al. 1999); the *Gnathodus postbilineatus* Zone and the *Gnathodus bilineatus – Adetognathus unicornis* Zone in the Donets Basin, Ukraine (Nemyrovska 1999); the *Gnathodus bilineatus* Zone in the Hina Limestone, Japan (Mizuno 1997) and the Kizil Formation, Southern Urals (Kulagina et al. 2001); the *Gnathodus bilineatus bollandensis* zone in the Nashui section, South China (Wang & Qi 2003) and the Aksu Section, Uzbekistan (Nemirovskaya & Nigmadganov 1994) (Table 3.8). This zone is equivalent to the latest Serpukhovian, Zapaltyubinsky horizon of the type Serpukhovian succession on the Russian Platform and Zapaltyubinsky-equivalents in the Donets Basin, Ukraine.

Rhachistognathus muricatus zone corresponds to the upper part of the *Eostaffella* ex gr. *ikensis-Eostaffella postmosquensis* zone along the same stratigraphic section and assigned to the late Serpukhovian (Zapaltyubinsky) (Atakul-Özdemir et al., 2011). This foraminiferal zone was defined in Atakul-Özdemir et al. (2011) by the overlapping ranges of two taxa, *Eostaffella* ex gr. *ikensis* and *E. postmosquensis* and was considered to be equivalent to the Zapaltyubinsky Horizon in the

Russian Platform and Donets Basin (Vachard & Maslo 1996; Shcherbakov 1997) to the E2 Zone in the Western Europe (Vdovenko et al. 1990; Shcherbakov 1997) and to the Ustsarbaisky Horizon in Urals.

Stratigraphic distribution: From the sample HB-33 to the sample HB-28.

Age: Zapaltyubinsky Horizon (Upper Serpukhovian).

3.1.7 *Declinognathodus inaequalis - Declinognathodus noduliferus* Zone

Definition: The base of this zone is defined on the first occurrence of *Declinognathodus inaequalis* and its top is marked by the apparent last occurrence of, *D. inaequalis* or the apparent last occurrence of *D. noduliferus*.

Remarks: In addition to the eponymous species, other taxa recorded from this zone are *Rhachistognathus minutus minutus, R. minutus declinatus, R. muricatus, Declinognathodus lateralis, Adetognathodus lautus* and *Kladognathus* sp. (Figure 3.4, Table 3.7). The Mid-Carboniferous boundary coincides with the base of this zone. The Mississippian conodont *Gnathodus girtyi simplex* became extinct and the first Pennsylvanian conodonts *Declinognathodus lateralis, D. noduliferus* and *D. inaequalis* originated in this zone.

Declinognathodus inaequalis – Declinognathodus noduliferus zone of the Taurides, Turkey can be correlated with the *Declinognathodus noduliferus* s.l. zone in the Arrow Canyon, Nevada (Lane et al. 1999); the *Declinognathodus noduliferus* zone in the Donets Basin, Ukraine (Nemyrovska 1999), in the Kizil Formation, Southern Urals (Kulagina et al. 2001) and in the Nashuie Section, South China (Wang & Qi 2003); the *Declinognathodus inaequalis – Gnathodusbilineatus* zone and *Declinognathodus noduliferus* zone in the Hina Limestone, Japan (Mizuno 1997) and the *Declinognathodus praenoduliferus* zone and *Declinognathodus noduliferus* zone in the Aksu Section, Uzbekistan (Nemirovskaya & Nigmadganov 1994) (Table 3.8). This zone is equivalent to the lowest Bashkirian, Bogdanovsky and lowest Syuransky horizons.

Declinognathodus inaequalis - Declinognathodus noduliferus zone corresponds to three foraminiferal zones defined by Atakul-Özdemir et al. (2011) in the lowermost Bashkirian rocks of the same stratigraphic section in the Central Taurides. Among these zones, the lower one, the *Plectostaffella bogdanovkensis – P. jakhensis* zone, is defined as the interval from the last appearance of *Eostaffella* ex gr. *ikensis* to the first occurrence of *Millerella marblensis* (Atakul-Özdemir et al., 2011). The most characteristic features of this zone are the first occurrences of *Plectostaffella bogdanovkensis* and *P. jakhensis* very close to the mid-Carboniferous boundary and disapperance of *Eostaffella* ex gr. *ikensis* at the boundary. This zone is considered to be equivalent of the Lower Voznesensky Horizon in the Russian Platform and the Donets Basin (Vdovenko et al. 1990; Vachard & Maslo 1996), the Lower H Zone (Homoceras Zone) in the Western Europe (Vdovenko et al. 1990; Vachard & Maslo 1996; Shcherbakov 1997) and the Lower Bogdanovsky Horizon in the Urals (Groves et al. 1994; Vachard & Maslo 1996; Shcherbakov 1997; Kulagina & Sinitsyna 1997).

The second foraminiferal zone of Atakul-Özdemir et al. (2011) corresponding partly to the *Declinognathodus inaequalis - Declinognathodus noduliferus* zone is the *Millerella marblensis* zone defined as the interval from the first occurrence of *Millerella marblensis* to the first occurrence of *Semistaffella* sp. The *Millerella marblensis* zone corresponds to the Upper Voznesensky Horizon of the Russian Platform (Vdovenko et al. 1990; Vachard & Maslo 1996), the Upper H Zone (Homoceras Zone) in the Western Europe (Vdovenko et al. 1990; Vachard & Maslo 1996; Shcherbakov 1997) and to the Upper Bogdanovsky Horizon of the Western Urals (Groves et al. 1994; Vachard & Maslo 1996; Shcherbakov 1997; Kulagina & Sinitsyna 1997).

The uppermost part of the *Declinognathodus inaequalis* – *Declinognathodus noduliferus* zone is the equivalent of the *Semistaffella* sp. zone of Atakul-Özdemir et al. (2011). The lower boundary of this zone is defined by the first occurrence of *Semistaffella* sp. and the upper boundary is not defined in this study because the top of the measured stratigraphic section is within this zone. The zone corresponds to the Krasnopolyansky Horizon of the Russian Platform (Vachard & Beckary 1991; Vachard & Maslo 1996; Shcherbakov 1997), the Feninsky Horizon in the Donets Basin (Vachard & Maslo 1996) and the Syuransky Horizon in the Urals (Vachard & Maslo 1996; Kulagina & Sinitsyna 1997; Shcherbakov 1997).

Stratigraphic distribution: From the sample HB-27 to the sample HB-04.

Age: Bogdanovsky - Syuransky Horizons (Lower Bashkirian).

Table 3.8. Comparision of Mid-Carboniferous boundary conodont zonation schemes.

		Turkey Central Taurides (This Study)	**USA Arrow Canyon Section** (Lane et al. 1985)	**Ukraine Donets Basin** (Nemyrovska 1999)	**Japan Hina Limestone** (Mizuno 1997)	**Southern Urals Kizil Formation** (Kulagina et al. 2001)	**South China Nashuie Section** (Wang and Qi 2003)	**Uzbekistan Aksu-I Section** (Nemyrovska & Nigmadganov 1994)
Carboniferous	**Bashkirian (part)**	*Declinognathodus noduliferus* - *Declinognathodus inaequalis*	*Declinognathodus noduliferus* s.l. - *Rhachistognathus Primus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*
					Declinognathodus inaequalis - Gnathodus bilineatus			*Declinognathodus praenoduliferus*
	Serpukhovian (part)	*Rhachistognathus muricatus*	*Rhachistognathus muricatus*	*Gnathodus postbilineatus*	*Gnathodus bilineatus*	*Gnathodus bilineatus*	*Gnathodus bilineatus bollandensis*	*Gnathodus bilineatus bollandensis*
				Gnathodus bilineatus bollandensis – Adetognahtus unicornis				

3.2 Lower Carboniferous Stage Boundaries

In an international platform multidiscipliner studies have been carried out on the delineation of stage boundaries. Currently, internationally proposed or accepted stage boundaries for the Lower Carboniferous, Tournaisian-Visean, Visean-Serpukhovian and Serpukhovian-Bashkirian, are defined by conodont and foraminifera species. Two of the Lower Carboniferous boundaries, Tournaisian-Visean and Serpukhovian-Bashkirian, have been ratified and GSSP points have been defined for these boundaries. The GSSP for the base of the Visean Stage ratified in late 2007 and is fixed at the base of bed 83 in the Pengchong section (South China). This point coincides with the first appearance of the benthic foraminifera, *Eoparastaffella simplex*, in the lineage of '*E. ovalis* group' to *E. simplex*. In 1996, Arrow Canyon has been selected as the GSSP for the Mid-Carboniferous Boundary by the first evolutionary appearance of the conodont *Declinognathodus noduliferus s. l.* The studies about the Visean-Serpukhovian boundary have still continued and nearly reached agreement that the conodont lineage *Lochriea nodosa – Lochriea ziegleri* can be used as the boundary marker event.

Of the studied sections, Visean – Serpukhovian and Mid-Carboniferous boundaries have been delineated by using conodonts. Tournaisian – Visean boundary sections, AP, BT and MT, delineated by foraminiferal biostratigraphy do not include conodont elements. The following section gives the details about the delineation of Lower Carboniferous stage boundaries in the Taurides.

3.2.1 Tournaisian - Visean Boundary

The Pengchong section in southern China proposed by Devuyst et al. (2003) has been selected as GSSP for the Tournaisian – Visean boundary in 2007 by the Subcommission on Carboniferous Stratigraphy (SCCS). *Eoparastaffella,* together with other foraminifers and conodont taxa, let to construct a high-resolution biostratigraphy in the Tournaisian - Visean boundary (Devuyst 2006; Devuyst and Kalvoda 2007; Devuyst and Hance in Poty et al. 2006; Kalvado et al. 2010). The Tournaisian – Visean boundary defined by the first occurrence of bentic foraminifer *E. simplex* and second marker is the lowest appearance of the conodont *Lochriea homopunctatus* (Menning, et al. 2006). In Visean, there is a marked decline in diversity and abundance of conodonts especially in shallow water limestone deposits (Austin 1987; Nolan 1989; Stone 1991; Strogen et al. 1996; Poty et al. 2006).

In the Central Taurides the Tournaisian - Visean boundary has been studied in detail by Peynircioğlu (2005) and Özkan-Altıner et al. (2007). In these studies, the Tournaisian - Visean boundary beds divided into 3 zones, A, B and C and the boundary has been delineated by the first appearance of *Eoparastaffella simplex.* To determine the boundary by using conodonts, the sections have been resampled. Unfortunately, the samples from the boundary sections in the Taurides do not contain any conodont elements. Therefore, in the Taurides the Tournaisian - Visean boundary could not be defined and correlated by conodonts. However, Hastarian - Ivorian (Kinderhookian - Osagean) substage boundary has been delineated by conodonts in the Taurides (Table 3.9). This boundary was defined by the first appreance of *Gnathodus cuneiformis.*

Table 3.9. Comparision of Tournaisian conodont zonation schemes.

	Stage	**N.A. Stage**	**Substage**	**Turkey Central Taurides** (This Study)	**North America Standard Conodont Zonation** (Lane et al. 1980)	**Mestognathus based Conodont Zones** (von Bitter et al. 1986)	**Polland** (Belka 1985)	**Carnic Alps** (Perri & Spalletta 1998)	**Europe** (Riley 1995 Jones & Sommerville 1996 Poty et al. 2006)		**Belgium** (Groessens 1976)
Carboniferous (part)	**Tournaisian (part)**	***Osagean***	***Ivorian***	*P. mehli mehli*	*Sc. anchoralis - D. latus*	*M. praebeckmani*	*Sc. anchoralis*	*Sc. anchoralis – D. latus*	*Sc. anchoralis* *D. latus* *D. bouckaerti* *P.mehli* *Ps. multistriatus*	*P.mehli*	*Sc. anchoralis*
					Upper *G. typicus*		*G.cuneiformis*	Upper *G. typicus*			*P. communis carina*
				G. cuneiformis	Lower *G. typicus*	*M. harmalai*		Lower *G. typicus*		*Ps. multistriatus*	
		Kinderhookian	***Hastarian***	*P. inornatus*	*S. isosticha – Upper S. crenulata*		*G. delicatus*	*S. isosticha – Upper S. crenulata*	*Gnathodus* *P.inornatus*		*Siphonodella*

3.2.2 Visean - Serpukhovian Boundary

There are two thoroughly examined candidates for the GSSP of Visean - Serpukhovian boundary: the Nashui section, Guizhou Province, south China and the Verkhnyaya Kardailovka section on the eastern slope of the southern Urals, Russia. The first appearance of *Lochriea ziegleri* in the lineage *Lochriea nodosa - Lochriea ziegleri* is currently under investigation as a marker for the GSSP identifying the Visean - Serpukhovian boundary (Menning *et al.* 2006). This lineage has been recently documented in numerous sections in Europe and Asia including the well known the Verkhnyaya Kardailovka section in the southern Urals of Russia (Nikolaeva et al. 2009b), the Nashui section in the southern China (Qi and Wang 2005, Qi 2008), the Cantabrian Mountains of the northern Spain (Nemyrovska, 2005; Sanz-López et al., 2007), and the Dombar Hills in the western Kazakhstan (Nikolaeva et al., 2009a).

Pazukhin at al. (2010) described the *Lochriea ziegleri* Zone in the Verkhnyaya Kardailovka Section (South Urals) by the first appearance of *Lochriea ziegleri.* The conodont assemblages of *Gnathodus girtyi simplex, Gnathodus pseudosemiglaber Gnathodus bilineatus bilineatus*, *Gnathodus girtyi girtyi, Lochriea costata*, *Lochriea monocostata* and *Lochriea mononodosa* have also been reported from this zone.

Lochriea ziegleri has been recovered in many sections from the basal part of Serpukhovian in the world so it is considered as the candidate for the delineation of the Visean-Serpukhovian boundary (Nemirovskaya, 1983, 1985, 1999, 2005; Alekseev et al., 2004; Richards, 2007; Nikolaeva et al., 2009a,b; Pazukhin et al. 2010).

In particular, several researchers stated that the first appearance of *Lochriea ziegleri* might be highly diachronous. However, some studies indicate that the degree of diachroneity is minimal. So, the task group and SCCS have not decided yet to use the first appearance of *L. ziegleri* for delineation of Visean - Serpukhovian boundary. The Subcommission on Carboniferous Stratigraphy task group continue to carry out a detailed analysis of the foraminifers, stable isotope geochemistry and sedimentology of the Nashui section and a nearby shallow-water limestone beds including Visean - Serpukhovian boundary.

Higgins (1985) documented conodont zonation for Silesian Subsystem in Great Britain and Ireland. In this study the *Kladognathus - Gnathodus girtyi simplex* Zone is defined in the Pendleian Stage and is characterized by the occurences of *Gnathodus bilineatus bilineatus, Gnathodus girtyi girtyi, Gnathodus girtyi intermedius, Lochriea commutata*, *Lochriea nodosa, Lochriea mononodosa, Neoprinoidus spathatus* and *Kladognathus macrodentata*. The base of this zone corresponding to the Visean - Serpukhovian boundary is marked by the first occurence of *Gnathodus girtyi simplex* (Higgins, 1985; Medina-Varea et al., 2005; Nemyrovska, 2005).

The *Kladognathus* - *Gnathodus girtyi simplex* Zone of Higgins (1985) corresponds to the *Lochriea cruciformis* Zone proposed by Skompski (1996) for the Lublin Basin, Poland. The lower boundary of the latter is marked by the first appearance of the index taxon, *Lochriea cruciformis*, The *Lochriea cruciformis* Zone is restricted to the lower and middle part of the Namurian A.

The BS and BSE sections cropping out in the Bademli region have been measured in order to determine the Visean - Serpukhovian boundary by conodont biostratigraphy. Based on the recorded conodont assemblages, this boundary has been recognized within the BSE section by the first appearance of *Gnathodus girtyi simplex* in the Taurides, Turkey*.* Foraminiferal assemblages across the Visean - Serpukhovian boundary in the Taurides have been determined by Altıner and Özgül (2001). In this study, Visean stage has been divided into 5 biozones and 3 biostratigraphic zones have been determined within the Serpukhovian stage. Altıner and Özgül (2001) defined the Visean -Serpukhovian boundary between the *Endostafella parva - Biseriella parva* and *Pseudoendothyra* ex gr. *illustria - Eostaffella pseudostruvei* zones.

3.2.3 Correlation of Visean - Serpukhovian boundary

The Visean - Serpukhovian boundary in the Taurides can be comparable to the boundary defined in Great Britain & Ireland (Higgins 1985); in the Donets Basin (Nemyrovska 1983, 1985, 1999); in the Moscow Basin (Alekseev et al. 2004); in the Southern Urals (Nikolaeva et al. 2009, Pazukhin et al. 2010); in the Northern Urals (Zhuravlev 2003); South China (Wang and Qui 2003); and in Spain (Nemyrovska 2005) (Figure 3.5, Table 3.6).

The boundary has been described in England at the base of the *Kladognathus* - *Gnathodus girtyi simplex* Zone by the first occurrence of *Gnathodus girtyi simplex* (Higgins 1985*).* However, the Visean - Serpukhovian boundary has been placed at the base of *Lochriea ziegleri* Zone in the Moscow Basin (Alekseev et al. 2004); the Southern Urals (Nikolaeva et al. 2009a,b, Pazukhin et al. 2010); South China (Wang and Qui 2003); and Spain (Nemyrovska 2005). These studies indicated that the first appearance of *Lochriea ziegleri* is a significant marker for the delineation of the boundary. Pazukhin et al. (2010) defined the *Lochriea ziegleri* Zone in the Southern Urals by the appearance of *Gnathodus girtyi simplex* and *Gnathodus* *pseudosemiglaber*. It can be concluded that *Gnathodus girtyi simplex* is an important conodont taxon for the identification of Serpukhovian stage. Medina-Varea et al. (2005) could not recognize the boundary in Spain due to the absence of index taxa. Zhuravlev (2003) has drawn the boundary at the base of the *Lochriea cruciformis* Zone by the first occurrence of the index species in the Northern Urals. In the Donets Basin the boundary falls within the *Gnathodus girtyi girtyi - Paragnathus mononodus* Zone (Nemyrovska 1983, 1985, 1999).

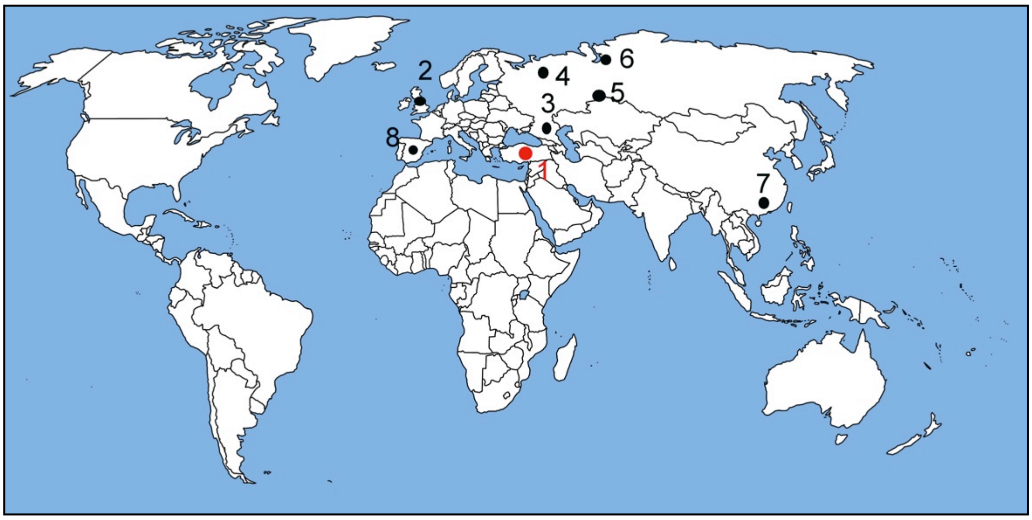


Figure 3.5. Map showing main localities including the Visean - Serpukhovian boundary sections: 1. Turkey, 2. Great Britain & Ireland, 3. Donets Basin (Ukraine), 4. Moscow Basin, 5. Southern Urals, 6. Northern Urals, 7. South China, 8. Spain.

3.2.4 Serpukhovian - Bashkirian (Mid-Carboniferous) Boundary

It is known from studies describing the evolutionary trends in conodonts that the characteristic Early Carboniferous taxa became extinct and the first Bashkirian *Declinognathodus* appeared at the Mid-Carboniferous boundary (Brenckle et al. 1997; Lane et al. 1999; Nemyrovska 1999, 2009; Richards & Aretz 2010). The most common genera to become extinct at the end of Serpukhovian are *Gnathodus*, *Lochriea* and

Cavusgnathus, whereas the Middle Carboniferous genera *Declinognathodus*, *Idiognathoides* and *Neognathodus* originated and later gave rise to all of the Late Carboniferous conodonts (Nemyrovska 1999).

In 1995, International Subcommission on Carboniferous Stratigraphy selected the Arrow Canyon, Nevada (USA) to be the GSSP for mid-Carboniferous boundary. The first appearances of index conodont taxa *Declinognathodus noduliferus* sensu lato including the subspecies *Declinognathodus noduliferus noduliferus, Declinognathodus noduliferus inaequalis* and *Declinognathodus noduliferus japonicus* were approved as the biostratigraphic marker for the Mid-Carboniferous boundary (Baesemann & Lane 1985; Nemirovskaya & Nigmadganov 1994; Nemyrovska 1999; Lane et al. 1999; Gradstein et al. 2004). This level falls at the base of the *noduliferus-primus* Zone of Baesemann and Lane (1985). Mizuno (1997) placed the mid-Carboniferous boundary at the base of *Declinognathodus inaequalis-Gnathodus bilineatus* zone by the first appreance of *Declinognathodus inaequalis* and it is concluded that the first appearance of *Declinognathodus noduliferus* is above the mid-Carboniferous boundary. Similarly, Nemirovskaya and Alekseev (1995) obtained *Declinognathodus noduliferus* just above the mid-Carboniferous boundary in the Askyn River section due to paleoenvironmental exclusion from shallow water lithologies of the underlying horizon.

Nemyrovskaya et al. (2008) studying the lower part of the Barcaliente Formation in the Millaró section, pointed out *Declinognathodus noduliferus bernesgae* and *Declinognathodus praenoduliferus* appear together with the *Declinognathodus noduliferus inaequalis* defining the mid-Carboniferous boundary. However, Sanz-López et al. (2006), Sanz-López and Blanco-Ferrera (2009) and Sanz-López et al. (2010) indicated that the youngest appearance of *Declinognathodus* *noduliferus bernesgae* and *Declinognathodus praenoduliferus* are in the latest Serpukhovian associated with conodonts that are clearly Mississippian, *Gnathodus* and *Lochriea*. The first appreance of those conodonts are close to the first appearance of *Declinognathodus noduliferus inaequalis* and hence close to the mid-Carboniferous boundary (Sanz-López and Blanco-Ferrera 2009). Based on Sanz-López et al. (2006) and Sanz-López and Blanco-Ferrera (2009) the first apperance of *Declinognathodus* at the Arrow Canyon is the first occurrence of *Declinognathodus noduliferus inaequalis*. Based on this information they claimed that the first appearance of this species should be used as the indicator of mid-Carboniferous boundary and the other *Declinognathodus* species can be used in the correlation of mid-Carboniferous beds. Richards and Aretz (2010) stated that well-documented conodont assemblages from the Cantabrian Mountains including several mid-Carboniferous boundary sections lead to a better understanding of order of conodont occurrence within the *Declinognathodus* group of species and guide to a solve the problem of using *Declinognathodus* sensu lato to indicate the mid-Carboniferous boundary.

In the Central Taurides, the Mid-Carboniferous boundary is recognized by the first appearance of *Declinognathodus inaequalis,* which is an index taxon for the basal part of the Bashkirian at important sections other than the GSSP (Mizuno, 1997; Brenckle et al., 1997; Sanz-López et al., 2006; Sanz-López and Blanco-Ferrera, 2009; Atakul-Özdemir et al., 2012a). In addition to *Declinognathodus inaequalis*, the first occurrences of *Declinognathodus lateralis* and *Declinognathodus noduliferus* are also indicative of earliest Bashkirian. The occurrence of *Declinognathodus bernesgae* together with the last occurrence of *Gnathodus girtyi simplex* indicates a latest Serpukhovian age for sample HB28, just below the Mid-Carboniferous boundary (Atakul-Özdemir et al., 2012a). In many sections, the Mid-Carboniferous boundary coincides with the first occurrence of *Declinognathodus* taxa (Baesemann & Lane 1985; Brenckle et al. 1997; Lane et al. 1999). It has also been documented in the La Lastra section (Cantabrian Mountains) that *Declinognathodus bernesgae* and *Declinognathodus praenoduliferus* occur together with *Declinognathodus inaequalis* at the Mid-Carboniferous boundary (Nemyrovska et al. 2008; Nemyrovska 2009). However, the first occurrences of *Declinognathodus bernesgae* and *Declinognathodus praenoduliferus* predate the first appearance of *Declinognathodus ineaqualis* in upper Serpukhovian beds at other Cantabrian sections (Sanz-López et al. 2006; Sanz-López & Blanco-Ferrera 2009). Therefore, following the rationale of Sanz-López et al. (2006) and Sanz-López & Blanco-Ferrera (2009), the first appearance of *Declinognathodus inaequalis* at the Arrow Canyon GSSP should be recognized exclusively as the formal boundary marker and the other *Declinognathodus* species should be regarded as useful taxa for correlating Mid-Carboniferous boundary beds. In our section near Hadim, the first occurrence of *Declinognathodus bernesgae* is observed just below the Mid-Carboniferous boundary, further indicating that some *Declinognathodus* taxa originated prior to the first occurrence of *Declinognathodus inaequalis*.

The location of the Mid-Carboniferous boundary at the base of the sample HB-27 in the studied section coincides with that foraminiferal zones proposed by Atakul-Ozdemir et al. (2011). The boundary was drawn by the appearances of *P. bogdanovkensis* and *P. jakhensis* and the last occurrences of *Eostaffella* ex gr. *ikensis*. The mid-Carboniferous boundary is drawn locally at the base of the sample HB-27, coincident with the boundary between the *Rhachistognathus muricatus* and *Declinognathodus noduliferus* - *inaequalis* conodont zones and *Eostaffella* ex gr. *ikensis* - *Eostaffella postmosquensis* and the *Plectostaffella bogdanovkensis* - *P. jakhensis* foraminiferal zones (Figure 3.6).

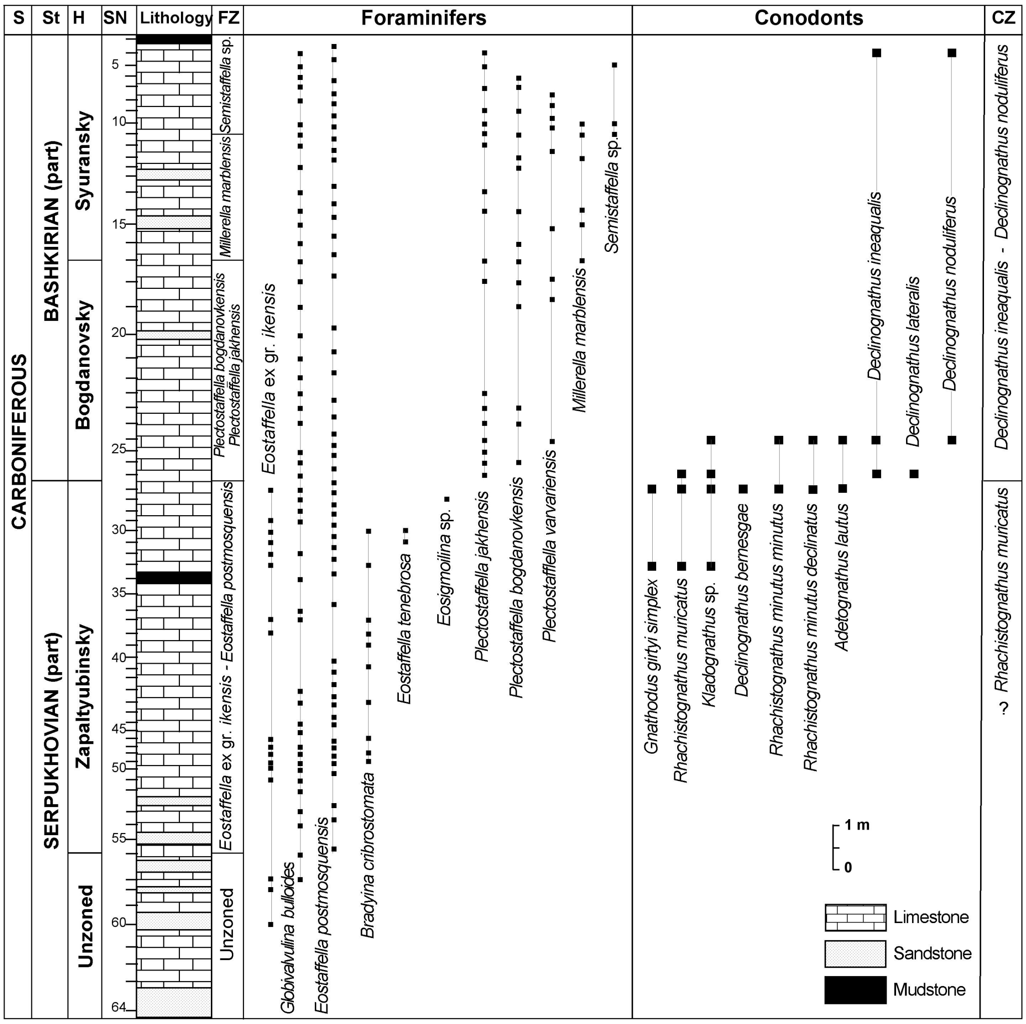


Figure 3.6. Correlation of foraminiferal and conodont occurrences around the Mid-Carboniferous boundary in the HB section in the Aladağ Unit (S:System, St: Stage, H: Horizon, SN: Sample Number, FZ: Foraminiferal Zones, CZ: Conodont Zones).

3.2.5 Correlation of mid-Carboniferous boundary

The *Declinognathodus noduliferus* zone is widespread over the world especially in where the mid-Carboniferous boundary beds were deposited. The conodont succession across the Mid-Carboniferous Boundary in the Taurides, Turkey, resembles that defined in North America and other parts of the world. The mid-Carboniferous boundary in the Taurides can be directly correlated with the Arrow Canyon, USA (Lane et al. 1999); the Donets Basin, Ukraine (Nemyrovska 1999); South China (Wang and Qui 2003); Japan (Mizuno 1997); Arctic Alaska (Krumhardt et al. 1996) and Uzbekistan (Nemyrovska and Nigmadganov 1994) (Figure 3.7, Table 3.8).

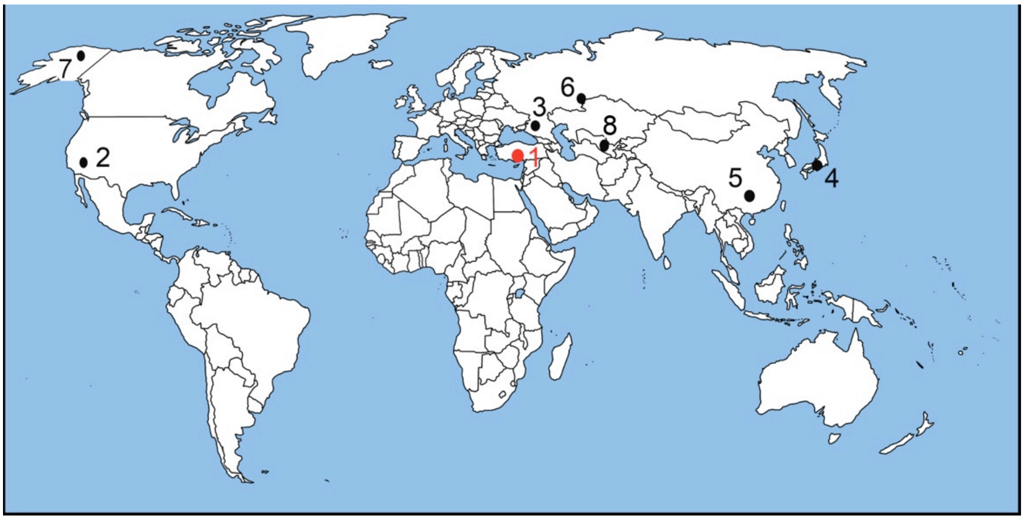


Figure 3.7. Map showing main localities including the Mid-Carboniferous boundary sections: 1. Central Taurides (Turkey), 2. Arrow Canyon Section (USA), 3. Donets Basin (Ukraine), 4. Hina Limestone (Japan), 5. Nashuie Section (South China), 6. Kizil Formation (Southern Urals), 7. Arctic Alaska, 8. Aksu-I Section (Uzbekistan).

The mid-Carboniferous boundary in GSSP at the Arrow Canyon, Nevada is drawn at the base of *Declinognathodus noduliferus – Rhachistognathus primus* zone that is defined by the first appearance *Declinognathodus noduliferus* s.l. (Baesemann and Lane 1985, Brenckle et al. 1997, Lane et al. 1999). Similarly, In Arctic Alaska, the mid-Carboniferous boundary drawn at the base of *noduliferus-primus* conodont zone delineated by the first appearances of *Declinognathodus noduliferus* and *Declinognathodus japonicas* (Krumhardt et al. 1996). In the Donets Basin, Ukraine (Nemirovskaya 1987, Nemirovskaya et al.

1991, Nemirovskaya 1999) and in the Nashuie Section, South China (Wang and Qui 2003), the boundary is defined by the entry of *Declinognathodus noduliferus* s.l. and is placed at the base of *Declinognathodus noduliferus* zone. In Japan, the mid-Carboniferous boundary delineated by the first apperance of *Declinognathodus inaequalis* and *Declinognathodus noduliferus* at the base of *Declinognathodus inaequalis-Gnathodus bilineatus* zone of Mizuno (1997). Sanz-Lopez et al. (2006) stated that the first appearance of *Declinognathodus noduliferus bernesgae* close to the mid-Carboniferous boundary so they placed the boundary on the beds overlying the first appearance of *Declinognathodus noduliferus bernesgae*. Nemirovskaya and Nigmadganov (1994) defined the mid-Carboniferous boundary by the first appearance of *Declinognathodus praenoduliferus* in Uzbekistan. They stated that this species is the first representative of *Declinognathodus noduliferus* s.l. and is the index taxon for the mid-Carboniferous boundary.

The mid-Carboniferous boundary in the Taurides cannot be correlated with the South Urals since an unconformity around the Mid-Carboniferous boundary in the Askyn River section, South Urals were detected by Groves et al. (1999) and Brand and Bruckschen (2002). Kulagina et al. (2001) reported the occurrence of *Declinognathodus inaequalis* together with *Declinognathodus noduliferus* in the *Declinognathodus noduliferus* zone above the mid-Carboniferous boundary in the Southern Urals.

CHAPTER 4

CONODONT AND FACIES RELATIONSHIPS

Conodont faunal variations, abundance and diversity of conodont elements, in Paleozoic to Triassic marine deposits are generally environmentally controlled. Two main paleoecologic models have been proposed to explain distribution patterns of conodonts. Bathymetric model suggests a depth stratification of conodont taxa (Seddon 1970; Seddon and Sweet 1971; Druce 1973) (Figure 4.1A). This model propose that the conodonts could be mainly pelagic. Davis and Webster (1985) proposed that in bathymetric model, shallower water deposits comprises few taxa, while deep water deposits would include abundant conodont taxa (Figure 4.1A). The second model, lateral segregation model, suggested that conodonts would be benthic or nekto-benthic (Barnes et al. 1973; Barnes and Fåhraeus 1975). This model supported that shallower water deposits include different faunal content from the deposits of deep water environments due to the lateral variations of conodont fauna (Figure 4.1B). Barnes and Fåhraeus (1975) indicated that some of conodonts have an extensive distribution and wide tolerance of facies.

The factors affecting the presence or absence of a species have been still under discussion. According to Merrill and von Bitter (1976), Klapper and Barrick (1978), Rexroad and Horowitz (1990), Pohler and Barnes (1990), evolution is not a single factor affecting the presence or absence of a species, paleogeographic, paleoenvironmental, and postmortem factors are also very important in order to control the distribution of conodonts.

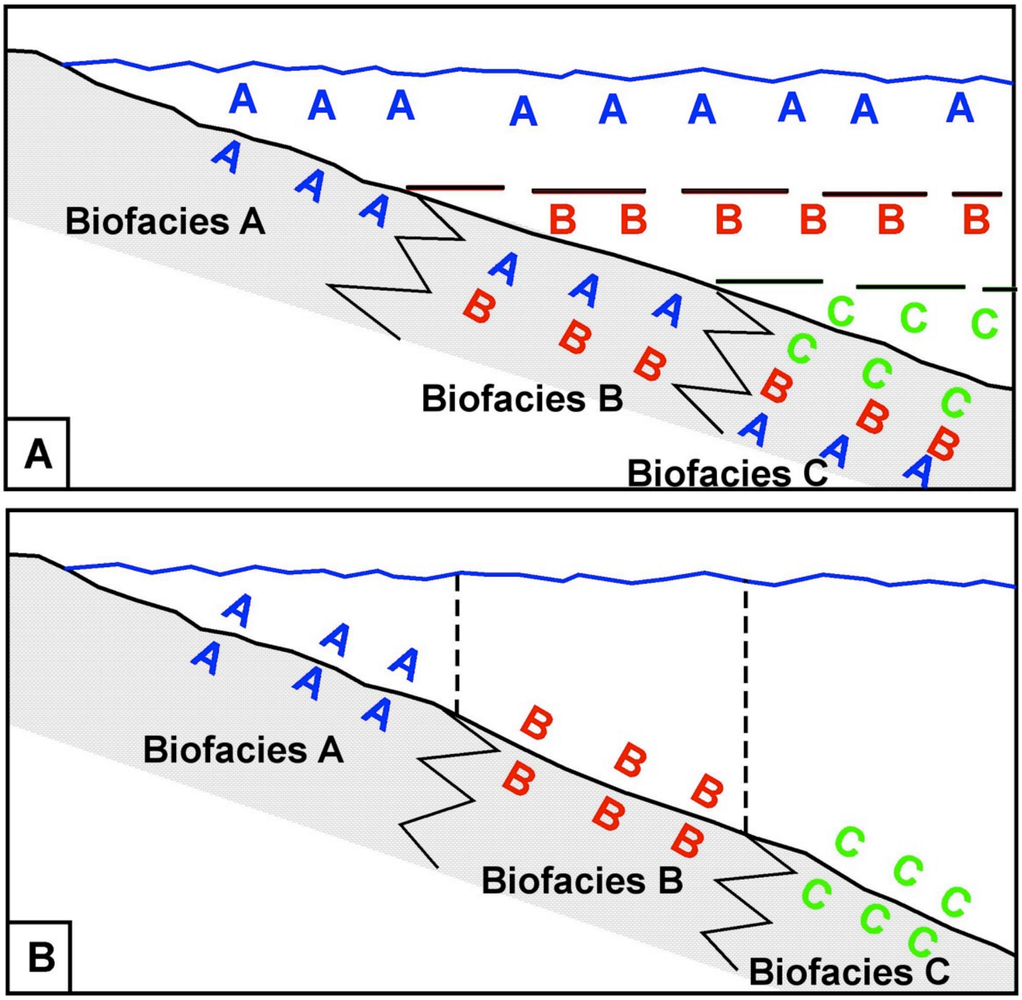


Figure 4.1. Two main types of paleoecologic models for conodonts (redrawn from Davis and Webster 1985), A. Bathymetric model for pelagic conodonts (Druce 1973); B. Lateral segregation model for benthic and necto benthic conodonts (Barnes &Fåhraeus 1975).

Moreover, a number of studies (Merrill and Martin 1976; Merrill and von Bitter 1976; Davis and Webster 1985; Rexroad and Horowitz 1990; Pohler and Barnes 1990; Krumhardt et al. 1996) indicated that the distribution of conodonts was essentially controlled by the physical and chemical properties of the water (such as, hydraulic energy, pH, biotic association and salinity) None of these models describes the depositional patterns of Carboniferous conodonts. Based on these studies, it can be concluded that several conodont species have been restricted to the shallow-water environments and others to the deep water, and some apparently extended into both shallow and deep environments (Davis and Webster 1985). Furthermore, Heckel (1972) proposed that diversity of conodonts is related to environmental stability and greatest diversity occurs in an environment in which salinity, oxygen and sedimentation rate changes are limited. Subsequently, he suggested that faunal diversity is fewer in shallow water than deep water areas as the shallow water is more intensely subjective to changes in temperature, sedimentation rate, river discharge and salinity. However, the deep water environment is further stable and provides a more water column thus the diversity is higher in the deep water environments.

Many studies (Varker 1967; Meischner 1970; Druce 1970; Seddon 1970; Merrill 1962; Merrill and King 1971; Barnett 1971; von Bitter 1972; Varker and Sevastopulo 1985; Somerville et al. 1992; Schönlaub and Kreutzer 1993; Jones and Somerville 1996; Somerville 2008) discussed the relationship between the depositional environments and the species of conodont taxa within the facies.

In this study, the Lower Carboniferous samples from the Central and Eastern Taurides (Turkey) yielded relatively low diversified and low abundant connodonts assemblages. Hence, it is possible to conclude that the existence and the distribution of some conodonts in the studied samples have been partly controlled by facies. Consequently the depositional environments of the studied samples are interpreted as shallow-water environments.

4.1 Upper Tournaisian Microfacies

4.1.1 Microfacies types and Depositional Environments

The AS section in the Sarız region and the AAO section in the Hadim region particularly maintain uniform lithologies throughout the successions. Shale, spiculite packstone, crinoidal bioclastic grainstone-packstone, ostracodal bioclastic grainstone and micritic sandstone have been recorded in the AS section (Figure 4.2, 4.3). However, crinoidal packstone-grainstone and peloidal packstone-grainstone microfacies have been described in the AAO section (Hadim) (Figure 4.4). Based on the defined microfacies and faunal contents, it can be concluded that these sequences were deposited in a shallow water shelf environment and this suggests that the depositional environments of each of the sections was rather uniform during the time of deposition.

Microfacies types through the AS sections:

Spiculite packstone. This microfacies contains abundant sponge spicules which are mainly oriented (Figure 4.2 A-B). Parallel orientation of spicules may cause a very fine lamination structure (Wilson 1969). Flügel (2004) reported this facies from deep-water basinal environment, as well as in mid-ramp and outer ramp settings. However, Gammon and James (2001) reported this facies as the product of shallow-marine environments. Like this study, the depositional environment of this facies is interpreted as a shallow water shelf environment due to the microfacies properties.

Crinoidal bioclastic packstone-grainstone. This facies is characterized by the presence of crinoids (Figure 4.2 C-D). Crinoids are associated with bryozoans, brachiopods, rare foraminifera, gastropods and intraclasts. This microfacies was developed around the wave base in shallow water environments (Flügel, 2004).

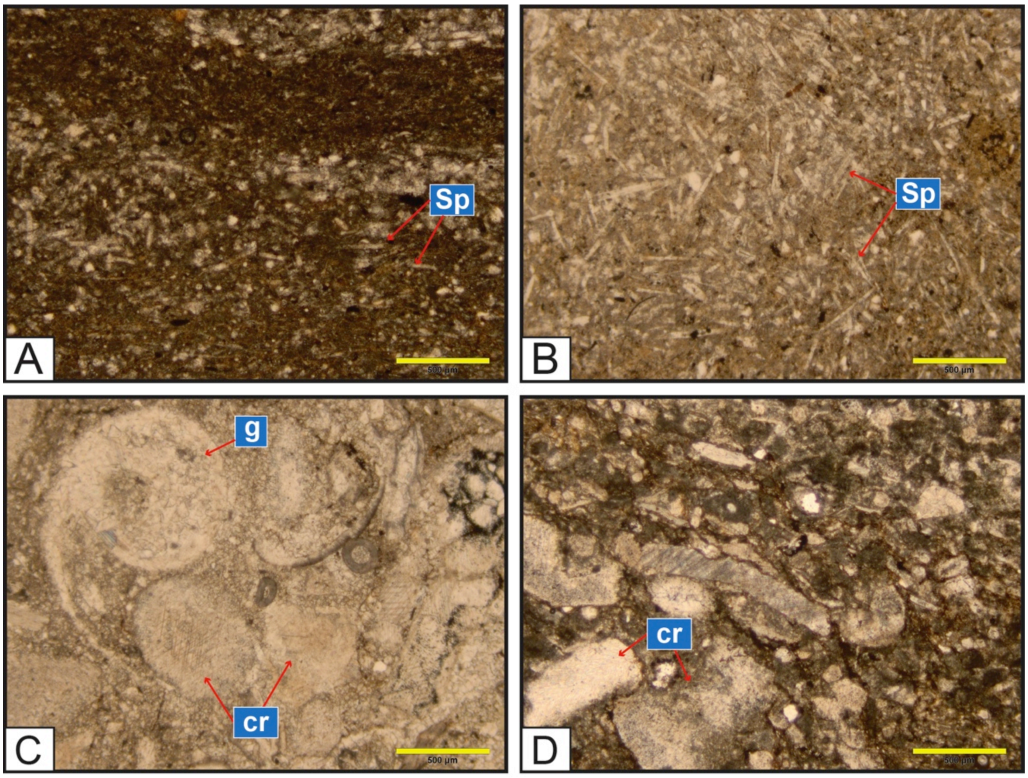


Figure 4.2. Photomicrographs of microfacies determined in the AS section in the Sarız region (Eastern Taurides). A-B spiculite packstone (A: sample AS 1, B: sample AS 2), C-D crinoidal bioclastic grainstone-packstone (C: sample AS 5, D: sample AS 12) (cr: crinoid fragment; g: gastropoda; sp: spicule). Horizontal bar is 500 µm.

Ostracodal bioclastic grainstone. It is composed of skeletal grains, mainly ostracoda, micritic intraclasts and bioclasts (Figure 4.3 A-B). Bioclasts are predominantly foraminifers, brachiopods, algae and corals. This microfacies is characteristic of shallow water environments around the wave base level (Flügel, 2004).

Micritic sandstone. The facies includes predominantly small-size quartz grains (Figure 4.3 C-D). Fossils, such as crinoid and echinoid fragments and other constituents are very rare in this facies. The depositional environment is an intertidal or shallow marine environment (Flügel, 2004).

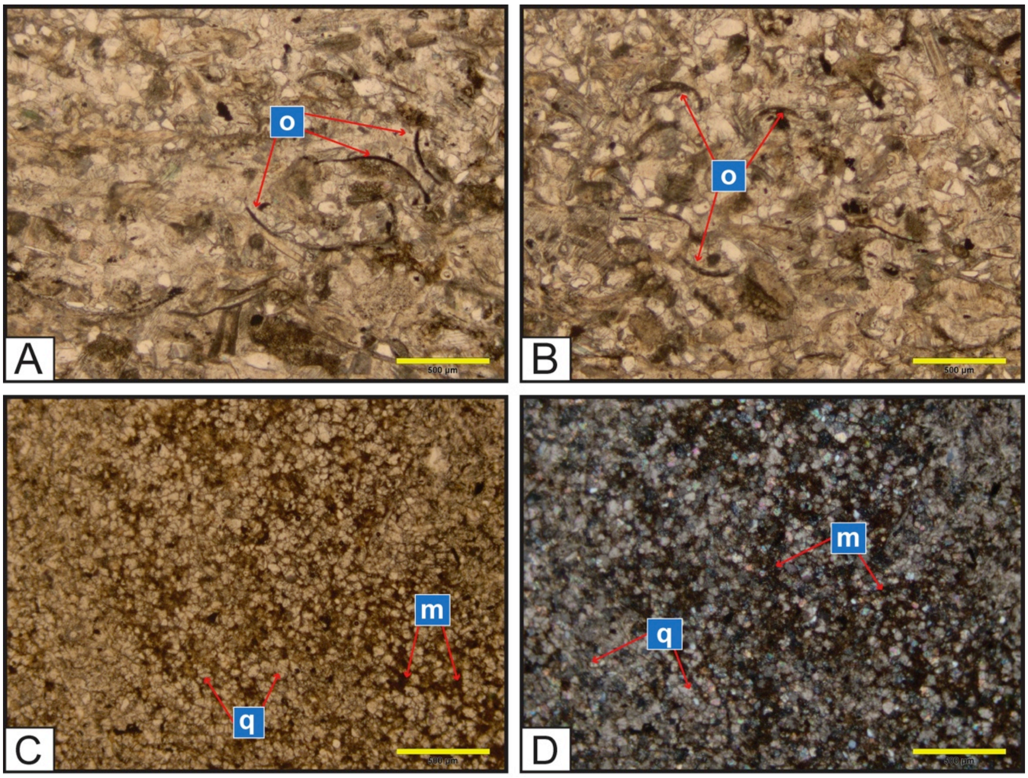


Figure 4.3. Photomicrographs of microfacies determined in the AS section in the Sarız region (Eastern Taurides). A-B ostracodal bioclastic grainstone (sample AS 8), C-D micritic sandstone (sample AS 3) (m:micrite; o: ostracoda; q: quartz grains). Horizontal bar is 500 µm.

Microfacies types through the AAO sections:

Peloidal packstone-grainstone. It is characterized by tiny, equal-sized peloids associated with echinoid and crinoid fragments, intraclasts, corals and rare foraminifers (Figure 4.4 A-B). It occurs in shallow platform interiors (Flügel, 2004).

Crinoidal packstone-grainstone. The main constituents of this facies are crinoid fragments. The accompanying fauna is composed of coral, bryozoans, echinoid fragments, foraminifers and brachiopods (Figure 4.4 C-D). This microfacies is common around the wave base in shallow water environments (Flügel, 2004).

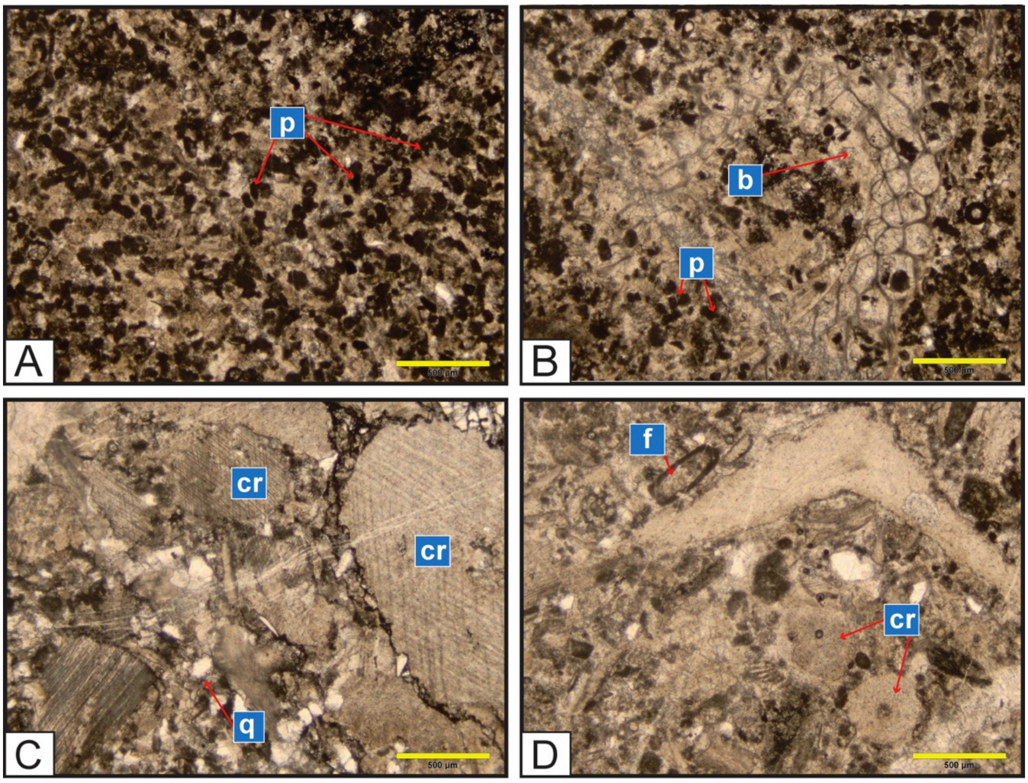


Figure 4.4. Photomicrographs of microfacies determined in the AAO section in the Hadim region (Central Taurides). A-B peloidal packstone-grainstone (sample AAO 3), C-D crinoidal packstone-grainstone (C: sample AAO 4; D: sample AAO 8) (b:bryozoan; cr: crinoid fragments; f: foraminifera; p: peloids; q: quartz grains). Horizontal bar is 500 µm.

