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CONODONT DISTRIBUTION ACROSS THE MID-CARBONIFEROUS BOUNDARY IN THE CENTRAL TAURIDES, TURKEY

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Abstract. The Mid-Carboniferous boundary in the Aladağ Unit of the Central Taurides, previously delineated on the basis of foraminifers, is now further recognizable on the basis of conodonts. Latest Serpukhovian conodonts are assigned to the *Rhachistognathus muricatus* Zone, whereas the early Bashkirian forms correspond to the *Declinognathodus inaequalis - Declinognathodus noduliferus* Zone. Conodont assemblages discovered in the Taurides are comparable to those described from Mid-Carboniferous boundary sections in North America, Japan, southern Urals, southern China, Ukraine and Uzbekistan. The Mid-Carboniferous boundary is located at a horizon marked by the first appearance of *Declinognathodus inaequalis*, just above the last appearance of the conodont *Gnathodus girtyi simplex*. This horizon coincides with the boundary indicated by foraminiferal data.

Riassunto. Il limite che suddivide il Carbonifero in due parti fu definito nell'Unità Aladağ nei Tauridi Centrali sulla base dei foraminiferi. Ora viene ulteriormente definito mediante i conodonti. I conodonti del Serpukhoviano sommitale sono assegnati alla Zona a *Rhachistognathus muricatus*, mentre le forme del Bashkiriano basale corrispondono a quelle delle Zona a *Declinognathodus inaequalis - Declinognathodus noduliferus*. Le associazioni a conodonti rinvenute nei Tauridi sono confrontabili con quelle descritte in Nord America, Giappone, Urali meridionali, Cina meridionale, Ucraina e Uzbekistan. Il limite della base del Carbonifero superiore è posizionato in corrispondenza della prima comparsa di *Declinognathodus inaequalis*, appena sopra l'ultima presenza del conodonte *Gnathodus girtyi simplex*. Questo orizzonte coincide con il limite indicato dai foraminiferi.

Introduction

The International Subcommission on Carboniferous Stratigraphy in 1995 selected Arrow Canyon, Nevada (USA) to be the GSSP for the Mid-Carboniferous boundary. The first appearance of the index conodont taxon *Declinognathodus noduliferus* sensu lato, including the subspecies *D. noduliferus noduliferus*, *D. noduliferus inaequalis*, *D. noduliferus lateralis* and *D. noduliferus japonicus,* was chosen as the biostratigraphic marker for this boundary (Baesemann & Lane 1985; Nemirovskaya & Nigmadganov 1994; Brenckle et al. 1997; Nemyrovska 1999; Lane et al. 1999; Gradstein et al. 2004). Subsequently, Sanz-López et al. (2006) and Sanz-López & Blanco-Ferrera (2009) reported *D. noduliferus bernesgae* and *D. praenoduliferus* in uppermost Serpukhovian rocks in northern Spain. Those authors also noted that the entry of *D. noduliferus inaequalis* (*D. inaequalis* in their nomenclature) should be used for the correlation and recognition of the Mid-Carboniferous boundary in the Arrow Canyon section, whereas the other *Declinognathodus* species can be used in the correlation of beds close to the Mid-Carboniferous boundary.

There are very few studies of conodont biostratigraphy in the Carboniferous of Taurides. Göncüoğlu et al. (2004, 2007) reported some conodont faunas from the lower Mississippian (Tournasian) of the Geyik Dağı Unit, an authochthon or parauthochton of the Taurides (Özgül 1976, 1984, 1997; Şengör & Yılmaz 1981). Ekmekçi & Kozur (1999) described Moscovian conodonts from the allochthonous Bolkar Dağ Unit. The Mid-Carboniferous boundary was first discussed within the foraminiferal biostratigraphic framework of Altıner (1981) and Altıner & Özgül (2001) in the well preserved Carboniferous sections of the allochthonous Aladağ