In addition to carbonate units, shale units have been recorded in the AAO and AS sections in the Taurides. The shale units are barren for conodonts. Skompski (1996) also recorded conodont elements only from the carbonate facies of shallow water environments but no conodonts could be obtained in the shale samples of Carboniferous successions in the Lublin Upland.

Conodont elements essentially obtained from the crinoidal bioclastic packstone-grainstone and spiculite packstone facies in the AS section and crinoidal packstone-grainstone facies in the AAO section (Table 4.1, 4.2).

Peloidal packstone-grainstone and crinoidal packstone-grainstone facies types obtained mainly throughout the AAO section in the Hadim region comprise important conodonts, such as *Polygnathus* and *Gnathodus.* However, the elements could not be recovered from the upper part of the succession though these samples have the same facies characteristics. Towards the upper part of the succession the content of the heavy minerals increases and the presence of these minerals probably affected the occurrence of conodonts. This supports the importance of physical and chemical properties of the water for the distribution of conodonts.

The conodont elements were mainly recovered from the crinoidal microfacies of the Lower Carboniferous deposits of the Taurides. These facies mainly include high amount of crinoid fragments and other bioclasts, such as ostracodes, foraminifers and brachiopods. The results indicate that the occurrence of abundant crinoids are indicative criteria for the presence of conodonts.

Table 4.1. Conodont and associated fauna identified within the microfacies of the AS section (Sarız, Eastern Taurides).

Facies Types	**Conodont Fauna**	**Associated Fauna**
Spiculite packstone	***Common*** (*Polygnathus communis communis, Polygnathus inornatus, Polygnathus longiposticus, Polygnathus symmetricus, Gnathodus cuneiformis, Bispathodus stabilis* and *Kladognathus* sp.)	Sponge spicules, brachiopods, crinoid and echinoid fragments
Crinoidal bioclastic packstone - grainstone	***Abundant*** (*Polygnathus communis communis, Polygnathus inornatus, Polygnathus longiposticus, Polygnathus symmetricus, Gnathodus cuneiformis, Bispathodus stabilis, Bispathodus utahensis, Hindeodus minutus, Hindeodus cristulus* and *Kladognathus* sp.)	Crinoid and echinois fragments, brachiopods, algae, coral, ostracodes
Ostracodal bioclastic grainstone	**Rare** (*Polygnathus communis communis, Kladognathus* sp.)	Ostracodes, crinoid and echinoid fragments, brachiopods
Micritic sandstone	**Rare or absent** (*Polygnathus communis communis, Kladognathus* sp.)	Brachiopods, crinoid and echinoid fragments

Table 4.2. Conodont and associated fauna identified within the microfacies of the AAO section (Hadim, Central Taurides).

Facies Types	**Conodont Fauna**	**Associated Fauna**
Crinoidal packstone - grainstone	**Relatively abundant** (*Polygnathus mehli mehli, Polygnathus communis communis, Gnathodus cuneiformis, Hindeodus cristulus, Hindeodus minutus, Kladognathus* sp. and *Vogelgnathus campbelli*	Broyozoans, brachiopods, gastropods, crinoid and echinoid fragments, foraminifers, coral
Peloidal packstone - grainstone	**Rare or absent** *(Polygnathus communis communis, Kladognathus* sp., *Polygnathus mehli mehli)*	Crinoid and echinoid fragments, foraminifers, coral

4.1.2 Conodont Species and Microfacies Relationships

Most of the studies on the early to late Tournaisian deposits indicated that there are two comparable conodont assemblages (Somerville and Jones 1985; Varker and Sevastopulo 1985; Somerville et al. 1992; Jones and Somerville 1996; Somerville 2008). One of them is deep water shelf and basin assemblage containing the species of *Siphonodella*, *Polygnathus communis carina* and *Scaliognathus anchoralis.* The second shallow water shelf assemblage comprises the conodont species like *Polygnathus spicatus, Polygnathus inornatus, Pseudopolygnathus multistriatus* and *Polygnathus mehli*. Though these shallow water and deep water basinal genera are related to facies types, some genera seem to be less facies controlled thus they can be obtained in both environments (Somerville 2008). This extensive distribution of some conodont taxa could be related to their habitat change or sedimentation rate (Somerville 2008). Sandberg and Gutschick (1984) proposed seven Mississippian conodont biofacies and stated that *Polygnathus communis communis* occurred ubiquitously in most of biofacies and *Bispathodus utahensis* dominates mainly nearshore environments (Figure 4.2).

In the Taurides, the Tournaisian sections (AS and AAO) are mainly composed of shallow marine shelf deposits. The sections mainly include the species of *Polygnathus, Bispathodus, Hindeodus*, *Kladognathus* and only one species of *Gnathodus*. The AS section in the Sarız region includes a diagnostic fauna containing the conodont elements of *Polygnathus inornatus, Polygnathus communis communis, Polygnathus longiposticus, Polygnathus symmetricus, Bispathodus stabilis*, *Bispathodus utahensis, Kladognathus* sp., *Hindeodus cristulus, Hindeodus minutus* and *Gnathodus cuneiformis.* Furthermore, the fauna recovered from the AAO section in the Hadim region is composed of *Polygnathus mehli mehli*, *Gnathodus cuneiformis, Hindeodus cristulus,* *Hindeodus minutus, Kladognathus* sp. and *Vogelgnathus campbelli*. (Table 4.2)

Dreesen (1992) reported that *Bispathodus* group species occurred abundantly in offshore environments while they are widespread in near shore areas. *Polygnathus communis communis, Bispathodus utahensis* and *Bispathodus stabilis* universally occurred in most of the marine environments and they inhabited euphotic zone and are independent of bottom facies (Austin and Davies 1984; Sandberg and Gutschick 1984; Dreesen 1992) (Figure 4.5).

In the same manner, the *Bispathodus* group species are recorded in the crinoidal bioclastic packstone-grainstone and spiculite packstone microfacies of the AS section which is characterized by the shallow water platform to deep water environments.

Polygnathus communis communis has been obtained from all carbonate facies defined in the AS section in the Taurides excluding shales. This species were also recorded commonly in the AAO section in the Hadim region. *Bispathodus utahensis* is exclusively obtained from crinoidal bioclastic packstone - grainstone facies in the AS section in the Taurides indicating shelf environments. Additionally, similar to Sandberg and Gutschick (1984), the habitat of the species of *Hindeodus* is interpreted as shallow water platform environments.

Like the study of Somerville (2008), the presence of *Kladognathus* and *Polygnathus mehli mehli* and *Polgnathus inornatus* suggests shallower conditions and indicates the shelf environments in the Taurides, Turkey.

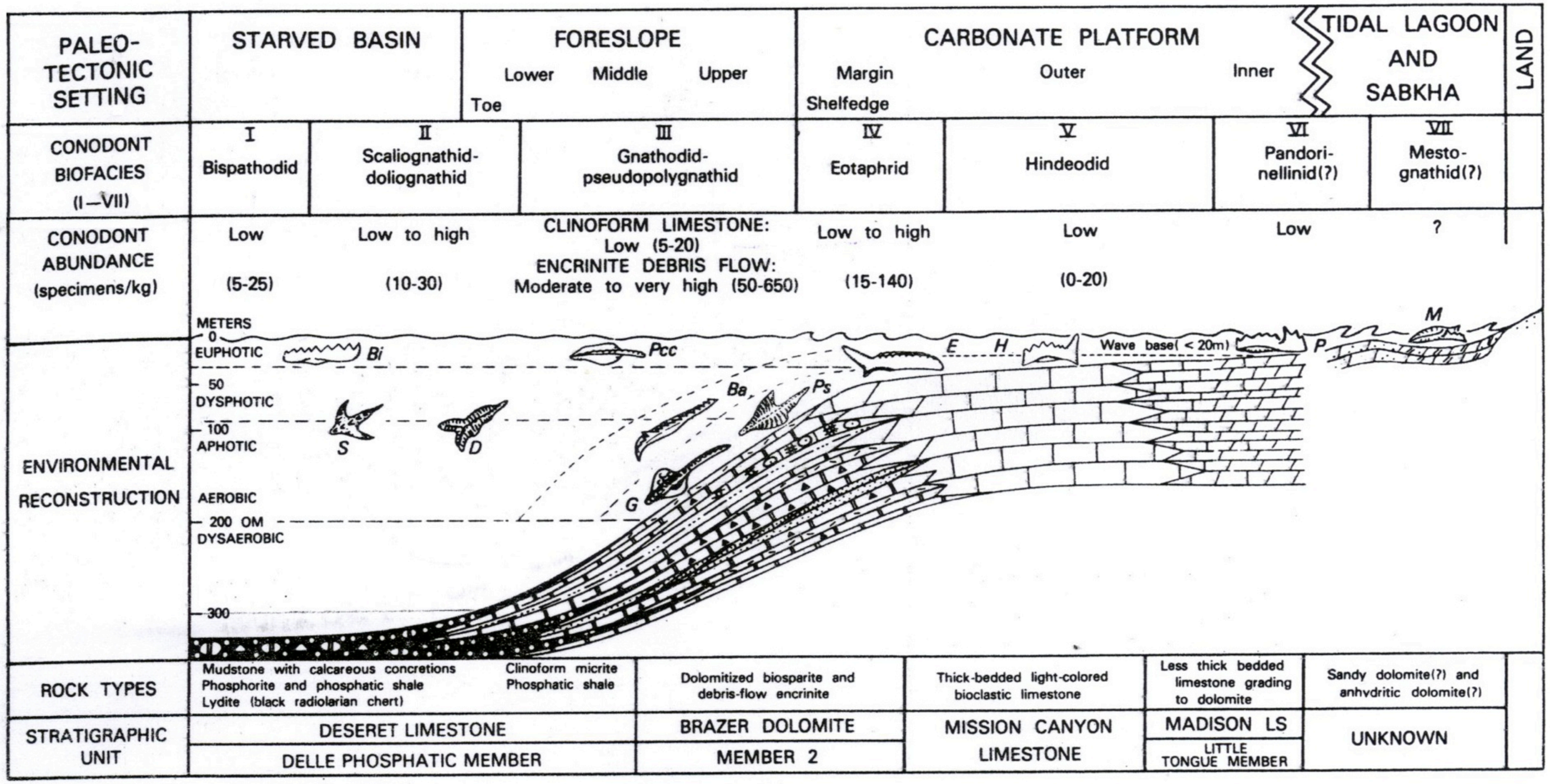


Figure 4.5. Conodont biofacies model displaying the paleoecology of conodonts of Upper Tournaisian (Sandberg and Gutschick, 1984).

The species of *Gnathodus* were thought to be nekton-benthic dwellers, having a low tolerance to change in salinity and they are generally obtained in open shelf deep water deposits (Druce 1973; Austin 1976; Von Bitter 1972, 1976; Sandberg and Gutschik 1984; Plint and Von Bitter 1986 and Boogaard 1992, Medina-Varea et al. 2005). Therefore the species of *Gnathodus* were hardly obtained in the Tournaisian AS and AAO sections. *Gnathodus cuneiformis* is the only species recorded through the sections. Sandberg (1980) reported *Gnathodus cuneiformis* within a moderately deep water deposits. Conversely, Purnell (1993b) and Chauffe (1983) interpreted this species as a shallow water form. This species recorded in crinoidal packstone - grainstone facies through AAO section in Hadim and crinoidal bioclastic packstone - grainstone and spiculite packstone within AS section in Sarız. These facies are interpreted as shallow water shelf deposits. In this study it can be concluded that *Gnathodus cuneiformis* were deposited in a shallow water envionments and this supports the environmental interpretations of Purnell (1993b) and Chauffe (1983).

4.2 Visean - Serpukhovian Boundary Microfacies

4.2.1 Microfacies types and Depositional Environments

The studied BSE section In the Bademli region including the Visean - Serpukhovian boundary is predominantly composed of uniform lithologies of sandstone and sandy limestones. The defined microfacies types in the BSE section are crinoidal bioclastic packstone, bioclastic grainstone, sandy oolitic grainstone, quartz-peloidal grainstone and quartz arenitic sandstone facies (Figure 4.6, 4.7). Based on the microfacies types and recorded fauna, it can be concluded that these formations were deposited in a shallow water shelf environment.

Microfacies types through the BSE section:

Bioclastic grainstone. This microfacies is basically composed of bioclasts. The major bioclastic components are foraminifers, ostracodes and brachiopods (Figure 4.6 A-B). It also includes dark intraclasts and peloids. This facies could be deposited around wave base (Flügel, 2004).

Crinoidal bioclastic packstone. This microfacies is principally composed of echinoid and crinoid fragments, foraminifers and quartz grains. Additionally, it comprises pelloids, dark intraclasts, brachiopods, ostracodes and gastropods (Figure 4.6 C-D). This microfacies was probably deposited in open marine conditions just around the wave base. The large amounts of quartz fragments points out the proximity to land (Flügel, 2004).

Sandy oolitic grainstone. This microfacies is composed of peloids, foraminifers, intraclasts, quartz grains, ooids, ostracodes, algae, broyozoans, gastropods, echinoid and crinoid fragments (Figure 4.7 A-B). The major component of this facies type is superficial ooids. This microfacies was deposited under high-energy, oolitic shoal environments (Atakul-Özdemir et al., 2011; Flügel, 2004).

Quartz-peloidal grainstone. This microfacies is composed of peloids, ooids, quartz grains, and skeletal fragments. It also contains coated bioclastic grains mainly crinoid and echinoid fragments (Figure 4.7 C). This microfacies is also recorded within the HB section in the Hadim region and the depositional environment of this facies has been interpreted as near shore environment by Atakul-Özdemir et al. (2011).

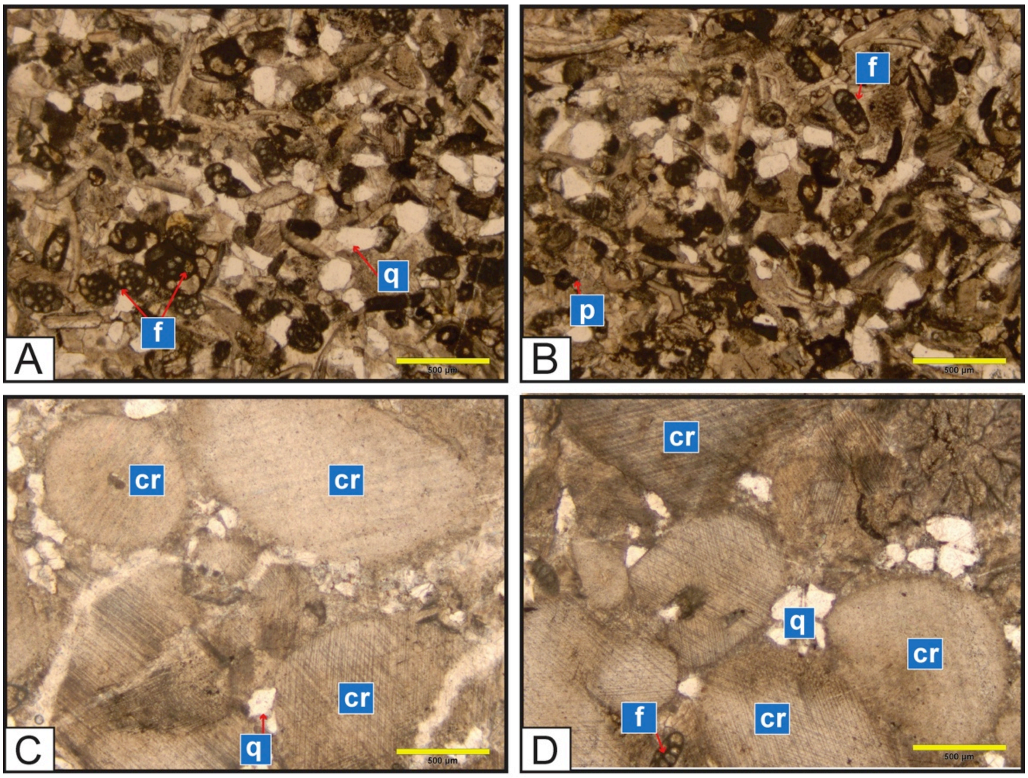


Figure 4.6. Photomicrographs of microfacies determined in the BSE section in the Bademli region (Central Taurides). A-B bioclastic grainstone (sample BSEc 4), C-D crinoidal bioclastic packstone (sample BSEc 7) (cr: crinoid fragments; f: foraminifera; p: peloids; q: quartz grains). Horizontal bar is 500 µm.

Quartz arenitic sandstone. This sandstone facies contains very fine quartz sand grains (Figure 4.7 D). Fossils and other constituents are very rare in this facies. The depositional environment of this facies was interpreted as an intertidal or shallow marine environment (Atakul-Özdemir et al., 2011; Flügel, 2004).

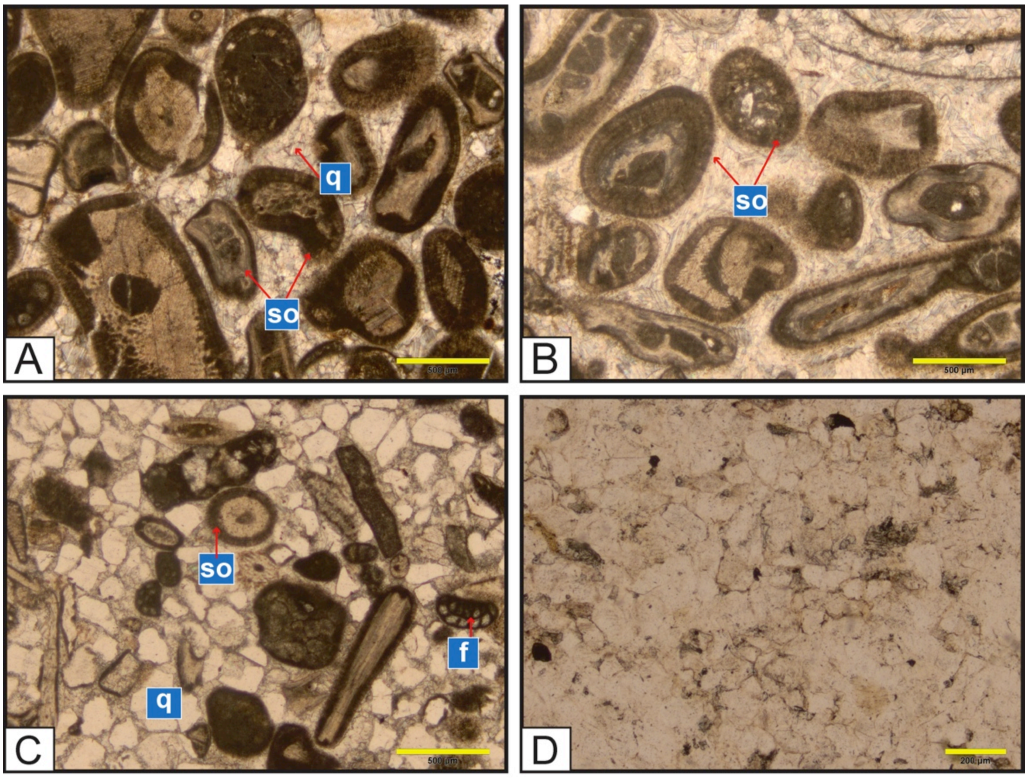


Figure 4.7. Photomicrographs of microfacies determined in the BSE section in the Bademli region (Central Taurides). A-B sandy oolitic grainstone (sample BSEc 5), C quartz-peloidal grainstone (sample BSEc 3), D quartz arenitic sandstone (sample BSEc 1) (so: superficial ooid; f: foraminifera; q: quartz grains). Horizontal bar is 500 µm.

4.2.2 Conodont Species and Microfacies Relationships

Numerous studies (Varker 1967; Aldriddge et al. 1968; von Bitter 1968; Austin 1974; Von Bitter 1976; Varker and Sevastopulo 1985; Plint and von Bitter 1986; Purnell 1993b; Somerville 2008) documented the Upper Visean - Lower Serpukhovian (Upper Dinantian) environmental variations of conodont taxa. Austin (1974) suggested a paleoecologic model for Upper Visean conodont fauna (Figure 4.8) but he did not explain the ecological factors for the distribution of the elements. von Bitter (1976) proposed a more complex model for Canadian Upper Dinantian conodonts and defined 3 biofacies assemblages based on the depth, salinity and energy gradient (Figure 4.9). In this study it was reported that the conodont distribution were mainly controlled by salinity variations. The Upper Visean and Lower Serpukhovian paleoecology and depositional environments of conodont genera has been summarized in Table 4.3 (Purnell 1993b).

In the Taurides, the Visean - Serpukhovian boundary section (BSE) is mainly composed of shallow marine shelf carbonate and sandstone deposits. The conodont fauna recovered form these sections mainly includes the species of *Lochriea, Gnathodus, Vogelgnathus* and *Kladognathus*.

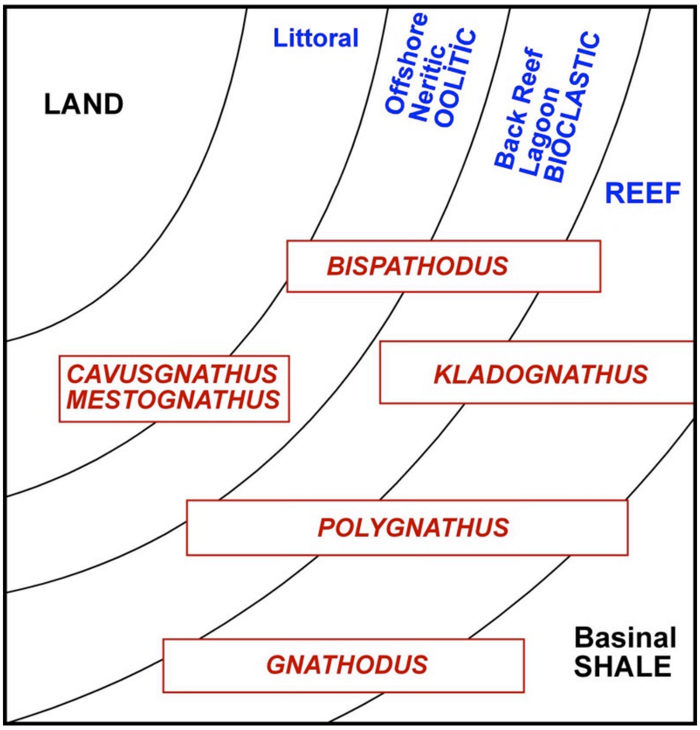


Figure 4.8. Paleoecological models of Upper Visean conodont distribution (Austin 1976).

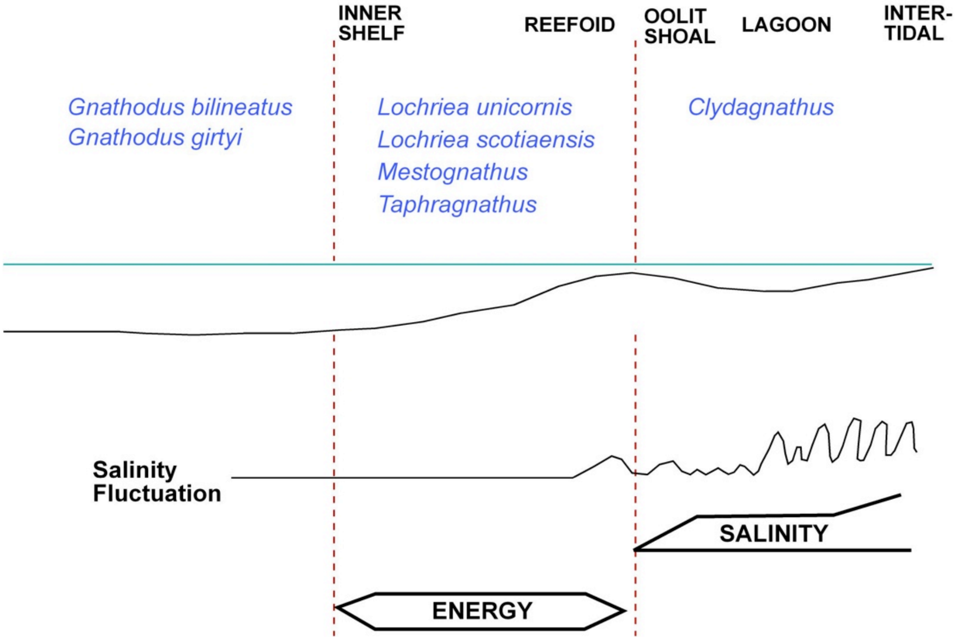


Figure 4.9. Paleoecological models of Upper Visean conodont distribution (von Bitter 1976).

Table 4.3. Distribution of Upper Visean - Lower Serpukhovian conodont taxa (Purnell 1993b).

Most Restricted Shelf Environments		Shelf Environments		Basin Environments	
Clydognathus	von Bitter 1976 Plint & von Bitter 1986	*Synclydognathus*	Varker 1967 Aldridge et al. 1968	*Gnathodus*	Austin 1974 Austin & Davis1984
Mestognathus	Sandberg & Gutschick 1984 von Bitter et al. 1986	*Mestognathus*	Austin 1974 von Bitter et al. 1976	*Lochriea*	Austin & Davis1984
		Patrognathus	Austin 1974 von Bitter et al. 1976 Austin & Davis1974		
		Cavusgnathus	Austin 1974 Austin 1976 von Bitter et al. 1976		
		Hindeodus	von Bitter et al. 1976		
		Polygnathus	Austin 1974		
		Lochriea	von Bitter et al. 1976		
		Vogelgnathus	Plint & von Bitter 1986		
		Kladodognathus	von Bitter 1976 Horowitz & Rexroad 1982		
		Latest Dinantian only			
		Gnathodus	Higgins 1981		
		Lochriea	Higgins 1981		

Varker (1967) reported that Upper Dinantian conodonts were mainly recorded from coral-brachiopod dominated facies. Similarly, the conodonts have been mainly obtained from crinoidal bioclastic packstone facies and a few elements have been recorded from quartz-peloidal grainstone. Crinoidal bioclastic packstone are very appropriate facies for conodonts owing to environmental conditions. Bioclasts associated with the conodonts are mainly crinoids, fusulinids, algae, echinoids, brachiopods and ostracods. The conodont elements obtained from the BSE section include *Polygnathus mehli mehli*, *Gnathodus cuneiformis, Gnathodus girtyi girtyi, Gnathodus girtyi simplex, Kladognathus* sp. and *Vogelgnathus campbelli* (Table 4.4)

No conodont elements have been recorded from sandy oolitic grainstone and quartz arenitic sandstone facies since these facies were mainly deposited in high energy environments under unstable conditions.

The conodont faunas in the Taurides are relatively similar to those of Guadiato Area in Spain (Medina-Varea et al. 2005), which is characterized by the occurrence of *Kladognathus, Vogelgnathus, Cavusgnathus* and *Idioprioniodus.* Plint and von Bitter (1986) described the species of *Vogelgnathus* in rocks deposited in shallow water environments with fluctuated salinity in Magdalen Islands (Canada).

Sandberg (1980) reported *Polygnathus mehli* in the carbonate platform environments in western United States. However, Chauffe (1983) stated that this species inhabited in near shore shallow water environments in North America. Similarly, Purnell (1993b) reported that *Polygnathus mehli* occurred in shallow subtidal environments above and below wave base in Northumberland Trough (England). Austin and Davis (1984) suggested that this species preferred agitated water around the wave base in the rocks of British Isles.

Table 4.4. Conodont and associated fauna identified within the facies of BSE section (Bademli).

Facies Types	**Conodont Fauna**	**Associated Fauna**
Crinoidal bioclastic packstone	***Common*** (*Lochriea commutata*, *Gnathodus girtyi girtyi, Gnathodus girtyi simplex, Gnathodus cuneiformis, Polygnathus mehli mehli* and *Kladognathus* sp.)	Foraminifers, echinoid and crinoid fragments, brachiopods, ostracodes and gastropods
Bioclastic grainstone	***Abundant*** (*Lochriea commutata*)	Foraminifers, ostracodes and brachiopods
Sandy oolitic grainstone	**Absent**	Foraminifers, ostracodes, algae, broyozoans, gastropods, echinoid and crinoid fragments
Quartz-peloidal grainstone	**Rare** (*Lochriea commutata*, *Gnathodus girtyi girtyi*)	Foraminifers, crinoid and echinoid fragments
Quartz arenitic sandstone	**Absent**	Unfossiliferous or rare

The conodont assemblages from the BSE section in the Taurides (Turkey), exhibit a mixed ecological composition where typical offshore fauna like *Gnathodus girtyi girtyi*, *Gnathodus girtyi simplex* and *Lochriea* (Skompski 1996) recorded together with the genera that dwelled relatively near shore environments with high energy and variable salinity, such as *Polygnathus mehli mehli*, *Vogelgnathus campbelli* and *Kladognathus.* Thus the depositional setting of the Bademli Limestone (BSE section) in the Bademli region is interpreted as shallower shelf environments.

4.3 Serpukhovian - Bashkirian Boundary Biofacies

4.3.1 Microfacies types and Depositional Environments

Microfacies types, sedimentary structures, and microfossil contents (foraminifera and conodont fauna) imply shallow marine depositional environments of the Yarıcak Formation in the Hadim region. Atakul-Özdemir et al. (2011) described eight different microfacies types, coated crinoidal packstone, coated bioclastic grainstone, oolitic grainstone, oolitic packstone-grainstone, intraclastic grainstone, mudstone-wackestone, quartz-peloid grainstone, and quartz arenitic sandstone, depending on the bioclastic components and sedimentological features (Figure 4.10, 4.11).

Microfacies types through the HB section:

Coated crinoidal packstone. This microfacies exhibits micritic envelops around crinoid fragments and bioclasts and contains ooids, pelloids, dark intraclasts, foraminifers, bioclasts, brachiopods and gastropods. (Figure 4.10 A). Atakul-Özdemir et al. (2011) stated that this facies was probably deposited in open marine conditions just below the wave base.

Coated bioclastic grainstone. This microfacies is basically composed of bioclasts with micritic envelopes. The major bioclastic components are foraminifers, crinoids, gastropods, brachiopods and echinoid fragments (Figure 4.10 B). This facies occurs at or above wave base (Atakul-Özdemir et al. 2011).

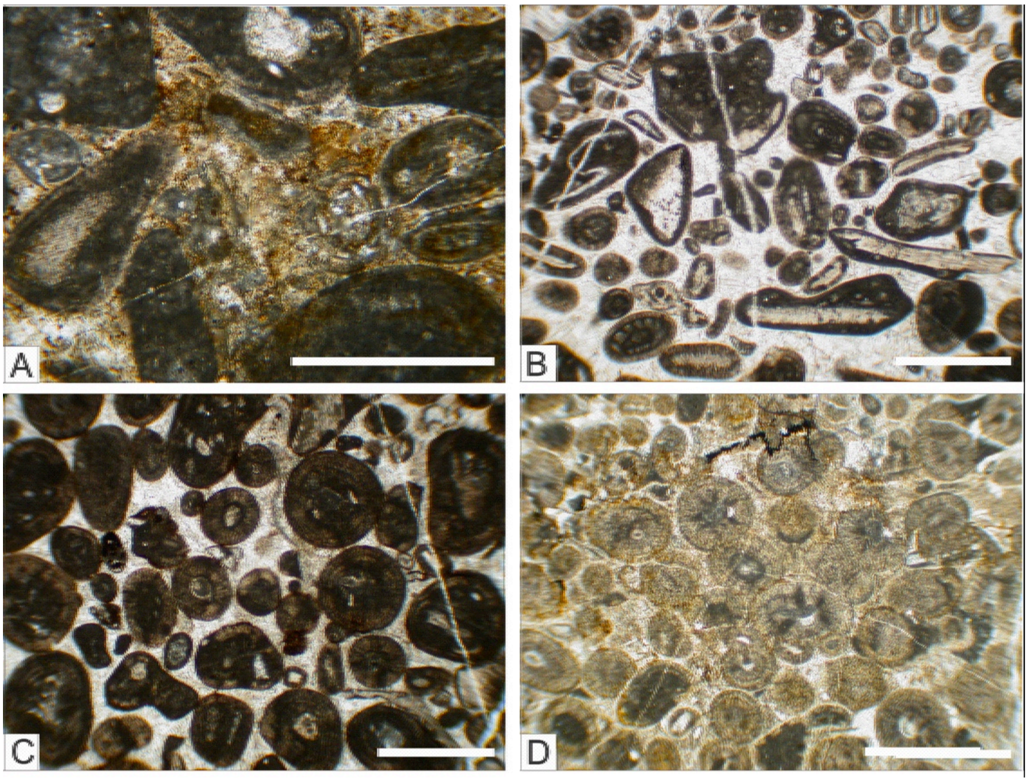


Figure 4.10. Photomicrographs of microfacies determined in the HB section in the Hadim region (Central Taurides). Scale bar is 0.5 mm in length and valid for each photograph, A coated crinoidal packstone (sample HB 09), B coated bioclastic grainstone (sample HB 47), C oolitic grainstone (sample HB 41), D oolitic grainstone-packstone (sample HB 21). Horizontal bar is 500 µm.

Oolitic grainstone. Ooids including intraclasts, quartz grains and skeletal fragments, particularly foraminifera as a nuclei are the major components of this microfacies. (Figure 4.10 C). The laminae of the ooid cortices exhibit radial fibrous structures. Atakul-Özdemir et al.

(2011) reported that this microfacies was deposited under high-energy, shallow-water environments.

Oolitic packstone-grainstone. This microfacies comprises principally radial fibrous ooids, intraclasts and pellets. The nuclei of ooids are composed of bioclast fragments and dark intraclasts (Figure 4.10 D). This microfacies was deposited landward of the oolitic sand shoal (Atakul-Özdemir et al., 2011; Flügel, 2004).

Intraclastic grainstone. This facies is marked by the presence of intraclasts, peloids, coated and micritized skeletal grains, aggregate grains, echinoid fragments and foraminifers (Figure 4.11 A). This microfacies was deposited in a shallow subtidal environment with restricted circulation (Atakul-Özdemir et al., 2011; Flügel, 2004).

Mudstone-Wackestone. This microfacies is characterized by abundant lime mud. It is poorly fossilliferous to unfossilliferous and contains pellets (Figure 4.11 B). It indicates a low-energy and restricted lagoonal depositional environment (Atakul-Özdemir et al., 2011; Flügel, 2004).

Quartz-peloidal grainstone. This microfacies is unfossiliferous and composed of peloids, quartz grains, ooids and skeletal fragments (Figure 4.11 C). This cross-bedded quartz-peloidal grainstone microfacies is interpreted as an eolianite (Atakul-Özdemir et al. 2011).

Quartz arenitic sandstone. This microfacies consists of very fine quartz sand to silt. Fossils and other constituents are absent (Figure 4.11 D) in this facies. It has herringbone cross-bedding sedimentary structure which was observed during the field study indicating depositional environment as an intertidal or possibly a foreshore environment (Atakul-Özdemir et al. 2011).

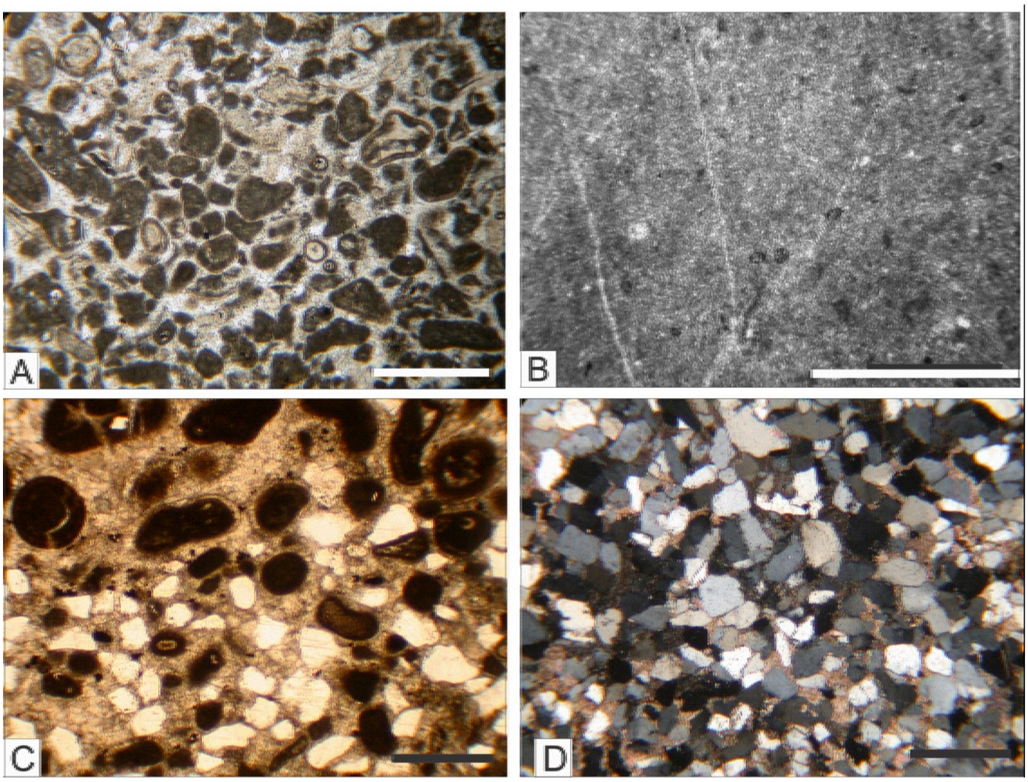


Figure 4.11. Photomicrographs of microfacies determined in the HB section in the Hadim region (Central Taurides). Scale bar is 0.5 mm in length and valid for each photograph, A intraclastic grainstone (sample HB 49), B mudstone-wackestone (sample HB 34), C quartz-peloidal grainstone (sample HB 53), D quartz arenitic sandstone (sample HB 64). Horizontal bar is 500 µm.

Based on the vertical evolution of these microfacies throughout the HB section in the Hadim region (Taurides, Turkey), Atakul-Özdemir et al. (2011) defined four distinct depositional belts of shallow marine deposits (peritidal flat, lagoon, oolitic shoal and open marine). The conodont assemblages recovered from the HB section in the Yarıcak Formation support the microfacies analysis and environmental interpretation identified by Atakul-Özdemir et al. (2011) in which shallow marine near shoal environments are dominated throughout the section.

In the Central Taurides, the Mid-Carboniferous boundary section (HB) is mainly composed of shallow marine peritidal carbonates. The conodont fauna of this section includes species of *Declinognathodus, Rhachistognathus, Adetognathus* and *Kladognathus*. In the following section, the conodont species and facies relationships will be discussed in detail.

4.3.2 Conodont Species and Microfacies Relationships

Biofacies studies of the mid-Carboniferous conodonts concern mainly shallow water environments (Merrill 1973; Merrill and von Bitter 1976; Davis and Webster 1985; Sweet 1988; Rexroad and Horowitz 1990; Morrow and Webster 1991, 1992; Krumhardt et al. 1996) and relatively deep water areas (Nemyrovska and Nigmadganov 1994). Davis and Webster (1985) and Morrow and Webster (1991, 1992) presented conodont biofacies and depositional environments of the Wahoo Limestone in Montana and Utah. Four conodont biofacies, (1) *Declinognathodus - Idiognathoides*, (2) *Rhachistognathus*, (3) *Adetognathus* and (4) *Neognathodus*, have been recognized by Davis and Webster (1985) for mid-Carboniferous beds of Central Montana. However, Morrow and Webster (1991) reported only two biofacies, (1) *Rhachistognathus* and (2) *Adetognathus* for middle Carboniferous offshore barrier-shoal and near shore environments in Utah. Krumhardt et al. (1996) defined three biofacies, (1) cavusgnathid, (2) cavusgnathid - kladognathid, (3) gnathodid - hindeodid, for Mississippian deposits and four biofacies, (1) adetognathid, (2) adetognathid - rhachistognathid, (3) rhachistognathid, (4) declinognathid related, for Pennsyvanian deposits of Wahoo Limestone (Figure 4.12).

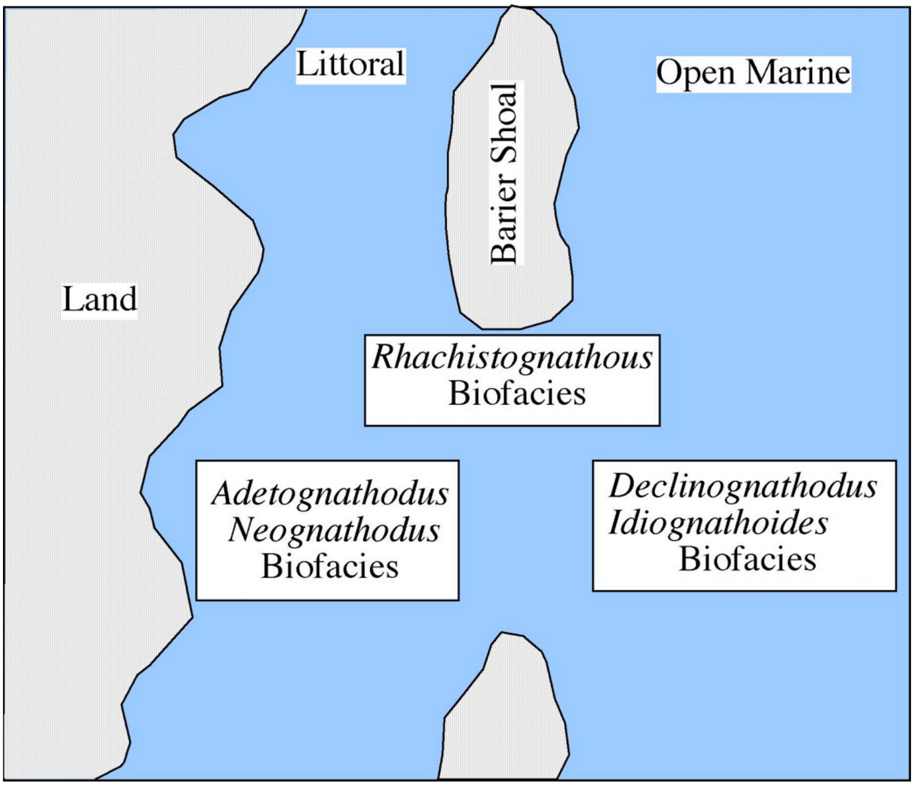


Figure 4.12. Missippian-Pennsyvanian generalized biofacies in Alaska Bench Formation in Central Montana (Davis and Webster 1985).

Nemirovska and Nigmadganov (1994) defined *Gnathodus bilineatus* s.l. - *Lochriea commutata* and *Idiognathoides* – *Declinognathodus* biofacies in deep water deposits of Uzbekistan. Based on the studies it can be concluded that adetognathid and cavusgnathid biofacies were deposited in the near shore environments, rhachistognathids occurs in shoal and shallow open-marine settings and declinognathid - idiognathoid biofacies deposited in open offshore and shallow marine conditions (Figure 4.13).

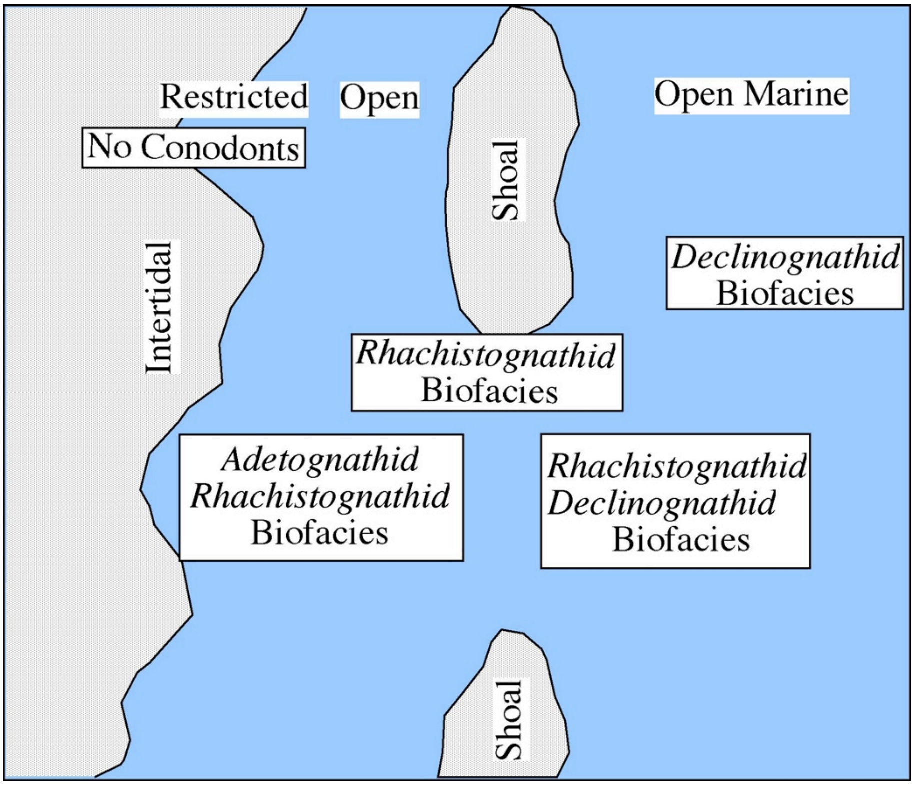


Figure 4.13. Missippian-Pennsyvanian generalized biofacies and conodont distribution in Wahoo Limestone in Utah (Krumhardt et al. 1996).

The conodont elements recorded in the HB section is very low in abundance and the species diversity is limited. The Mid-Carboniferous in the Taurides section includes *Rhachistognathus muricatus*, *Rhachistognathus minutus minutus*, *Rhachistognathus minutus declinatus, Gnathodus girtyi simplex, Declinognathodus bernesgae, Adetognathodus lautus, Declinognathodus lateralis, Declinognathodus inaequalis, Declinognathodus noduliferus* and *Kladognathus* sp. (Table 4.5). This assemblage has been recorded in the other Carboniferous conodont biofacies studies (Merrill and Martin, 1976; Merrill and von Bitter, 1976; Davis and Webster, 1985; Rexroad and Horowitz, 1990; Pohler and Barnes, 1990; Krumhardt et al. 1996), For defining the shallow water Carboniferous conodonts, Sweet (1988) stated that the species of *Adetognathus* mainly recorded in near shore or marginal marine environments. Moreover, Davis and Webster (1985) and Krumhardt et al. (1996) reported that the species of *Rhachistognathodus* is tremendously dominated in the higher energy shoal, tidal-channel and open platform environments. They also indicated that the presence of *Declinognathodus noduliferus* and *Rhachistognathus minutus* indicate a near shoal, open marine environment. Because of the dominance of *Rhachistognathus* and *Declinognathodus* in studied section, it can be concluded that the depositional environment of the Yarıcak formation ranges from near shore to open marine environments.

In the Taurides, the conodonts have been recorded only from coated bioclastic grainstone and intraclastic grainstone facies throughout the HB section (Table 4.5). Beside the conodont elements, these types of facies include echinoid and crinoid fragments and abundant foraminifers. These microfacies are the most appropriate ones for the concentration of conodont elements. No conodonts were obtained from the other types of facies defined in the Hadim region (Taurides, Turkey). Like the Mid-Carboniferous biofacies in Northeast Brooks Range (Alaska) described by Krumhardt et al. (1996), coated bioclastic grainstone and intraclastic grainstone facies in the Taurides which were deposited in shoal to open marine environments contain mainly *Rhachitognathus* - *Declinognathus* biofacies.

Table 4.5. Conodont and associated fauna identified within the facies of HB section (Hadim).

Facies Types	**Conodont Fauna**	**Associated Fauna**
Coated crinoidal packstone	**Absent**	Crinoid fragments, foraminifers, bioclasts, brachiopods and gastropods
Coated bioclastic grainstone,	**Rare** *(Gnathodus girtyi simplex, Kladognathus* sp.)	Foraminifers, crinoids, gastropods, brachiopods and echinoid fragments
Oolitic grainstone,	**Absent**	Foraminifers
Oolitic packstone-grainstone	**Absent**	Foraminifers and other bioclast fragments
Intraclastic grainstone	**Common** *(Declinognathodus inaequalis, Declinognathodus lateralis, Declinognathodus inaequalis Rhachistognathus minutus minutus, R. minutus declinatus, R. muricatus, Declinognathodus lateralis, Adetognathodus lautus* and *Kladognathus* sp.)	Foraminifers, crinoid and echinoid fragments
Mudstone-wackestone	**Absent**	Unfossiliferous
Quartz-peloid grainstone	**Absent**	Rare foraminifers and skeletal fragments
Quartz arenitic sandstone	**Absent**	Unfossiliferous

CHAPTER 5

GEOMETRIC MORPHOMETRICS

Recently, paleontology is becoming a quantitative science, statistical and analytical methods are intensely used in paleontological studies. Paleontology is a multidisciplinary field so both standard statistical techniques and specific methods which are unique to paleontology and geology can be applied to the paleontological data. These data include a wide range of topics, from morphometrics and systematics to ecology and stratigraphy. One of the quantitative applications in palaeontology is multivariate statistical data analysis to palaeoecological and palaeobiogeographical data sets. These multivariate techniques can be classified in two groups, classification (cluster analyses) and ordination (component analyses) analyses (Figure 5.1). The other quantitative methods used in paleontology are cladistics and morphometrics. Cladistics is a specific technique to express the relationships between organisms based on the evolutionary tree. Morphometrics is a branch of statistics concerning the size and shape changes by using morphological measurements. Considering the quantitative characterization of morphological data, morphometric methods have been widely used in paleontology for taxonomic and evolutionary studies. The morphometric analyses can independently test the taxonomic, phylogenetic and evolutionary hypotheses, and identify morphological variations through ontogeny (Rohlf and Bookstein 1990; Temple 1992; Marcus et al. 1996; Haines and Crampton 2000). Two morphometric approaches, traditional and geometric morphometrics, have been widely used in paleontological data analysis (Figure 5.2).

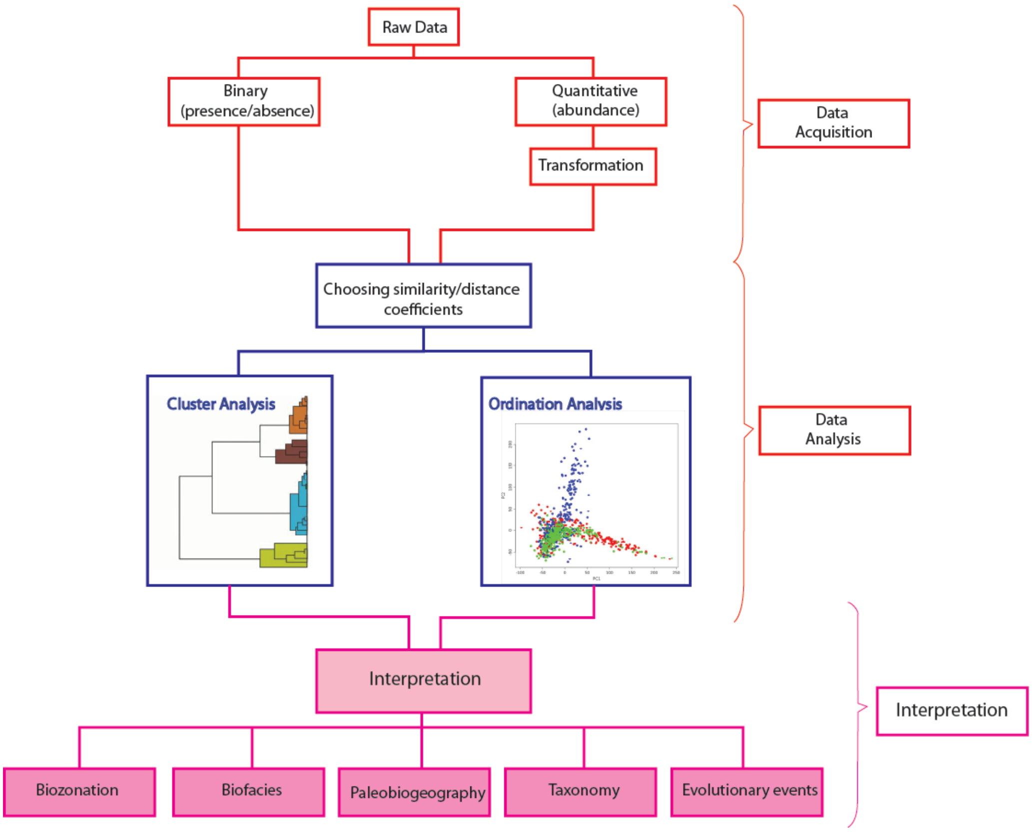


Figure 5.1. Procedure for multivariate analysis of paleontological data (Shi 1993).

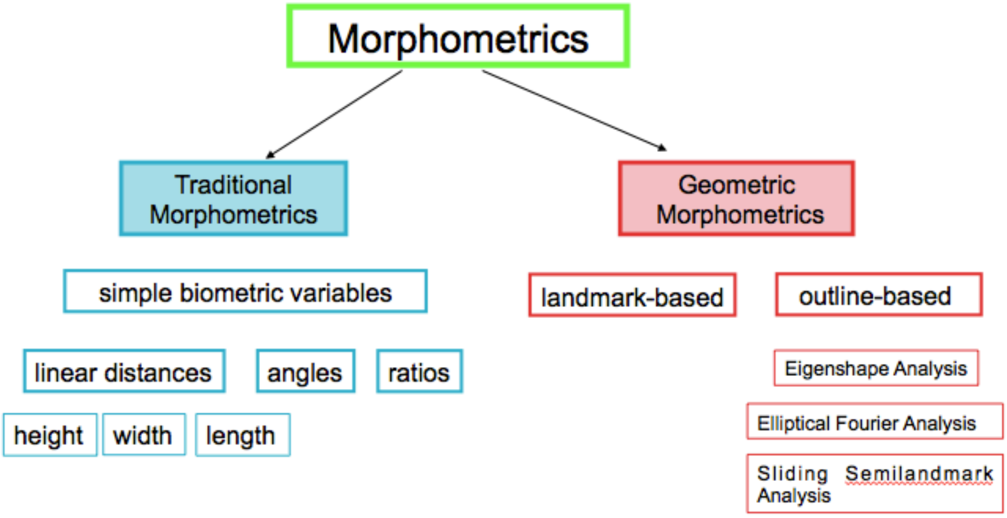


Figure 5.2. Types of morphometric analysis.

5.1 Traditional Morphometrics

Traditional morphometrics or *multivariate morphometrics* is the application of multivariate statistical analyses to morphological data based on the measurements of simple biometric variables such as linear distances (height, width and length), angles and ratios (Blackith and Reyment, 1971; Marcus 1988, 1990; Reyment, 1991). The most important analyses applied to these measurements are principal components analysis (PCA), canonical variate analysis (CVA), factor analysis and discriminant function analysis.

Traditional morphometric method has some strengths. The major advantage of this method is that it is so simple and easy to apply. Additionally, measuring incomplete forms can also increase the sample size. However, it has several limitations and drawbacks. The most important problem is that linear measurements give information about the size changes and this makes shape analysis difficult. Moreover, it is impossible to reconstruct graphical illustrations of the shape changes.

5.2 Geometric Morphometrics

Because of the limitations of traditional morphometrics, the methodology of morphometrics underwent a revolution during the last years and researchers created a new sophisticated method termed as Geometric Morphometrics to analyze morphological shape changes by measuring size and shape components of organisms (Bookstein 1991, 1996, 1997; Rohlf and Marcus 1993; Marcus et al. 1996). The techniques used in geometric morphometrics can be divided into two basic groups, landmark-based geometric morphometrics and outline-based geometric morphometrics.

Landmark-based geometric morphometrics uses a set of homologous points, landmarks, to describe shape. The biological homology is generally considered as a key for the landmark-based morphometrics (Bookstein 1991). Biological homology can be recognized by the morphological and topological similarity of features shared with a common ancestor. Shape changes can be determined by the analysis of these homologous points, landmarks. The results of the analysis are mainly depending on the quality of landmark points so the selection of these points is very important for landmark-based geometric morphometric methods.

Sometimes the number of landmark points available is insufficient to define the shape of an organism and in some cases it is impossible to define landmarks. Under these circumstances an alternative method is developed named as outline-based geometric morphometric analysis. By this method the boundary of an organism is digitized and the points around the boundary fitted with a mathematical function. Different methods based on the coefficients of mathematical functions have been used to make an outline analysis. The most common methods for outline analysis are Eigenshape Analysis, Elliptical Fourier Analysis (EFA) and Sliding Semilandmark Analysis. Elliptical Fourier Analysis uses Fourier decomposition and generate harmonics based on the points around the outline. Eigenshape Analysis measures angles between the points around an outline so principal components scores are defined from the angular data. Semilandmarks are points around an outline that capture information about curvature (Green, 1996; Sampson et al., 1996; Bookstein, 1997; Sheets et al., 2004; Perez et al., 2006). Particular superimposing methods like procrustes, are necessary for semilandmark analyses (Bookstein 1997; Webster and Sheets 2010). In Sliding Semilandmark Analysis semilandmarks are iteratively moved around the outline to find the point of best correspondence as part of the superimposition process. After superimposing, the coordinates can be treated as routine landmark methods.

Outline-based geometric morphometric analysis has also some drawbacks. The data obtained by this method includes information only about the boundary of an organism. Information about the shape changes inside of an organism cannot be determined by this method.

5.3 Application of Morphometric Analyses to Conodont Elements

Conodont is an important fossil group for Paleozoic biostratigraphic studies so it requires a stable taxonomic basis. Nevertheless, conodont taxonomy is commonly challenging. The species boundaries have been mainly defined based on incomplete skeletal material, which displays complex morphological variations. Therefore, it become necessary to apply morphometric methods to the taxa. However, there are very few morphometric studies on the conodonts. The objects of conodont morphometric studies comprise morphological variations in a conodont taxa (Jones and Purnell 2007), examining evolutionary trends (Barnett 1971; Murphy and Cebecioglu 1987; Renaud and Girard 1999; Girard et al. 2004; Jones 2009), size distribution analyses (e.g. Jeppsson 1976), detecting biostratigraphically useful morphologies (Barnett 1972, Murphy and Cebecioglu 1984, Murphy and Springer 1989, Ritter 1989), testing hypotheses of feeding mechanisms (Purnell 1993b, 1994), describing ontogeny and survivorship (Murphy and Cebecioglu 1986, Tolmacheva and Löfgren 2000, Tolmacheva and Purnell 2002), taxonomy (Croll et al. 1982, Klapper and Foster 1986, 1993, Ritter 1989, Sloan 2000, Jones and Purnell 2007) and qualitative assessments of homology (Jones 2009). Besides the morphometric studies, abundance data analyses have been also perfomed on conodont elements to figure out the morphological features and fossil distribution regarding the environmental changes (Seddon and Sweet 1971, Sandberg et al. 1988, Girard and Renaud 2007).

In this study, several morphometric methods have been performed in conodont taxa within a taxonomic context. Morphometric analyses in this study have been carried out by using data from literature. Specifically the Lower Carboniferous genus *Gnathodus* is the focus of this study. *Gnathodus* is an important taxon for quantitative analysis because it displays variable morphological changes on P1 element (Figure 5.3 and Figure 5.4). The species of *Gnathodus* are widely distributed in deep-water successions of the Mississippian age. Many species of this genus are used as indicators of the Early Carboniferous standard conodont zones and consequently, many papers focus on *Gnathodus*. It ranges from the mid-Tournaisian to the mid-Namurian age. Taxonomic studies of *Gnathodus* have been entirely based on P1 elements and the criteria used include platform outline (in upper view), nature of parapets or ornamentation and degree of lateral expansion of the posterior tip of the carina (Lane et al. 1980). Many workers have attempted clarification of the phylogeny of *Gnathodus* through taxonomic splitting, mainly based on isolated studies of just P1 elements. However, Stone (1991) stated that many of the resulting species and subspecies are phenotypic variations with little biostratigraphical significance. Lane et al. (1980) have recognized four groups based on the basis of parapet length and the degree of expansion of the posterior tip of the carina. While Stone (1991) argued that the nomenclature of Lane et al. (1980) produces unsatisfactory results since he thought that the development of the posterior tip does not appear to be a genetically significant feature and he proposed that its development is often associated with ontogenetic development. Therefore, this study tests the validity of taxonomy and species recognition of the biostratigraphically important Lower Carboniferous genera *Gnathodus* based on the morphometric analysis.

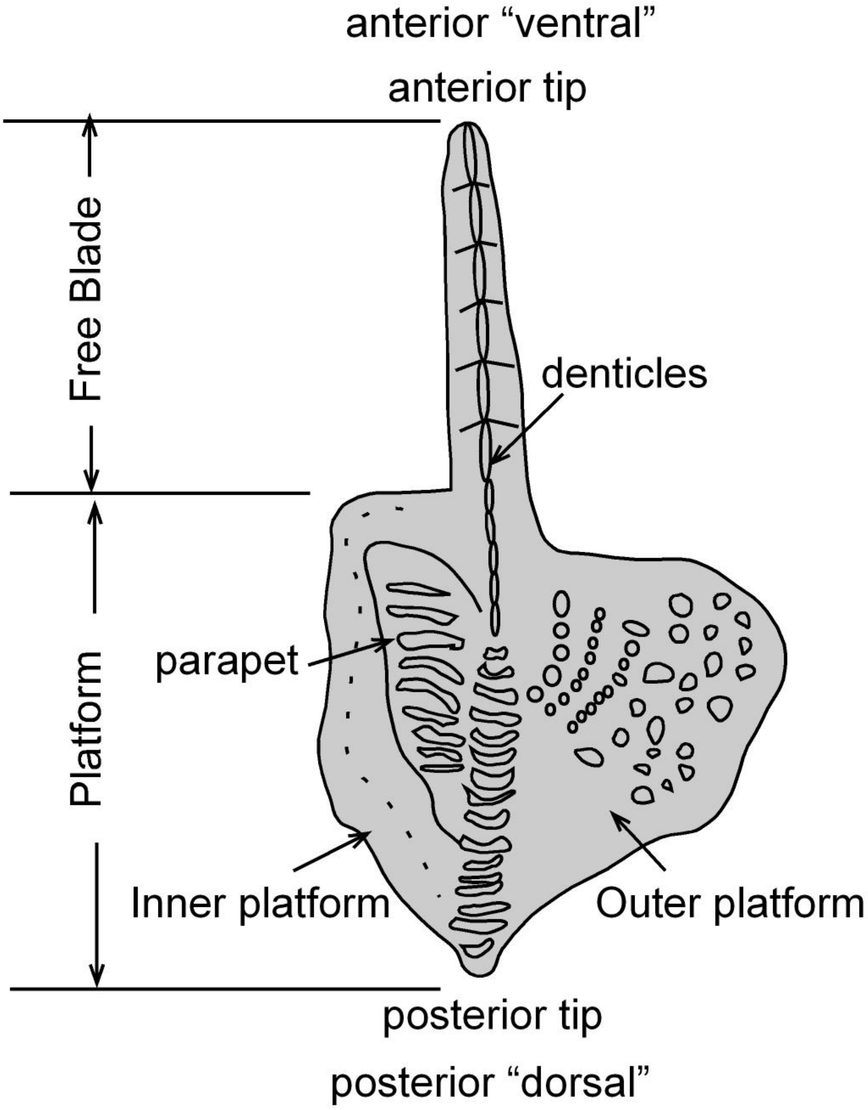


Figure 5.3. General morphological features of Gnathodus (modified from Sanz Lopez et al., 2007).

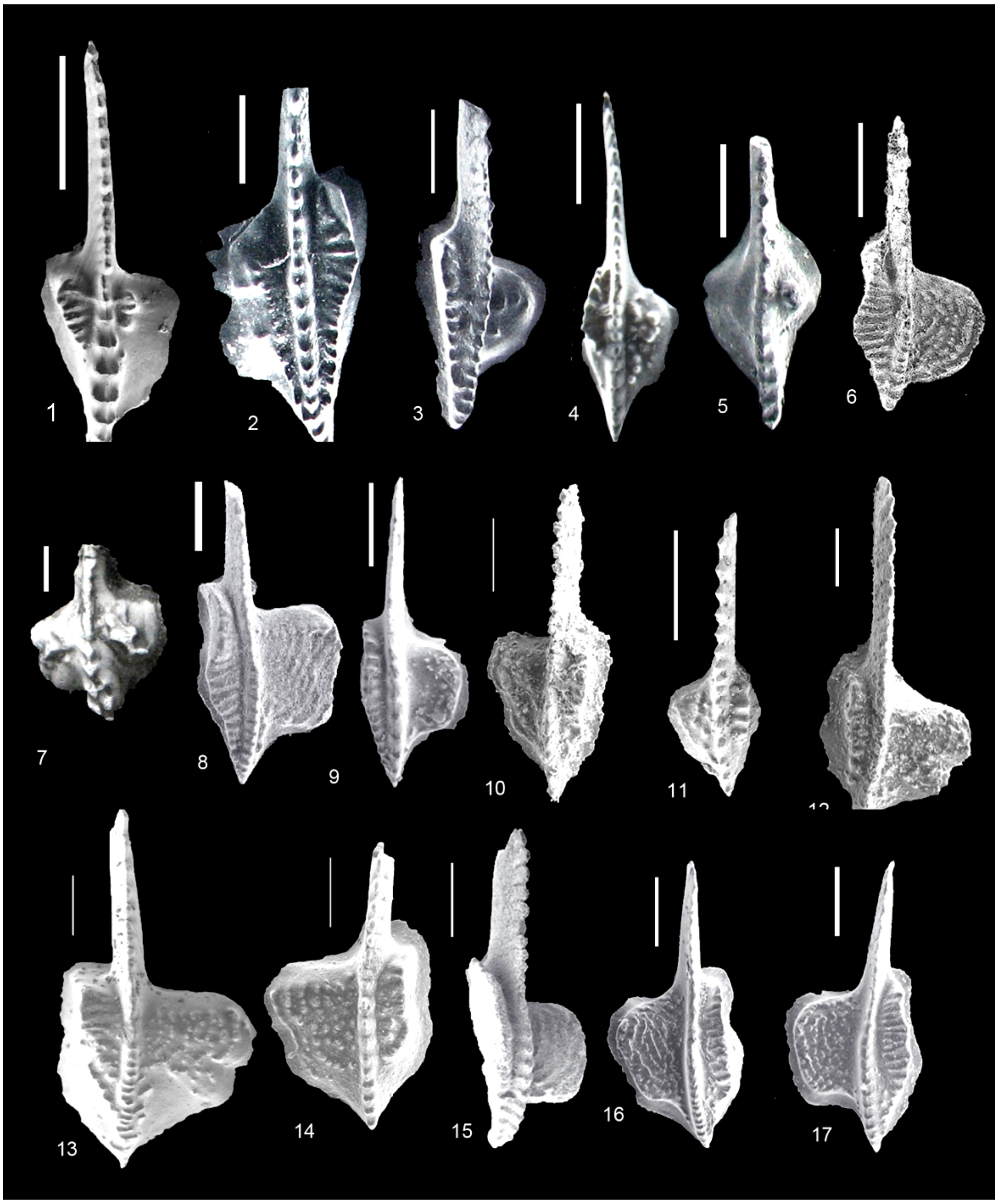


Figure 5.4. Morphological variations within the species of *Gnathodus*, (1) *G. texanus* (Nemyrovska et al., 2006); (2) *G. cuneiformis,* (3) *G. delicatus,* (4) *G. typicus,* (5) *G. texanus* (Lane et al., 1980); (6) *G. bilineatus remus* (Nemyrovska et al., 2006); (7) *G. bulbosus,* (8) *G. bilineatus bilineatus,* (9) *G. bilineatus bollandensis,* (10) *G. preabilineatus,* (11,13) *G.joseramoni,* (14) *G. kinesis,* (15) *G. millarensis,* (Sanz-Lopez et al., 2004); (16,17) *G.trulyosi,* (Sanz-Lopez et al., 2007).

5.4 Procedure of Geometric Morphometric Analyses

A total sample of 159 P1 elements belonging the 23 species and subspecies of Gnathodus and 3 specimens of outgroup, *Polygnathus* inornatus, have been analyzed. The illustrations of the elements were mainly recovered from the previously published papers and the *Gnathodus* species identified in this study were also used for the analyses (Figure 5.4). The analyses have been carried out on the platform part of the elements since the blade part of the most elements were broken. The list of the species names and their references have been given in the Appendix.

TpsDig2 software downloaded from http://life.bio.sunysb.edu/morph (Rohlf 2004) has been used to acquire 2D outline and landmark coordinates of the conodont elements from digital images. Two different digitizing methods have been applied on the oral view of P1 elements. Firstly, 200 (x, y) coordinates around the outlines of the elements were digitized starting from the posterior tip in order to perform Eigen Shape and Elliptical Fourier Analyses (Figure 5.5A). Eigen Shape (ES) analysis was conducted from the website http://www.morpho-tools.net and Elliptic Fourier analysis (EFA) was excuted by using EFA software downloaded from the http://life.bio.sunysb.edu/morph website. The eigen shape scores and fourier coefficients were used to carry out a principal component analysis (PCA) to illustrate the shape variation within the genera. Secondly, for each specimen 4 landmark and 15 semilandmark points were digitized to execute Sliding Semilandmark Analysis by using TpsDig2 software (Rholf) (Figure 5.5B). For this analysis, a slider file indicating which points are landmarks and which points are semilandmarks has been prepared.

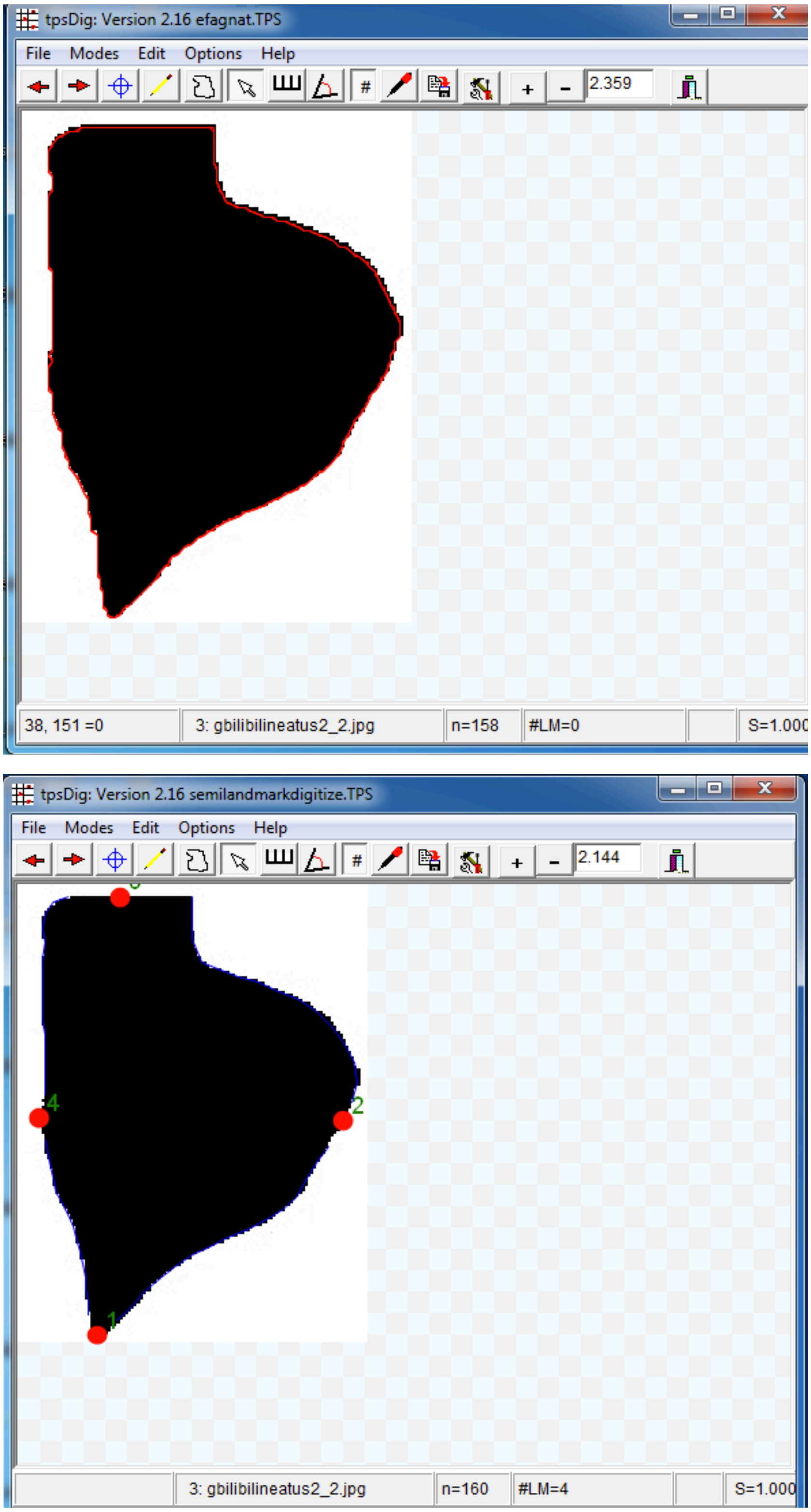


Figure 5.5. Illustrating the digitizing methods, pure outline digitizing (A) and landmark and semilandmark points around the outline (B).

The semilandmarks slide along the outline to obtain closely sampled outline. The sliding method has been performed using TpsUtil software (Rholf 2008). The landmark and semilandmark points of each specimen were superimposed in order to rotate and translate the arrangements of points into a common location and remove non-shape size differences (Figure 5.6).

Two commonly used optimization procedures to slide points along an outline are minimum bending energy (Bookstein 1996; Green 1996; Bookstein et al. 2002, Webster and Sheets 2010) and minimum procrustes distance (Sampson et al. 1996; Bookstein et al. 2002; Sheets et al. 2004, Webster and Sheets 2010). The Generalized Procrustes Analysis (GPA) superimposition has been performed by using TpsRelw software (Rholf 2008). This program proposes the bending energy or the Procrustes distance options for optimizing sliding semilandmark during superimposition (Webster and Sheets 2010). A Relative Warp analysis typically known as PCA of the partial warp plus uniform component scores, has been carried out using tpsRelw (Rohlf 2008).

In order to depict the whole shape variation within the taxa, the relative warps scores (known as also PCA scores) were used for Canonical Variate Analysis (CVA). Canonical Variate Analysis (CVA) were also performed by using NTSYSpc software package. NTSYSpc (Numerical Taxonomy SYStem for personal computer) is a statistical software to find and display structure in multivariate data. This program has also been widely used in morphometrics, ecology and in other disciplines (Rohlf, 1998).

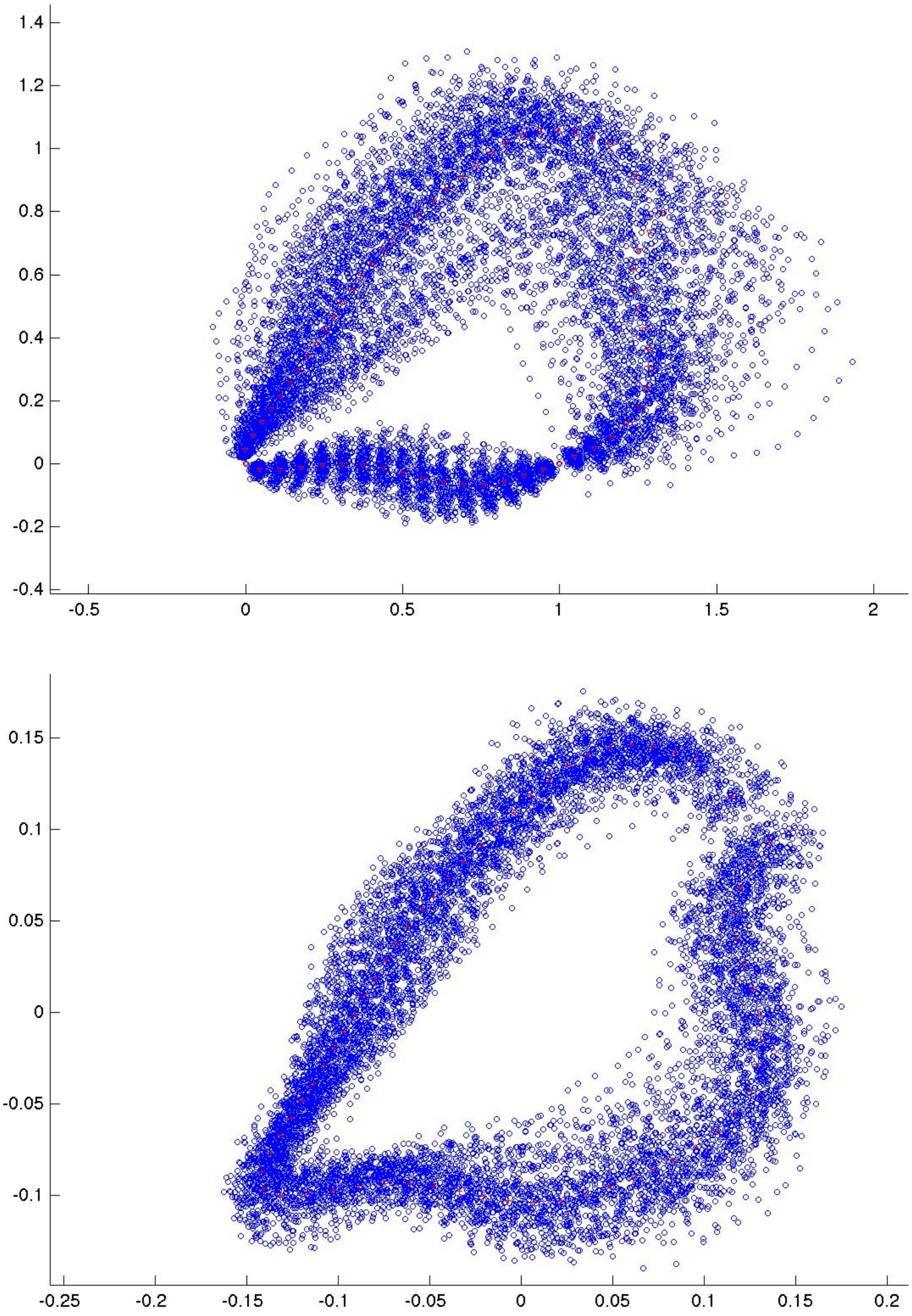


Figure 5.6. Scatterplot of landmark coordinates for configurations of 4 landmark and 60 semi-landmarks on the species of *Gnathodus* without semilandmark superimposition (A) and with minimum Procrustes distance superimposition (B).

5.5 Results of Geometric Morphometric Analyses

5.5.1 Sliding Semilandmark Analysis

Relative Warp Analysis

Relative Warp (RW) scores have been calculated to illustrate the shape variation between the species of *Gnathodus* regarding the partial warp scores. Relative Warp analysis also matches with Principal Component analysis (PCA) of the partial warp scores. The analysis resulted in 124 relative warp scores (RWs) for the *Gnathodus* species and revealed that the eleven of them described a 95% of the shape variation. The first three RWs define 56.54%, 14.33% and 7.95% of the total variation among the species respectively (Table 5.1).

The scatter plot of the first two RWs of all 23 species and subspecies of *Gnathodus* shows some clustering of the groups but they are mainly scattered around the axis (Figure 5.7). The RWs predominantly indicates two major subdivision of the *Gnathodus*, *bilineatus* group and *girtyi* group (Figure 5.8). Subsequently, the first RW axis (RW1, indicating 56.54% variation) specifies the size of the platform. The negative values on the axis correspond to the elements having wider platforms but the positive values match with the narrow platform elements (Figure 5.8).

Table 5.1. First eleven relative warp scores (RWs) obtained from Relative Warp Anlysis (PCA of the partial warps).

No	SV	%	Cum %
RW1	1.27354	56.54%	56.54%
RW2	0.64123	14.33%	70.87%
RW3	0.47743	7.95%	78.81%
RW4	0.39171	5.35%	84.16%
RW5	0.27724	2.68%	86.84%
RW6	0.25873	2.33%	89.18%
RW7	0.21823	1.66%	90.84%
RW8	0.20279	1.43%	92.27%
RW9	0.18147	1.15%	93.42%
RW10	0.15954	0.89%	94.30%
RW11	0.14209	0.70%	95.01%

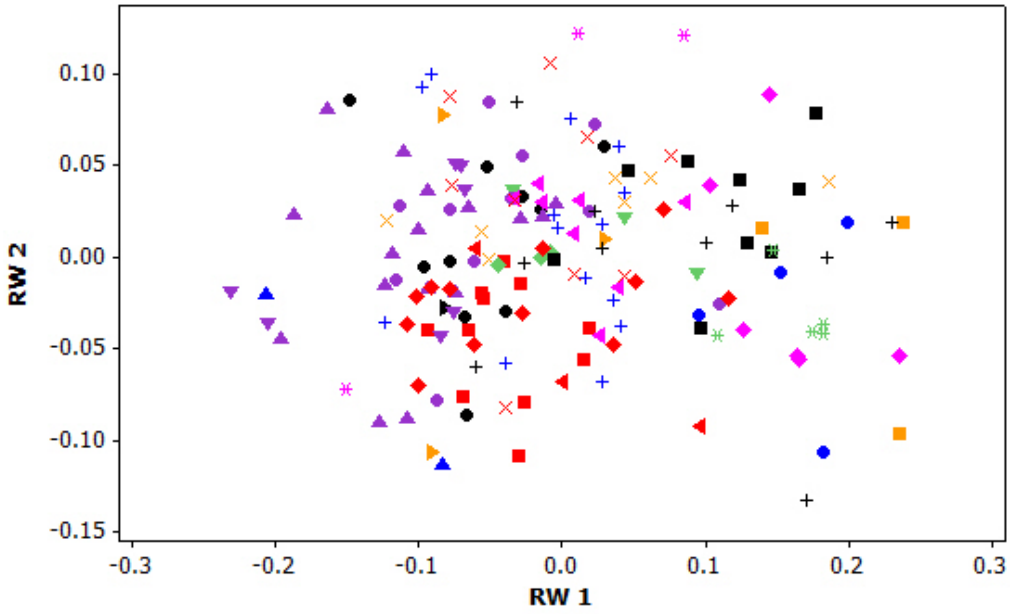


Figure 5.7. Scatter plot of relative warps scores of *Gnathodus* species.

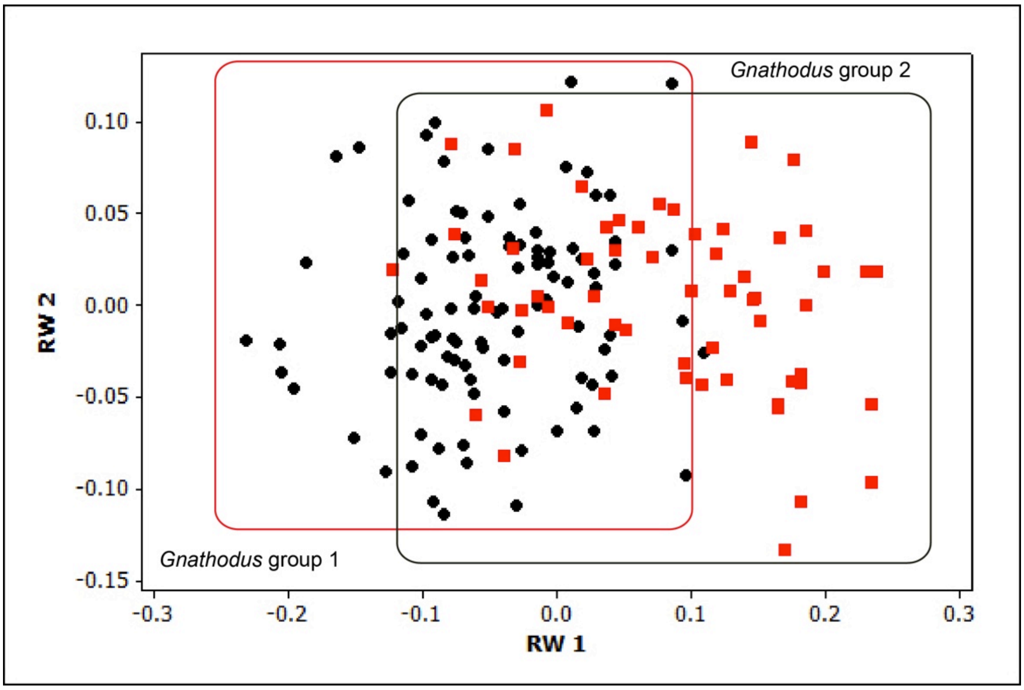


Figure 5.8. Scatter plot of relative warps scores of *Gnathodus* species.

When the subspecies of *G. bilineatus* and related species *G. jaseromoni* have been plotted, it can be concluded that *G. bilineatus bilineatus* is morphometrically different than the subspecies *G. bilineatus bollandensis* (Figure 5.9). However, the *G. bilineatus leonicus* is in between these two subspecies. *G. jaseromoni* is in a close relationship with the subspecies of *G. bilineatus* but it is morphologically different from them.

The scatter plot of RW1 and RW2 of subspecies of *G. girtyi* exhibits that all the subspecies differ in shape (Figure 5.10).

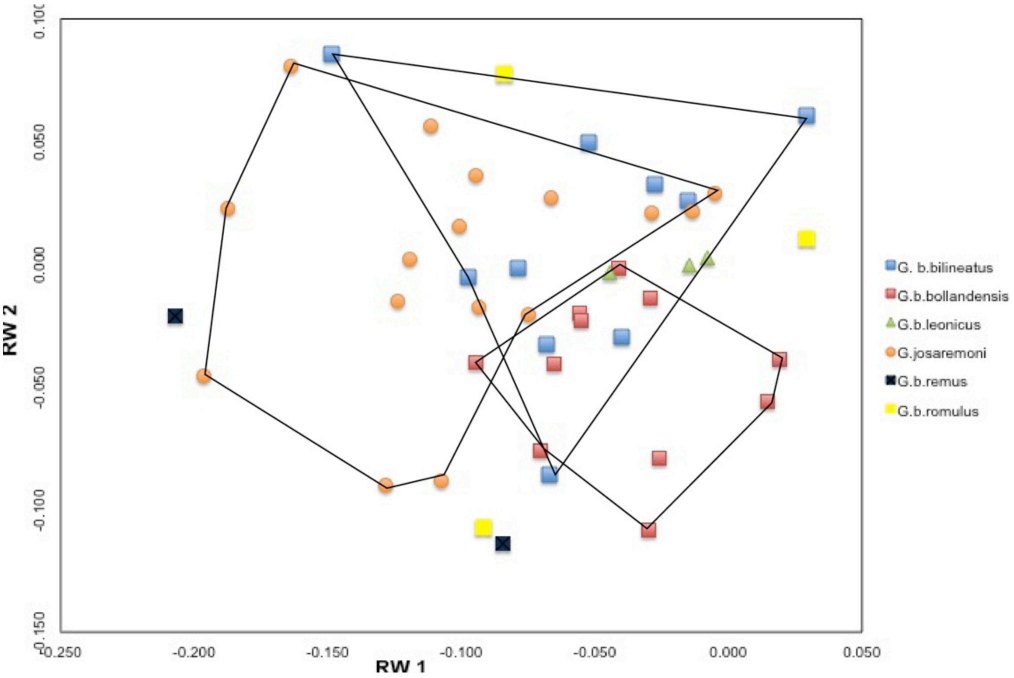


Figure 5.9. Graph of relative warps scores of *Gnathodus bilineatus* subspecies and *Gnathodus joseramoni*.

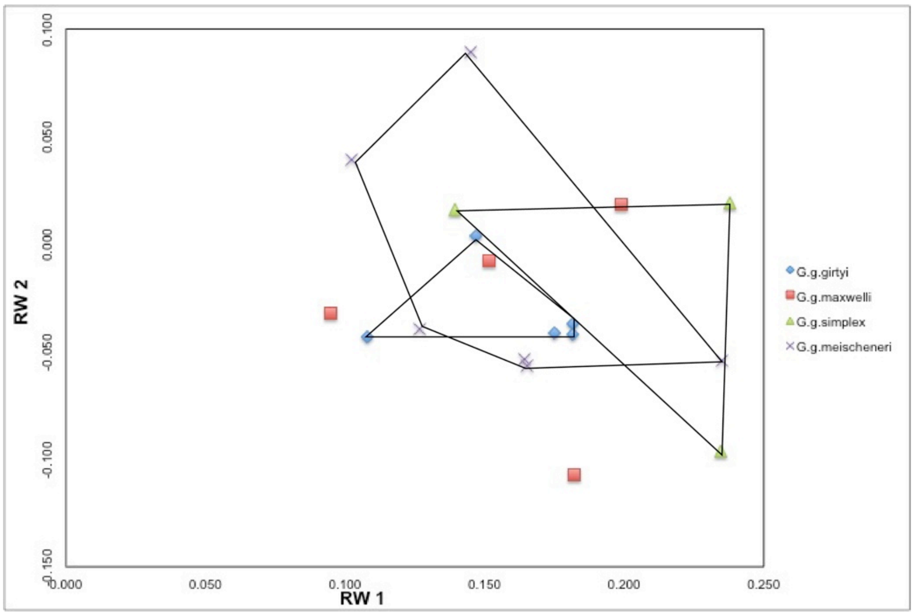


Figure 5.10. Graph of relative warps scores of *Gnathodus girtyi* subspecies.

Canonical Variate Analysis (CVA)

To evaluate the variation between the species of *Gnathodus*, CVA (Canonical Variate Analysis) has been applied to the relative warp scores. CVA is an important method to obtain various axes to distinguish different groups. CVA of relative warp scores was performed using NTSYSpc software which determines distinctive CVA axes and calculates the canonical variates scores of all the species. The first ten eigen values have been reported in Table 5.2. The first CVA axis establishes 38.61% of the variance, the second CVA axis encompasses 21.12% of the variance, the third one is 10.28%. Consequently, more than 70% of the variance is described by the first three CVA axis for interpreting the shape variation.

Table 5.2. First ten eigen values obtained from the CVA analysis.

No	SV	%	Cum %
1	0.00420317	38.61%	38.61%
2	0.00229982	21.12%	59.73%
3	0.00111870	10.28%	70.01%
4	0.00063774	5.86%	75.87%
5	0.00043242	3.97%	79.84%
6	0.00037594	3.45 %	83.29%
7	0.00028489	2.62%	85.91%
8	0.00022938	2.10 %	88.02 %
9	0.00021301	1.96 %	89.97%
10	0.00013695	1.26%	91.23 %

The ordination for the 1st and 2nd Canonical Variate Analysis (CVA) is illustrated in Figure 5.11 and 3-D graph of the results is in Figure 5.12. Moreover, a tree has been also drawn based on the canonical variate analysis (Figure 5.13). From the results of the analysis, it can be concluded that *G. rugulatus* (symbol 19) is totally different from the other *Gnathodus* species since it is plotted away from the cluster of *Gnathodus* species. All of the *G. bilineatus* subspecies clustered in distinctive places indicating that they are different subspecies. Moreover, *G. bilineatus romulus* (symbol 5) and *G. bilineatus leonicus* (symbol 3) places completely different from the other subspecies. It can be concluded that these subspecies should be excluded from *G. bilineatus* and they can be named as different species. Considering the subspecies of *G. girtyi, G. girtyi girtyi* and *G. girtyi simplex* are in a close relationship but they totally differ from *G. girtyi maxwelli* and *G. girtyi meiseheneri* since they appear away from them.

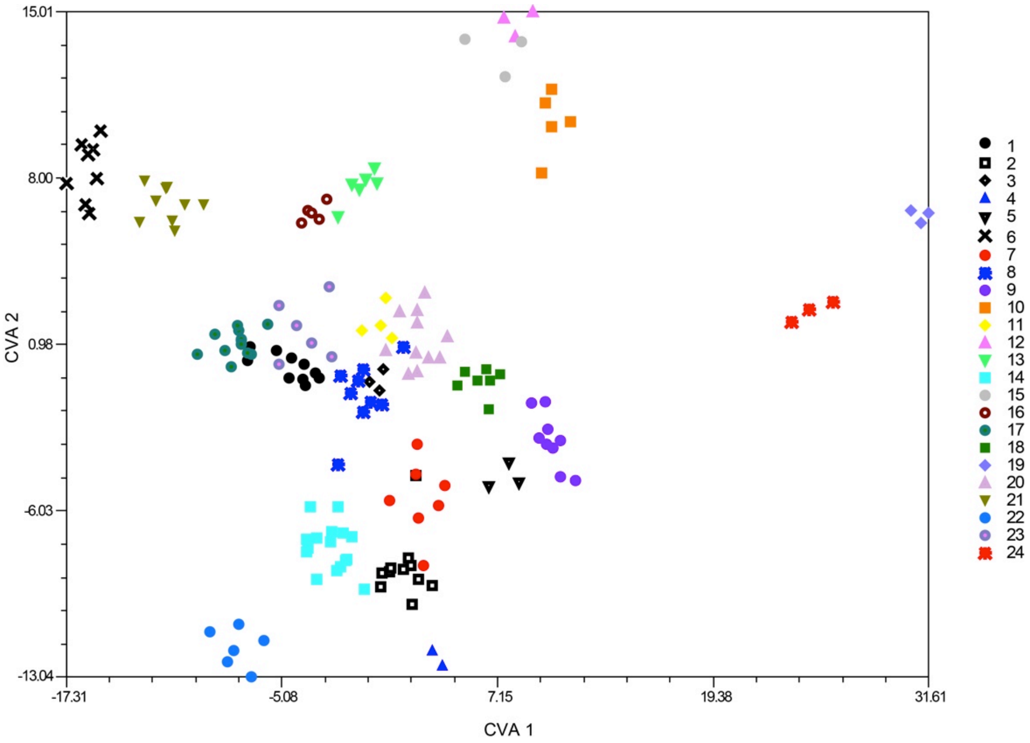


Figure 5.11. Scatter plot of Canonical Variate Analysis (CVA) first and second axes of individuals of *Gnathodus (1:G.bilineatus bilineatus; 2: G.bilineatus bollandensis; 3: G.bilineatus leonicus; 4: G.bilineatus remus; 5: G.bilineatus romulus; 6: G. bulbosus; 7: G.cantabricus: 8:G. cuneiformis; 9: G. delicatus; 10: G. girtyi girtyi; 11: G. girtyi maxwelli; 12: G. girtyi simplex; 13: G. girtyi meischeneri; 14: G. joseramoni; 15: G. millarensis; 16: G.postbilineatus; 17: G. preabilineatus; 18: G. pseudoemiglaber; 19: G. rugulatus; 20: G. semiglaber; 21: G. texanus; 22: G. trulyosi; 23: G. typicus: 24:* outgroup *Polygnathus inornatus).*

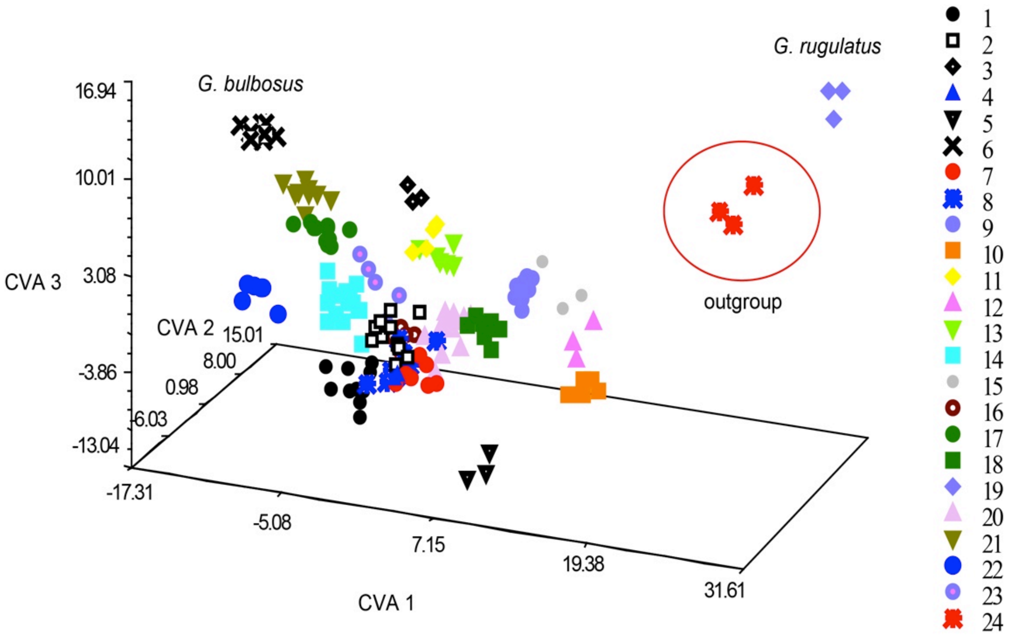


Figure 5.12. Scatter plot of Canonical Variate Analysis (CVA) first and second axes of individuals of *Gnathodus* (legend explained in Figure 5.11).

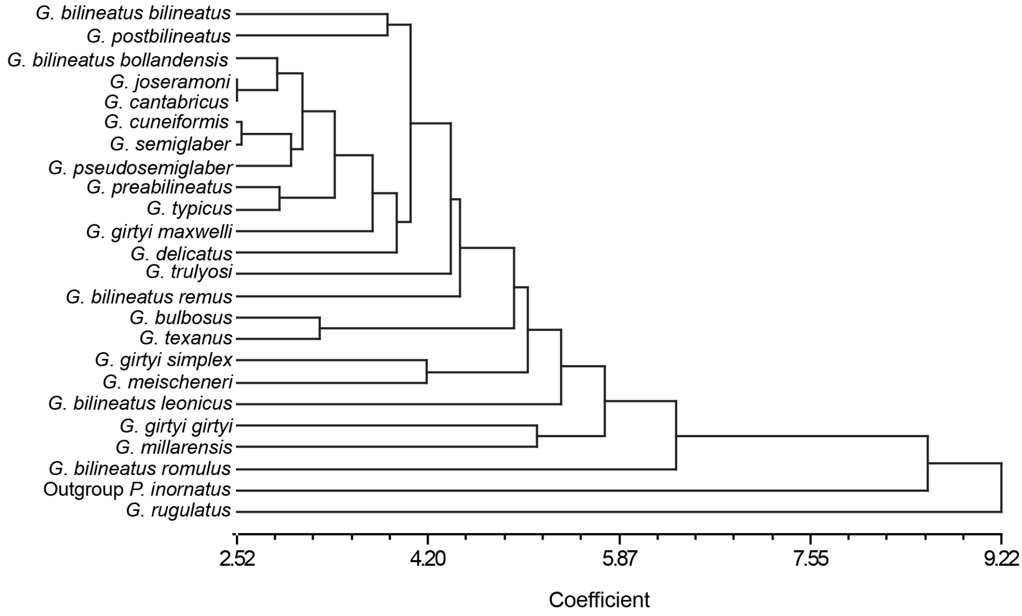


Figure 5.13. A dendrogram derived from the results of CVA analysis of *Gnathodus*.

5.5.2 Eigen Shape (ES) Analysis

Based on the Eigen Shape (ES) Analysis different ES scores have been calculated in order to depict the shape changes of the species of *Gnathodus*. The first 15 eigen values have been reported in Table 5.3. The first 15 ES values describe the 70% of the total variation. The first eigen value (ES-1) determines 23% of the variance, the ES-2 establishes 7.9% of the variance and the ES-3 defines the 6.8% of the variance.

Table 5.3. First 15 eigen values obtained from the ES analysis.

	Eigen Value	%	Cum %
ES1	5.16784232	23.05258697	23.05258697
ES2	1.770820579	7.899233932	30.9518209
ES3	1.533992709	6.842797855	37.79461876
ES4	1.047918141	4.674528087	42.46914684
ES5	1.005077205	4.483424268	46.95257111
ES6	0.748563099	3.339172303	50.29174341
ES7	0.722480381	3.222823143	53.51456656
ES8	0.595068848	2.654468834	56.16903539
ES9	0.55968862	2.496645561	58.66568095
ES10	0.509446814	2.272528118	60.93820907
ES11	0.48330098	2.155897409	63.09410648
ES12	0.423749765	1.890252779	64.98435926
ES13	0.40178797	1.792286133	66.77664539
ES14	0.383314269	1.70987909	68.48652448
ES15	0.346295749	1.544747766	70.03127225

Eigenshape axes 1,2,3, (ES-1, ES-2 and ES-3) mainly define the platform shape changes (Figure 5.14). Negative values in ES-1 correspond to the species having larger platforms and more positive values in the axis are related to the forms with narrower platforms (Figure 5.14). Hence, the ES-1 axis represents shape variations within the taxa. Remarkably, ES-1 indicates the difference between two major *Gnathodus* groups, *G. bilineatus* group having larger outer platform and *G. girtyi* having narrower outer platform (Figure 5.14 and Figure 5.15). The scatter plot of ES-1 and ES-2 and the matrix plot of ES-1, ES-2, ES-3 and ES-4 illustate the division of the *Gnathodus* into two groups like in relative warp analysis (Figure 5.15 and Figure 16).

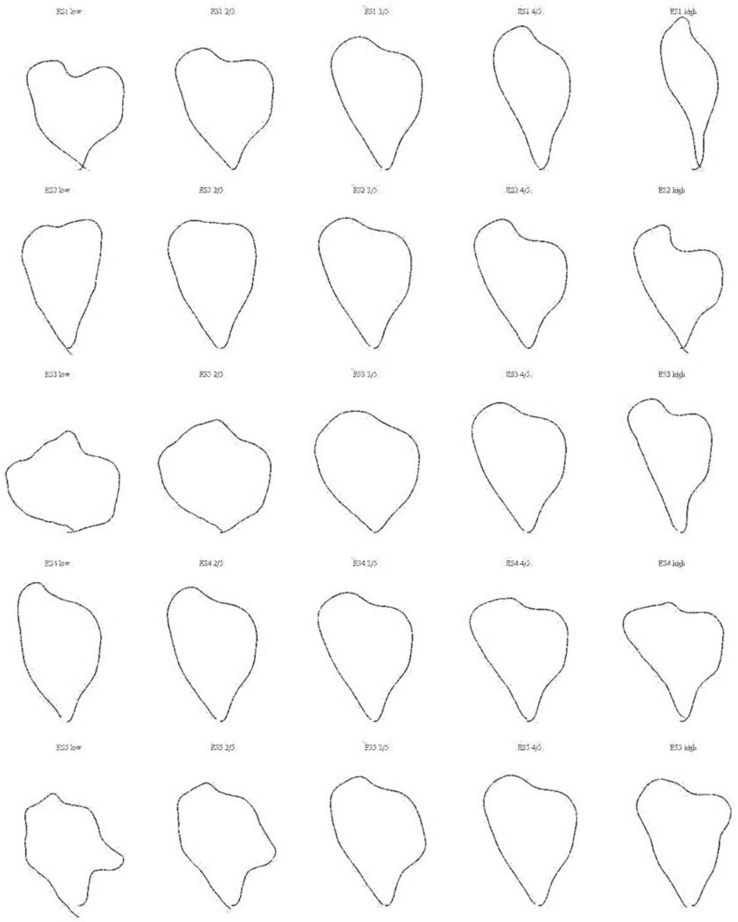


Figure 5.14. First five Eigen score models for Eigen Shape Analysis (AS) of *Gnathodus*.

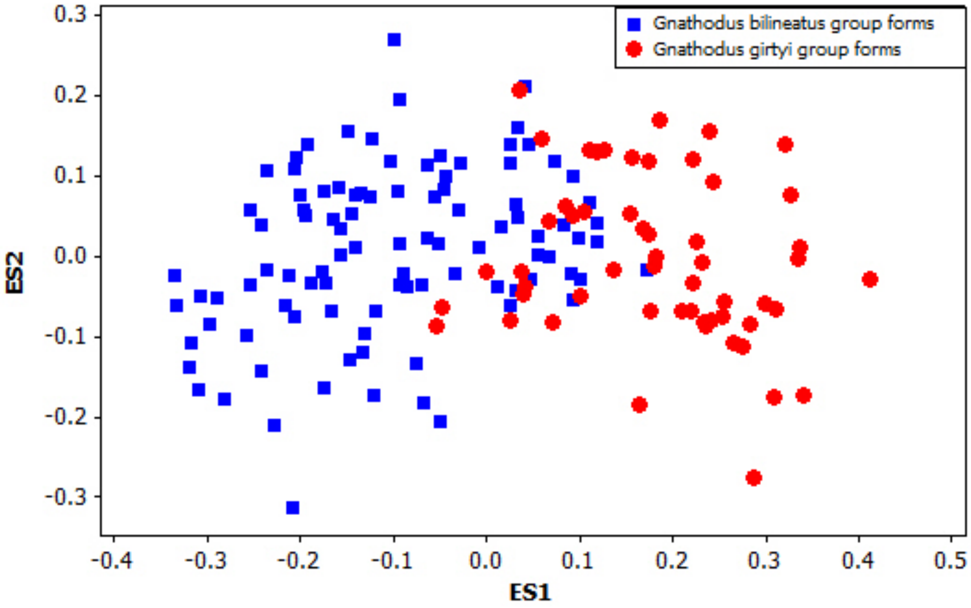


Figure 5.15. Scatter plot of individuals of *Gnathodus* on Eigen shape Analyisi axis ES-1 and ES-2.

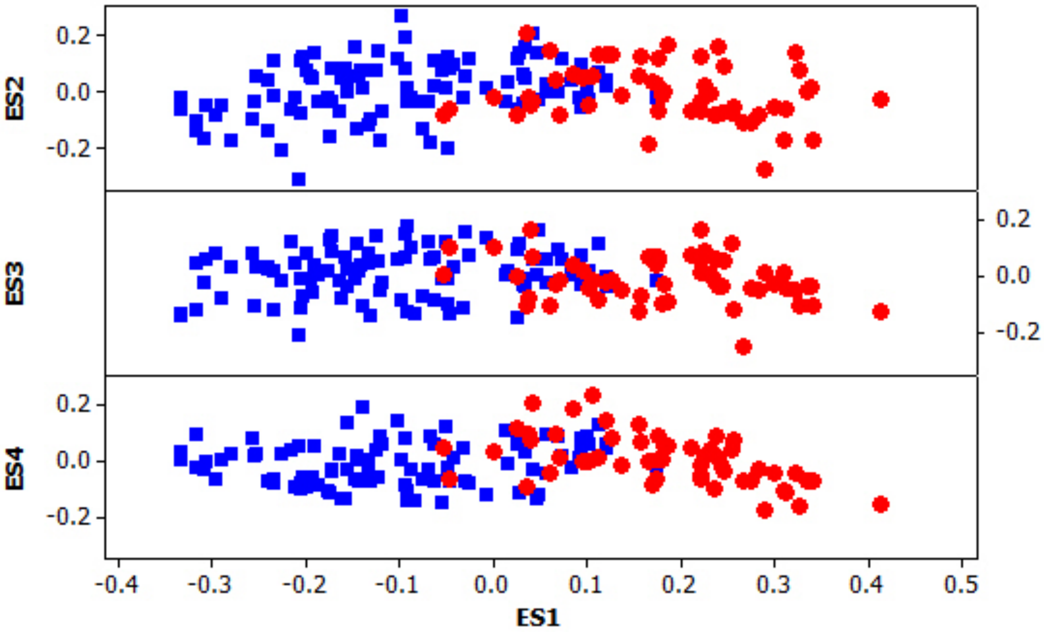


Figure 5.16. Matrix plot of ES-1, ES-2, Es-3 and ES-4 of *Gnathodus* individuals.

5.5.3 Eliptical Fourier Analysis (EFA)

Elliptical Fourier function has been used to fit outline of the conodont elements. The Fourier coefficients were used as input variables to a Principal Component Analysis (PCA) to illustrate the structures of variation. Table 5.4 illustrates the first 16 eigen values obtained from the EFA. The first 16 values describes approximately 74 % of total variation.

Table 5.4. First 16 eigen values obtained from the Elliptical Fourier Analysis (EFA).

PCA No	Eigenvalue	%	Cum. %
1	8.58	15	15
2	5.06	9	24
3	4.08	7	32
4	3.12	6	37
5	2.79	5	42
6	2.36	4	46
7	2.08	4	50
8	1.97	4	54
9	1.80	3	57
10	1.66	3	60
11	1.57	3	63
12	1.51	3	65
13	1.40	3	68
14	1.23	2	70
15	1.16	2	72
16	1.11	2	74

PC scores 1 and 2 mainly define the platform shape changes (Figure 5.17). Negative values in PC 1 correspond to the larger platforms and more positive values in the axis are related to the narrower platforms (Figure 5.17).

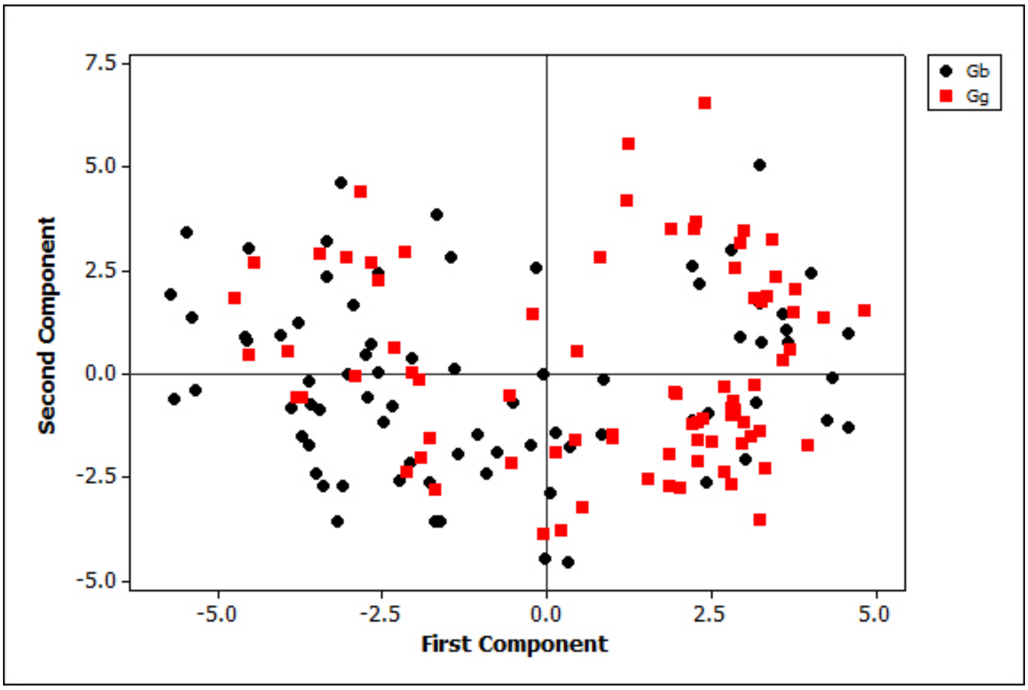


Figure 5.17. Scatter plot of Principal Component Analysis (PCA) first and second axes of individuals of *Gnathodus* as a two groups (Gb: *Gnathodus bilineatus* group and Gg: *Gnathodus girtyi* group).

5.6 Summary of Geometric Morphometric Analyses

In order to illustrate the morphological variations in conodont taxa, quantitative analyses have been carried out to outline data and numerical taxonomy have been applied to conodont taxa, *Gnathodus.* Sneath and Sokal (1973) emphasized the importance of numerical taxonomy and introduced the term *numerical taxonomy* to explain the grouping by numerical methods of taxonomic units into taxa based on the character states. Classification in numerical taxonomy is commonly based on a resemblance matrix. The results obtained from the quantitative methods are mainly objective.

In order to illustrate the relationships between the species of *Gnathodus,* mainly geometric morphometric methods have been applied to literature data. These methods are Sliding Semilandmark, Eigen Shape and Elliptical Fourier Analyses. Canonical variate analysis has been applied to the outline data set obtains from Sliding Semilandmark method. The results of the Eigen Shape and Elliptical Fourier Analyses display two main groups within the *Gnathodus* species based on the platform outline. However, the results of the canonical variate analysis to Sliding Semilandmark method are more informative and clearly show the distinction between the species of *Gnathodus* based on morphological data in the literature. Some species within this genus indicate considerable morphological differentiation and their nomenclature should be reviewed.

Concisely, geometric morphometric, especially Sliding Semilandmark, analyses of biostratigraphically important genus, *Gnathodus,* on the basis of data available in the literature highlighted the importance of numerical taxonomy and revealed that taxonomic revision of this genus is needed.

CHAPTER 6

GEOCHEMISTRY

6.1 Introduction

The Sr, O and C isotopic composition of some biogenic constituents and carbonates reflects the isotopic properties of seawater revealing information about climate, volcanic activity, plate tectonics or chemistry, circulation, temperature of ocean water (Schidlowski and Aharon 1992; Grossman 1994; McArthur 1994; Bruckschen et al. 1999). Strontium (Sr) is the ninth most abundant dissolved constituent in seawater. When Sr precipitates in marine carbonates, the $^{87}Sr/^{86}Sr$ ratio in the carbonate is a direct reflection of seawater at the time of deposition. The isotopic composition of strontium in seawater is constant during a specified time interval. On the other hand, the $^{87}Sr/^{86}Sr$ ratio changes regularly over geological time and, therefore, allows age estimation and correlation of sediments. A study of the oxygen isotopes in sedimentary carbonates can be used to determine the origin of seawater and offer the calculation of the seawater temperature (Rollinson, 1993). Generally, calculated temperature reflects the original seawater temperature or temperature of diagenesis. A study of the carbon isotopes allows the origin of carbon in carbonate rocks (Rollinson, 1993). A combined study of the carbon and oxygen isotopes in carbonates is a powerful means of distinguishing between carbonates of different origins (Rollinson, 1993).

6.2 The ^{87}Sr / ^{86}Sr Record

The Sr isotope composition of marine limestones and calcerous fossils proposes a powerful tool in estimating the changes in paleoocean chemistry. There are two major sources that affect the ocean chemistry. One is mantle–strontium with low radiogenic values. It dissolved from basalts at mid ocean ridges by hydrothermal circulation (Korte et al., 2006). The second source for Sr is the riverine input. Continental inputs have higher radiogenic Sr than MOR (Mid-Ocean Ridge) magmatism. Other sources like fluxes from carbonate diagenesis or groundwater discharge directly into the seawater have less influence on the ratio of ^{87}Sr/^{86}Sr (Korte et al. 2006). During the Carboniferous time interval the ^{87}Sr/^{86}Sr isotope ratios range from 0.707 to 0.709 (Figure 6.1) (Burke 1982; Veizer 1989).

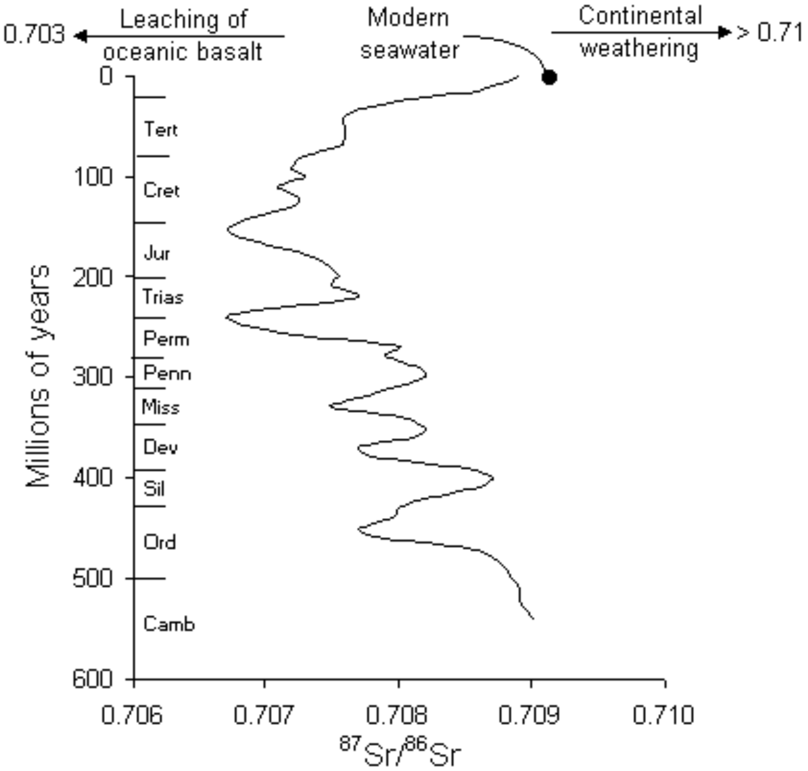


Figure 6.1. Variation of Sr isotope ratios through the Phanerozoic (Veizer 1989).

$^{87}Sr/^{86}Sr$ isotopic compositions of 8 samples for Lower Carboniferous Tournaisian - Visean boundary from Hadim and Bademli AP and BV sections and 7 samples for Mid-Carboniferous Serpukhovian - Bashkirian boundary from Hadim HB section are listed in Table 6.1. All of the samples are from allochtonous Aladağ Unit of Central Taurides.

Table 6.1. $^{87}Sr/^{86}Sr$ isotope values of carbonate rock samples obtained from the Tournaisian-Visean and Mid-Carboniferous boundary beds.

Age	**Sample #**	**$^{87}Sr/^{86}Sr$ Normalised**	**Error (+/-2s)**
Visean	AP58	0,708402	0,000007
Tournaisian	AP57	0,708547	0,000008
Tournaisian	AP56	0,708370	0,000007
Tournaisian	AP55	0,708361	0,000010
Visean	BV17	0,708159	0,000007
Visean	BV18	0,708203	0,000007
Tournaisian	BV19	0,708206	0,000008
Tournaisian	BV20	0,708301	0,000008
Bashkirian	HB25	0,708394	0,000008
Bashkirian	HB26	0,708465	0,000008
Bashkirian	HB27	0,708420	0,000009
Serpukhovian	HB28	0,708408	0,000008
Serpukhovian	HB29	0,708414	0,000008
Serpukhovian	HB30	0,708312	0,000010
Serpukhovian	HB33	0,708463	0,000008

The $^{87}Sr/^{86}Sr$ ratios of Tournaisian – Visean boundary samples of AP section in Hadim region have a range of 0.708361 – 0.708547, however isotopic compositions of Bademli region display slightly more depleted values and display a range of ratios between 0.708159 – 0.708301 (Table 6.1, Figure 6.2). The $^{87}Sr/^{86}Sr$ ratios of the Mid-Carboniferous boundary beds in HB section are ranging between 0.708312 and 0.708465 (Table 6.1, Figure 6.3). These values are relatively higher than the Lower Carboniferous boundary samples.

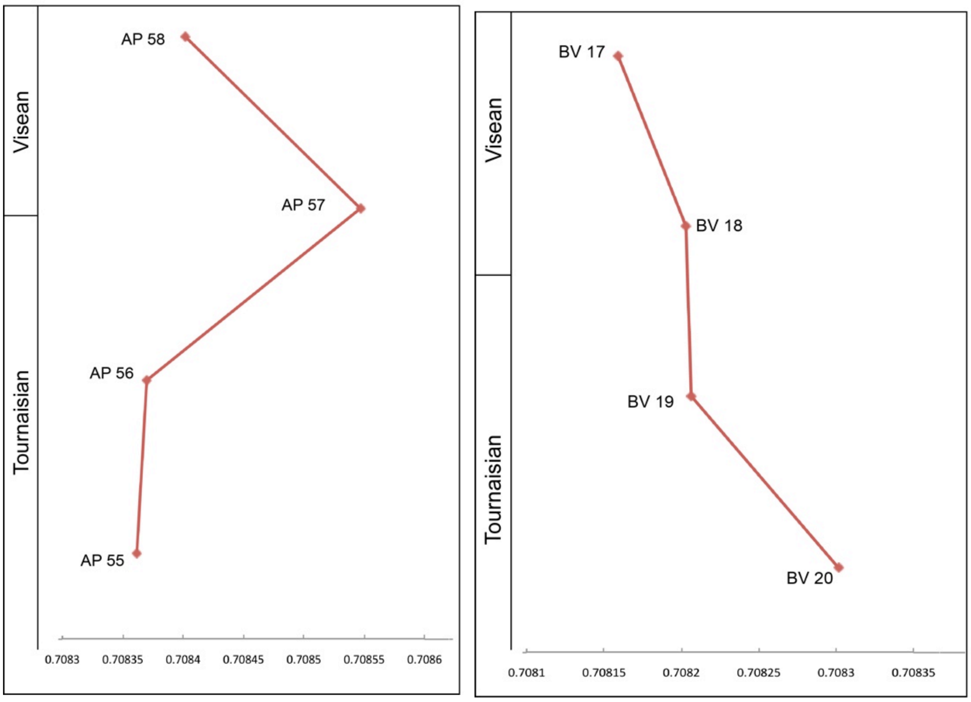


Figure 6.2. $^{87}Sr/^{86}Sr$ isotope variations through the Tournaisian – Visean boundary AP section in Hadim region (A) and BV section in Bademli region (B).

Sr isotopic compositions from Lower and Mid Carboniferous boundaries of Aladağ Unit are compared with European and North American Carboniferous in Figure 6.4. The Europen data is brachiopod based, whereas North American data is whole rock based. Sr isotope data from Bademli and Hadim sections are more radiogenic than European and North American Lower Carboniferous boundary samples. However

Bademli section displays more akin values to European boundary (Figure 6.4). Sr isotope data of Mid-Carboniferous boundary from Hadim section have been correlated with the North American and Europe Carboniferous data. Two of the samples are shifted towards more radiogenic areas above the North American and Europe field (Figure 6.4).

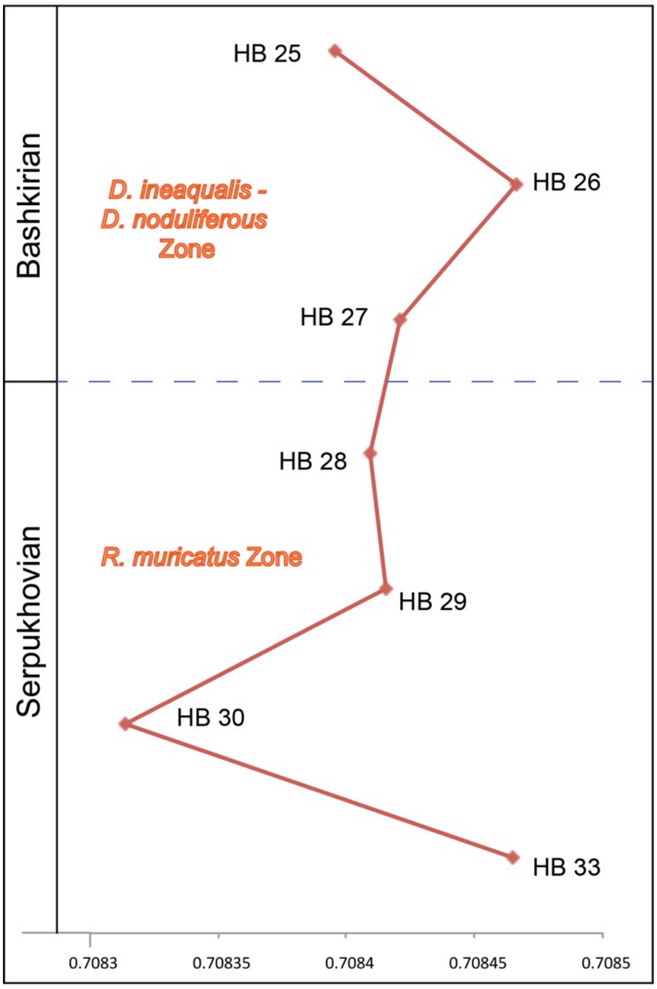


Figure 6.3. $^{87}Sr/^{86}Sr$ isotope variations through the Mid-Carboniferous boundary HB section in Hadim region.

As mentioned previously the main sources of Sr in seawater are hydrothermal circulation at mid-ocean ridges (MOR flux) which is characterized by a $^{87}Sr/^{86}Sr$ close to 0.703, continental input (riverine flux) with $^{87}Sr/^{86}Sr$ ratios ranging around 0.708-0.718 (François et al., 1993) and diagenetic alteration. The first two sources have more effect on the Sr ratio of seawater than the third one.

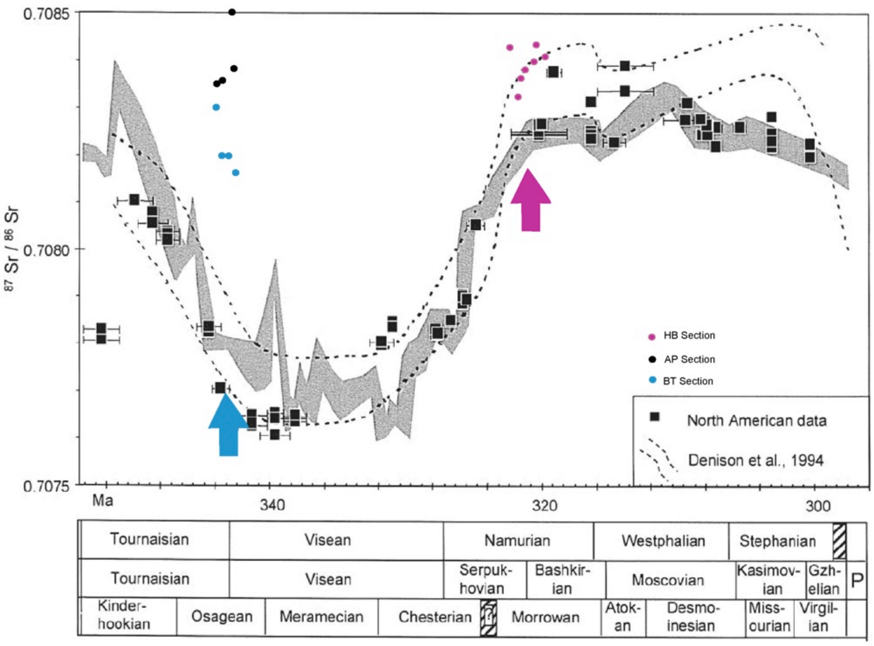


Figure 6.4. Correlation of 87Sr/86Sr isotopes ratios of Lower Carboniferous boundary samples in Taurides with the North American (Brukschen et al. 1999; Denison et al. 1994) and Europe data (Brukschen et al. 1999).

Bruckschen et al. (1999) explain the Carboniferous $^{87}Sr/^{86}Sr$ isotope variations by the riverine flux and also they report that the this record could not reproduce solely from MOR flux. The ratios obtained from the samples mainly represent the source of Sr in Aladağ Unit (Turkey) as riverine influx. Moreover, the presence of higher Sr contents in Tournasian-Visean boundary relative to the European and North American record can also point diagenetic alteration. Consequently, the results of Sr in Taurides have been primarily influenced by diagenetic events. Especially this alteration is more pronounced in Tournaisian –

Visean boundary samples due to the dolomitization in the studied sections.

6.3 The $\delta^{18}O$ Records

Oxygen isotopes are widely used to infer the paleotemperatures in sedimentary rocks. Minerals precipitated from seawater at low temperatures are rich in ^{18}O compared to seawater, however, minerals precipitated at higher temperatures display less enrichment. Oxygen isotope composition variations are typically expressed in terms of $\delta^{18}O$, which represents the permil (‰) difference in the ratio of $^{18}O/^{16}O$ between the sample and Vienna Standard Mean Ocean Water (V-SMOW) or between a carbonate sample and the international carbonate isotope standard (V-PDB). Another factor that effect the global ocean $\delta^{18}O$ is glacial and interglacial cycles. The $\delta^{18}O$ value homogenous modern oceans is about -0.28±0.5 ‰SMOW (Shackleton and Kennett 1975), however $\delta^{18}O$ value of the planet with no ice would be around -1.4 ‰ (Lhomme et al. 2005). Oxygen isotope ratios of carbonates exhibit a definite increase in values from -8 ‰ in the Cambrian to the present 0 ‰ (Veizer et al., 1999; Veizer, 2004; Figure 6.5).

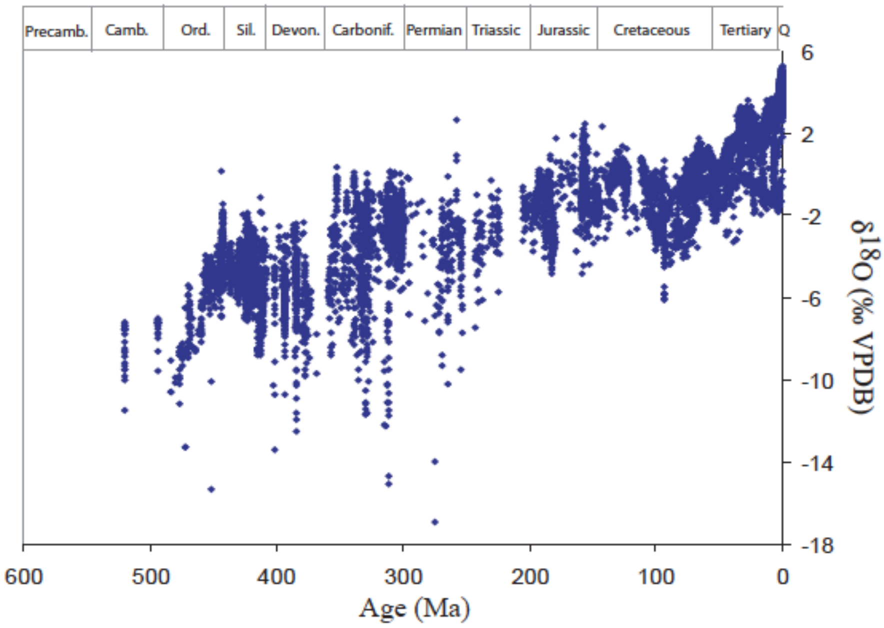


Figure 6.5. $\delta^{18}O$ variation through the Phanerozoic based on the literature (Veizer, 2004).

The results of the 15 samples that characterize the Lower Carboniferous (Tournaisian - Visean) and Mid-Carboniferous (Serpukhovian - Bashkirian) boundaries are given in Table 6.2. $\delta^{18}O$ vaues of the Tournaisian - Visean boundary samples are ranging between (-) 6.853 – (-) 6.011 in Hadim AP section and (-) 6.862 - (-) 6.031 in Bademli BV section (Table 6.2, Figure 6.6). Mid-Carboniferous values of $\delta^{18}O$ in Hadim HB section have relatively low ranges compared to the Lower Carboniferous boundary samples and ranging between (-) 4.259 - (-) 5.625 (Table 6.2, Figure 6.7). There are no significant variations in the isotopic compositions across the Lower and Mid-Carboniferous boundary samples (Figure 6.6, Figure 6.7).

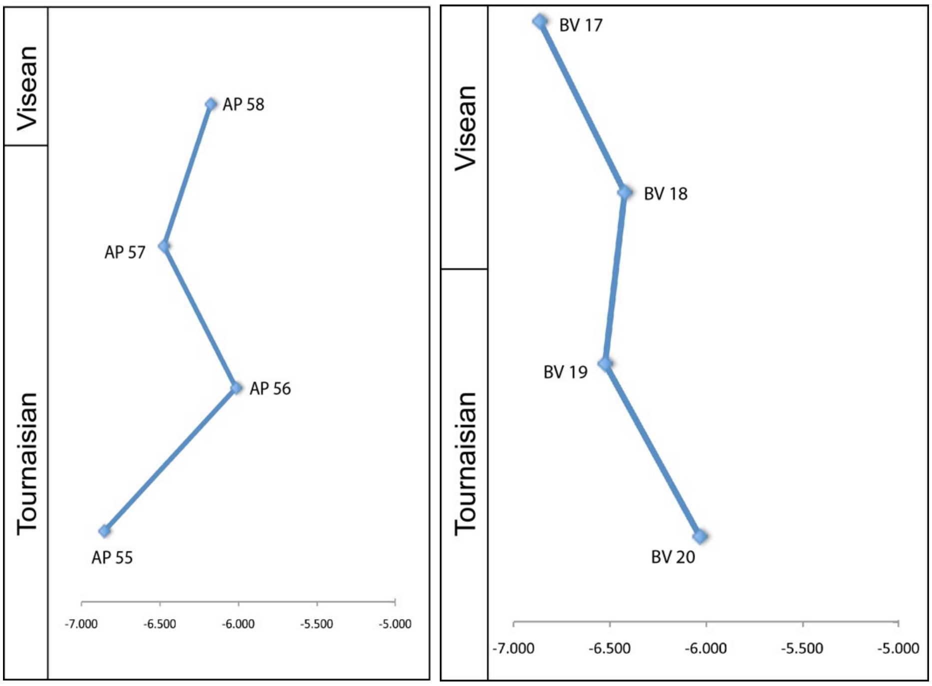


Figure 6.6. $\delta^{18}O$ isotope variations through the Tournaisian – Visean boundary AP section in Hadim region (A) and BV section in Bademli region (B).

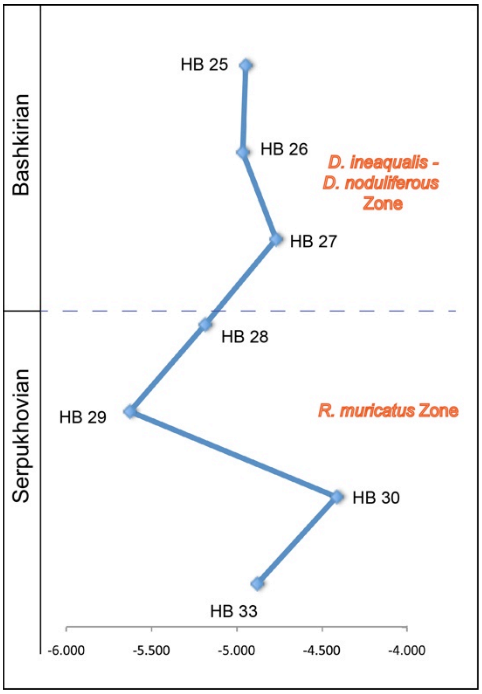


Figure 6.7. $\delta^{18}O$ isotope variations through the Mid-Carboniferous boundary HB section in Hadim region.

Table 6.2. $\delta^{18}O$ and $\delta^{13}C$ isotope values of carbonate rock samples obtained from the Tournaisian - Visean and Mid-Carboniferous boundary beds.

Age	Sample #	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (SMOW)	$\delta^{18}O$ (VPDB)
Visean	AP58	4,936	24,496	-6,178
Tournaisian	AP57	4,158	24,193	-6,472
Tournaisian	AP56	4,648	24,669	-6,011
Tournaisian	AP55	4,077	23,800	-6,853
Visean	BV20	4,495	24,648	-6,031
Visean	BV19	4,105	24,136	-6,528
Tournaisian	BV18	4,367	24,242	-6,424
Tournaisian	BV17	4,155	23,792	-6,862
Bashkirian	HB25	0,727	25,766	-4,947
Bashkirian	HB26	-0,140	25,746	-4,966
Bashkirian	HB27	0,257	25,947	-4,771
Serpukhovian	HB28	-0,320	25,520	-5,185
Serpukhovian	HB29	-0,408	25,066	-5,625
Serpukhovian	HB30	1,171	26,475	-4,259
Serpukhovian	HB33	-0,350	25,835	-4,880

6.4 The $\delta^{13}C$ Records

The ratio of the carbon isotopes (^{12}C and ^{13}C) in carbonate rocks is expressed as $\delta^{13}C$. This ratio is used in paleoceanography as indicator of changes in production, burial and preservation of organic matter (Broecker, 1982). Post-depositional thermal alteration of organic matter often preserves primary carbon isotopic signatures in carbonate phases (Kah et al., 1999). Therefore, ancient carbonates commonly retain their primary carbon isotopic compositions (Marshall, 1992; Buick et al., 1995; Kaufman and Knoll, 1995; Knoll et al., 1995). Modern marine carbonate sediments generally have $\delta^{13}C$ values ranging from 0 ‰ to 4 ‰ (Hudson 1977; Moore 2001).

The results of the 15 samples characterizing the Lower Carboniferous (Tournaisian - Visean) and Mid-Carboniferous (Serpukhovian - Bashkirian) boundaries are given in Table 6.2. $\delta^{13}C$ ratios of Lower - Middle Carboniferous rocks from Taurides are quite different from each other. $\delta^{13}C$ ratios of the Tournaisian - Visean rocks have higher values than Serpukhovian - Bashkirian samples. They have a range of 4.077 to 4.936 ‰ (Table 6.2, Figure 6.8). During the Tournaisian $\delta^{13}C$ values are between 4.077 and 4.648 ‰ with an average of 4.297‰. Carbon isotope compositions of Visean rocks have similar ratios and a range of 4.105 to 4.936 ‰ with an average of 4.486 ‰. Although they have similar ratios, there is a minor increase in the carbon isotope composition around the Tournaisian - Visean boundary thus Visean rocks have relatively higher carbon isotopes ratios than Tournaisian rocks.

Serpukhovian - Bashkirian rocks presents more depleted values of $\delta^{13}C$ than the Lower Carboniferous rocks and these values range between –0.408 and 1.171 ‰ (Table 6.2, Figure 6.9). Serpukhovian isotope compositions are between –0.408 and 1.171 ‰ with an average of 0.221. Similarly, Bashkirian samples show a narrow range of – 0.140 to 0.727 ‰ with an average of 0.281 ‰. In general carbon isotopes ratios do not display distinct variation around the Serpukhovian – Bashkirian boundary.

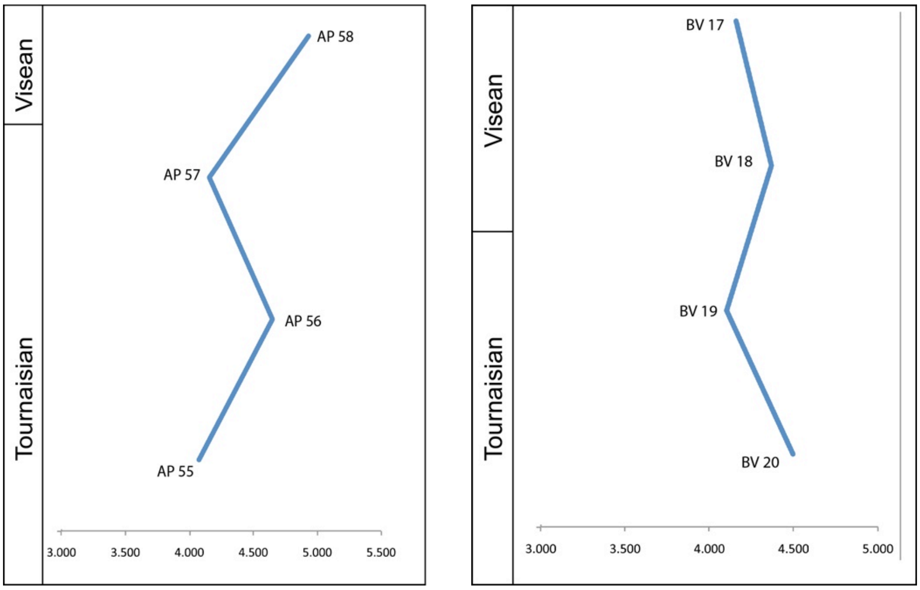


Figure 6.8. δ^{13}C isotope variations through the Tournaisian – Visean boundary AP section in Hadim region (A) and BV section in Bademli region (B).

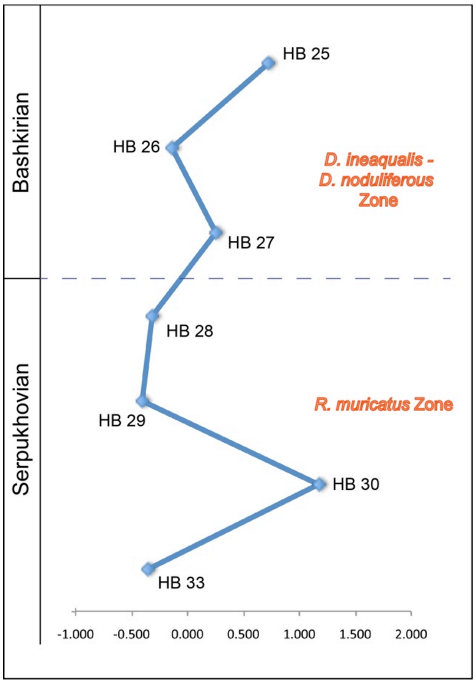


Figure 6.9. δ^{13}C isotope variations through the Mid-Carboniferous boundary HB section in Hadim region.

6.5 Analyses and Global Correlation of Stable Isotope Results

Recently, many studies focused on the $\delta^{13}C$ and $\delta^{18}O$ signatures of Carboniferous carbonate rocks to identify the ancient paleoenvironmental conditions (Veizer et al. 1992a, 1992b, 2004; Bruckschen and Veizer 1997; Mii 1999; Bruckschen etal. 1999). There are several criteria to understand the diagenesis of carbonate rocks using the oxygen and carbon isotope ratios. One criterion is the positive covariation between $\delta^{18}O$ and $\delta^{13}C$ which is generally interpreted as effect of meteoric diagenesis (Meyers and Lohmann 1985). The oxygen and carbon values from Lower Carboniferous boundary sections display positive relationship (Figure 6.10). There is a high covariance between oxygen and carbon isotopes which is sign of diagenesis (Figure 6.10). Secondly, several researchers (Gavish and Friedman 1969; Allan and Matthews 1982; Pálfy et al. 2001) have recognized a covariant trend in carbon and oxygen isotopes where $\delta^{13}C$ and $\delta^{18}O$ values are more depleted with increasing degree of diagenesis. A similar trend has been observed in the studied samples in that as decreasing carbon isotope ratios oxygen ratios become more negative (Figure 6.11). Moreover, Kaufman and Knoll (1995), Xiao et al. (1997) and Qie et al. (2011) suggested that oxygen isotope ratios ($\delta^{18}O$) <−5 ‰ indicate possible diagenetic alteration, and isotopic data with $\delta^{18}O$ values lower than −10 ‰ should not be used for isotope analyses. $\delta^{18}O$ values of Tournaisian – Visean rocks are between (-) 6.853 – (-) 6.011 ‰, however Mid-Carboniferous boundary rocks present (-) 4.259 – (-) 5.625 ‰. All of the values are above the -10 ‰ and most of them are below the -5 ‰. Lastly, in a diagram of $\delta^{18}O$ versus $\delta^{13}C$, Lower Carboniferous samples of this study mainly plotted within the marine limestones and late cement fields (Figure 6.12). So it can be concluded that although diagenetic imprints are present on the values of carbonate samples, responses of isotopes to paleoenvironmental changes were observable.

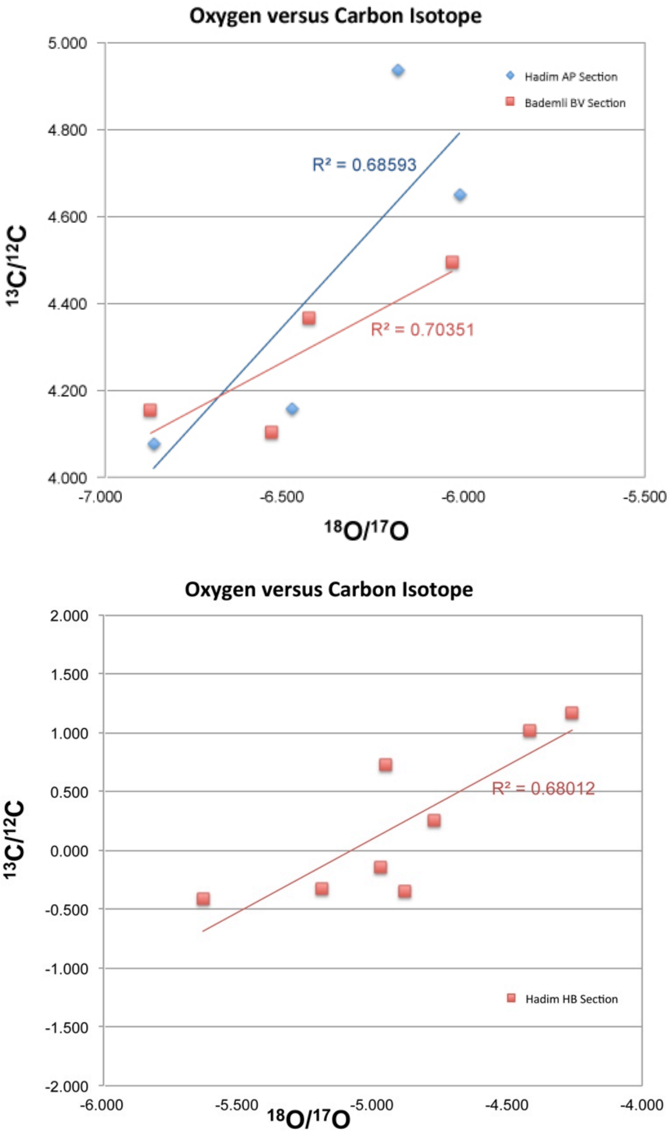


Figure 6.10. Cross plots of oxygen and carbon isotope ratios illustrating positive correlation in Tournasisian - Visean (A) and Serpukhovian - Bashkirian rocks (B).

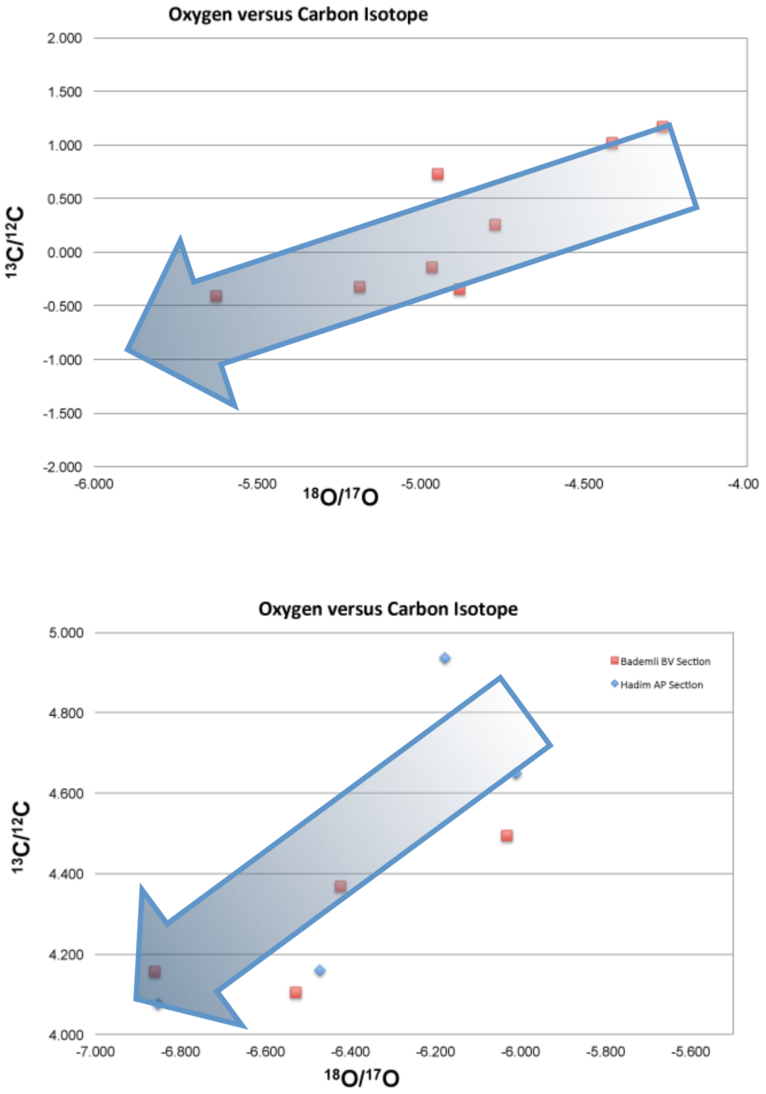


Figure 6.11. Cross-plots oxygen and carbon isotope ratios illustrating the diagenetic trend towards depleted carbon and oxygen isotope values.

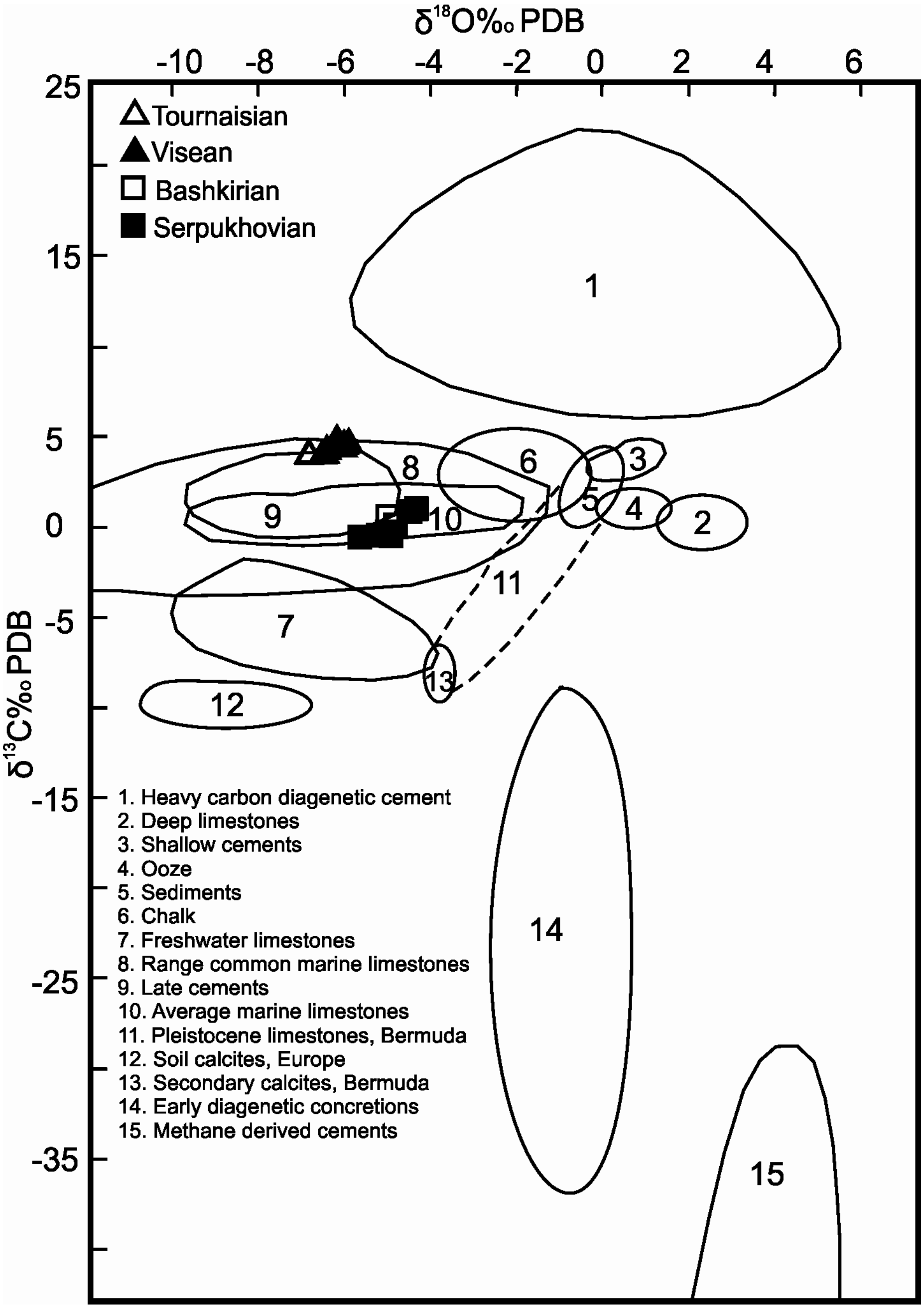


Figure 6.12. Cross plot of $\delta^{13}C$ and $\delta^{18}O$ isotope ratios for the Lower Carboniferous Tauride limestones along with the different fields for carbonate rocks proposed by Hudson (1977).

Brand and Brenckle (2001) reported that $\delta^{18}O$ isotope values of unaltered brachiopods from GSSP (Arrow Canyon Nevada) are approximately -2.38 ‰ for the latest Mississippian and -2.19 ‰ for the earliest Pennsylvanian. The oxygen isotope data obtained in this study cannot be directly correlated with the GSSP data from Arrow Canyon for Mid-Carboniferous boundary. While there is no overlap between isotope ratios of the latest Mississippian and earliest Pennsylvanian GSSP (Arrow Canyon) and our study, they bear some similarities in their trend. The $\delta^{13}C$ isotope ratios from the GSSP for the latest Mississippian have a mean of 2.01 ‰ for the latest Mississippian and 2.42 ‰ for the earliest Pennsylvanian. The carbon isotope values of this study are more depleted than the GSSP since the results are bulk rock and display the digenetic effects. When the results plotted into the global isotope curve (Figure 6.13), the $\delta^{18}O$ and $\delta^{13}C$ isotope ratios obtained in this study fall outside of the global records. However, they have a close relation with them.

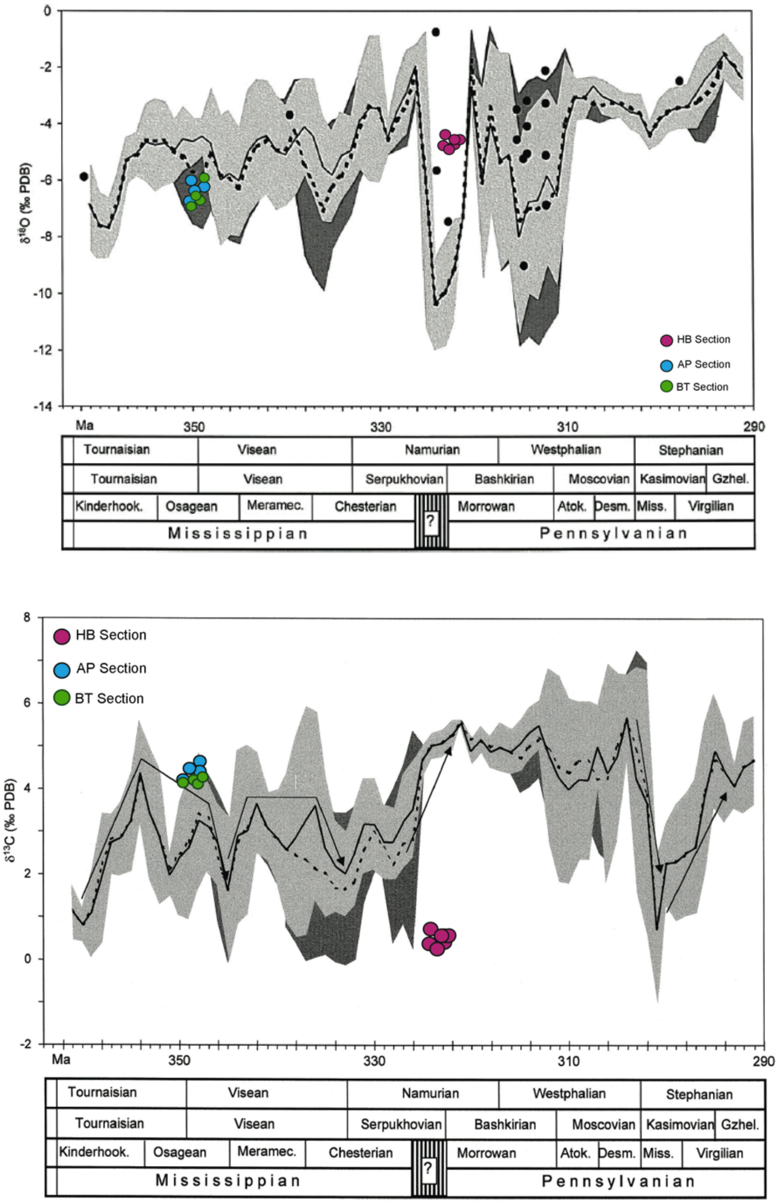


Figure 6.13. Comparison of δ18O (A) and δ13C (B) isotope ratios with North American data (Brukschen et al. 1999). The solid line, dotted line shading areas and black circles are all reflect Lower Carboniferous isotopic compositions.

CHAPTER 7

MICROPALEONTOLOGY

7.1 What are Conodonts?

Conodonts are a group of extinct soft-bodied marine organisms which are primarily known from the scattered elements of their feeding apparatuses. Conodont elements, a type of microfossil typically less than 2 mm in size, are composed of calcium phosphate and tooth-like in appearance (Aldridge et al. 1993). They range from the Cambrian to the end of the Triassic, with a peak in diversity during the Ordovician (Sweet 1985). Conodont is an important index fossil group for marine strata of Lower Ordovician to Upper Triassic.

Soft-body preservations of conodonts are known only two places in the world, the Upper Ordovician Soom Shale of Cape Province, South Africa and the Lower Carboniferous Granton Shrimp Bed of Edinburgh, Scotland. The investigation of these exceptionally preserved soft-bodies permitting a reconstruction of the morphology of conodont animal revealed that the conodont was eel-like in appearance, with paired eyes at the anterior end of the body, and a ray-supported caudal fin at the posterior end (Figure 7.1) (Briggs et al. 1983; Aldridge et al. 1986, 1993; Aldridge, 2005; Donoghue et al. 2000). The Conodont animal has a short head with a pair of ring like structures interpreted as eyes (Donoghue et al. 2000; Aldridge, 2005). The head of conodont animal, which accommodated the skeletonized feeding apparatus, was followed by a trunk consisting of V-shaped muscle blocks, which terminated in a ray-supported caudal fin (Aldridge et al. 1993) (Figure 7.1).

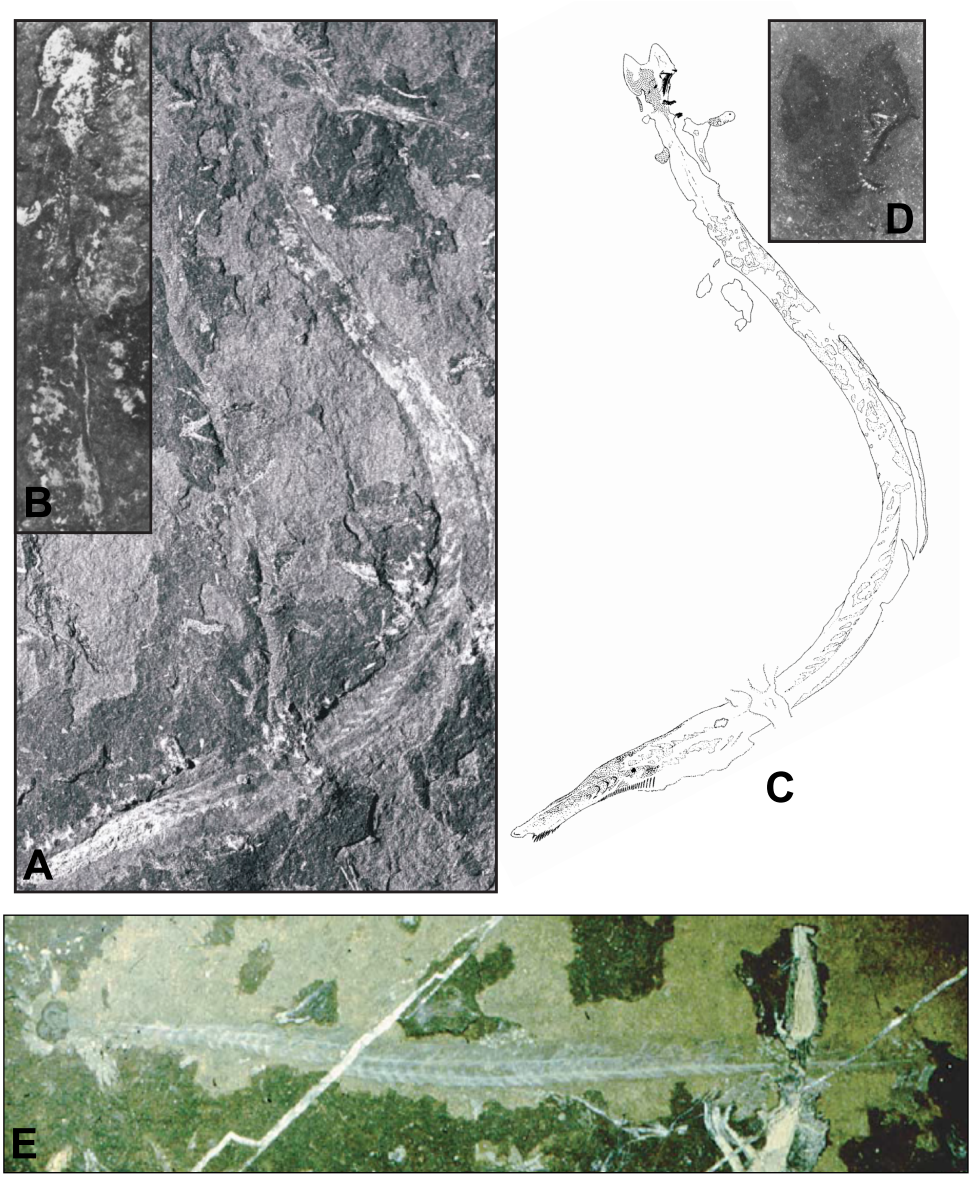


Figure 7.1. Conodont specimens with preserved soft tissues; A, whole animal of Clydagnathus windsorensis (Globensky) from the Dinantian of Scotland; B, head and anterior trunk; C, Camera-lucida drawing of A; D, close up view of head region detailing the dark organic ‘lobes’ and associated structures including skeletonized feeding apparatus (from Briggs et al. 1983; Sweet and Donoghue, 2001); E, whole animal of genus Clydagnathus, Lower Carboniferous Granton Shrimp Bed, Edinburgh, Scotland (Alridge, 2005).

Certain morphological features, such as the V-shaped muscle blocks, rod-like notochord, ray-supported caudal fin, phosphatic skeletal elements and paired eyes, place conodont animals within the chordates, among the earliest vertebrates (Aldridge et al. 1993). The conodont elements, therefore, are the earliest examples of a bio-mineralized skeleton within the vertebrates (Figure 7.2, Figure 7.3) (Briggs 1992; Aldridge et al. 1993; Aldridge and Purnell 1996).

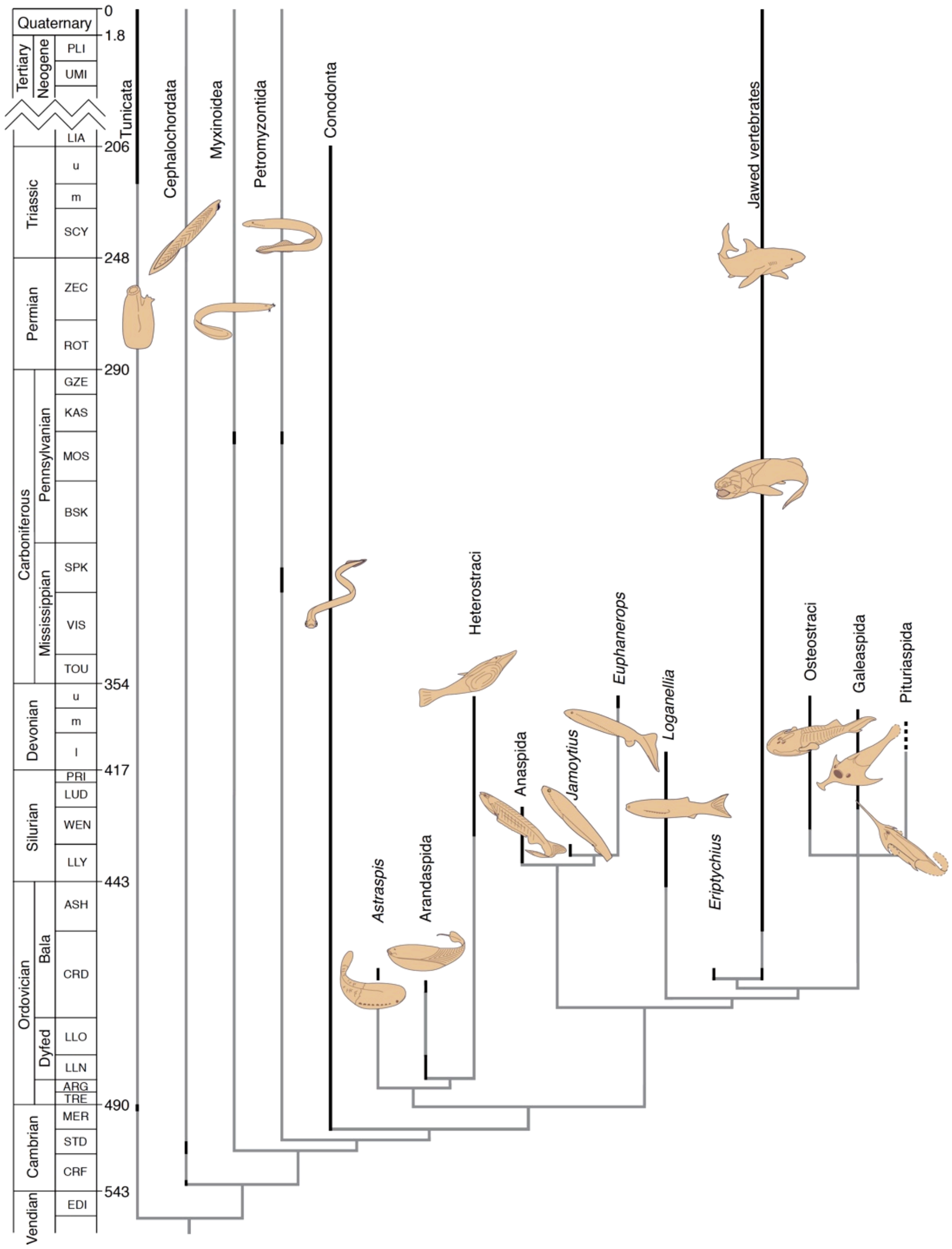


Figure 7.2. Cladistic tree showing the position of conodonts as basal Gnathostomata (From Donoghue et al. 2000).

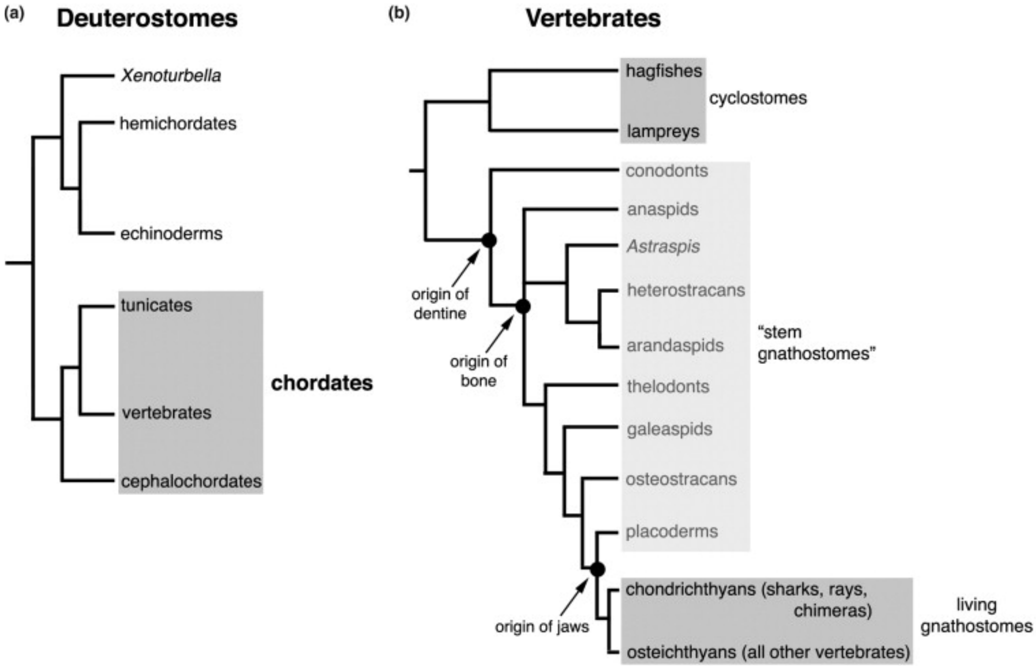


Figure 7.3. Current deuterostome phylogeny (a), Current vertebrate phylogeny (b) (Baker, 2008).7.2 Morphology and the Internal Structure of the Conodont Elements

Conodonts are characterized by a feeding apparatus which generally consists of three or four types of mineralized denticles (Sweet, 1988; Benton, 1997; Donoghue et al. 2000; Aldridge, 2005). These mineralized elements display a range of morphologies, from coniform shapes through denticulated bars and blades to highly ornamented plates (Figure 7.4). The more primitive conodonts possessed coniform elements which vary in characteristics such as the degree of curvature, presence or absence of surface striations and the development of costae (Donoghue et al. 2000; Aldridge 2005). More derived conodont groups possessed elements of more complex morphology with greater morphological variations within each apparatus (Donoghue et al. 2000; Aldridge 2005). In natural assemblages of complex conodont elements, the apparatus is divided into three groups, named P, M, and S (Figure 7.4) (Aldridge et al. 1993; Donoghue et al. 1998; Donoghue et al. 2000;

Sweet and Donoghue 2001; Aldridge 2005). The cusp, the denticle just above the basal cavity, is most prominent denticle of an element. A process which is continuous with the posterior side of the cusp is the posterior process and one projected towards the anterior side is an anterior process.

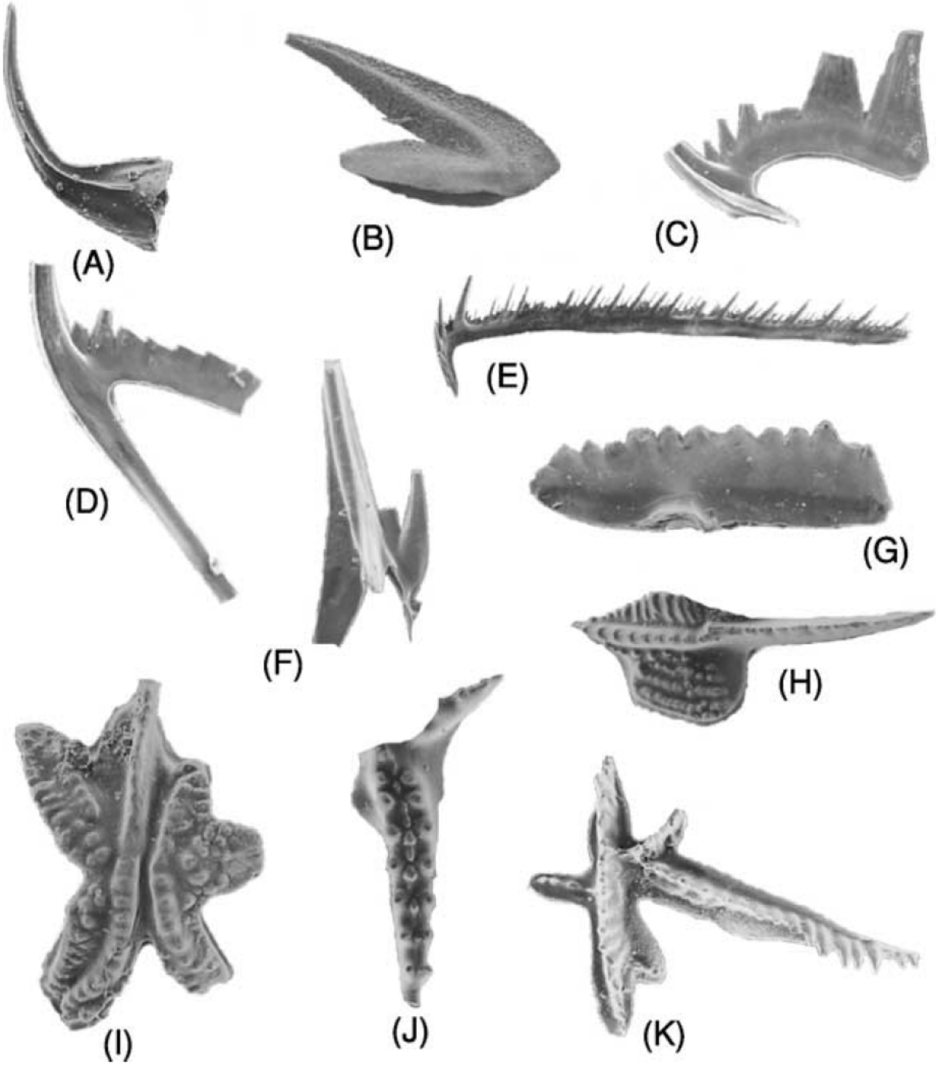


Figure 7.4. Illustration of the variety of conodont element morphologies. (A-B) Coniform elements (C-F) Ramiform elements (G-K) Pectiniform elements (Alridge, 2005) (not to scale).

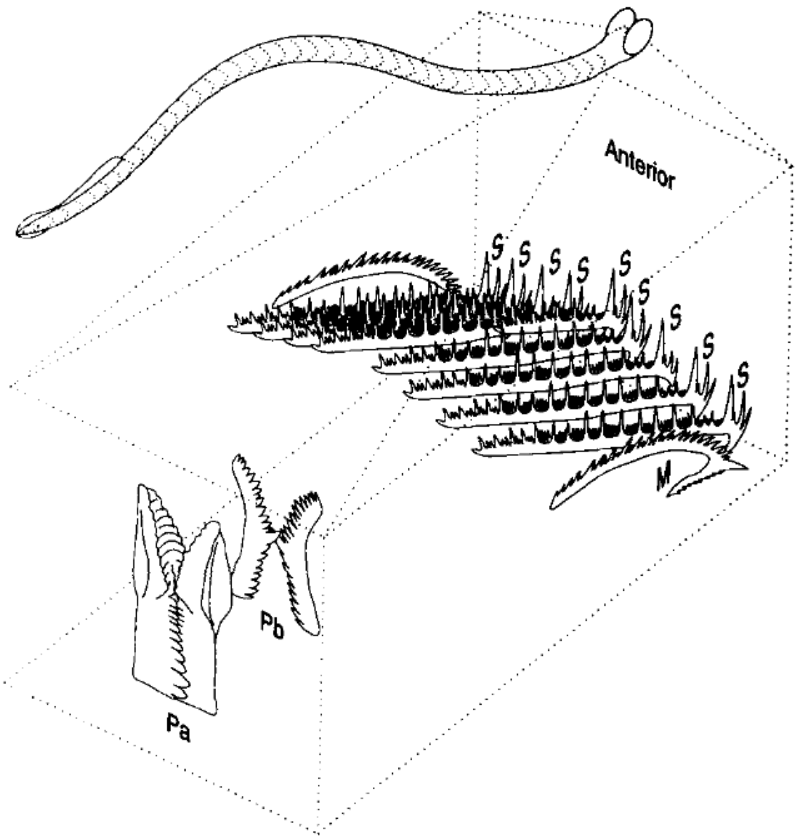


Figure 7.5. Architectural diagram of the complete ozarkodonid conodont apparatus and its location in the animal (Purnell, 1993b and Purnell, 1994). Animal morphology is based on Aldridge et al. (1993).

The P elements of complex conodonts are mainly pectiniform elements. The pectiniform elements are used for the blade-like, platform and platform plus blade morphologies (Figure 7.6). The P elements mainly display different morphological variations such as presence of polygonal structures on platform, unornamented platforms, nodes, transversal ridges and denticles on carina (Figure 7.7). S and M elements are generally ramiform.

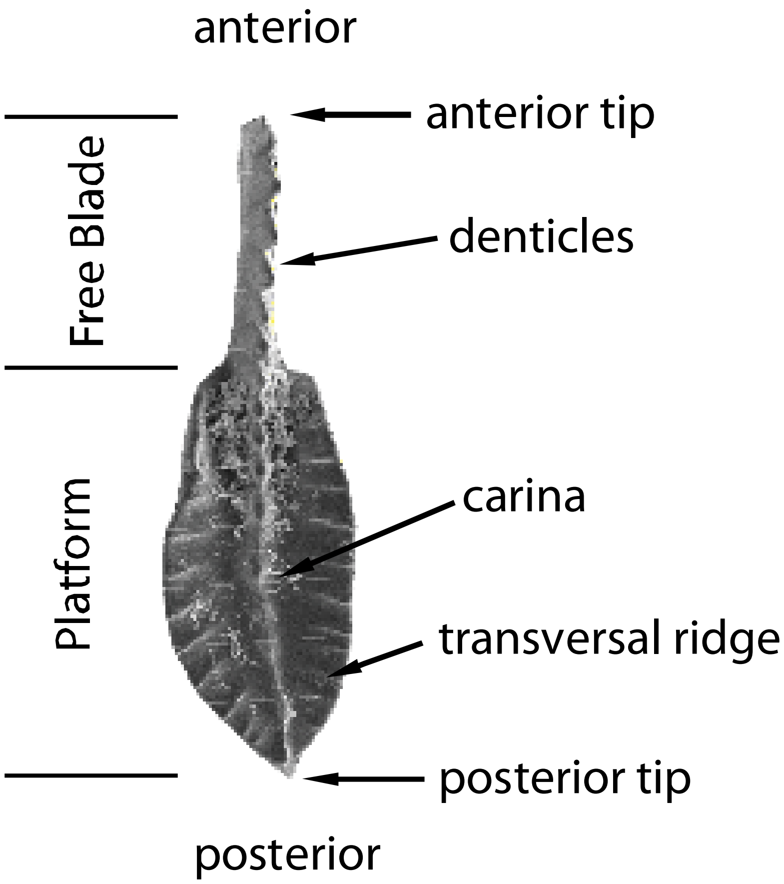


Figure 7.6. Morphological features of pectiniform conodont element (*Polygnathus symetricus*, sample AS 5).

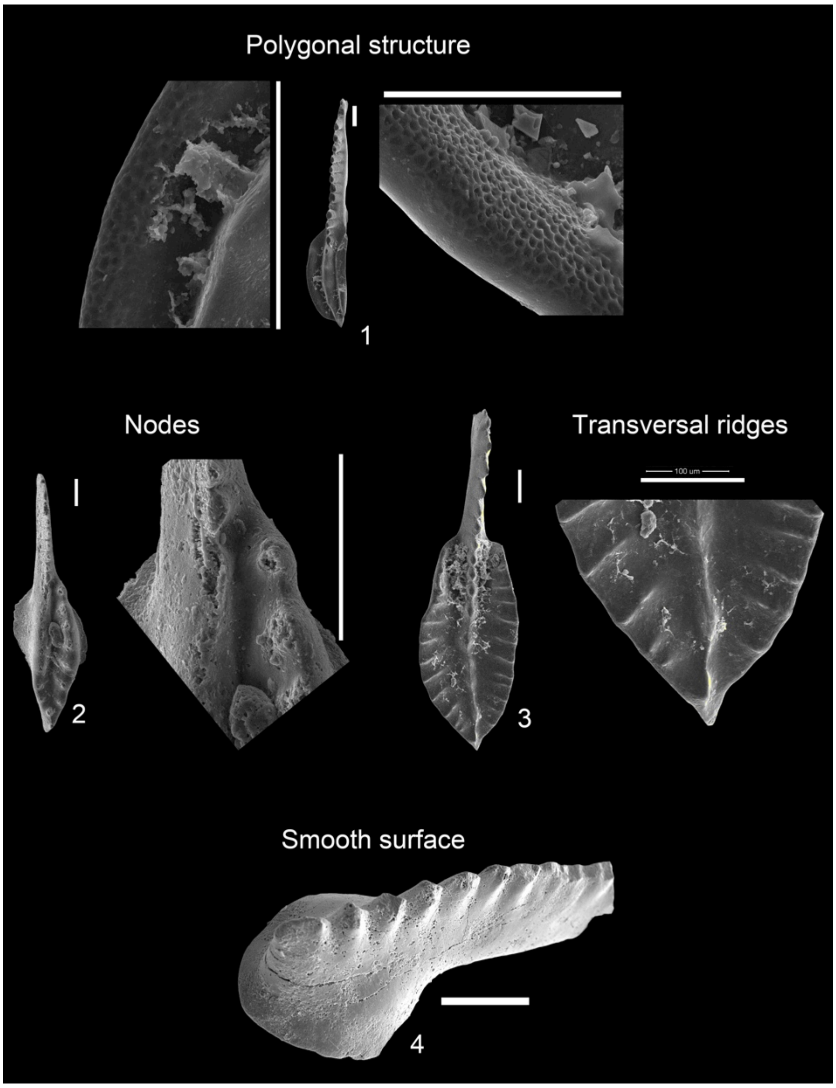


Figure 7.7. Morphological variations within platform elements. (1) *Polygnathus communis communis* sample AS 5, (2) *Rhachistognathus minutus minutus* sample HB 28, (3) *Polygnathus symetricus* sample AS 5, (4) *Lochriea commutata* sample BSEc 7 (Horizontal bars are 100µm).

7.3 Function of Conodont Apparatus

Conodont elements are generally believed to be a feeding device (Purnell and von Bitter, 1992; Purnell, 1993b, 1994, 1995; Purnell, 1995; Donoghue and Purnell, 1999a,b), although other theories of element function have been proposed (see Aldridge and Purnell, 1996 for a review). Functional interpretation of conodont elements have focused on two hypotheses. Based on the first model, conodonts were microphagous suspension feeders in which S and M elements supported a ciliated sieve structure capturing food and passed back to the tissue covered P elements to be kindly crushed and ingested (Purnell, 1993b; Aldridge and Purnell, 1996; Aldridge, 2005). The alternative model is that conodonts were macrophagous with the elements having acted in a tooth-like manner; the S and M elements would grasp food items, which would be passed back along the oral cavity to the P elements which would have crushed and sliced the food item prior to digestion (Aldridge et al. 1987; Purnell and von Bitter 1992; Purnell 1993b, 1995; Aldridge and Purnell 1996; Aldridge 2005).

Direct evidence of function can be determined by studying the microwear structures on the elements (Figure 7.8). Like mamal teeth, microwear textures occur on conodont elements like pitting on the surface of platform elements showing that food was crushed between the platform surfaces, and scratching on the sides of elements indicating a shearing movement and striations on the cusps specifying shearing movement (Jeppsson, 1976; Purnell, 1995; Aldridge and Purnell, 1996).

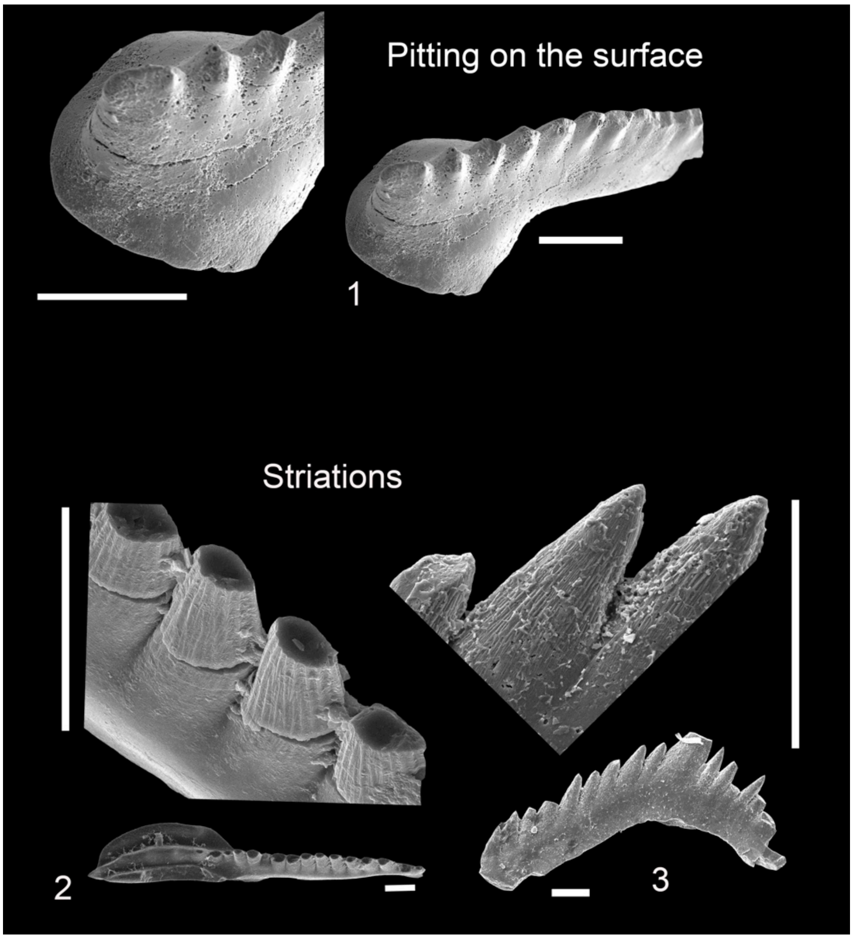


Figure 7.8. Microvear structures on conodont elements. (1) *Lochriea commutata* sample BSEc 7, (2) *Polygnathus communis communis* sample AS 5, (3) P2 element sample AS 7 (Horizontal bars are 100μm).

7.5 Classicification of Conodonts

From 1856 to about 1966, classifications of conodonts were based on the shapes of the individual elements of conodonts, called as form taxonomy. In 1966, a shift in conodont systematics from form taxonomy to multi element taxonomy was started. In 1971, at an international conference of conodont workers in Marburg, Germany, it was decided that multi element taxonomy was to be preferred over form taxonomy (Sweet and Donoghue, 2001). Each element type was regarded as a distinct taxon, and supragenic categories consisted of groupings of elements that showed overall morphological similarities (Aldridge and Smith 1993). Subsequently, classifications have been developed that take account of the multi-element nature of conodont apparatuses. The most comprehensive are those of Lindström (1970), Clark et al. (1981) and Sweet (1988). Lindström (1970), the first to give serious attention to a suprageneric classification of conodonts, distributed 21 families among two orders and eight superfamilies, all based on similarities in the multielement apparatuses of the genera and species included (Sweet and Donoghue, 2001). Based on Lindström's Clark et al. (1981) published the influential volume W of the Treatise on Invertebrate Paleontology dealing with conodonts. Later, Sweet (1988) recognized 206 genera in 41 families and seven orders very unevenly divided into two classes. Aldridge and Smith (1993) noted that Sweet classification was not based on the cladistic and they rearranged several families and added to seven new unknown families. Sweet's classification with modification in Dzik (1991) and Aldridge and Smith (1993), is the one that has been used most widely. Donoghue et al. (2008) addresses the relationships of conodonts using cladistics which is an appropriate methodology to test previous classification and the evolutionary relationships of conodonts (Figure 7.9).

7.6 Historical Background

Conodonts were firstly described in 1856 by the Russian paleontologist Christian Heinrich Pander as the remains of an unknown group of fossil fishes. He named these microscopic fossils as *Conodonten* (conodonts). Pander more or less confidently concluded that conodonts were extinct group of fishes. From 1856 until 1926, conodonts were regarded as paleontologic curiosities having debate about their zoologic affinities. George Jennings Hinde (1879) firstly suggested that conodonts of varying morphology were associated in an assemblage representing a single animal. By 1926 there were only two different opinions (Pander's and Hinde's) as to the appropriate taxonomic base. Pander and most other authors favored the idea that individual conodonts formed hard parts that were all the same shape and Hinde supported the idea that at least some conodonts had" several different skeletal components.

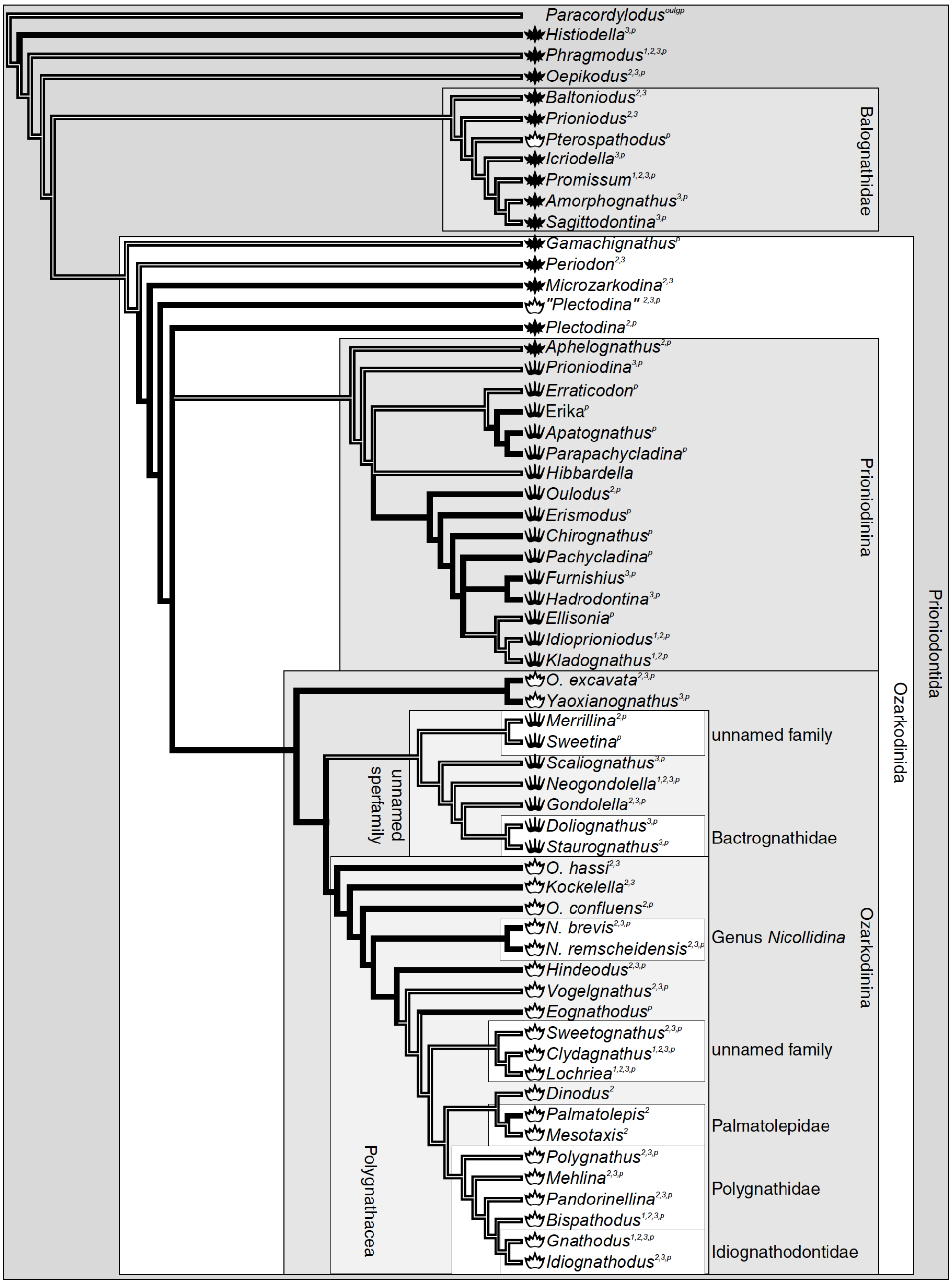


Figure 7.9. Summary tree reflecting hypotheses of relationship and classification of conodonts proposed by Donoghue et al. (2008).

In 1926, E. O. Ulrich and R. S. Bassler described new genera and species of conodonts, presented a new suprageneric classification and suggested that conodonts were common fossil group in the Devonian-Mississippian shales. Their 1926 paper encouraged American paleontologists to study this microfossil group. In the early 1930's, E. B. Branson and M. G. Mehl, vertebrate paleontologists at the University of Missouri, published a volume of systematic essays about conodonts. Their conodont studies in the next two decades led expanded knowledge of the nature and distribution of the conodonts in North America.

In 1934, H. Schmidt in Germany and H. Scott in the United States independently reported the clusters of morphologically different Carboniferous conodont elements on the surface of black-shales. Like Hinde, Schmidt and Scott regarded these natural assemblages as the more or less complete apparatus of individual conodonts. Nowadays, the natural assemblages play an important role in the development of conodont taxonomy. Prior to 1941, most of the conodont elements were recovered from shales, carbonate rocks were ignored. However, in 1941 Ellison and Graves demonstrated that much more conodont elements can be obtained from carbonates by using acetic or formic acid techniques. The increased size of collections encouraged micropaleontologists interested in conodonts to broaden their studies.

By 1959, conodonts had been recovered from rocks that range in age from Late Cambrian to Late Triassic. The stratigraphic range of conodonts had been considerably broadened and geographic distribution had been extended due to the improvements in laboratory techniques. As the number of large, stratigraphically controlled collections grew through the 1950's and 1960's concern, there was a concern about the taxonomic base of conodonts. The middle 1960's in the history of conodont research might be characterized as the era of multielement taxonomy.

In the 1966, there began a shift in conodont systematic from form taxonomy to multielement taxonomy. In 1971 at an international conodont conference in Marburg, Germany, it was concluded that for conodonts multielement taxonomy was more desirable than form taxonomy. A revised version of volume W of the Treatise on Invertebrate Paleontology (Clark et al. 1981) is expressed mostly in terms of multielement taxonomy. In 1983, new era in conodont research began by Briggs, Clarkson and Aldridge describing a more or less complete conodont assemblage of Dinantian specimen from Scotland. This and additional specimens from the same locality (Aldridge et al. 1986, 1987, 1993) and the Upper Ordovician of South Africa (Aldridge et al. 1993; Gabbott et al. 1995) allowed an comprehensive understanding of conodont anatomy and support the vertebrate affinities of conodonts.

7.7 Conodont Processing Methods

Before 1950, conodont elements were mainly disaggregated from sandstones and shales (Sweet and Donoghue, 2001). Later, it was recognized that the elements could also be obtained from carbonate rocks by using different acid techniques (Table 7.1). It can be concluded that conodont elements could be extracted from any type of marine sedimentary rocks. This discovery led to increase the amount of recovered elements and to determine stratigraphic distribution of conodonts precisely (Sweet and Donoghue, 2001).

Extraction of conodont elements is mainly influenced by processing techniques; principally main criteria are the acid type, percentage of acid solution, the choice of buffering, the size of the sample, duration of process and concentration methods (Jeppsson et al., 1999). Initially, hydrochloric acid was used to extract conodont elements. However, it is known that hydrochloric acid ruin phosphatic fossils. In 1895, Wiman (1895, 1896) used the acetic acid to extract graptolites from carbonate rocks but conodonts could not be detected in his studies because of using large sieve openings (Jeppsson et al., 1999). The method was firstly discovered by Furnish in 1936 and firstly published by Gaves and Ellison (1941) (Jeppsson et al., 1999). Until, the early 1970's both acetic and monochloracetic acids were used for conodont extraction. Ziegler, Lindstrom and McTavish (1971) reported that the monochloracetic acid destroys the elements and therefore the usage of this acid has been abandoned. Jeppsson et al. (1985) indicated that the usage of standard acid method extraction or the concentration processes might ruin elements and cause different amounts of etching. They carried out different experiments to develop a standard technique and proposed a buffered acetic acid technique for conodont extraction that considerably increase conodont yields. Further experiments have been performed by researches to find out the best way for extraction methods. Jeppsson and Anehus (1995) suggested a new alternative, a buffered formic acid technique, for conodont recovery. They indicated that the formic acid method has some advantages over acetic acid; the former is more rapid and also dissolves dolomites. Furthermore, Jeppsson et al. (1999) presented a new buffered acetic acid method and claimed that conodont yield mainly depends on the processing procedure. Even though, similar chemicals have been used in processing, the percentage of acid solution, the choice of buffering and the time duration vary in particular. There is no ideal procedure in conodont extraction, so researchers continue to carry out experiments to discover the most appropriate technique (Table 7.1).

During this study, in order to obtain more elements, different techniques proposed in the literature have been performed. In this study, the two main types of acid, acetic acid and formic acid, have been used to extract conodont elements from the limestone samples. For all methods approximately 1 kg of rock has been processed. First of all, acetic acid techniques have been applied to samples. In the first trial, 1 kg rock sample placed into a % 10 acetic acid solution for a week and allowed to react until digestion of the carbonate ceased. The same procedure was repeated two times more. At the end of this process, it is reported that the obtained elements were corroded therefore; the duration of process has been reduced. New samples were placed into a % 10 acetic acid solution for 5 days and washed through nested sieves. The process is repeated until all the samples have been dissolved. Accordingly this method lead to increase in the quality and quantity of the recovered conodont elements.

In addition to the acetic acid techniques, formic acid methods have been also used in conodont extraction. The crushed samples were placed in a plastic bucket and then processed with % 20 formic acid solution for 2 days. Following this procedure, no conodont elements were recovered from samples. Later, new samples were placed into % 8-10 formic acid solutions for 24 hours. This procedure has been also repeated until all the samples were dissolved. Finally, it is concluded that this method is also appropriate for conodont extraction.

Furthermore, another critical method used in this study to extract conodonts is the buffered acid technique which improves the recovery of uncorroded elements and increases yields (Jeppsson et al., 1985). When extracting or cleaning phosphatic fossils using acid, the solution should be buffered. Buffering can be done in two ways. In the first way, previously reduced acetic acid solution can be used and in the second way, new limestone fragments can be added to the solution. Buffering reduces the corrosion and dissolving of conodonts. Buffering is thought to be the best method for conodont extraction, as well.

The summary of buffered acetic acid processing method is as follows (Figure 7.10-11-12):

- Rock samples are cleaned and broken up into pieces.
- Place up to 1 kg of sample into a plastic bucket.
- Add 5000 mls of water to the bucket.
- Put 2400 mls of spent Acetic acid into a polypropylene container and add this to the water in the bucket. This spent Acetic acid acts as a buffer, controlling the vigour of the reaction and minimising the etching of phosphatic microfossils.
- Add 700 mls of Acetic acid into a polypropylene container and add this to the bucket.
- Place a lid on the bucket and store in a fume cupboard for up to 7 days to allow digestion takes place.
- At the end of the digestion process the acid solution is reclaimed for use as buffer and the contents of the bucket are washed through nested sieves, to concentrate the respective size fractions, each of which washed into labelled glass plate and dried in the oven.
- Procedure can be repeated for any rock sample that is undigested.
- Concentration and separation of microfossils can be done using Sodium Polytungstate heavy liquid.

After all these acid reactions, the samples have been washed through nested sieves (425μ, 250μ, 125μ, 63μ openings) and then the residue placed into glass plates and were put in an oven to dry at approximately 50°C (Figure 7.11). This residue was sorted and thoroughly examined under a binocular microscope and picked conodont elements stored in microfossil slides (Figure 7.12). When the residue was quite large, it results in missing of some elements therefore heavy liquid concentration method should be used to recover more conodont elements.

Figure 7.10. a-b. A calcareous rock sample broken into small pieces, c-e. digestion of carbonate by acid solution.

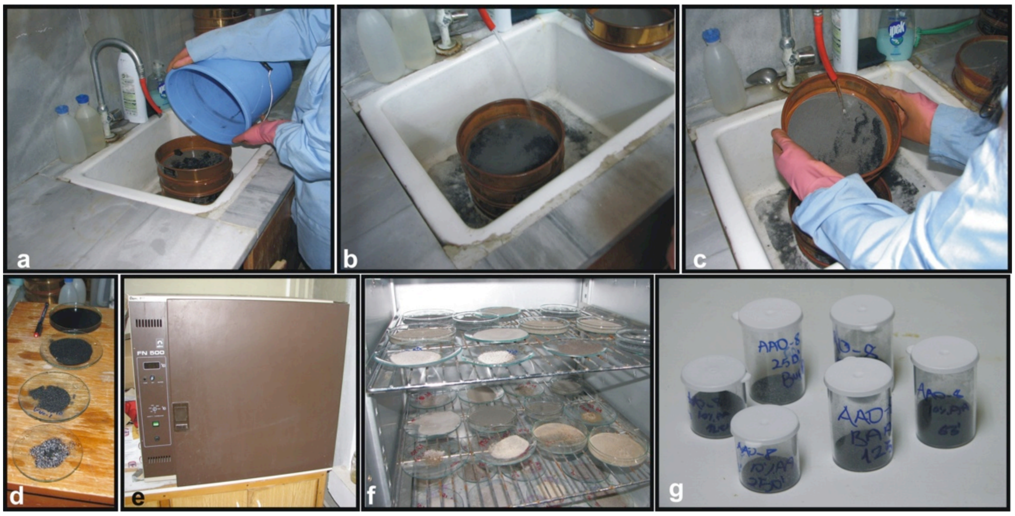


Figure 7.11. a-d. Washing undissolved residues of the sample and sifted through sieves, e-g. drying the samples in 50°C oven and packing the dried samples.

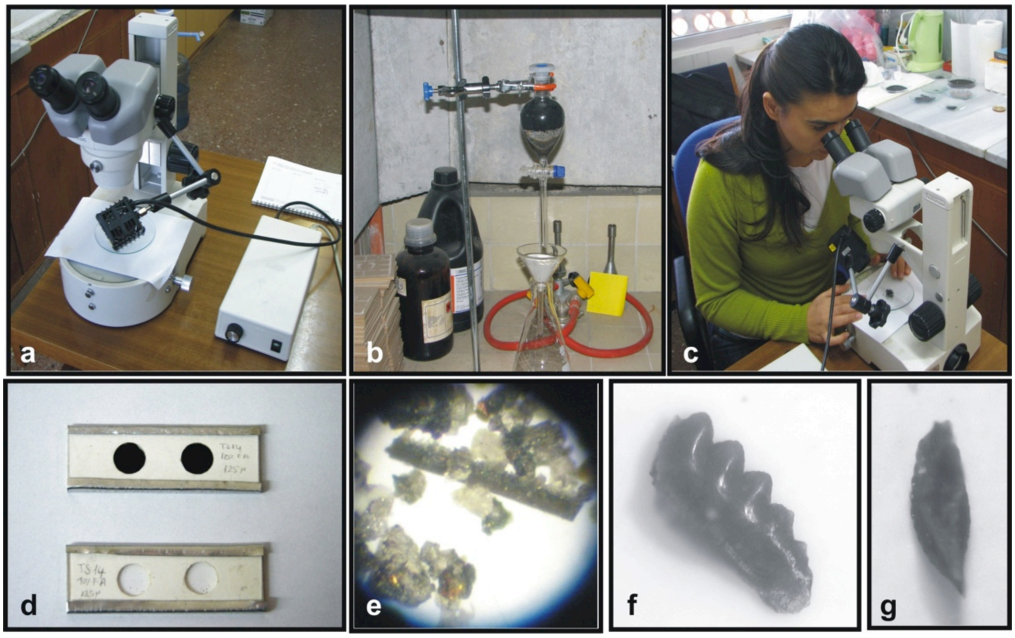


Figure 7.12. a-c. Detailled investigation of conodont elements under the binocular microscope and seperation of conodonts from the residues by using heavy liquid (bromoform), d. Microslides including conodont elements, e. photograph of residues under microscope (arrow indicates the conodont element), f-g. obtained conodont elements.

Paleontologists who work with smaller phosphatic fossils have exploited the relatively high specific gravity of apatite to separate these fossils using density separation techniques with several heavy liquids (Merrill, 1985). The most common heavy liquids in use are tetrabromoethane (sp. gr. = 2.96), bromoform (sp. gr. = 2.89), and methylene iodide (sp. gr. 3.33). Each of these substances is toxic and is carcinogenic and collectively constitutes a hazard to human health (Brem et al., 1974; Hauff and Airey, 1980). Alternative interfacial methods have been proposed by researchers against the use of dangerous heavy liquids (Freeman, 1982; Merrill 1985; Belka et al. 1989). Moreover, a non-toxic heavy liquid, Sodium Polytungstate (sp. gr. = 2.85-3.1), has been widely used in conodont concentration (Callahan 1987; Stone 1987; Swift 1987; Krukowski 1988; Savage 1988; Anderson et al. 1995; Jeppssons and Anehus, 1999). Today, many paleontologists use this heavy liquid because it has several advantages over other mediums, (1) safety: The use maintenance and storage of the compound pose no known health problems, and (2) effectiveness: Recovery rates of near 100% of the conodont elements have been realized.

Some samples were placed in bromoform (sp. gr.= 2.84) to recover conodont elements. The high specific gravity of conodonts (sp. gr. =2.9-3.2) causes them to sink in bromoform while most of the rest of the material in the residue floats. Finally, the conodont elements have been collected from the remaing residue. Moreover, Sodium Polytungstate heavy liquid has been mostly used for conodont separation in this study (Figure 7.13). Each time after the recovery of the liquid, the specific gravity of the solution have been adjusted. Specific gravity of Sodium Polytungstate is adjusted as approximately 2.80.

Figure 7.13. Concentration of conodont elements using Sodium Polytungstate heavy liquid.

Table 7.1. Conodont processing methods used by different authors.

Author	Journal information	Time	Location	Lithology	Weight	Acid type
Collinson et al.	Journal of Paleontology, 1959, 33	Devonian and Missisippian	Upper Missisippi Valley	Shale		Stoddard solvent
Collinson et al.	Journal of Paleontology, 1959, 33	Devonian and Missisippian	Upper Missisippi Valley	Limestone Calcareous Sandstone		10% acetic acid
Zhansherg et al.	Paleogeography, Paleoclimatology, Paleobiology (PPP), 2007	Permian-Triassic boundary	Chaotian in Northern Sichuan, China	Carbonate	average 2,5 kg	acetic acid
Norris G. E.	Journal of Paleontology, 1981	Missisippian	Brazer Dolomite Crawford Mountains, UTAH		1 kg samples from 104 at 3 m intervals	10% acetic acid
Irwin, WP	Journal of Paleontology, 1983	Paleozoic-Triassic	Klamath Mountains, California Oregon	limestone, chert		acedic acid
Çapkınoğlu Ş., Bektaş O.		Early Devonian	Amasya, Turkey	limestone	1 kg total 25 samples	acetic acid or formic acid.
Çapkınoğlu, Ş., Gedik, İ.	2000	Late Devonian	Eastern Taurides Turkey	limestone	form 170 smpls 107 smpls yield conodont	10% formic acid
Laishi, Z. et al.	2007	Lower Triassic	Chaohu Anhui province, China	limestone	averaging approx. 1 to 3 kg.	10-12% solution of acetic acid
This study	2012	Early Carboniferous	Taurides, Turkey	limestone	Approximately 1 to 3 kg.	acetic acid and formic acid

7.8 Systematic Paleontology

The systematic paleontology of conodont fauna underpins both biostratigraphic and paleoecologic studies. The systematic taxonomy of conodonts has been carried out by analyzing washed residues obtained from the systematically collected samples. For the identification of conodonts Sweet (1988), Dzik (1991), Aldridge and Smith (1993) and Donoghue et al. (2008) have been used. The systematic study is mainly based upon P1 elements due to the less abundance of the P2, S and M elements for describing the conodont fauna.

The multielement concept gave rise to notational system for assigning positions of different elements within an apparatus. Although Sweet's notational scheme has been widely accepted, some workers utilize alternative systems. Table 8.2 and Figure 7.13 illustrated the different notational schemes. Purnell et al. (2000) suggested new terms for orientation of conodont elements and a modified system of anatomical notation. The notation system for conodont elements used here follows that of Purnell et al. (2000). Taxa are described based on the most specific characters within the apparatus whose details are given in the explanation of genera and species in the following parts.

It should be noted that taxonomic study given in this chapter consists of short descriptions of the forms. The remarks explaining the main identification criteria and difficulties encountered during the taxonomical study have been depicted and a synonym list comprising the most recent studies has been given.

Table 7.2. Anatomical notation scheme of conodont elements.

Purnell et al. (2000)	P1	P2	S0	S1	S2	S3	S	M
Dzik (1997)	sp	oz	tr	lo	pl	hi	ke	Ne
Chauffe & Nichols (1995)	Pa	Pb	Sa	Sb1	Sb2	Sb3	Sc	M
Sweet (1981)	Pa	Pb	Sd	Sb	Sb	Sc	Sc	M

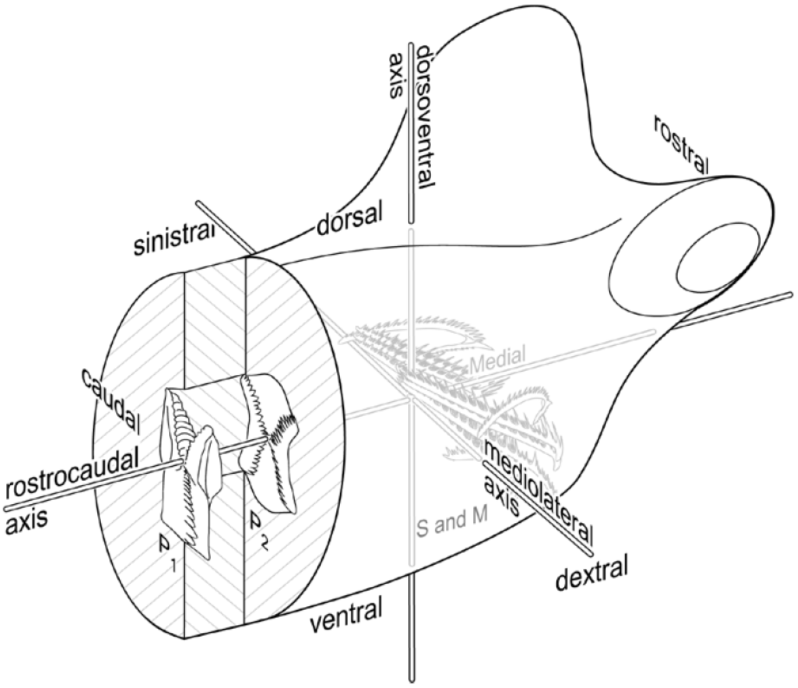


Figure 7.14. Biological orientation of elements in conodont terminology proposed by Purnell et al. (2000) as applied to the head of an ozarkodinid conodont.

Phylum CHORDATA Pander, 1856
Subphylum VERTEBRATA Pander, 1856
Class CONODONTA Eichenberg, 1930
Order OZARKODINIDA Dzik, 1976
Suborder OZARKODININA Dzik, 1976

Superfamily POLYGNATHACEA Bassler, 1925

Family ANCHIGNATHODONTIDAE Clark, 1972

Genus *HINDEODUS* Rexroad and Furnish, 1964
Type species: *Trichonodella imperfecta* Rexroad, 1957.

Diagnosis: P1 element is carminate is straight or rather arched. It contains one enlarged cusp followed dorsally by eight to twelve denticles. The denticle size is uniform until the dorsal-most denticles and decrease in height to the aboral margin of the element. The basal cavity is flaring and unornamented, usually centered on the ventral end of the element.

Remarks: The discrimination of species must apperantly involve consideration of all elements rather than P1 elements.

Hindeodus cristulus (Youngquist & Miller, 1949)
Pl. 1, figs. 1, 2

1949 *Spathognathodus cristula* n. sp. - Youngquist & Miller, p. 621, pl. 101, figs. 1-3.

1961 *Spathognathodus cristula* - Rexroad & Burton, pl. 141, fig. 9.

1964 *Spathognathodus cristula* - Rexroad & Furnish, p. 674, pl. 111, fig. 15.

1967 *Spathognathodus cristula* - Globensky, p. 447, pl. 57, figs. 15-16.

1982 *Hindeodus cristulus* - von Bitter & Plintgeberl, p. 200, pl. 4, figs. 15-19; pl. 5, fig. 12; pl. 7, fig. 21.

1987 *Hindeodus cristula* - von Bitter & Plint, p. 358-359, pl. 2, fig. 9; pl. 3, figs. 11, 15-16.

1990 *Hindeodus cristula* - Rexroad & Horowitz, p. 502-504, pl. 1, figs. 21-42.

1991 *Hindeodus cristula* - Stone, p. 12-13, pl. 1, figs. 1-2, 5, 8.

1996 *Hindeodus cristulus* - Skompski, pl. 5, fig. 15.

1999 *Hindeodus cristula* - Somerville, pl. 4, figs. 6-14.

1999 *Hindeodus cristula* - Somerville & Somerville, pl. 1, figs. 4-6.

2002 *Hindeodus cristulus* - Draganits et al., pp. 30-31, Pl. 4, figs. 3, 6.

2005 *Hindeodus cristula* - Medina-Varea et al., p.34, 36, pl.2, figs.15-18.

2008 *Hindeodus cristulus* - Habibi et al., p.769, 771, fig.4.3.

Diagnosis: P1 element consists of short, moderately arched and compressed blade. It is composed of about seven to nine denticles. Base of the blade is flared reaching maximum lateral extent about midlength on the blade. Cusp is three to four times as wider and longer than the other denticles. The basal cavity is broad and shallow.

Remarks: This species is characterized by arcuate blade and a broad shallow basal cavity (Sweet, 1977). The most distinguishing feature of the studied samples is the presence of large cusp.

Range: *Hindeodus cristulus* ranges from the Lower *crenulata* Zone (Draganits et al., 2002) to *texanus* Zone (von Bitter and Plint, 1987) (Missippian – Lower Carboniferous).

Stratigrafic Distribution: *Hindeodus cristulus* occurs commonly in AS and AAO sections in Sarız and Hadim regions within the Ivorian substage. The elements have been documented from the sample AS 5 and AS 7 in Sarız and the sample AAO 6 in Hadim. In this study this species has been found in the *Gnathodus cuneiformis - Polygnathus communis communis* Zone in the AS section *Polygnathus mehli mehli* Zone in the AAO section. It has been recorded in the Ivorian substage.

Hindeodus minutus (Ellison, 1941)

Pl. 1, fig. 3

1941 *Spathodus minutus* - Ellison, p. 120, pl. 20, figs. 50-52.

1964 *Spathognathodus echigoensis* - Igo and Koike, p. 187, pl. 28, figs. 24, 25.

1965 *Spathognathodus minutus* - Dunn, p. 1149, pl. 140, figs. 15,21, 24.

1967 *Spathognathodus minutus* - Koike, p. 311, pl. 3, figs. 3942.

1969 *Spathognathodus minutus* - Palmieri, p. 9, 10, pl. 5, figs. 17, 18.

1973 *Spathognathodus minutus* - Merrill, p. 305-308, pl. 1, figs. 1-14; pl. 2, figs. 1-28.

1973 *Anchignathodus minutus*. - Sweet, p. 15-17, pl. 1, fig. 2.

1974 *Spathognathodus minutus* - Lane and Straka, p. 101, figs. 44: 7, 12.

1974 *Anchignathodus rninutus* - Merrill, pl. 2, fig. 8.

1981 *Hindeodus minutus*. - Landing & Wardlaw, p. 1259, 1260, pl. 1, figs. 11, 12, 18, 23.

1984 *Anchignathodus rninutus* - Grayson, pl. 2, figs. 3, 26.

1985 *Hindeodus rninutus* - Rexroad and Merrill, pl. 3, figs. 21, 22.

1985 *Hindeodus minutus*.- Wardlaw, p. 400, pl. 3, fig. 1.

1986 *Hindeodus minutus*.- Mapes & Rexroad, pl. 1, figs. 7-15.

1987 *Hindeodus minutus*.- Grayson et al., pl. 9, fig. 1.

1989 *Hindeodus minutus* - Wang & Higgins, p. 279, pl. 13, figs. 6, 7.

1990 *Hindeodus minutus* - Grayson, pl. 2, figs. 6, 7, 8.

1991 *Hindeodus minutus* - Brown et al., figs. 7. 12-19.

1992 *Hindeodus minutus*.- Sutherland & Grayson, pl. 2, fig. 1.

1992 *Hindeodus minutus*.- Weibel & Norby, pl. 1, fig. 21.
1993 *Hindeodus minutus*.- Rexroad, figs. 3. 14-17, 19.

Diagnosis: P1 element includes a short free blade. It has a cusp with a triangular shape followed by discrete denticles. The denticles of the carina decline in elevation following the cusp, to the dorsal edge of the platform. Denticles are fused with only the tips free. The basal cavity is slightly expanded, robust and unornamented.

Remarks: Rexroad and Horowitz (1990) indicated that *Hindeodus cristulus* has the same anterior denticulation as *Hindeodus minutus*. It differs from the *Hindeodus minutus* by having nearly straight blade and more denticles.

Range: The range of this species is from upper Chesterian through at the Lower Permian (Krumhardt et al.1996).

Stratigrafic Distribution: *Hindeodus cristulus* occurs commonly in AS and AAO sections in Sarız and Hadim regions within the Ivorian substage. The elements have been identified from the sample AS 5 and AS 12 in Sarız and the sample AAO 6 and AAO 8 in Hadim. Our specimens were recorded in the *Gnathodus cuneiformis - Polygnathus communis communis* Zone in the AS section *Polygnathus mehli mehli* Zone in the AAO section.

Genus *LOCHRIEA* (Scott 1942)

Type species: *Lochriea montanaensis* (a subjective junior synonym of *Spathognathodus commutus* Branson and Mehl 1941).

Diagnosis: P1 element is carminiscaphate with free blade and large, lanceolate, posterior basal cavity. The oral surface is either unornamented or bears a few nodes or rows of nodes. P2 element is angulate. M element is makellate, with large cusp, and arched ‘postero-lateral’ process. Process height and denticle length decreases distally. S0 element is alate. S1-4 elements are bipennate in appearance. S1-4 elements have an anterior process that is deflected upwards distally.

Remarks: Lochriea differs from *Protognathodus* by more symmetrical platform and wider and higher carina. Based on some authors (Norby, 1976; Nemyrovska, 1999), this genus is characterized by rectangular shape of the posterior end in lateral view. However, Atakul-Özdemir et al. (2012b) stated that the distinctive subrectangular profile of the free blade in lateral view, and the variation in size of denticles along the blade are no longer shared by all members of the genus, but may be useful in species recognition. M element morphology is diagnostic for *Lochriea.*

***Lochriea commutata* (Branson & Mehl, 1941)**

Plate 1, figs. 4-9

1941 *Spathognathodus commutatus* - Branson & Mehl, p. 172, pl. V, figs. 19-22.
1969 *Gnathodus commutatus* - Thompson & Goebel, p. 23, 24, pl. 4, figs. 4, 6,7.
1979 *Gnathodus commutatus* - Aisenverg et al., pl. 6, figs. 3,4.
1979 *Gnathodus commutatus commutatus* - Einor et al., pl. 14, figs. 2, 3.
1986 *Paragnathodus commutatus* - Ji, pl. 2, figs. 1-4, 5, 6.
1987 *Lochriea commutate* - Armstrong & Purnell, pl. 3, fig. 1.
1987 *Paragnathodus commutatus* - Riley et al., pl. 2, figs. 1, 3.
1987 *Paragnathodus commutatus* - Wang et al., p. 130, 131, pl. 2, fig. 12.
1988 *Gnathodus commutatus commutatus* - Dong & Ji, pl. 5, figs. 1-3.

1989 *Paragnathodus commutatus* - Wang & Higgins, p. 285, pl. 8, figs. 4, 5.

1990 *Lochriea commutata* - Grayson, pl. 1, figs. 14-24.

1990 *Lochriea commutata*.- Ramovs, p. 94,95, pl.4, figs. 6,7, 10, 11.

1990 *Lochriea commutate* – Rexroad & Horowitz, p. 508-510, pl. 2, figs. 10-24.

1990 *Lochriea commutate* - Whiteside & Grayson, pl. 1, figs. 1, 2.

1991 *Paragnathodus commutatus* - Nemirovskaya et al., pl. 3, fig. 4.

1991 *Paragnathodus commutatus* - Varker et al., pl. 1, figs. 13-15.

1992 *Lochriea commutate* - Weibel & Norby, pl. 2, figs. 35, 36.

1993 *Paragnathodus commutatus* - Alekseev & Kononova, pl. 29, fig. 11.

1994 *Lochriea commutate* - Kolar-Jurkovsek & Jurkovsek, 432-433, pl. 1, figs. 3,4.

1994 *Lochriea commutate* - Nemirovskaya et al., pl. 2, fig. 1.

1994 *Lochriea commutata* - von Bitter & Norby, p. 861-869, figs. 2-7.

1996 *Lochriea commutata* - Krumhardt et al., p.46, pl.3, figs. 26, 27.

1999 *Lochriea commutata* - Nemyrovska, p.74.

2005 *Lochriea commutata* - Blanco-Ferrera et al., p.21, fig. 6.2, 3.

Diagnosis: P1 element is carminiscaphate. The free blade is same size as the platform or longer. It is completely straight or slightly curved. The platform is oval and unornamented. The shape of the platform is subrectangular in lateral view. The height of the denticles decreases gradually towards the posterior part of the platform and continues on the platform in a hull that curves ends abruptly. The basal cavity is wide, deep and oval in shape. It expands slightly towards the end of the platform. The M element has a short, arched, ‘postero-lateral’ process which declines in height distally. It bears large ‘laterally compressed’ denticles which decrease slightly in height and are increasingly inclined distally. The cusp is longer than the process and is compressed with straight sides, and a sharply pointed tip. The basal cavity is small but extends beneath the ‘postero-lateral’ process. The S3-4 elements have an ‘anterior’ process that is shorter than the ‘posterior’, with the typical upswept distal termination of *Lochriea* species. The processes are ‘laterally compressed with flat sides. The cusp is wider and longer than any denticles on either process; it is ‘laterally compressed’ towards the base, but becomes more rounded in cross section towards the tip. The small basal cavity extends beneath the posterior process, and may be flanked by recessive basal margin, especially ‘anteriorly’.

Remarks: The P1, M and S elements of *Lochriea commutata* have been recovered from the studies sections. This species differs from other species of *Lochriea* based on the P1 element by the absence of ornamentation. It is distinguished from *Lochriea cracoviensis*, by simple narrow carina (Nemyrovska, 1999).

Range: This species ranges from lower Meramecian into the lowermost Morrowan (*noduliferus* Zone or earliest Bashkirian) in the Donets Basin, Ukraine (Nemirovskaya et al., 1991), and South Tienshan, Uzbekistan (Nigmadganov and Nemirovskaya, 1992). It is recovered from the upper part of the Lower Carboniferous of Japan and China and Upper Mississippian (Chesterian) of North America (Nemyrovska, 1999).

Stratigrafic Distribution: *Lochriea commutata* occurs commonly in BSE measured section in Bademli region. The elements have been identified from the BSEc 4 and 7 samples within the *Gnathodus girtyi girtyi* and *Gnathodus girtyi simplex* Zones.

Genus *VOGELGNATHUS* Norby and Rexroad, 1985
Type species: *Spathognathodus campbelli* Rexroad, 1957

Diagnosis: P1 element is carminiscaphate. It has denticulated anterior and posterior processes. The basal cavity is located at the posterior part of the element or occupies whole of lower surface. P1 elements vary significantly in their length, the size and discreteness of denticles, and the relative size of the basal cavity.

Remarks: *Vogelgnathus* is distinguished from *Diplognathodus* by their distinctive nonplatform elements (Purnell and von Bitter, 1992). Furthermore, unlike *Diplognathodus*, the range of P1 element variation in the species of *Vogelgnathus* does not include the development of a spatulate posterior process (von Bitter and Merrill, 1990).

Vogelgnathus campbelli **(Rexroad, 1957)**

Plate 1, figs. 10,11

1957 *Spathognathodus campbelli* – Rexroad, p. 37, pl. 3, figs. 13-15.

1965 *Spathognathodus werneri* - Budinger, p. 82, pl. 5, figs. 14-18, text-fig. 26.

1965 *Spathognathodus campbelli* - Budinger, p. 80, pl. 5, figs. 9-13, text-fig. 26.

1985 *Vogelgnathus campbelli* - Norby & Rexroad, pp. 3-11, pl. 1, figs. 1, 2 (assemblage); pl. 2, figs. 3-10 (Pa elements); pl. 2, figs. 1, 2 ; pl. 3, figs. 5, 9, 10 (Pb elements); pl. 3, figs. 1-4 (M elements); pl. 3, fig. 6 (Sa elements); pl. 3, figs. 7, 8 (Sb elements); pl. 3, figs. 11, 12 (Sc elements).

1990 *Vogelgnathus campbelli* - Rexroad & Horowitz, p. 511, 512, pl. 2, figs. 3-8.

1992 *Vogelgnathus campbelli* - Boogaard, pl. 1, figs. a-e, pl. 2, fig. c, pl. 3, figs. a-d.

1992 *Vogelgnathus campbelli* - Purnell & von Bitter, p. 317, 318, figs. 4.1 - 4.4.

1999 *Vogelgnathus campbelli* - Meischner & Nemyrovska, pl. 4, fig. 15.

Diagnosis: P1 element is carminiscaphate, elongated and denticulated. The length of the element is greater than the height. Mature elements have approximately twenty denticles. The tips of the denticles are subequal in size. The cusp is located slightly posterior to midlength and commonly slightly larger than other denticles. Lateral line present on anterior blade. Basal cavity is located one-half to one-third length of element and extends to posterior tip.

Remarks: P1 elements of *Vogelgnathus campbelli* closely resemble those of *Vogelgnathus postcampbelli* but can be differentiated by the characteristics of the posterior process, number of denticles and larger basal cavity (Purnell and von Bitter, 1992). The studied specimens differentiated by the presence of ten to fifteen denticles and a slight line at the base of denticles.

Range: This species is recorded in Upper Mississippian (Chesterian) of the United States, and in Visean and Serpukhovian of Eurasia (Nemyrovska, 2005).

Stratigrafic Distribution: *Vogelgnathus campbelli* occurs commonly in the AAO measured section in the Hadim region and the BSE section in the Bademli region. The elements have been recognized from the samples AAO 6 witih the *Polygnathus communis communis* Zone and BSEc 7 within the *Gnathodus girtyi simplex* Zone.

Family CAVUSGNATHIDAE Austin & Rhodes, 1981

Genus *ADETOGNATHODUS* Lane, 1967

Type species: *Cavusgnathus lautus* Gunnell, 1933

Diagnosis: P1 element is carminiscaphate with lateral junction of free blade and two parapets. These parapets meet at the posterior end of the element and may be ornamented by nodes or short transverse ridges. The free blade is attached to one platform margin and joins with a short fixed blade. Long, free blade continues onto the platform as an outer parapet. A short, fixed anterior blade attached to anterior end of outer parapet. The parapets are divided by a deep median trough with high elevation platform margins. Basal cavity is wide, relatively deep and longitudinally elongate.

Remarks: *Adetognathus* is separated from very similar genus *Cavusgnathus* on the basis of characteristics of the blade. *Adetognathus* has a short fixed blade and longer free blade. However, *Cavusgnuthus* has a free blade equal in length or less than that of the fixed blade. *Adetognathus* has both left- and right-sided forms. *Cavusgnathus* is only right-sided.

Adetognathus lautus **(Gunnell, 1933)**
Plate 4, figs. 15, 16

1971 *Adetognathus gigantus* - Lane et al., pl. 1, fig. 6.
1971 *Adetognathus lautus* - Lane et al., pl.1, fig 5.
1971 *Cavusgnathus lautus* - Merrill & King, p.655, pl. 75, figs. 23,24,26-29.
1972 *Cavusgnathus lautus* - von Bitter, p. 61-63, pl. 4, figs. 3; pl. 5, figs. 1.
1973 *Adetognathus lautus* - Baesemann, p. 697, pl. 2, figs. 29-31, 34.
1974 *Adetognathus lautus* - Lane & Straka, p. 64-65, figs. 36.17, 21, 22, 25-31; figs. 38.14, 20; figs. 39. 14, 15, 19, 20; figs. 40. 1-3, 7-14.
1974 *Cavusgnathus lautus* - Merrill, pl. 1, figs. 8,9.
1975 *Adetognathus lautus* - Perlmutter, p. 101, pl. 3, figs. 34-39,42-45.
1975 Cavusgnathus lautus - Merrill, p. 44-46, figs. 14.8, 9; figs. 15. 1, 2, 13-16; figs. 16. 3,4, 36,37
1979 *Cavusgnathus lautus*.- Einor et al., pl. 14, figs. 13a-c.

1979 *Adetognathus gigantus*.- Semichatova et al., pl. 22, fig. 16.

1980 *Adetognathus lautus* - Bender, p. 8, 9, pl. 4, figs. 26-33.

1980 *Cavusgnathus lautus* - Merrill & Powell, pl. 1, figs. 30-33.

1984 *Adetognathus lautus*.- Grayson, pl. 3, figs. 8, 9, 26, 27.

1985 *Adetognathus glgantus* - Skipp et al., pl. 8, fig. 7.

1985 *Adetognathus lautus* Skipp et al., pl. 8, fig. 6.

1989 *Cavusgnathus lautus*.- Merrill & Grayson, pl. 1, figs. 31, 32; pl. 2, figs. 20-23.

1991 *Adetognathus lautus* - Brown et al., figs. 7. 8-1 1.

1991 *Adetognathus lautus* - Morrow & Webster, pl. 1, figs. 4-1 1.

1991 *Adetognathus lautus* - Nemirovskaya et al., pl. 3, figs. 20-24.

1992 *Adetognathus lautus* - Morrow & Webster, pl. 1, fig. 12.

1996 *Adetognathus lautus* - Krumhardt et al., p.32,33, pl.1, figs. 13-15, 21-24.

1996 *Adetognathus lautus* - Sobolev & Nakrem, p.45, pl.15 I,K.

2005 *Adetognathus lautus* - Rosscoe, p.78, figs.37.11 – 37.14.

2005 *Adetognathus lautus* - Nascimento et al., fig. 2-J.

2009 *Adetognathus lautus* - Nascimento et al., fig. 4-D.

Diagnosis: P1 element is slightly arched and has a curvature. Platform margins are raised and ornamented by short transverse ridges. The free blade is attached to the platform at the rostral margin. The short fixed blade consists of only one or two denticles. The deep medial trough splits the platform. The platform margins decrease in elevation from the ventral to the dorsal end of the element. Basal cavity is large and deep.

Remarks: *Adetognathodus lautus* is generally more sinuous in shape than other species of *Adetognathodus* (Lane, 1967). *Adetognathodus lautus* can be differentiated from specimens of *Adetognathodus unicornis* by the presence of a very short fixed blade in *Adetognathodus lautus* (Rosscoe, 2005). In the studied samples; this species is identified by the presence of deep median trough and distinct transversal ridges on the platform.

Range: *Adetognathodus lautus* has a known range from lower Morrowan (Lane, 1967) to Lower Permian (Ellison, 1941). Krumhardt et al. (1996) reported the range of it from uppermost Chesterian (base of Upper *muricatus* Subzone) to Lower Permian.

Stratigraphic Distribution: In our samples, *Adetognathus lautus* occurs in the *Rhachistognathus muricatus* and *Declinognathdus ineaqualis - Declinognathus noduliferus* Zones of the HB section in the Hadim region. The elements have been reported from the samples HB 28 and HB 24.

Family IDIOGNATHODONTIDAE, Harris & Hollingsworth, 1933

Genus *DECLINOGNATHODUS* Dunn, 1966

Type species: *Cavusgnathus nodulifera* Ellison & Graves, 1941

Diagnosis: P1 element is lanceolate with elongate narrow platform including two unequal parapets. Free blade joins platform in medial or nearly medial position along the outer margin. Median carina representing posterior continuation of blade denticles onto the platform declines to one side, merges with outer parapet at different distance from the posterior end and continues posteriorly as one of platform parapets. An isolated node or nodes may be present on the outer part of the platform. A medial trough extends to the posterior tip. Basal cavity is deep, wide and slightly asymmetrical.

Remarks: The specified morphological features, like medial juncture of blade with platform, declination of the carina to an outer platform and presence of one or more nodes anteriorly from a declined carina, are important characteristics to distinguish *Declinognathodus* from other genus. It differs from *Idiognathoides* by the central position of the free blade and from *Gnathodus* and *Neognathodus* by declination of carina to the outer parapet.

***Declinognathodus bernesgae* Sanz-López et al., 2006**
Pl. 2, figs. 1, 2

1962 *Cavusgnathus nodulifera* - Higgins, pl. 3, fig. 27.

1992 *Declinognathodus praenoduliferus* - Nigmadganov & Nemirovskaya, p. 262-263, pl. 2, figs 10-14; pl. 3, figs 1,2.

1992 *Declinognathodus noduliferus* s.l. - Nigmadganov & Nemirovskaya, pl. 3, figs 3, 7, 9.

1992 *Idiognathoides asiaticus* - Nigmadganov & Nemirovskaya, pl. 4, figs 8, 10.

1996 *Gnathodus girtyi* subspp. transitional to *Declinognathodus* spp. - Krumhardt et al., p.42, pl. 2, figs 29, 30.

1996 *Declinognathodus noduliferus japonicus* - Krumhardt et al., p. 36-37, pl. 3, figs. 1-3; figs 4-8.

1997 *Declinognathodus noduliferus* - Mizuno & Ueno, pl. 1, figs. 10, 11.

1997 *Declinognathodus japonicus* - Mizuno & Ueno, pl. 1, figs. 12, 13.

1997 *Declinognathodus japonicus* - Mizuno, p. 249, pl. 12, figs. 9-12.

2001 *Declinognathodus praenoduliferus* - Kulagina et al., pl. 7, figs. 22, 23.

2002 *Declinognathodus noduliferus* - García-López & Sanz-López, pl. 5, fig. 5.

2006 *Declinognathodus noduliferus bernesgae* - Sanz-López et al., p. 10,11, pl. 1, figs. 8-13, 15-18.

2011 *Declinognathodus noduliferus bernesgae* - Nemyrovska et al.; p.155, pl.3, figs. 11,13,14; pl.4, figs. 16,17, 25,26.

Diagnosis: P1 element has narrow platform two ornamented parapets. The margins of platform are covered by transverse ridges. One or two nodes are located on the anterior margin of outer platform. The nodes or ridges are neighbors and form continuous margins, where the ornamentation is normal to the carina. The carina is deflected and slopes to the outer platform. The central groove is shallow and disappears in the posterior part of the platform, where short transverse ridges occur. The basal cavity is wide and asymmetric.

Remarks: *Declinognathodus bernesgae* resembles *Declinognathodus praenoduliferus* and *Declinognathodus noduliferus*. *Declinognathodus bernesgae* has mostly ridged parapets as in *Declinognathodus praenoduliferus,* but not the nodular ones, as occur in the *Declinognathodus noduliferus*. Unlike *Declinognathodus praenoduliferus, Declinognathodus bernesgae* has a shallow median groove disappearing in the posterior part of the platform whereas *Declinognathodus noduliferus* has a deep groove between the parapets. *Declinognathodus bernesgae* displays the development of a medial trough by its deepening and widening. This was probably followed later by the transformation of transverse ridges into rows of nodes on both sides of the platform and, thus, into a formation of nodular parapets as in *Declinognathodus noduliferus*. The studied specimens belonging to species differs from other *Declinognathodus* species by having one or two nodes on the outer part of the platform.

Range: The range of this species is reported as Uppermost Missippian through Lower Bashkirian in the Cantabrian Mountains (Spain) and in the Pyrenees (France); Lowermost Bashkirian in South Tienshan, (Uzbekistan); Lowermost Pennsylvanian in Hina Limestone (Southwestern Japan) (Nemyrovska, 2011).

Stratigraphic Distribution: *Declinognathodus bernesgae* occurs in the HB measured section in the Hadim region just below the Mid-

Carboniferous boundary within the *Rhachistognathus muricatus* Zone. The elements have been recorded from the sample HB 28.

Declinognathodus ineaqualis **(Higgins, 1975)**

Pl. 2, figs. 3-7

1968 *Idiognathoides nodulifera* - Igo and Koike, p. 28, 29, pl. 3, figs. 8, 9.

1975 *Idiognathoides noduliferus inaequalis* - Higgins, p.53, pl.12, figs. 1-7; pl.14, figs. 11-13; pl.15, figs. 10,14.

1980 *Idiognathoides noduliferus inaequalis* - Metcalfe, p.306, pl. 38, fig. 15.

1983 *Declinognathodus noduliferus inaequalis* - Nemirovskaya: pl. 1, fig. 27.

1985 *Declinognathodus noduliferus* - Grayson et al., p.163, pl.1, figs. 1, 5, 10.

1987 *Declinognathodus noduliferus inaequalis* - Nemirovskaya: pl. 1, figs. 6, 9, 13-14.

1987 *Declinognathodus inaequalis* - Riley et al., pl. 3, figs. 28-40.

1991 *Declinognathodus noduliferus inaequalis* - Nemirovskaya et al., pl. 4, figs. 3, 5,15.

1992 *Declinognathodus noduliferus* - Nigmadganov & Nemirovskaya, pl. 3, figs.5, 8.

1992 *Declinognathodus inaequalis* - Kulagina et al., pl. 30, figs. 5, 6, 11.

1993 *Declinognathodus noduliferus inaequalis* - Duan, p. 206, pl. 3, figs. 7, 8, 9.

1996 *Declinognathodus noduliferus inaequalis* - Soboloev & Nakrem, p.47, pl.1-F

1997 *Declinognathodus inaequalis* - Mizuno, p.248, figs.12.1-5.

Diagnosis: P1 element is carminiscaphate including narrow and elongate platform. Parapet is well developed along the inner platform and merges with the carina to form transversal ridges on the posterior part of the platform. Four or more nodes are well developed at the anterior part of the outer platform. Blade is free and slightly curved inward and continues onto platform as a carina. Carina curves faintly on the anterior part and becomes straight on the posterior end. Median trough is rather deep. Basal cavity is deep and wide.

Remarks: The species defined in the studied samples differs form the *Declinognathodus noduliferus* by having longest carina which merges with the parapet close to the posterior end of the element. In the studied samples mainly P1 elements have been recorded.

Range: The range of his species is Namurian in Great Britain, lowermost Bashkirian of the Russian Platform and the Urals (Sobolev and Nakrem, 1996) and Voznesensky and Cheremshansky horizons in Donetz basin (Nemyrovska, 1999). Mizuno (1997) reported he occurrence of *Declinognathodus inaequalis* from the *Declinognathodus inaequalis - Gnathodus bilineatus* Zone to *Declinognathodus noduliferus* Zone (Lower Pennsylvanian).

Stratigraphic Distribution: *Declinognathodus inaequalis* appears in the HB measured section in the Hadim region. This species has been recorded just above the Mid-Carboniferous boundary in the *Declinognathodus ineaqualis – Declinognathodus noduliferus* Zone. The elements have been reported from the samples HB 27, HB 24 and HB 04.

***Declinognathodus lateralis* (Higgins & Bouckaert, 1968)**
Pl. 2, figs. 19-29

1968 *Streptognathodus lateralis* - Higgins & Bouckaert, 45, pl. 5, figs. 1-4, 7.

1970 *Declinognathodus lateralis* - Dunn, 330, pl. 62, figs. 5-7.

1975 *Streptognathodus lateralis* - Higgins, 73, pl. 12, fig. 9; pl. 17, figs. 10-11, 13-14.
1980 *Declinognathodus lateralis* - Bender, 11, pl. 1, figs. 1-2, 4-7.
1983 *Declinognathodus lateralis* - Nemirovskaya, pl. 1, figs. 24-25, 30, 32
1983 *Declinognathodus lateralis* - Park, 60, pl. 5, fig. 4-5.
1985 *Declinognathodus lateralis* - Higgins, pl. 6.3, figs. 3, 5, 8.
1987 *Declinognathodus lateralis* - Nemirovskaya, pl. 1b, figs. 17-18, 22-24.
1989 *Declinognathodus lateralis* - Wang & Higgins, 276, pl. 1, figs. 10-13.
1991 *Declinognathodus lateralis* - Nemirovskaya et al., pl. 4, figs. 19, 23.
1992 *Declinognathodus lateralis* - Kulagina et al., pl. 30, figs. 16, 18-22.
1993 *Declinognathodus lateralis* - Nemirovskaya & Alekseev, pl. 4, fig. 8.
1993 *Declinognathodus lateralis* - Nigmadganov & Nemirovskaya, pl. 4, fig. 8.
1994 *Declinognathodus lateralis* - Nemirovskaya & Alekseev, pl. 1, figs. 5-6, 8.
1999 *Declinognathodus lateralis* - Nemyrovska, p. 53, pl. 1, figs. 13-14; pl. 2, figs. 5, 13.

Diagnosis: P1 element is lanceolate and includes elongate platform with pointed or rounded posterior end. Carina declines and touches to the outer parapet but not merge. It continues to the posterior end of the platform as a longitudinal row of nodes. Inner and outer parapets are equally high, and include straight parallel transversal ridges. Basal cavity is deep and wide.

Remarks: This species differs from other *Declinognathodus* secies by the slight declination of its carina to the outer parapet and the continuation of this transverse-ridged structure to the posterior end of the platform (Nemyrovska, 1999). *Declinognathodus lateralis* is thought to differ from *Declinognathodus noduliferus* in that in the latter the carina declines strongly to meet the outer margin, which does not form transversal ridges. The defined specimens are distinguished from the other species of *Declinognathodus* by having larger platform.

Range: The range of *Declinognathodus lateralis* is Bashkirian in Eastern Europe, Urals and Central Asia, Namurian in Western Europe, Pennsylvanian (especially Morrowan) in North America and Weiningian in China (Nemyrovska, 1999)

Stratigraphic Distribution: *Declinognathodus lateralis* occurs in the HB measured section in the Hadim region. The elements have been reported from the sample HB 27 at the base of *Declinognathodus ineaqualis – Declinognathodus noduliferus* Zone.

***Declinognathodus noduliferus* (Ellison & Graves, 1941)**
Pl. 2, figs. 8-18

1941 *Cavusgnathus nodulifera* - Ellison & Graves: 4, pl. 3, fig. 4.
1960 *Streptognathodus parallelus* - Clarke, p. 29, pl. 5, figs. 6-8, 14, 15.
1967 *Gnathodus nodulifera* - Koike, p. 297, 298, pl. 3, figs. 10, 12.
1968 *Gnathodus noduliferus* - Higgins & Bouckaert, p. 33-35, pl. 2, figs. 6, 12.
1969 *Streptognathodus noduliferus* - Webster, p. 48,49, pl. 4, figs. 7, 8.
1970a *Declinognathodus noduliferus* - Dunn. 330, pl. 62, figs. 1-2.
1972 *Streptognathodus lateralis* - Austin, pl. 2, fig. 31.
1974 Idiognathoides noduliferus - Lane & Straka, p. 85-87, pl. 35, figs. 11-13; pl. 41, figs. 15-17.
1974 *Gnathodus noduliferus* - Merrill, pl. 1, figs. 28, 29.

1975 *Idiognathoides noduliferus noduliferus* - Higgins, p. 54, pl. 14, figs. 15, 16.

1979 *Declinognathodus noduliferus* - Aisenverg et al., pl. 6, figs. 17, 18.

1979 *Streptognathodus noduliferus* - Einor et al., pl. 14, figs. 6,7.

1980 *Idiognathoides noduliferus noduliferus* - Metcalfe, p.306, pl.38, figs. 16, 18.

1983 *Declinognathodus noduliferus noduliferus* – Nemirovskaya, pl. 1, fig. 28.

1987 *Declinognathodus noduliferus noduliferus* – Nemirovskaya, pl.16, figs. 7, 9, 11, 20-21.

1988 *Declinognathodus noduliferus noduliferus* - Dong & Ji, pl. 6, figs. 5, 6.

1989 *Declinognathodus noduliferus noduliferus* - Wang & Higgins, p. 276, 277, pl. 2, figs. 5-9.

1990 *Declinognathodus noduliferus* - Grayson, pl. 1, figs. 10, 13; pl. 3, fig. 29.

1990 *Declinognathodus noduliferus noduliferus* - Gibshman & Akhmetshina, pl. 5, figs. 7, 8.

1992 *Declinognathodus noduliferus* - Morrow & Webster, pl. 1, fig. 5.

1992 *Declinognathodus noduliferus* - Nigmadganov & Nemirovskaya, pl. 3, figs. 3-17.

1993 *Declinognathodus noduliferus* - Nemirovskaya & Alekseev, pl. 3, figs. 4, 12.

1994 *Declinognathodus noduliferus* - Nemirovskaya & Alekseev, pl. 1, figs. 2-4, 7.

1996 *Declinognathodus noduliferus noduliferus* - Krumhardt et al., p. 37,38, pl.3, figs. 10-14, 32.

1997 *Declinognathodus noduliferus* - Mizuno, p.20, Fig.12. 6-8.

2006 *Declinognathodus noduliferus noduliferus* - Sanz-Lopez et al., p.5, pl.1, figs. 3,4.

Diagnosis: P1 element is carminiscaphate and includes elongate, narrow, and oval shape platform with pointed or rounded posterior tip. Platform contains nodose and (or) transversely ridged parapet. Two or three nodes are well developed at the anterior part of the outer platform. Blade is free and slightly curved inward and continues onto platform as a carina. Denticulated carina merges with the outer parapet within the anterior half of the platform. Shallow median groove between the parapets gets deeper and wider posteriorly behind the declination of carina to the outer parapet. Basal cavity is deep and wide.

Remarks: Higgins (1975) distinguished three subspecies within *Declinognathodus noduliferus* based on the distance between the point of mergence of carina with the outer parapet and the posterior end of the element. However, recent studies (Mizuno, 1997) and also this study, interpreted the subspecies of *Declinognathodus noduliferus* as independent species because of their different forms and stratigraphic appearances. *Declinognathodus noduliferus* in the studied samples differs from other *Declinognathodus* species by having two or three nodes on the outer side of the carina.

Range: This species ranges from lowest Morrowan (base of noduliferus-primus Zone) to lower Desmoinesian series of North America (Krumhardt et al., 1996), from Bashkirian to Early Moscovian of Russian Platform and Urals and in Namurian of Western Europe (Sobolev and Nakrem, 1996).

Stratigraphic Distribution: *Declinognathodus noduliferus* occurs in the HB section in the Hadim region within the *Declinognathodus ineaqualis* – *Declinognathodus noduliferus* Zone. The elements have been reported from the samples HB 24 and HB 04.

Genus *GNATHODUS* Pander, 1856

Type species: *Gnathodus bilineatus* (Roundy, 1926)

Diagnosis: P1 element is scaphate. Long blade attaches to the platform in median position and extends to the posterior end as nodular carina. Posterior end of the platform is pointed. Platform contains two parapets with ridged or nodular ornamentations and the length of the parapets varies. Outer flanking of the platform is smooth, or ornamented with nodes. Ornamentation on the upper surface of the platform differs greatly among species. Basal cavity is deep, wide and asymmetrical.

Remarks: Taxonomic studies of *Gnathodus* have been entirely based on P1 elements. The important characteristic features used in the determination of the species are nature and ornamentations of parapets, platform outline and degree of lateral expansion of the posterior tip of the carina (Lane et al. 1980). Species in *Gnathodus* are differentiated primarily on shape and ornamentation of the platform (Pierce and Langenheim, 1974). *Gnathodus* is distinguished from *Protognathodus* and *Lochriea* by the presence of parapets (Nemyrovska, 1999). It differs from its descendant *Neognathodus* by the relative height of parapets and carina. The parapets are of greater height in *Neognathodus* but carina is higher in *Gnathodus* (Nemyrovska, 1999).

***Gnathodus cuneiformis* Mehl and Thomas, 1947**
Pl. 3, figs. 1-2

1947 *Gnathodus cuneiformis* n. sp. - Mehl & Thomas, p. 10, pl. 1, Fig. 2.

1974 *Gnathodus cuneiformis* - Pierce & Langenheim, p.159, 160, pl.1 fig.15, pl.2, figs. 2, 3, 7, 17.

1980 *Gnathodus cuneiformis* – Lane et al., p. 130, pl. 4, figs. 5-13; pl. 10, Fig. 7.

1991 *Gnathodus cuneiformis* - Stone, p.21, pl.2 figs. 1,2.
1994 *Gnathodus cuneiformis* - Belka & Korn, pl. 1, figs. 11–14; pl. 2, Figs. 1, 2.
1998. *Gnathodus cuneiformis* - Perri & Spalletta, pl. 1, figs. 3, 4; pl. 3, figs. 1, 2.
2008 *Gnathodus cuneiformis* - Habibi et al., p.772, fig.4.1.

Diagnosis: P1 element includes an asymmetrical platform with relatively wider outer and narrower inner side. Inner platform starts anterior to outer platform. Parapets are developed on both sides of the platform. Inner parapet is strongly formed and consists of seven to nine fused denticles. Outer parapet is shorter than the inner one and consists of four to five nodes. Blade is laterally compressed and fairly tall. Denticulated carina decreases in size towards the posterior tip. Basal cavity is large and deep.

Remarks: The characteristic feature of this species is the height of the outer margin and carina forming a depression on each side of the carina. *Gnathodus cuneiformis, Gnathodus typicus* and *Gnathodus antetexanus* probably belong to the same lineage, and are similar to each other by the addition of a second row of nodes along the platform (Lane et al., 1980).

Range: This species ranges from the highest part of the *isosticha* - Upper *crenulata* Zone to the *anchoralis* - *latus* Zone (Lane et al., 1980). *Gnathodus cuneiformis* have been recovered from Early Osagian rocks of Missouri (Thompson and Fellows, 1970).

Stratigraphic Distribution: *Gnathodus cuneiformis* occurs within the section in Hadim, Bademli and Sarız regions. The elements have been described from the samples AAO 6 in Hadim within the *Polygnathus mehli mehli* Zone, BSEc 7 in Bademli within the *Gnathodus girtyi girtyi*

Zone and AS 5, AS 6, AS 7 in Sarız in the *Gnathodus cuneiformis - Polygnathus communis communis* Zone.

***Gnathodus girtyi* Hass, 1953**

***Gnathodus girtyi girtyi* Hass, 1953**

Pl. 3, figs. 3-6

1953 *Gnathodus girtyi* - Hass, p. 80, pl. 14, figs. 22-24.

1956 *Gnathodus girtyi* - Elias, p.118, pl.III, figs.30,31.

1957 *Gnathodus girtyi* - Bischoff, p.24, 25, pl.4, figs.17, 22, 23.

1960 *Gnathodus clavatus* - Clarke, p.25, pl.4, figs. 4-8.

1969 *Gnathodus girtyi girtyi*. - Rhodes et al., p. 98, 99, pl. 17, figs. 9, 10.

1969 *Gnathodus girtyi simplex*. - Webster, p. 32, pl. 5, fig. 10.

1970 *Gnathodus girtyi*. - Reynolds, p. 10, pl. 1, figs. 10-12.

1972 *Gnathodus girtyi*. - Austin, pl. 2, figs. 11, 15.

1973 *Gnathodus girtyi*. - Austin & Aldridge, pl. 1, figs. 4 -6; pl. 2, figs. 2, 13, 14, 15.

1974 *Gnathodus girtyi*. - Matthews & Thomas, pl. 51, figs. 16, 17, 28-31.

1974 *Gnathodus* sp. - Matthews & Thomas, pl. 51, figs. 8, 9.

1974 *Gnathodus girtyi girtyi*.- Pierce & Langenheim, pl. 1, figs. 15, 16.

1975 *Gnathodus girtyi girtyi*. - Higgins, p. 31, pl. 10, figs. 5, 6.

1980 *Gnathodus girtyi simplex* - Metcalfe, p. 304, pl. 38, fig. 1.

1980 *Gnathodus girtyi girtyi*.- Tynan, p. 1302, pl. 1, figs. 16-18.

1981 *Gnathodus girtyi*. - Metcalfe, p. 23, 25, pl. 4, figs. 2,4, 5,7.

1985 *Gnathodus girtyi girtyi*. - Higgins, p. 220, pl. 6.2, fig. 2.

1985 *Gnathodus girtyi girtyi* - Wardlaw, pl. 1, fig. 12.

1987 *Gnathodus girtyi*. - Armstrong & Purnell, pl. 2, figs. 12, 13.

1987 *Gnathodus girtyi*. - Grayson et al., pl. 7, fig. 29.

1988 *Gnathodus girtyi girtyi*. - Dong & Ji, pl. 5, fig. 14.

1988 *Gnathodus girtyi simplex*.- Dong & Ji, pl. 6, fig. 4.

1991 *Gnathodus girtyi collinsoni*. - Higgins et al., pl. 3, fig. 2.

1991 *Gnathodus girtyi girtyi*. - Higgins et al., pl. 3, figs. 3-5.

1991 *Gnathodus girtyi girtyi*. - Morrow & Webster, pl. 3, fig. 9.

1992 *Gnathodus girtyi girtyi*. - Morrow & Webster, pl. 1, fig. 3.

1996 *Gnathodus girtyi girtyi* - Krumhardt et al., p.40,41, pl.2, fig.20-22.

2005 *Gnathodus girtyi girtyi* - Nemyrovska, p.36,37, pl.7, fig.15.

Diagnosis: P1 element is carminiscaphate with lanceolate platform including two parapets. Anterior inner parapet is very well developed and transversely ridged that continues to or close to the posterior tip of the platform. The anterior part of the inner parapet is as high as or higher than the carina. The outer parapet begins posterior to inner parapet and terminates slightly anterior of the inner parapet. The height of the outer parapet is lower than the carina. The carina is central, straight and continues to the posterior tip of the platform

Remarks: *Gnathodus girtyi girtyi* is characterized by the prominent carina that continues to the posterior end of the element or extends a little beyond the platform posteriorly, and two high, well-developed marginal parapets. Some researchers (Webster, 1969; Metcalfe, 1981; Dong and Ji, 1988) named this species as *Gnathodus girtyi simplex ,* but due to the presence of more nodes on the outer platform, they should be named as *Gnathodus girtyi girtyi.* The species differs from *Gnathodus girtyi meischneri* by the form and height of outer parapet, which is much better developed in the former.

Range: The range of this subspecies is Upper Visean - lowermost Serpukhovian in Europe and Upper Mississippian in North America (Nemyrovska, 1999).

Stratigraphic Distribution: *Gnathodus girtyi girtyi* occurs in BSEc measured section in the Bademli region. The elements have been reported from the samples BSEc 2 and BSEc 7 within the *Gnathodus girtyi girtyi* Zone.

Gnathodus girtyi simplex **Dunn, 1965**
Pl. 3, figs. 7-9

1965 *Gnathodus girtyi simplex* - Dunn, p. 1148, pl. 140, figs. 2, 3, 12.
1974 *Gnathodus girtyi simplex*.- Pierce & Langenheim, pl. 1, figs. 17, 18.
1975 *Gnathodus girtyi collinsoni* - Higgins, p. 30, 31, pl. 10, figs. 1, 2.
1975 *Gnathodus girtyi simplex* - Higgins, p. 33, pl. 9, figs. 6,7, 11.
1980 *Gnathodus girtyi collinsoni* - Tynan, p. 1301, pl. 1, figs. 10, 11.
1980 *Gnathodus girtyi simplex* - Tynan, p. 1303, pl. 1, figs. 5-7.
1984 *Gnathodus girtyi collinsoni* - Qiu, pl. 2, figs. 17-19.
1984 *Gnathodus girtyi simplex* - Qiu, pl. 2, figs. 15, 16.
1986 *Gnathodus girtyi simplex* - Ji, pl. 1, figs. 15-17.
1988 *Gnathodus girtyi simplex* - Dong & Ji, pl. 5, figs. 1-3.
1991 *Gnathodus girtyi simplex* - Higgins et al., pl. 3, figs. 6, 12.
1991 *Gnathodus girtyi simplex*. - Morrow & Webster, pl. 3, fig. 8.
1992 *Gnathodus girtyi simplex* - Morrow & Webster, pl. 1, fig. 4.
1993 *Gnathodus girtyi simplex* - Dumoulin & Harris, fig. 8C.
1996 *Gnathodus girtyi simplex* - Krumhardt et al., p. 41,42, pl.2, figs.25-27.

Diagnosis: P1 element is carminiscaphate with platform including two parapets. The inner platform parapet is well developed and extends to the posterior of the platform as a row of nodes fused to the carina. The outer platform margin is ornamented by one or two nodes. A thin denticulated blade joins platform at a medial position and continues as a nodose carina to posterior tip of the platform. Carina is sinuous, and bends toward the outer platform margin before merging with the nodes of the inner platform margin. Basal cavity is asymmetrical and broad.

Remarks: Our samples differ from *Gnathodus girtyi girtyi* by having an outer parapet consisting of one or two nodes that are restricted to the anterior half of the platform.

Range: The range of this subspecies is Chesterian in *noduliferus-primus* Zone (Krumhardt et al. 1996).

Stratigraphic Distribution: *Gnathodus girtyi simplex* occurs in BSEc and HB measured sections in Bademli and Hadim regions. The elements have been reported from the samples BSEc 7 and BSEc 8 within the *Gnathodus girtyi simplex* Zone in Bademli and HB 33, HB 28 witihin the *Rhachistognathus muricatus* Zone in Hadim.

Genus *RHACHISTOGNATHUS* Dunn, 1966

Type species: *Rhachistognathus* prima Dunn, 1966

Diagnosis: P1 element is scaphate with long, lanceolate platform. The upper surface of the platform is ornamented by nodes and fused nodes that may form discontinuous ridges. The anterior blade is attached to the platform in a median position, or very close to it. Nodose carina may be developed only at the posterior end of the element. A median narrow trough is present on the anterior part of the platform. The basal cavity is large, slightly asymmetrical.

Remarks: *Rhachistognathus* is similar to *Bispathodus* but differs from the latter by structure of the basal cavity, the shape and ornamentation of the platform. It differs from *Cavusgnathus*, *Adetognathus* and *Idiognathoides* by a median position of its blade-carina junction and by the ornamentation of the platform, as well (Nemyrovska 1999).

Rhachistognathus minutus **(Higgins & Bouckaert, 1968)**

Rhachistognathus minutus declinatus **Baesemann & Lane, 1985**

Pl. 4, figs. 7-9

1985 *Rhachistognathus minutus declinatus* - Baesemann & Lane, p. 108, 109, pl. 1, figs. 1-10.
1987 *Rhachistognathus minutus declinatus* - Nemirovskaya, pl.1, figs. 1,4.
1987 *Rhachistognathus minutus declinatus* - Riley et al., pl.3, figs. 1. 11.
1991 *Rhachistognathus minutus declinatus* - Nemirovskaya et al., pl.4, figs. 1-2.
1991 *Rhachistognathus minutus declinatus* - Varker et al., pl.1, figs. 30, 31.
1996 *Rhachistognathus minutus declinatus* - Krumhardt et al., p.7, pl.4, figs.1-9.

Diagnosis: P1 element includes lanceolate, symmetrical and pointed posteriorly platform. Blade meets platform almost in a median position, closer to its outer side, and extends a very short distance. Anteriormost part of the outer parapet is strongly declined outward away from the blade. Deep medial trough is present between the nodes or ridges. The posterior end can bear several nodes behind the median trough.

Remarks: The subspecies differs from the other subspecies of *Rhachistognathus minutus* by more median position of its blade-platform junction and by a considerable declination of the anteriormost part of the outer parapet outwards away from the blade (Nemyrovska,

1999). It differs from *Rhachistognathus minutus havlenai* in that the anterior margin of the parapet is straight in the latter, but it curves strongly outward in the former.
Range: This species ranges from Uppermost Mississippian (Chesterian) to Lower Pennsylvanian (Morrowan) in North America (Krumhardt et al. 1996), from the lowermost Chokierian lower Atokan in England (Varker et al., 1991), and Uppermost Zapaltyubinsky to lowermost Bashkirian in the Donets Basin (Nemyrovska, 1999).

Stratigraphic Distribution: *Rhachistognathus minutus declinatus* occurs commonly in the HB measured section in the Hadim region. The elements have been identified from the samples HB 28 and HB 24. In our samples this species appeares in *Rhachistognathus muricatus* Zone of the measured section and continues towards to the *Declinognathus ineaqualis - Declinognathus noduliferus* Zone.

***Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968)**

Pl. 4, figs. 1-6

1969 *Streptognathodus lanceolatus* - Webster, p. 47, 48, pl. 6, fig. 15.
1985 *Rhachistognathus minutus minutus* - Baesemann and Lane, p. 111, 112, pl. 2, figs. 7, 10, 11; pl. 3, figs. 1-12.
1985 *Rhachistognathus minutus* - Higgins, p. 220, pl. 6.2, figs. 3-9.
1985 *Rhachistognathus minutus* n. subsp. C - Skipp et al., pl. 8, fig. 5.
1987 *Rhachistognathus minutus minutus* - Riley et al., pl. 3, figs. 1-7.
1991 *Rhachistognathus minutus minutus* - Varker et al., pl. 1, figs. 16, 17, 20-22,25.
1996 *Rhachistognathus minutus minutus* - Krumhardt et al., p. 48, pl.4, figs. 13-15.

Diagnosis: P1 element consists of lanceolate, sligthtly asymmetrical to symmetrical platform with two parapets. Parapets are usually noded but occasionally transversally ridged. A deep medial trough seperates the parapets. Posterior end of the platform is pointed. Blade meets platform almost in a median position and is shorter than the platform.

Remarks: Baesemann and Lane (1985) recognized three subspecies of *Rhachistognathus minutus* - *Rhachistognathus minutus declinatus*, *Rhachistognathus minutus havlenai*, and *Rhachistognathus minutus minutus* - on the basis of the position of the blade junction and the degree of curvature of the anterior part of the platform margin (Krumhardt et al. 1996).

Range: The range of this species is lower Morrowan (base of *sinuatus-minutus* Zone) in North America, but below the Mid-Carboniferous boundary and within the lowermost Chokierian to lower Atokan in England (Varker et al., 1991).

Stratigraphic Distribution: *Rhachistognathus minutus minutus* occurs commonly in the HB measured section in the Hadim region. The elements have been recognized from the samples HB 28 and HB 24 within the *Rhachistognathus muricatus* and *Declinognathus ineaqualis* - *Declinognathus noduliferus* Zones.

***Rhachistognathus muricatus* (Dunn, 1965)**

Pl. 4, figs. 10-14

1965 *Cavusgnathus muricata* - Dunn, p. 1147, pl. 1409, figs. 4.
1966 *Cavusgnathus transitoria* - Dunn, p. 1299, pl. 157, fig. 9.
1968 *Idiognathoides minuta* - Higgins & Bouckaert, p.40, pl.6, figs.7-12.
1969 *Gnathodus muricatus* - Webster, p. 32, pl.5, figs, 2, 4-7,
1971 *Spathogfiathodus muricatus* - Lane et al., pl. 1, fig. 1.
1974 *Rhachistognathus muricatus* - Lane & Straka, p.97, 98, fig. 35. 16, 17, 24, 30, 31.
1985 *Rhachistognathus muricatus* - Skipp et al., pl.8, fig. 9.

1985 *Rhachistognathus muricatus* - Wardlaw, pl.1, fig. 9.

1987 *Rhachistognathus muricatus* - Grayson et al., pl.4, figs. 23, 30, 32, 38.

1987 *Rhachistognathus* aff. *muricatus* - Wang et al., p.131, 132, pl.7, figs. 5, 6.

1991 *Rhachistognathus muricatus* - Higgins et al., pl. 3, figs. 8, 13.

1991 *Rhachistognathus minutus havlenai* - Higgins et al., pl. 3, figs. 7, 11.

1991 *Rhachistognathus muricatus* - Morrow & Webster, pl. 4, figs. 1-5.

1992 *Rhachistognathus muricatus* - Morrow & Webster, pl. 1, fig. 6.

1993 *Rhachistognathus muricatus* - Lemos, p. 88, 90, pl. 4, figs. 3,4,5.

1996 *Rhachistognathus muricatus* - Krumhardt et al., p.48, pl.4, figs. 27-30.

1999 *Rhachistognathus muricatus* - Scomazzon, p.65, est. II, fig.3.

2008 *Rhachistognathus muricatus* - Nascimento, p. 80, fig.16. 23, fig.16. 24.

Diagnosis: P1 element is scaphate with long platform. The posterior end of the platform is pointed. Platform consists of two parapets. The outer parapet is slightly curved outward at the anterior half of the platform. The upper surface of the platform, parapets, is ornamented by nodes. The nodes on the outer parapet tend to fuse and form discontinuous ridges. A moderately deep narrow trough is present on the anterior part of the platform. The anterior blade is attached to the platform in a median position, or very close to it. The basal cavity is shallow and slightly asymmetrical.

Remarks: Baesemann and Lane (1985) differentiated *Rhachistognathus muricatus* based on the platform ornamentation, which includes two rows of nodes on the parapets. Krumhardt et al. (1996) stated that this species is intermediate form between *Rhachistognathus minutus* and *Rhachistognathus primus*. Higgins et al., (1985) named this species as

Rhachistognathus minutus havlenai but based on the parapets it should be named as *Rhachistognathus muricatus.* The presence of deep medial trough in the studied specimens distinguishes *Rhachistognathus muricatus* from the other species.

Range: The range of this species is from Upper Missippian to Lower Pennlyvanian (Krumhardt et al. 1996).

Stratigraphic Distribution: *Rhachistognathus muricatus* occurs commonly in HB measured section in the Hadim region. The elements have been recognized from the samples HB 33, HB 28 and HB 27.

Family POLYGNATHIDAE Bassler, 1925

Genus *BISPATHODUS* Müller, 1962

Type species: *Spathodus spinulicostatus* Branson, 1934.

Diagnosis: P element is defined by one or more accessory (clearly separated) or satellite (barely split) denticles on right side of the blade. Where the side denticles are clearly separated, they may occur as round peg-like nodes, transverly elongate ridge-like nodes, nodes connected to the main blade by ridges, or sharp transverse ridges. The basal cavity, which is expanded laterally beyond the vertical sides of the blade, is either centered approximately below the midpoint of the blade or extended from there to the posterior tip.

Remarks: Ziegler et al. (1974) divided informally the genus into two branches, bispathodus and aculeatus. The former branch has a relatively large basal cavity that extends or close to posterior tip. The latter branch is characterized by a relatively small basal cavity that does not extend to the posterior tip. Both branches display a more or less parallel development of accessory denticles.

Bispathodus stabilis **(Branson & Mehl, 1934)**

Pl. 3, figs. 10-12

1934 *Spathodus stabilis* n. sp. - Branson & Mehl, p.188, pl. 17, fig. 20.
1962 *Spathognathodus stabilis* - Ziegler, p.110, pl. 13, figs. 4, 5, 9, 10.
1974 *Bispathodus stabilis* – Ziegler et al., p. 103, pl. 3, figs. 1–3.
1983 *Bispathodus stabilis* - Huber, p.131-132, pl.1, fig.14.
1992 *Bispathodus stabilis* - Over, p.59, fig.6.1,16,21,26,28.
1997 *Bispathodus stabilis* - Mawson & Talent, p. 208, figs. 11.10-11.
1999 *Bispathodus stabilis* - Yazdi, pl. 6, figs. 18, 19.
2000 *Bispathodus stabilis* - Çapkınoğlu, p.99, pl.4, figs. 12-16.
2004 *Bispathodus stabilis* - Göncüoglu et al., pl. 1, figs. 1, 2.
2008 Bispathodus stabilis - Habibi et al., p.774, fig. 4.5.

Diagnosis: Carmininate P1 element is thin and nearly straight. It contains 10 to 18 erect denticles. Denticles become higher and larger on the anterior blade. This species does not have accessory denticles on the either side of the blade. Basal cavity slightly asymmetric, positioned under posterior half of blade.

Remarks: Ziegler et al. (1974) differentiated three morphotypes within this species, on the basis of the basal cavity. Morphotypes 1 and 2 of Ziegler et al. (1974) have been recovered in this study. Morphotype 1 is distinguished by a small, symmetrical basal cavity that does not extend to the end of the blade; Morphotype 2 is characterized by a wider, slightly asymmetrical basal cavity that extends to the tip of the blade. Both morphotype 1 (Plate III, Figures 10, 12) and morphotype 2 (Plate III, Figure 111) have been recorded in our studied samples. *Bispathodus stabilis* is distinguished from *Bispathodus utahensis* by being generally shorter and higher.

Range: Based on Ziegler (1974) and Ziegler and Sandberg (1984), *Bispathodus stabilis* Morphotype 1 ranges from the Upper *marginifera* Zone (Famennian - Late Devonian) to the *isosticha*–Upper *crenulata* Zone (Middle Tournaisian - Early Carboniferous) and *Bispathodus stabilis* Morphotype 2 ranges from the base of the Lower *expansa* Zone (Famennian - Late Devonian) through the *isosticha*-Upper *crenulata* Zone (Middle Tournaisian - Early Carboniferous). Ziegler (1980) extended the upper range of *Bispathodus stabilis* into the *texanus* Zone.

Stratigrafic Distribution: *Bispathodus stabilis* occurs commonly in AS measured section in the Sariz region. The elements have been recovered from the samples AS 2, AS 3, AS 5, AS 6 and AS 9 within the *Gnathodus cuneiformis - Polygnathus communis communis* Zone.

Bispathodus utahensis **Sandberg & Gutschick, 1984**
Pl. 3, figs. 13-15

1979 “*Spathognathodus*” n.sp. - Sandberg & Gutschick, p.130, fig. 16.
1980 “*Bispathodus stabilis*” - Lane et al., pl.10, fig.5.
1983 “*Bispathodus stabilis*” - Gutschick & Sandberg, fig.7-D.
1984 *Bispathodus utahensis* n.sp. - Sandberg & Gutschick p.150,152, pl.4, figs. 1-22.

Diagnosis: Carmininate P1 element is long and nearly straight. The element is relatively long and has more than 20 denticles on the P1 element. The blade is low to moderate high and has even sized denticles. Basal cavity is narrow asymmetric, positioned under posterior half of blade.

Remarks: *Bispathodus utahensis* differs from *Bispathodus stabilis*, by having extremely long blade and posterior process on the P1 element (Over, 1992). In our samples, this species was described based on long blade.

Range: This species ranges from Lower *typicus* Zone into Cavusgnathus Zone (Sandberg and Gutschick, 1984).

Stratigrafic Disrtibution: *Bispathodus utahensis* occurs commonly in AS measured section in the Sariz region. The elements have been recovered from the sample AS 5 witihn the *Gnathodus cuneiformis - Polygnathus communis communis* Zone.

Genus *POLYGNATHUS* Hinde, 1879

Type species: *Polygnathus dubius* Hinde, 1879

Polygnathus brevilaminus Thompson, 1967

Pl. 5, figs. 20-22

1934 *Polygnathus brevilamina* - Branson & Mehl, p. 246, pl. 21, figs. 3-6.
1989 *Polygnathus brevilaminus* - Metzger, p. 518, fig. 15.4.
2006 *Polygnathus brevilaminus* - Ashouri, p.51, pl. 8, figs. 15-24.
2008 *Polygnathus brevilaminus* - Sánchez de Posada et al., pl.1, fig.17.
2007 *Polygnathus brevilaminus* - Gholomalian, p.469, fig 10. J,K.
2010 *Polygnathus brevilaminus* - Kakhki & Hosseininezhad, pl.1, figs. 8-11,16.
2011 *Polygnathus brevilaminus* - Bahrami et al., pl. 1, figs.5-7.

Diagnosis: P1 element is characterized by narrow and flat platform. Platform is nearly asymmetrical. It is ornamented by marginally placed short transversal ridges. Carina is high and massive-looking but in some forms it is well denticulated at the posterior part of platform. It projects beyond the posterior end of the platform. Blade is long and almost straight.

Remarks: *Polygnathus brevilaminus* differs from the other *Polygnathus* species by the projection of carina beyond the posterior end of the platform.

Range: Narkiewicz & Narkiewicz (2008) reported the first appearance of *Polygnathus brevilaminus* in the Lower *rhenana* Zone in Upper Frasnian (Upper Devonian). Ashouri (2006) stated that the precise range of this species globally is uncertain. It has been reported mainly from the Late Devonian (Ashouri, 2006) but was reported by Wang & Yin (1988) recovered from the Lower Carboniferous (Kinderhookian).

Stratigrafic Distribution: *Polygnathus brevilaminus* occurs commonly in AS measured section the in Sariz region. The elements have been recovered from the sample AS 2, AS 4 and AS 7.

Polygnathus communis **Branson and Mehl, 1934**

Polygnathus communis communis **Branson and Mehl, 1934**

Pl. 6, figs.1-27

1934 *Polygnathus communis* - Branson & Mehl, p.293, pl.24, figs 1-4.
1964 *Polygnathus communis* - Rexroad & Scott, p. 34, pl. 2, figs 17, 18.
1968 *Polygnathus communis* - Canis, p.544, pl. 72, figs. 12, 14-17.
1969 *Polygnathus communis* - Rexroad, p. 33, 34, pl. 5, figs. 7-10.
1969. *Polygnathus communis communis* - Schönlaub, p.333, pl. 1, figs. 11–13.
1970 *Polygnathus communis* - Thompson & Fellows, p. 93.
1974 *Polygnathus communis communis* - Pierce & Langenhaim p.164, 165, pl. 2, figs. 11,12; pl.3, figs 7,9,13,14,17; pl.4, figs 8,12.
1979 *Polygnathus communis communis* - Nicoll & Druce, p.29, pl.15, fig.1.

1979. *Polygnathus communis communis* - Sandberg & Ziegler, p.188, pl.2, figs 1-9.

1981 *Polygnathus communis* - Norris, p.1280, pl.1, figs. 1, 2; pl.2, figs. 11, 12.

1981 *Polygnathus communis communis* - Metcalfe, pl. 9, figs. a,b.

1982 *Polygnathus communis* - Wang & Ziegler, pl. 1, figs. 2, 3.

1985 *Polygnathus communis* - Hayes, pl. 2, figs. 9-11.

1985 *Polygnathus communis communis* - Higgins, pl. 5.1, figs.12,16,17.

1991 *Neopolygnathus communis* - Barskov et al., p. 115, pl. 31, figs. 6–9.

1991 *Polygnathus communis communis* - Johnston & Chatterton, p. 171, pl. 2, figs. 11,12.

1993 *Polygnathus communis communis* - Ji & Ziegler, p. 76, pl. 35.

1993 *Polygnathus communis communis* - Wang, p. 231, pl. 40, fig 13; pl.41, figs 11,12.

1997 *Polygnathus communis communis* - Mawson & Talent, p. 212, figs.10.9-11, 11. 7

1997 *Polygnathus communis communis* - Molloy et al. pl. 8, figs. 4-5.

1999 *Polygnathus communis communis* - Yazdi, pl. 7, figs. 7–13, 15.

2006 *Polygnathus communis communis* - Ashouri, p.55, pl.8, figs. 1-14

2007 *Polygnathus communis communis* - Boncheva et al., p. 342, pl.5 figs.1-4

2008 *Polygnathus communis communis* - Habibi et al., p. 772-773, fig. 5 (4,6).

2009 *Polygnathus communis* group - Gholamalian et al., pl. 3, figs. 6-10

Diagnosis: Platform, ovate to lanceolate, is unornamented or weakly ornamented with upturned or thickened platform edge. Straight or slightly incurved carina bears three to five medial nodes. Narrow troughs on each side of platform are parallel to the carina. The upper surface exhibits a polygonal micro-ornamentation along the upturned rims of platform. Free blade, having a variable number of fused denticles, is about same length as platform. The basal cavity placed at the intersection of the platform and free blade is subcircular, elliptical and is as wide as platform. Thin, narrow keel extends from basal pit to posterior tip of blade. The entire basal area is bisected by a furrow extending through the length of the conodont.

Remarks: Rexroad and Scott (1964) reported that *Polygnathus communis* is the most common and longest ranging species of *Polygnathus*. A number of subspecies have been determined based on the platform ornamentation. Only *Polygnathus communis communis* has been recovered in this study. The unornamented, smooth platform of this subspecies distinguishes it from other subspecies of *Polygnathus communis*.

Range: This subspecies occurs from Late Devonian (Famennian) through middle Osagean (Early Mississippian) in North America. Sandberg and Ziegler (1979) indicated the range of this subspecies as from within the Devonian *Palmatolepis crepida* Biozones into the Mississipplan *Doliognathus latus* Biozone; however, Lane et al. (1980) reported the range extending into the *Gnathodus texanus* Biozone.

Stratigrafic Distribution: *Polygnathus communis communis* is the most common and the best-preserved taxa within the studied conodont elements. This have been recovered from the samples AS 3, AS 4, AS 5, AS 6, AS 7 and AS 8 within the AS section in the Sariz Region through the *Polygnathus inornatus* and *Gnathodus cuneiformis - Polygnathus communis communis* Zones and samples AAO 2, AAO 6 and AAO 8 from the AAO samples in Hadim Region within the *Polygnathus mehli mehli* Zone.

Polygnathus inornatus **Branson, 1934**

Pl. 5, figs. 1-8

1934 *Polygnathus inornata* - Branson, p.309, pl. 25, figs. 8, 26.

1939 *Polygnathus inornata* - Cooper, p.400, pl.39, figs. 11,12.

1941 *Polygnathus inornata* – Branson & Mehl, pl. 32, figs.15, 51,52, pl. 39, fig.37.

1949 *Polygnathus sagittaria* - Youngquist & Patterson, p. 66, pl. 15, figs. 9,10.

1957 *Polygnathus inornata* – Cloud et al., pl. 5, fig. 6.

1957 *Polygnathus inornata* - Ziegler, p.46, Pl. 2, fig. 7.

1958 *Polygnathus inornata* - Klapper, p.1089, Pl. 142, figs. 2, 3.

1959 *Polygnathus inornata* - Hass, pl.49, fig. 22.

1959 *Polygnathus inornata* - Voges, p. 291, pl. 34, figs. 12-20.

1964 *Polygnathus lobata* - Rexroad & Scott, p. 35, 36, pl. 2, figs. 15, 16.

1966 *Polygnathus inornata* - Klapper, p. 19, 20, pl. 1, figs. 9, 10, 13, 14.

1968 *Polygnathus inornata* - Canis, p. 544, pl. 72, fig. 25.

1969 *Polygnathus lobatus lobatus* – Rhodes et al., p. 191-192; Pl. 9, Figs. 5–8.

1969 *Polygnathus inornatus inornatus* - Rhodes et al., p. 186, pl. 10, fig. 4-6.

1969 *Polygnathus inornatus inornatus* - Druce, p. 98, pl. 20, fig. 1-3.

1971 *Polygnathus inornatus* sensu - Klapper, Pl. 1, fig. 11, 12.

1981 *Polygnathus* cf. *inornatus* - Boogaard & Schermerhorn, p.9, pl.2 FigA.

1982 *Polygnathus inornatus*, - Wang & Ziegler, pl. 1, fig. 21.

1985 *Polygnathus inornatus* - Hayes, pl. 1, figs. 1, 2.

1989 *Polygnathus inornatus* - Metzger, p.520, fig. 15.24.

1997 *Polygnathus* cf. *inornatus* - Mawson & Talent, p. 216, figs. 10.7-8, 11.5-6.

1998 *Polygnathus inornatus* - Mawson & Talent, pl. 5, figs. 1, 2, 7, 8, 11, 14; Pl. 6, Figs. 6, 7, 9; Pl. 7, Figs. 1, 2.

1999 *Polygnathus inornatus* - Yazdi, pl. 8, figs. 1–5.

2008 *Polygnathus inornatus inornatus* - Habibi et al., p.773, fig. 5.10-13.

Diagnosis: Platform is slightly asymmetrical and lanceolate. The platform is ornamented by transversal ridges. Lateral margins of the anterior part of the platform are strongly upturned, above the level of carina. One anterior margin is generally higher than the other so two-adcarinal troughs are developed in the anterior half of the platform. Posterior end may be attenuate and sharply pointed. The blade is short and high. The carina is nearly straight to incurved. The basal cavity is relatively large and circular to ovate. Growth lines are observed in the aboral side of the platform.

Remarks: *Polygnathus inornatus* in the studied samples is distinguished by the strong upturning of the lateral margins above the level of the carina. Some authors (Rexroad, 1969; Rhodes et al. 1969; Thompson and Fellows, 1970) recognized subspecies of *Polygnathus inornatus*. Klapper (1975) included all forms with subspecific determinations as variations of *Polygnathus inornatus*. Klapper (1975) and Branson (1934) determined that the elements of this species exhibited a wide range of morphologic variation. The bilateral symmetry of this form differentiates it from *Polygnathus lobatus*. *Polygnathus inornatus* differs from *Polygnathus longiposticus* by having small basal cavity. The edges of the platform of this species are more steeply inclined than the nearly flat *Polygnathus longiposticus.* This inclination of the platform edges can also be criteria to distinguish *Polygnathus inornatus inornatus* from *Polygnathus lobatus*.

Range: *Polygnathus inornatus* occurs in the Lower Carboniferous (Klapper, 1975) and is abundant in rocks of Kinderhookian age (Klapper, 1966). The species has, however, been reported in Late Devonian strata of Germany, as well (Bischoff & Ziegler, 1956). Barskov et al. (1991) defined the range of this species from the Lower *expansa* Zone to the *anchoralis latus* Zone.

Stratigrafic Distribution: *Polygnathus inornatus* occurs commonly in AS measured section in the Sariz region. The elements have been recovered from the samples AS 2, AS 3, AS 5, AS 6 and AS 7 within the *Polygnathus inornatus* and *Gnathodus cuneiformis - Polygnathus communis communis* Zones.

Polygnathus longiposticus **Branson and Mehl, 1934**

Pl. 5, figs. 12-19

1934 *Polygnathus longipostica* - Branson & Mehl, p. 294, pl. 24, figs. 8-11.

1934 *Polygnathus longipostica* - Branson, p. 311, pl.25, fig.18.

1939 *Polygnathus macra* - Cooper, p.401, pl.140, figs. 7, 8,15,16.

1939 *Polygnathus toxophora* - Cooper, p.404, pl.39, figs. 67, 70.

1949 *Polygnathus adunca* - Youngquist & Patterson, p.60-61, pl.16, figs.18, 19.

1949 *Polygnathus cymbilormis* - Youngquist & Patterson, p.62, pl. 17, figs. 14, 15.

1949 *Polygnathus inopinata* - Youngquist & Patterson, p.64, pl. 16, figs. 20, 21.

1949 *Polygnathus longipostica* - Youngquist & Patterson, p.65, pl.15, figs. 16-20.

1949 *Polygnathus longipostica* - Thomas, Pl. 3, fig. 38;

1956 *Polygnathus longipostica* - Bischoff, p.133, pl.9, fig. 22.

1956 *Polygnathus longipostica* - Hass, pl.2, fig.28.

1964 *Polygnathus longipostica* - Rexroad & Scott, p.36-37, pl. 2,fig.26.

1966 *Polygnathus longipostica* - Klapper, p. 20-21, figs. 1,5.

1968 *Polygnathus longipostica* - Canis, p. 545, pl. 72, fig. 26.

1969 *Polygnathus longiposticus* - Rexroad, p. 35, 36, pl. 5, figs. 11, 12.

1970 *Polygnathus longiposticus* - Thompson & Fellows, p.95, 96, pl. 4, figs. 4, 16, 19.

1975 *Polygnathus longiposticus* - Klapper, p. 303-306, pl. 6, fig.1.
1984 *Polygnathus longiposticus* - Wang & Yin, pl. 2, fig. 8.
1987 *Polygnathus longiposticus* - Webster et al., pl. 1, figs. 14, 15.
1999 *Polygnathus longiposticus* - Yazdi, pl. 8, fig. 18.
2008 *Polygnathus longiposticus* - Habibi et al., p.773, fig.5.7

Diagnosis: Platform, bilaterally symmetrical, is lanceolate, elongate and narrow. The median line is straight to slightly sinuous. Anterolateral margins of platform upturned to about level of carina. Platform is ornamented by transversal ridges normal to carina. Carina is made up of numerous fused nodes. Free blade is high and composed of broad denticles. Basal cavity is circular or ovate and relatively large. Aboral keel is narrow, sharp, and reduced in height posteriorly.

Remarks: In our samples, P1 elements of *Polygnathus longiposticus* have been recorded. They have been differenatiated from the other species by its platform shape. This species is similar to *Polygnathus inornata* Branson & Mehl (1934) and Canis (1968) indicated that *Polygnathus longiposticus* was characterized by less upfolding of the anterolateral margins of the plate than *Polygnathus inornatus* and often has a prominent denticle near the posterior end of the carina. Klapper (1975) noted that *Polygnathus longiposticus* and *Polygnathus symmetricus* are morphologically very similar and should be synonymized. The separation of *Polygnathus longiposticus* and *Polygnathus symmetricus* is based on the attenuation of the blade, presence of a prominent posterior node, and the posterior extension of the carina in *Polygnathus longiposticus* (Klapper, 1966; Anderson, 1969; Huber, 1983). *Polygnathus cymbilormis* and *Polygnathus inopinata* described by Youngquist and Patterson (1949) were defined as synonmy of this species regarding the degree of upturning of the anterolateral margins of the platform (Klapper, 1966).

Range: According to Rexroad & Scott (1964) and Klapper (1975) the species is restricted to the Early Carboniferous, Kinderhookian Series. It may range into Osagean strata (Lane et al. 1980). Lane et al. (1980) reported the range of *Polygnathus longiposticus* as from the *Siphonodella sulcata* Biozone into the Lower *Gnathodus typicus* Biozone. Shugang and Coen (2005) indicated that the first appearance of this species is very important for stratigraphic division in South China and they reported that the species appeared firstly at the bottom of the *anchoralis-pseudosemiglaber* zone, and disappeared in the upper of the *praebilineatus* zone.

Stratigrafic Distribution: *Polygnathus longiposticus* occurs commonly in AS measured section in the Sariz region. The elements have been recovered from the samples AS 3, AS 5 and AS 6 within the *Polygnathus inornatus* and *Gnathodus cuneiformis - Polygnathus communis communis* Zones.

Polygnathus mehli **Thompson, 1967**

Polygnathus mehli mehli **Thompson, 1967**
Pl. 5, figs. 10-11

1967 *Polygnathus mehli* - Thompson, p. 47, pl. 2, figs. 1-6.
1971 *Polygnathus lacinatus* - Higgins, pl. 1, figs. 6,8.
1975 *Polygnathus mehli* - Klapper, pl. 6, fig. 4.
1976 *Polygnathus lacinatus* - Austin, pl. 1, figs. 28, 29, 31, 32.
1979 *Polygnathus* aff. P. *lacinatus* sensu - Nicoll & Druce, pl. 16, fig. 10.
1981 "*Polygnathus*" *mehli* - Chauffe, pl. 2, figs. 9, 10, 22-25, 35, 36.
1984 *Polygnathus mehli* - Austin & Davies, pl.1, fig. 2; pl.2, fig. 33; pl.3, figs.10, 12.
1984 *Polygnathus lacinatus* - Austin & Davies, text-fig.1, pl.2, figs.1, 32.
1985 *Polygnathus mehli mehli* - Varker & Sevastopulo, pl.5.2, figs.11,

12, 15, 18.

1985 *Polygnathus mehli* - Belka, pl. 14, fig. 13.

1992 *Polygnathus mehli* - Purnell, p. 34, pl.6 figs. 2,4.

1992 *Polygnathus bischoffi* - Purnell, pl.6, figs. 1,3.

Diagnosis: Platform is narrow and elongate with ornamentation of distinct transversal ridges. The transversal ridges on the platform ranges from faint in some specimens to strong and distinct on others. This subspecies has quite a varied platform shape including almost symmetrical and asymmetrical varieties. Small and shallow adcarinal troughs are developed in the anterior part of the platform. Posterior end may be pointed or rounded. The blade is short and high. The carina is nearly straight to incurved. The basal cavity is elongate with a broad raised keel. Growth lines, defined as recessive basal margin, can be observed in the aboral side of the platform.

Remarks: *Polygnathus mehli mehli* can be distinguished from *Polygnathus mehli lautus* in having fainter ribs, a narrower basal cavity, and a narrower platform (Johnston and Higgins, 1981). In our samples, the long basal cavity, high broad keel, and transverse ridges on the platform distinguish *Polygnathus mehli mehli* from *Polygnathus communis communis*. *Polygnathus mehli mehli* closely resembles *Polygnathus denticulatus* in platform ornamentation but the basal cavity is more elongate in *Polygnathus mehli mehli*. It is also morphologically very similar to *Polygnathus spicatus* but it differs by its wider platform.

Range: Pierce and Langenheim (1974) reported *Polygnathus mehli mehli* in the *Bactrognathus distorta - Gnathodus cuneiformis* Zone of Missouri.

Stratigrafic Distribution: *Polygnathus mehli mehli* occurs commonly in the AAO section in the Hadim region. The elements have been recovered from the samples AAO 2, AAO 5, AAO 6 and AAO 8 in the HB section within the *Polygnathus mehli mehli* Zone.

Polygnathus symmetricus **Branson, 1934**
Pl. 5, fig. 23

1934 *Polygnathus symmetrica* - Branson, p. 310, pl.25, fig. 11.

1938 *Polygnathus symmetrica* - Branson & Mehl, p.146, pl.33, fig. 11; pl.34, fig. 33.

1939 *Polygnathus longipostica* - Cooper, p.401, pl. 39, figs. 31, 32.

1949 *Polygnathus longipostica* - Thomas, p. 436, pl.3, fig. 38.

1956 *Polygnathus inornata* - Bischofi & Ziegler, p.157, pl. 12, fig. 5.

1956 *Polygnathus longipostica* - Hass, p. 25, pl. 2, fig. 28.

1966 *Polygnathus symmetrica* - Klapper, p. 21, pl. 4, figs. 7, 9; pl. 6, figs. 1, 5.

1970 *Polygnathus symmetricus* - Thompson & Fellows, p. 97, pl.4, fig. 17, 18.

1975 *Polygnathus symmetricus* - Klapper, p. 325-326, pl. 6, fig. 7.

1992 *Polygnathus symmetricus* - Over, p.309, fig. 7.24, fig.7.26.

Diagnosis: P1 element is characterized by an elongate, narrow platform, which is about twice as long as wide. Platform is nearly bilaterally symmetrical. Platform is widest in posterior half and tapers posteriorly to a point. Anterolateral margins of platform slightly upturned. Carina terminating at posterior end of the platform is medium height, narrow and straight. Transversal ridges terminating in a shallow depression on either side of carina are developed on the platform edges. Blade is thin, long and includes about seven denticles. Basal cavity is usually deep and ovate with a small pit. A low median keel developed from the pit to near posterior end of the platform.

Remarks: *Polygnathus symmetricus* differs from *Polygnathus* *longiposticus* and *Polygnathus inornatus* in that the antero-lateral margins are not as strongly upturned on the former (Klapper 1966, Anderson, 1969, Huber, 1983). Also, the carina of *Polygnathus symmetricus* is nearly straight and does not project beyond the posterior end of the platform (Anderson 1969).

Range: Klapper (1975) reported that *Polygnathus symmetricus* is essentially a Kinderhookian element. Over (1992) stated that *Polygnathus symmetricus* is common in the Lower *praesulcata* Zone and Lower Carboniferous strata, from late Famennian to Kinderhookian. This species is distinguished in our samples by its asymmetrical platform shape.

Stratigrafic Distribution: *Polygnathus symmetricus* occurs commonly in AS measured section in the Sariz region. The elements have been recovered from the samples AS 3, AS 5, AS 6 and AS 7 within the *Polygnathus inornatus* and *Gnathodus cuneiformis - Polygnathus communis communis* Zones.

Suborder PRINIODININA Sweet, 1988

Family PRINIODINIDAE Bassler, 1925

Genus *KLADOGNATHUS* Rexroad, 1958

Type species: *Cladognathus prima* Rexroad, 1957

Diagnosis: Apparatus is seximembrate. P elements are bipennate with short posterior process and short, posteriorly directed, outwardly flexed anterolateral process. P elements are differentiated into morphologically distinct anterior (P2) and posterior (P1) pairs and both pairs bear discrete, robust denticles. M elements are dolabrate with large cusp and well-developed edentate anticusp. Sa elements are alate with short lateral processes. Sb elements are bipennate with short, posteriorly directed lateral process. Sc elements are bipennate with short anterior process which may bifurcate. S elements have long, delicate posterior processes. Lateral and anterior processes bear elongate, discrete denticles with round cross section. All elements, except Sa, symmetrically paired.

Remarks: The apparatus of *Kladognathus* is well known owing to statistical studies by Horowitz & Rexroad (1982) and analysis of natural assemblages by Purnell (1993a). The elements of *Kladognathus* display a well developed intercalary denticulation (Dzik, 1997).

Kladognathus **sp.**

Pl. 7, figs. 1-12

Diagnosis: S1 element is a ramiform bipennate element with a broken posterior process that bears two small rounded denticles and a lateral process that curves inwards and downwards. A wide large rounded cusp is present between the processes which is slightly curved to the posterior part. The basal cavity is semi-circular and is situated beneath the cusp. S2 element is a ramiform bipennate element that has a broken posterior process and a short inner and downflexed anterolateral process. The anterolateral process has discrete rounded and delicate denticles that are straight or curve to the outer part of the element and posteriorly. The cusp is markedly wider and larger than the denticles and curves posteriorly. The semi-circular basal cavity is situated immediately beneath the cusp.

Remarks: The element notation for *Kladognathus* sp. follows that of Purnell (1993a) and Purnell et al. (2000). Purnell (1993a) reconstructed Kladognathus based on a bedding-plane assemblage. Only S3 and S4 elements have recovered within the studied sections.

Stratigrafic Distribution: *Kladognathus* sp. appears commonly in AS, AAO, BSE and HB sections in Taurides. The elements have been recovered from the samples AS 5, AS 6, AS 8 within within the *Gnathodus cuneiformis - Polygnathus communis communis* Zone; samples AAO 2, AAO 4, AAO 6, AAO 8 in the *Polygnathus mehli mehli* Zone; sample BSEc 7 at the base of *Gnathodus girtyi simplex* Zone and samples HB 33, HB 28, HB 27 and HB 24 within the *Rhachistognathus muricatus* and *Declinognathdus ineaqualis - Declinognathus noduliferus* Zones.

CHAPTER 8

DISCUSSIONS AND CONCLUSIONS

In order to define the Lower Carboniferous stage boundaries in Turkey, several stratigraphic sections covering the best preserved Lower Carboniferous boundary successions have been studied in four different localities of the Central (Hadim and Bademli) and Eastern (Melikgazi and Sarız) Taurides. This study focused on the Lower Carboniferous deposits of the Aladağ and the Geyik Dağı Units including a continuous Paleozoic carbonate sequences. A high-resolution conodont biostratigraphy following the detailed taxonomical analysis, microfacies, morphometric and geochemical studies have been completed on the Lower Carboniferous carbonates in Taurides, Turkey.

Conodonts are, undoubtedly, important biostratigraphic tools for the Paleozoic and Triassic deposits and primarily used in this study to delinate the Lower Carboniferous stage boundaries. Conodont elements recovered in the studied sections in Taurides occur in low abundance, however, the sections contain all important Lower Carboniferous boundary conodonts. Standard Carboniferous conodont zonations (Lane et al., 1980) could not be readily applied to the Tournaisian sections due to the absence of *Siphonodella* and other index species. However, the conodont zones in the studied sections compared to the standard zonation by the presence of *Gnathodus*, *Polygnathus* and *Bispathodus* species. Among the studied sections, conodont elements have been obtained from AAO, HB (Hadim) and

BSE (Bademli) sections in Central Taurides and AS (Sarız) section in Eastern Taurides. Based on the appearance of biostratigraphically significant species, the following zones were established across the Lower Carboniferous in Taurides; (1) *Polygnathus inornatus* Zone (Hastarian-Lower Tournaisian); (2) *Gnathodus cuneiformis – Polygnathus communis communis* Zone (Ivorian-Upper Tournaisian); (3) *Polygnathus mehli mehli* Zone (Ivorian-Upper Tournaisian); (4) *Gnathodus girtyi girtyi* Zone (Brigantian-Upper Visean); (5) *Gnathodus girtyi simplex* Zone (Pendelian-Lower Serpukhovian); (6) *Rhachistognathus muricatus* Zone (Zapaltyubinsky-Upper Serpukhovian) and (7) *Declinognathodus inaequalis - Declinognathodus noduliferus* Zone (Bogdanovsky-Lower Bashkirian).

Recently, most of the studies focused on the delineation of stage boundaries in an international platform. The stage boundaries have been defined by mostly using the biostratigraphic framework. Internationally proposed or accepted stage boundaries for the Lower Carboniferous, Tournaisian-Visean, Visean-Serpukhovian and Serpukhovian-Bashkirian, are mainly defined by conodont and foraminifera taxa. The GSSP for the Tournaisian-Visean boundary is defined in the Pengchong section (South China) and this point corresponds to the first appearance of the *Eoparastaffella simplex*. The GSSP for the Mid-Carboniferous Boundary is described in Arrow Canyon (Nevada) by the first appearance of the conodont species *Declinognathodus noduliferus* s. l. However, studies about the GSSP for the Visean-Serpukhovian boundary are still under discussion and the conodont lineage *Lochriea nodosa – Lochriea ziegleri* has been proposed as the boundary marker event.

In Taurides, Visean – Serpukhovian and Mid-Carboniferous boundaries have been determined by using important conodont assemblages while conodonts could not be obtained from the Tournaisian – Visean boundary beds previously defined by foraminiferal biostratigraphy. Based on the recovered conodont assemblages, the Visean - Serpukhovian boundary in the Taurides from BSE section (Bademli) has been recognized by the first appearance of *Gnathodus girtyi simplex*. The Mid-Carboniferous boundary section (HB) in the Aladağ Unit of the Central Taurides, exhibits a biostratigraphically complete Upper Serpukhovian – Lower Bashkirian succession and includes an important assemblage of conodont taxa, *Rhachistognathus minutus minutus, Rhachistognathus minutus declinatus, Gnathodus girtyi simplex, Declinognathodus bernesgae, Adetognathodus lautus, Kladognathus* sp., *Declinognathodus inaequalis, Declinognathodus lateralis,* and *Declinognathodus noduliferus.* The Mid-Carboniferous boundary in the Central Taurides have been recognized by the first apperance of *Declinognathodus inaequalis*, while the other *Declinognathodus* taxa provide a biostratigraphic framework for the correlation of Mid-Carboniferous beds between different basins in the world.

Conodonts in Paleozoic deposits are generally environmentally controlled and there are different types of paleoecologic models in order to explain the distribution patterns of conodonts within depositional environments. Recent studies indicated that the distribution of conodonts was fundamentally controlled by the physical and chemical properties of the water. Moreover, it is reported that several conodont species have been restricted to the shallow-water environments and others to the deep water, and some apparently extended into both shallow and deep environments. Heckel (1972) reported that faunal diversity is less in shallow water areas since the shallow water is more subjective to changes in temperature, sedimentation rate, river discharge. However, the deep water environment is more stable and the diversity and abundance of the conodonts elements are relatively higher in these environments. The studied successions in the Central and Eastern Taurides were mainly deposited in a shallow marine environment during the Carboniferous time so they comprise less diversified conodont fauna and the conodonts elements are low in abundance.

AS section in Sarız and AAO section in Hadim particularly maintain uniform lithologies throughout the successions. The defined facies types in the AS section are shale, spiculite packstone, crinoidal bioclastic grainstone-packstone, ostracodal bioclastic grainstone and micritic sandstone. Moreover, crinoidal packstone-grainstone and peloidal packstone-grainstone facies have been described in AAO section (Hadim). In Bademli region BSE section including the Visean - Serpukhovian boundary is predominantly composed of uniform lithologies of sandstone and sandy limestones. The defined facies types in BSE section are crinoidal bioclastic packstone, bioclastic grainstone, sandy oolitic grainstone, quartz-peloidal grainstone and quartz arenitic sandstone facies. Eight different microfacies types have been described by Atakul-Özdemir et al. (2011) around the Mid-Carboniferous boundary section in the Hadim region. These are coated crinoidal packstone, coated bioclastic grainstone, oolitic grainstone, oolitic packstone-grainstone, intraclastic grainstone, mudstone-wackestone, quartz-peloid grainstone, and quartz arenitic sandstone.

Based on the microfacies studies it can be stated that conodont elements essentially obtained from the crinoidal bioclastic packstone-grainstone, crinoidal packstone-grainstone, coated bioclastic grainstone, intraclastic grainstone and spiculite packstone facies in the studied sections. These facies mainly includes high amount of crinoid fragments and other bioclasts, such as foraminifers, ostracodes, echinoids and brachiopods. Consequently, it can be concluded that the occurrence of abundant crinoids are indicative criteria for the presence of conodonts.

Conodonts are one of the most important microfossil groups for the Paleozoic biostratigraphy hence it requires a stable taxonomic foundation. However, conodont taxonomy is frequently problematic. This necessitates the application of morphometric analysis to the conodonts elements. Considering the quantitative analysis on morphological data, morphometric methods have been widely used in paleontology for taxonomic and evolutionary studies. In this study, some geometric morphometric analyses have been carried out on the conodont, *Gnathodus* by using literature data. *Gnathodus* is an important taxon for quantitative analysis because it displays variable morphological changes on P1 element. Moreover, the species of *Gnathodus* are widely distributed in Caboniferous successions and used as indicators of the early Carboniferous standard conodont zones. Eigen Shape, Elliptical Fourier and Sliding Semilandmarks Methods have been applied to this genus in order to illustrate the morphological variations in conodont taxa within a taxonomic context. Remarkably, the results of the Eigen Shape and Elliptical Fourier Analyses indicated that there are two major groups in *Gnathodus*, *G. bilineatus* group having larger outer platform and *Gnathodus girtyi* having narrower outer platform. The result of the Sliding Semilandmark method is more informative and indicates the clustering of different species of *Gnathodus.*

In addition to the high-resolution biostratigraphic, microfacies and morphometric studies, geochemical analyses are carried out for the determination of paleoenvironmental changes across the stage boundaries and correlation of the results. The Sr ratios obtained from the samples mainly represent the source of Sr in Aladağ Unit (Turkey) as riverine influx. Moreover, the presence of higher Sr contents in Tournasian-Visean boundary relative to the European and North American record can also point diagenetic alteration. Lower

Carboniferous samples of this study mainly plotted within the marine limestones and late cement fields in tge diagram of $\delta^{18}O$ versus $\delta^{13}C$. It can be concluded that although diagenetic imprints are present on the values of carbonate samples, responses of isotopes to paleoenvironmental changes were also observable.

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APPENDIX A

EXPLANATION OF PLATES

PLATE I

Scale bar = 100 µm

Figure 1. *Hindeodus cristulus* (Youngquist & Miller, 1949), AAO-section, sample no: AAO-6, P_1 element.

Figure 2. *Hindeodus cristulus* (Youngquist & Miller, 1949), AAO-section, sample no: AAO-8, P_1 element.

Figure 3. *Hindeodus minutus* (Ellison, 1941), section, AAO-section, sample no: AAO-6, P_1 element.

Figure 4. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-7, P_1 element.

Figure 5. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-7, P_1 element.

Figure 6. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-4, M element.

Figure 7. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-4, M element.

Figure 8. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-4, S element..

Figure 9. *Lochriea commutata* (Branson & Mehl, 1941), BSE-section, sample no: BSEc-7, S element..

Figure 10. *Vogelgnathus campbelli* (Rexroad, 1957), AAO-section, sample no: AAO-6.

Figure 11. *Vogelgnathus campbelli* (Rexroad, 1957), AAO-section, sample no: AAO-6.

Figures 12-25 S elements, 12: AS-6; 13-15: AS-5; 16: AAO-6; 17: HB-27; 18, 19: AS-4; 20-22: AAO-6; 23: HB-27; 224: AS-2; 25: AS-11.

PLATE I

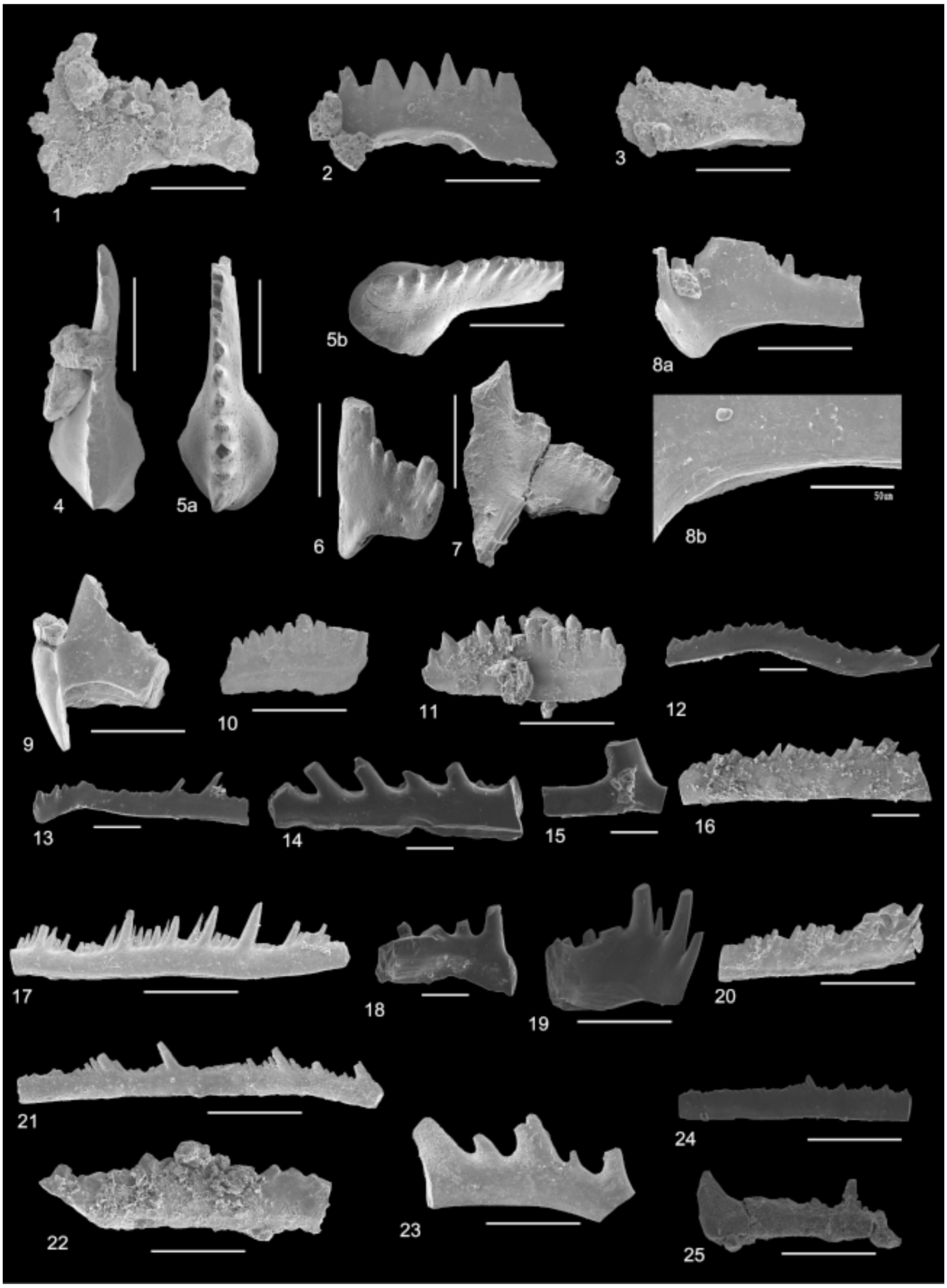
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PLATE II

Scale bar = 100 µm

Figure 1. *Declinognathodus bernesgae* (Sanz Lopez et al.)*,* HB section, sample no: HB-28, P_1 element.

Figure 2. *Declinognathodus bernesgae* (Sanz Lopez et al.)*,* HB section, sample no: HB-28, P_1 element.

Figure 3. *Declinognathodus inaequalis* (Higgins), HB section, sample no: HB-27, P_1 element.

Figure 4. *Declinognathodus inaequalis* (Higgins), HB section, sample no: HB-27, P_1 element.

Figure 5. *Declinognathodus inaequalis* (Higgins), HB section, sample no: HB-24, P_1 element.

Figure 6. *Declinognathodus inaequalis* (Higgins), HB section, sample no: HB-24, P_1 element.

Figure 7. *Declinognathodus inaequalis* (Higgins), HB section, sample no: HB-04, P_1 element.

Figure 8. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 8. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 9. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 10. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 11. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 12. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 13. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 14. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 15. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-04, P_1 element.

Figure 16. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-04, P_1 element.

Figure 17. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-04, P_1 element.

Figure 18. *Declinognathodus noduliferus* (Ellison & Graves), HB section, sample no: HB-24, P_1 element.

Figure 19. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-27, P_1 element.

Figure 20. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-27, P_1 element.

Figure 21. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-27, P_1 element.

Figure 22. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-27, P_1 element.

Figure 23. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 24. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 25. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 26. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 27. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 28. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

Figure 29. *Declinognathodus lateralis* (Higgins and Bouckaert), HB-section, sample no: HB-24, P_1 element.

PLATE II

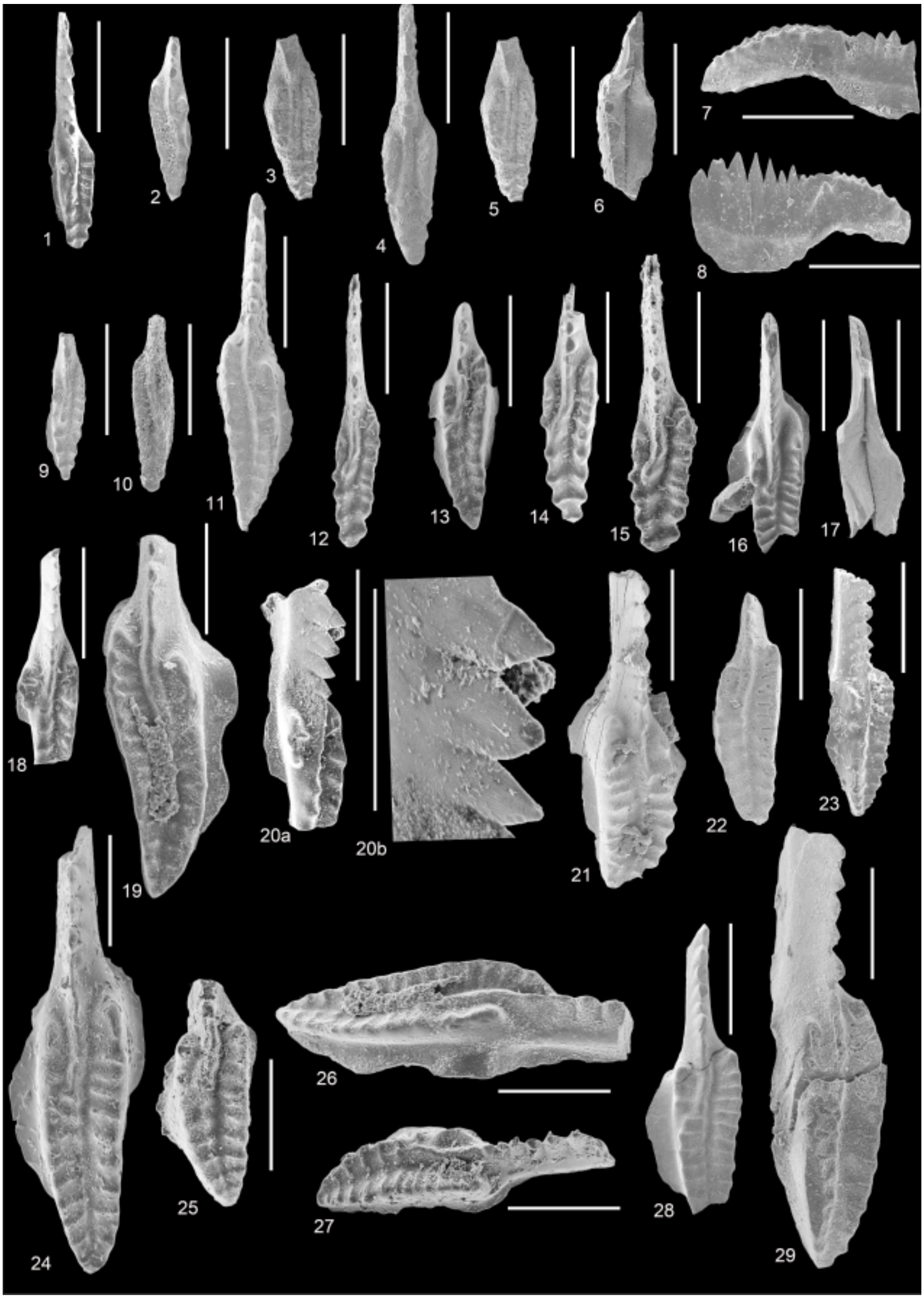
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PLATE III

Scale bar = 100 µm

Figure 1. *Gnathodus cuneiformis* Mehl and Thomas, 1947*,* BSE-section, sample no: BSEc-7, P_1 element.

Figure 2. *Gnathodus cuneiformis* Mehl and Thomas, 1947*,* AS-section, sample no: AS-5, P_1 element.

Figure 3. *Gnathodus girtyi girtyi Hass, 1953*, section, BSE-section, sample no: BSEc-7 P_1 element.

Figure 4. *Gnathodus girtyi girtyi Hass, 1953*, section, BSE-section, sample no: BSEc-7, P_1 element.

Figure 5. *Gnathodus girtyi girtyi Hass, 1953*, section, BSE-section, sample no: BSEc-2, P_1 element.

Figure 6. *Gnathodus girtyi girtyi Hass, 1953*, section, BSE-section, sample no: BSE-7, P_1 element.

Figure 7. *Gnathodus girtyi simplex Dunn, 1965,* section, BSE-section, sample no: BSEc-8, P_1 element.

Figure 8. *Gnathodus girtyi simplex Dunn, 1965,* section, BSE-section, sample no: BSEc-7, P_1 element.

Figure 9. *Gnathodus girtyi simplex Dunn, 1965,* section, BSE-section, sample no: BSEc-7, P_1 element.

Figure 10. *Bispathodus stabilis* (Branson & Mehl, 1934), AS-section, sample no: AS-6, P_1 element.

Figure 11. *Bispathodus stabilis* (Branson & Mehl, 1934), AS-section, sample no: AS-2, P_1 element.

Figure 12. *Bispathodus stabilis* (Branson & Mehl, 1934), AS-section, sample no: AS-6, P_1 element.

Figure 13. *Bispathodus utahensis* Sandberg & Gutschick, 1984, AS-section, sample no: AS-5, P_1 element.

Figure 14. *Bispathodus utahensis* Sandberg & Gutschick, 1984, AS-section, sample no: AS-5, P_1 element.

Figure 15. *Bispathodus utahensis* Sandberg & Gutschick, 1984, AS-section, sample no: AS-5, P_1 element.

Figures 16-22 P_2 elements, 16: AS-6; 17: AS-7; 18, 19: HB-27; 20-22: AAO-6.

PLATE III

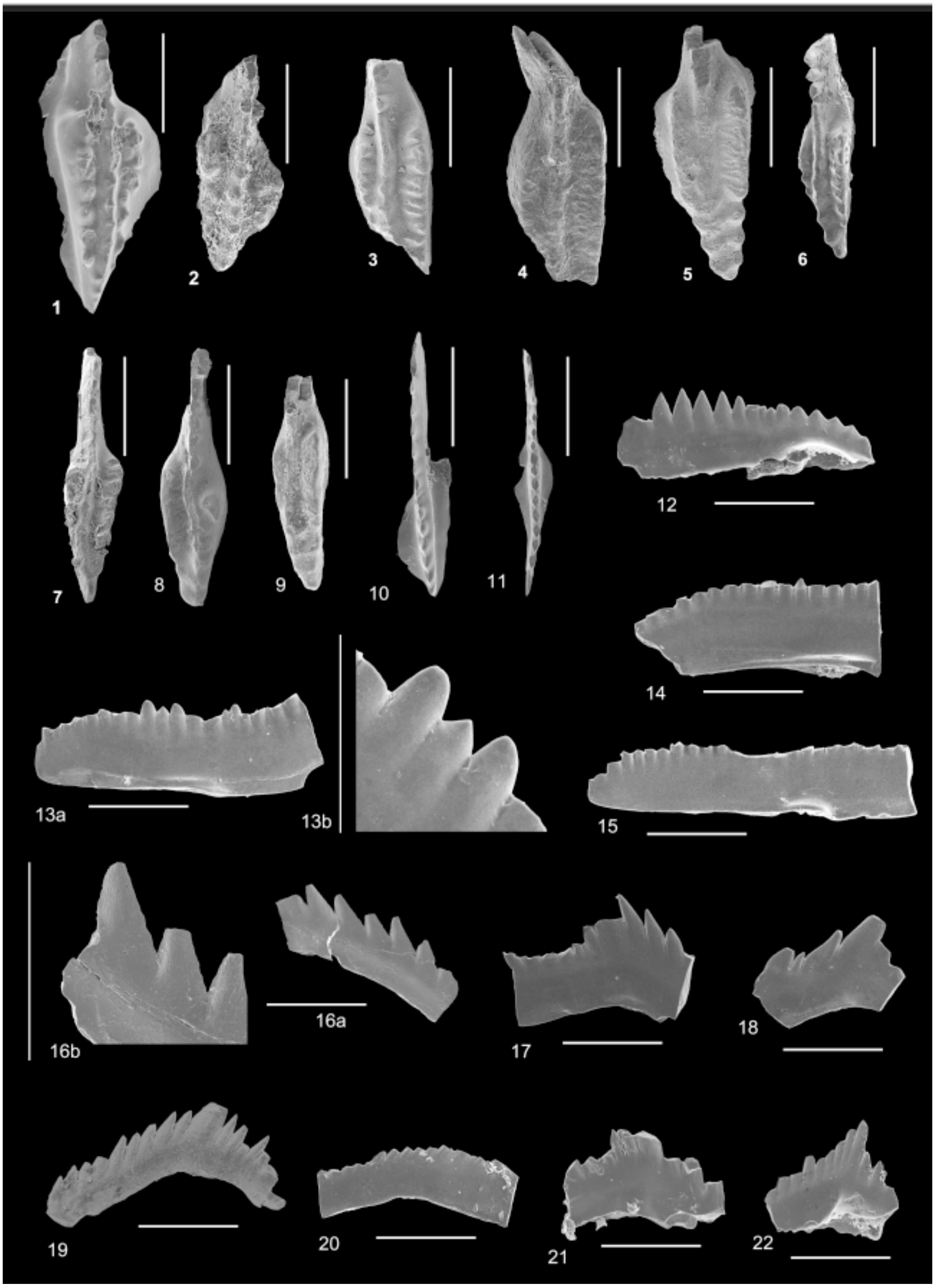


PLATE IV

Scale bar = 100 µm

Figure 1. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-28, P_1 element.

Figure 2. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-28, P_1 element.

Figure 3. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-28, P_1 element.

Figure 4. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-28, P_1 element.

Figure 5. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-24, P_1 element.

Figure 6. *Rhachistognathus minutus minutus* (Higgins and Bouckaert, 1968), HB-section, sample no: HB-24, P_1 element.

Figure 7. *Rhachistognathus minutus declinatus* Baesemann & Lane, 1985, HB-section, sample no: HB-28, P_1 element.

Figure 8. *Rhachistognathus minutus declinatus* Baesemann & Lane, 1985, HB-section, sample no: HB-24, P_1 element.

Figure 9. *Rhachistognathus minutus declinatus* Baesemann & Lane, 1985, HB-section, sample no: HB-28, P_1 element.

Figure 10. *Rhachistognathus muricatus* (Dunn, 1965), HB section, sample no: HB-28, P_1 element.

Figure 11. *Rhachistognathus muricatus* (Dunn, 1965), HB section, sample no: HB-28, P_1 element.

Figure 12. *Rhachistognathus muricatus* (Dunn, 1965), HB section, sample no: HB-28, P_1 element.

Figure 13. *Rhachistognathus muricatus* (Dunn, 1965), HB section, sample no: HB-27, P_1 element.

Figure 14. *Rhachistognathus muricatus* (Dunn, 1965), HB section, sample no: HB-27, P_1 element.

Figure 15. *Adetognathus lautus* (Gunnell, 1933), HB section, sample no: HB-24, P_1 element.

Figure 16. *Adetognathus lautus* (Gunnell, 1933), HB section, sample no: HB-24, P_1 element.

PLATE IV

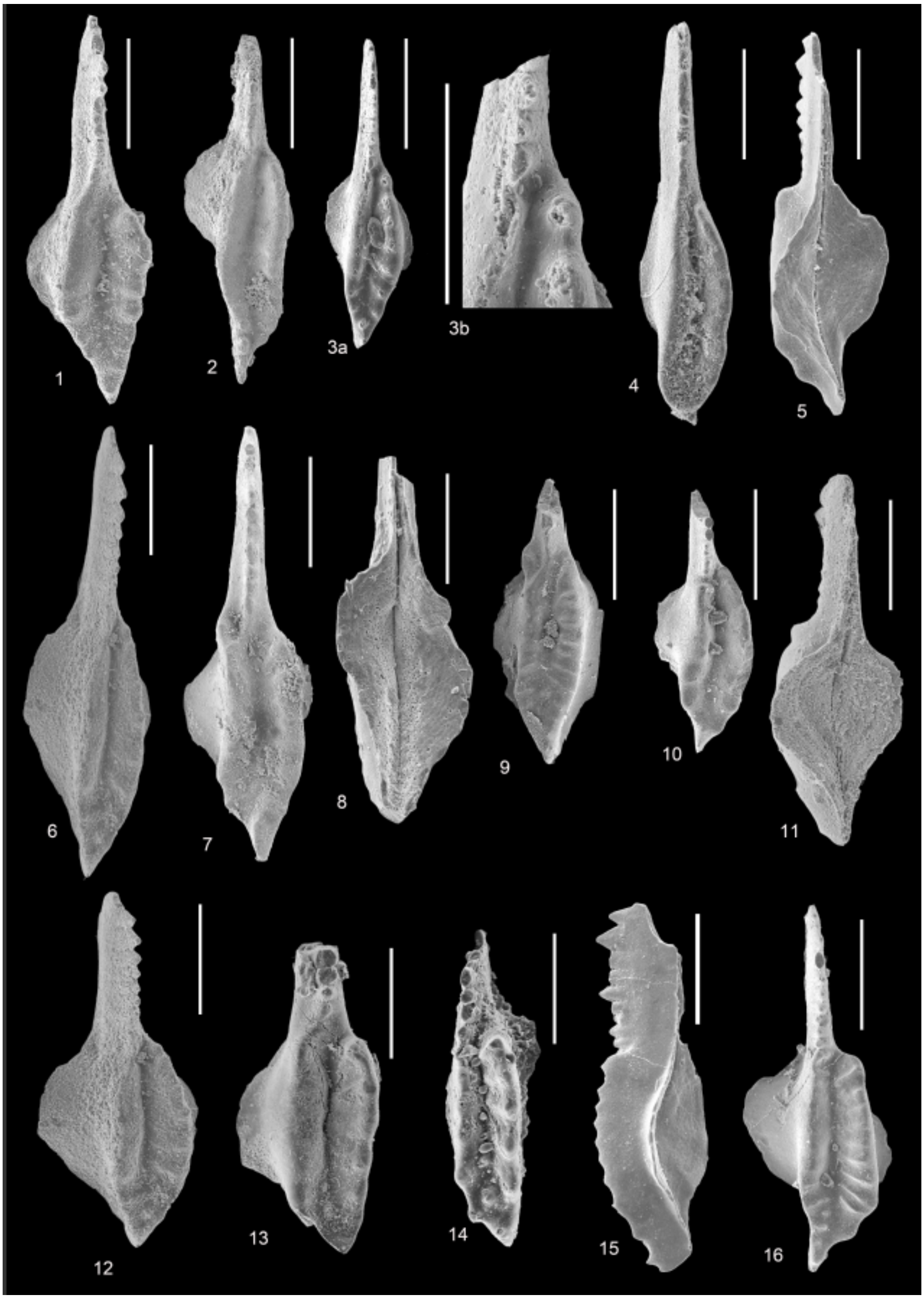


PLATE V

Scale bar = 100 μm

Figure 1. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-6, P_1 element.

Figure 2. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-6, P_1 element.

Figure 3. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 4. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 5. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 6. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 7. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 8. *Polygnathus inornatus* Branson, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 9. *Polygnathus mehli mehli* Thompson, 1967, AAO-section, sample no: AAO-6, P_1 element.

Figure 10. *Polygnathus mehli mehli* Thompson, 1967, AAO-section, sample no: AAO-6, P_1 element.

Figure 11. *Polygnathus mehli mehli* Thompson, 1967, AAO-section, sample no: AAO-5, P_1 element.

Figure 12. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 13. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 14. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-3, P_1 element.

Figure 15. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-6, P_1 element.

Figure 16. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-6, P_1 element.

Figure 17. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 18. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 19. *Polygnathus longiposticus* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 20. *Polygnathus brevilaminus* Thompson, 1967, AS-section, sample no: AS-2, P_1 element.

Figure 21. *Polygnathus brevilaminus* Thompson, 1967, AS-section, sample no: AS-7, P_1 element.

Figure 22. *Polygnathus brevilaminus* Thompson, 1967, AS-section, sample no: AS-7, P_1 element.

Figure 23. *Polygnathus symmetricus* Branson, 1934*,* AS-section, sample no: AS-5, P_1 element.

Figure 24. *Siphonodella* sp., AS-section, sample no: AS-14, P_1 element.

Figure 25. *Siphonodella* sp., AS-section, sample no: AS-14, P_1 element.

PLATE V

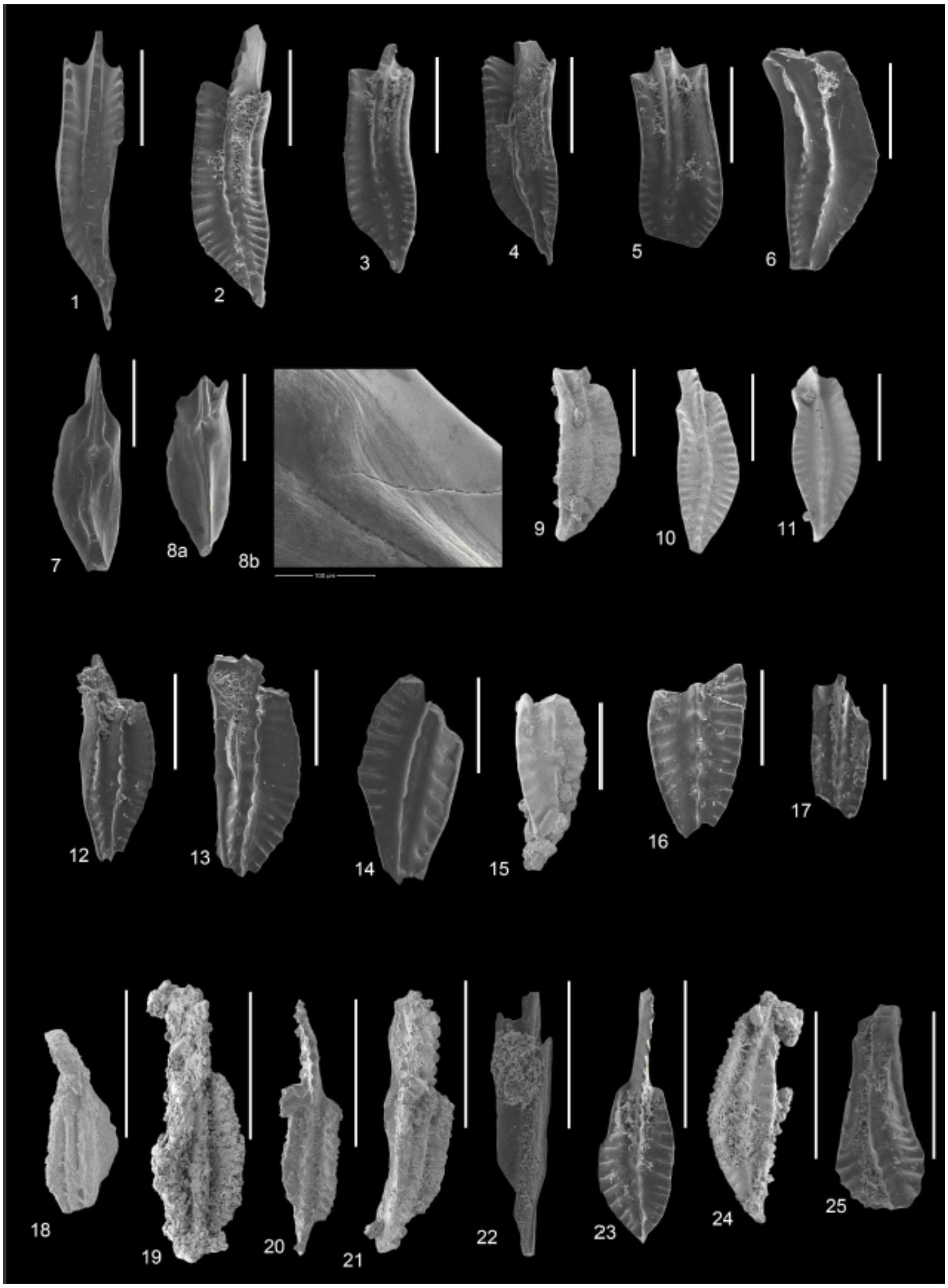


PLATE VI

Scale bar = 100 μm

Figure 1. *Polygnathus communis communis* Branson and Mehl, 1934, AAO-section, sample no: AAO-6, P_1 element.

Figure 2. *Polygnathus communis communis* Branson and Mehl, 1934, AAO-section, sample no: AAO-6, P_1 element.

Figure 3. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 4. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 5. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 6. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 7. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 8. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-8, P_1 element.

Figure 9. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-8, P_1 element.

Figure 10. *Polygnathus communis communis* Branson and Mehl, 1934, AAO-section, sample no: AAO-8, P_1 element.

Figure 11. *Polygnathus communis communis* Branson and Mehl, 1934, AS-section, sample no: AS-5, P_1 element.

Figure 12. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-6, P_1 element.

Figure 13. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-6, P_1 element.

Figure 14. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 15. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 16. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 17. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 18. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 19. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 20. *Polygnathus communis communis* Branson and Mehl, 1934*,* AS-section, sample no: AS-8, P_1 element.

Figure 21. *Polygnathus communis communis* Branson and Mehl, 1934*,* AAAO-section, sample no: AAO-8, P_1 element.

Figure 22. *Polygnathus communis communis* Branson and Mehl, 1934*,* AAAO-section, sample no: AAO-8, P_1 element.

Figure 23. *Polygnathus communis communis* Branson and Mehl, 1934*,* AAAO-section, sample no: AAO-8, P_1 element.

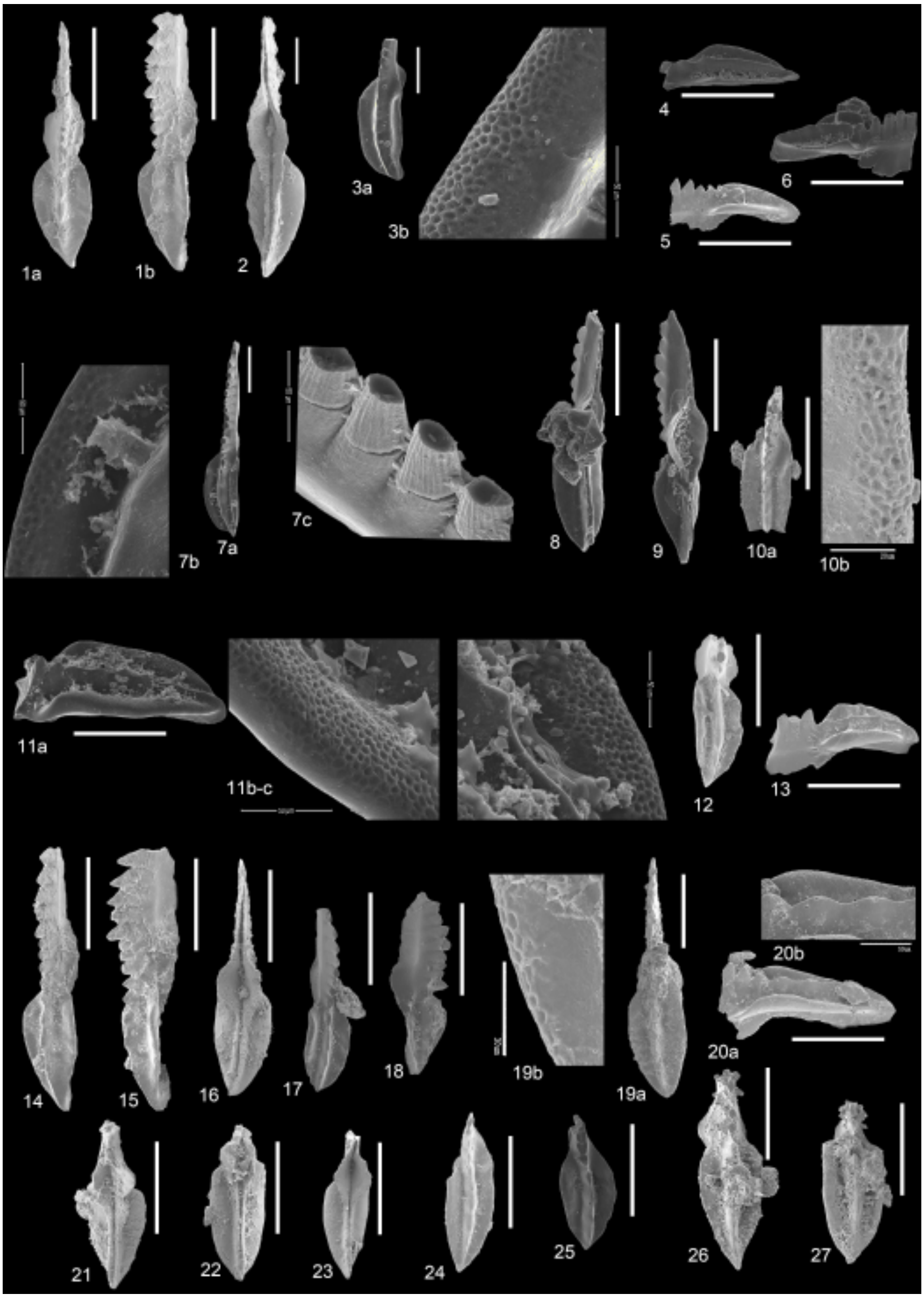
Figure 24. *Polygnathus communis communis* Branson and Mehl, 1934, AAAO-section, sample no: AAO-8, P_1 element.

Figure 25. *Polygnathus communis communis* Branson and Mehl, 1934, AAAO-section, sample no: AAO-8, P_1 element.

Figure 26. *Polygnathus communis communis* Branson and Mehl, 1934, AAAO-section, sample no: AAO-6, P_1 element.

Figure 27. *Polygnathus communis communis* Branson and Mehl, 1934, AAAO-section, sample no: AAO-6, P_1 element.

PLATE VI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7c
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10a
10b
11a
11b-c
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20a
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PLATE VIII

Scale bar = 100 µm

Figure 1. *Kladognathus* sp., AAO-section, sample no: AAO-6, S element.

Figure 2. *Kladognathus* sp., AAO-section, sample no: AAO-6, S element.

Figure 3. *Kladognathus* sp., AAO-section, sample no: AAO-8, S element.

Figure 4. *Kladognathus* sp., AAO-section, sample no: AAO-8, S element.

Figure 5. *Kladognathus* sp., AAO-section, sample no: AAO-6, S element.

Figure 6. *Kladognathus* sp., AAO-section, sample no: AAO-8, S element.

Figure 7. *Kladognathus* sp., AS-section, sample no: AS-6, S element.

Figure 8. *Kladognathus* sp., AS-section, sample no: AS-5, S element.

Figure 9. *Kladognathus* sp., AS-section, sample no: AS-5, S element.

Figure 10. *Kladognathus* sp., AS-section, sample no: AS-5, S element.

Figure 11. *Kladognathus* sp., AS-section, sample no: AS-6, M element.

Figure 12. *Kladognathus* sp., AS-section, sample no: AS-8, M element.

Figures 12-22. M elements, 12: AAO-6; 13,14: AAO-8; 15,16: AS-8; 17,18: AS-8; 19,20: AS-6; 21: AAO-2; 22: AS-8.

Figure 23. S_0 element, 16, AS-section, sample no: AS-8.

PLATE VII

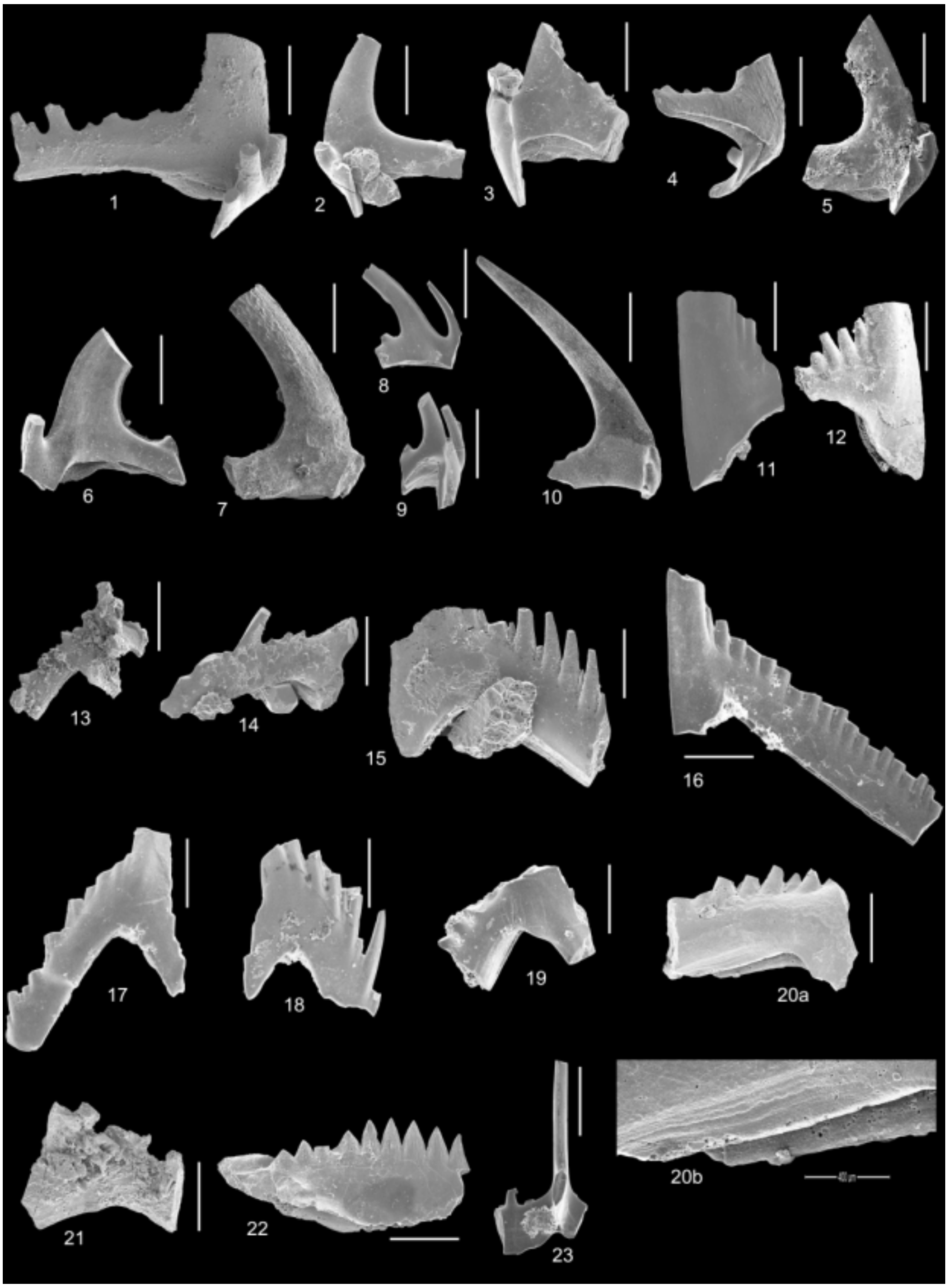


PLATE VIII

Figures 1-4 Ostracoda, AS-section, sample no: AS-8.

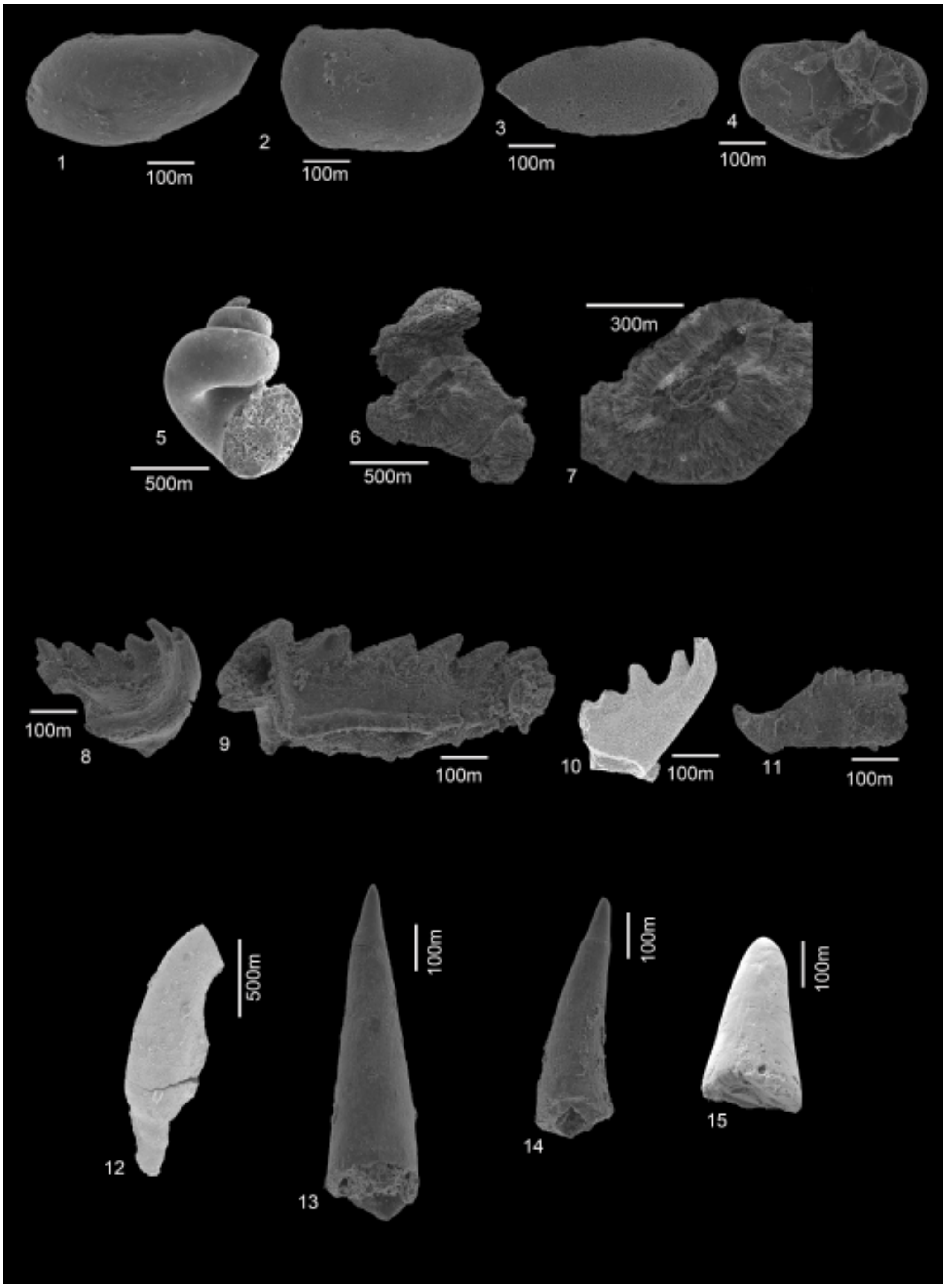
Figures 5 Gastropoda, AS-section, sample no: AS-5.

Figures 6-7 Coral, AS-section, sample no: AS-5.

Figures 8-11 Scolecodont, AS-section, 6: AS-3; 7-11: AS-13.

Figures 12-15 Fish Teeth, 12: AAO-8; 13,14: AS-3; 15: AAO-6.

PLATE VIII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12
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13
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14
100m
15

APPENDIX B

List of species names used in morphometric studies and their references.

	Species Name	Reference
1	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
2	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
3	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
4	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
5	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
6	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
7	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
8	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
9	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
10	*G.bilineatus bilineatus*	Sanz-Lopez et al. (2004)
11	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
12	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
13	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
14	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
15	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
16	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
17	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
18	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
19	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
20	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
21	*G. bilineatus bollandensis*	Sanz-Lopez et al. (2004)
22	*G. bilineatus leonicus*	Medina-Varea et al. (2005)
23	*G. bilineatus leonicus*	Medina-Varea et al. (2005)
24	*G. bilineatus leonicus*	Medina-Varea et al. (2005)
25	*G. bilineatus remus*	Nemrovska (2005)
26	*G. bilineatus remus*	Nemrovska (2005)
27	*G. bilineatus romulus*	Nemrovska (2005)
28	*G. bilineatus romulus*	Nemrovska (2005)
29	*G. bilineatus romulus*	Nemrovska (2005)
30	*G. bulbosus*	Jenkins et al. (1993)
31	*G. bulbosus*	Jenkins et al. (1993)
32	*G. bulbosus*	Jenkins et al. (1993)
33	*G. bulbosus*	Jenkins et al. (1993)
34	*G. bulbosus*	Jenkins et al. (1993)

35	*G. bulbosus*	Jenkins et al. (1993)
36	*G. bulbosus*	Jenkins et al. (1993)
37	*G. bulbosus*	Jenkins et al. (1993)
38	*G. cantabricus*	Nemrovska (2005)
39	*G. cantabricus*	Nemrovska (2005)
40	*G. cantabricus*	Nemrovska (2005)
41	*G. cantabricus*	Nemrovska (2005)
42	*G. cantabricus*	Nemrovska et al. (2008)
43	*G. cantabricus*	Nemrovska et al. (2008)
44	*G. cantabricus*	Nemrovska et al. (2008)
45	*G. cuneiformis*	This study, AAO section
46	*G. cuneiformis*	Stone (1991)
47	*G. cuneiformis*	Lane et. al. (1980)
48	*G. cuneiformis*	Lane et. al. (1980)
49	*G. cuneiformis*	Lane et. al. (1980)
50	*G. cuneiformis*	Lane et. al. (1980)
51	*G. cuneiformis*	Lane et. al. (1980)
52	*G. cuneiformis*	Lane et. al. (1980)
53	*G. cuneiformis*	Lane et. al. (1980)
54	*G. delicatus*	Lane et. al. (1980)
55	*G. delicatus*	Lane et. al. (1980)
56	*G. delicatus*	Lane et. al. (1980)
57	*G. delicatus*	Lane et. al. (1980)
58	*G. delicatus*	Lane et. al. (1980)
59	*G. delicatus*	Lane et. al. (1980)
60	*G. delicatus*	Lane et. al. (1980)
61	*G. delicatus*	Lane et. al. (1980)
62	*G. delicatus*	Lane et. al. (1980)
63	*G. girtyi girtyi*	This study, BSE section
64	*G. girtyi girtyi*	Medina-Varea et al. (2005)
65	*G. girtyi girtyi*	Medina-Varea et al. (2005)
66	*G. girtyi girtyi*	Medina-Varea et al. (2005)
67	*G. girtyi girtyi*	Medina-Varea et al. (2005)
68	*G. girtyi maxwelli*	Jenkins et al. (1993)
69	*G. girtyi maxwelli*	Jenkins et al. (1993)
70	*G. girtyi maxwelli*	Jenkins et al. (1993)
71	*G. girtyi maxwelli*	Jenkins et al. (1993)
72	*G. girtyi simplex*	This study, BSE section
73	*G. girtyi simplex*	Medina-Varea et al. (2005)
74	*G. girtyi simplex*	Medina-Varea et al. (2005)
75	*G. girtyi meischeneri*	Medina-Varea et al. (2005)
76	*G. girtyi meischeneri*	Medina-Varea et al. (2005)
77	*G. girtyi meischeneri*	Nemrovska et al. (2008)
78	*G. girtyi meischeneri*	Nemrovska et al. (2008)
79	*G. girtyi meischeneri*	Nemrovska et al. (2008)
80	*G. girtyi meischeneri*	Nemrovska et al. (2008)

81	*G. joseramoni*	Sanz-Lopez et al. (2007)
82	*G. joseramoni*	Sanz-Lopez et al. (2007)
83	*G. joseramoni*	Sanz-Lopez et al. (2007)
84	*G. joseramoni*	Sanz-Lopez et al. (2007)
85	*G. joseramoni*	Sanz-Lopez et al. (2007)
86	*G. joseramoni*	Sanz-Lopez et al. (2007)
87	*G. joseramoni*	Sanz-Lopez et al. (2007)
88	*G. joseramoni*	Sanz-Lopez et al. (2007)
89	*G. joseramoni*	Sanz-Lopez et al. (2007)
90	*G. joseramoni*	Sanz-Lopez et al. (2007)
91	*G. joseramoni*	Sanz-Lopez et al. (2007)
92	*G. joseramoni*	Sanz-Lopez et al. (2007)
93	*G. joseramoni*	Sanz-Lopez et al. (2007)
94	*G. joseramoni*	Sanz-Lopez et al. (2007)
95	*G. joseramoni*	Sanz-Lopez et al. (2007)
96	*G. joseramoni*	Sanz-Lopez et al. (2007)
97	*G. kiensis*	Sanz-Lopez et al. (2007)
98	*G. millarensis*	Sanz-Lopez et al. (2007)
99	*G. millarensis*	Sanz-Lopez et al. (2007)
100	*G. millarensis*	Sanz-Lopez et al. (2007)
101	*G. postbilineatus*	Lane et. al. (1980)
102	*G. postbilineatus*	Lane et. al. (1980)
103	*G. postbilineatus*	Lane et. al. (1980)
104	*G. postbilineatus*	Lane et. al. (1980)
105	*G. postbilineatus*	Lane et. al. (1980)
106	*G. preabilineatus*	Sanz-Lopez et al. (2004)
107	*G. preabilineatus*	Sanz-Lopez et al. (2004)
108	*G. preabilineatus*	Sanz-Lopez et al. (2004)
109	*G. preabilineatus*	Sanz-Lopez et al. (2007)
110	*G. preabilineatus*	Sanz-Lopez et al. (2007)
111	*G. preabilineatus*	Sanz-Lopez et al. (2007)
112	*G. preabilineatus*	Nemrovska et al. (2008)
113	*G. preabilineatus*	Nemrovska et al. (2008)
114	*G. preabilineatus*	Nemrovska et al. (2008)
115	*G. preabilineatus*	Nemrovska (2005)
116	*G. preabilineatus*	Nemrovska (2005)
117	*G. preabilineatus*	Nemrovska (2005)
118	*G. pseudosemiglaber*	Lane et. al. (1980)
119	*G. pseudosemiglaber*	Lane et. al. (1980)
120	*G. pseudosemiglaber*	Lane et. al. (1980)
121	*G. pseudosemiglaber*	Lane et. al. (1980)
122	*G. pseudosemiglaber*	Lane et. al. (1980)
123	*G. pseudosemiglaber*	Lane et. al. (1980)
124	*G. pseudosemiglaber*	Lane et. al. (1980)
125	*G. rugulatus*	Jenkins et al. (1993)
126	*G. rugulatus*	Jenkins et al. (1993)

127	*G. rugulatus*	Jenkins et al. (1993)
128	*G. semiglaber*	Sanz-Lopez et al. (2004)
129	*G. semiglaber*	Sanz-Lopez et al. (2004)
130	*G. semiglaber*	Sanz-Lopez et al. (2004)
131	*G. semiglaber*	Lane et. al. (1980)
132	*G. semiglaber*	Lane et. al. (1980)
133	*G. semiglaber*	Lane et. al. (1980)
134	*G. semiglaber*	Lane et. al. (1980)
135	*G. semiglaber*	Lane et. al. (1980)
136	*G. semiglaber*	Lane et. al. (1980)
137	*G. semiglaber*	Lane et. al. (1980)
138	*G. semiglaber*	Lane et. al. (1980)
139	*G. texanus*	Leicester samples
140	*G. texanus*	Stone (1991)
141	*G. texanus*	Stone (1991)
142	*G. texanus*	Lane et. al. (1980)
143	*G. texanus*	Lane et. al. (1980)
144	*G. texanus*	Lane et. al. (1980)
145	*G. texanus*	Lane et. al. (1980)
146	*G. texanus*	Lane et. al. (1980)
147	*G. texanus*	Lane et. al. (1980)
148	*G. trulyosi*	Sanz-Lopez et al. (2007)
149	*G. trulyosi*	Sanz-Lopez et al. (2007)
150	*G. trulyosi*	Sanz-Lopez et al. (2007)
151	*G. trulyosi*	Sanz-Lopez et al. (2007)
152	*G. trulyosi*	Sanz-Lopez et al. (2007)
153	*G. trulyosi*	Sanz-Lopez et al. (2007)
154	*G. typicus*	Lane et. al. (1980)
155	*G. typicus*	Lane et. al. (1980)
156	*G. typicus*	Lane et. al. (1980)
157	*G. typicus*	Lane et. al. (1980)
158	*G. typicus*	Lane et. al. (1980)
159	*G. typicus*	Lane et. al. (1980)
160	*Polygnathus inornatus*	This study, AS section
161	*Polygnathus inornatus*	This study, AS section
162	*Polygnathus inornatus*	This study, AS section

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EDUCATION

2006 - 2012	Middle East Technical University,Department of Geological Engineering, Ph.D.
2003 - 2006	Middle East Technical University,Department of Geological Engineering, M. Sc. “Lower-Middle Carboniferous Boundary in Central Taurides (Hadim Area): Paleontological and Sequence Stratigraphic Approach”
1999 - 2003	Orta Doğu Teknik Üniversitesi, Jeoloji Mühendisliği Bölümü, B.S.

WORK EXPERIENCES

Year	**Place**	**Enrollment**
2011-present	Turkish Republic Ministry of Energy and Natural Resources Directorate of Mining Affairs	Engineer
2004-2011	METU, Dept. of Geol. Eng.	Research Assistant
2009	Dept. of Earth Sciences, University of Leicester	Academic Visitor

PUBLICATIONS

Articles published in periodicals recognized by SCI

Atakul-Özdemir, A., Purnell, M. A. and Riley, N. J. 2012: Cladistic tests of monophyly and relationships of biostratigraphically significant conodonts using multielement skeletal data - Lochriea homopunctatus and the genus Lochriea. Palaeontology, 55, 6, 1279-1291.

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Conference Papers

Altıner, D., Özkan-Altıner, S., Yılmaz İ. Ö. and **Atakul-Özdemir A.** Bashkirian-Moscovian Boundary Beds In Southern Turkey: Foraminiferal Biostratigraphy and Sequence Stratigraphy, 2012 GSA Annual Meeting in Charlotte (4–7 November 2012), Charlotte, North Carolina.

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Atakul-Özdemir A., Altıner, D. and Özkan-Altıner, S. The Mid-Carboniferous Boundary in Central Taurides (Turkey): Conodonts, Foraminifers and Sequence Stratigraphy, Geological Society of America (GSA) Northeastern (46th Annual) and North-Central (45th Annual) Joint Meeting (20–22 March 2011), Pittsburgh, Pennsylvania.

Özdemir A. and Purnell, M.A. 2009. A new skeletal reconstruction reveals the phylogenetic affinities of the stratigraphically important conodont Lochriea homopunctatus (Ziegler), University of Birmingham, Palaeontological Association53rd Annual Meeting13th–16th December 2009, 68.

Atakul A., Altıner D., Özkan-Altıner S. ve Yılmaz İ. Ö., Orta Toroslar'da (Hadim, Türkiye) foraminifer paleontolojisi ve sekans stratigrafisi ile belirlenen Serpukhoviyen-Başkiriyen sınırının istatistiksel yöntemlerle analizi (Statistical analysis of Seroukhovian-Bashkirian boundary delineated by using foraminiferal paleontology and, sequence stratigraphy in Central Taurides (Hadim, Turkey)). Stratigrafi Komitesi Çalıştayı, 22-23 Kasım 2007, Ankara, Özler (Abstracts), s.3.

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COURSES and SUMMER SCHOOLS ATTENDED

June - July 2006 Participated in summer program in Analytical Paleobiology by the National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara

09-14 October 2006, Radiogenic and Stable Isotope Geology, Dokuz Eylül Üniversitesi, İZMİR.

FOREIGN LANGUAGES

English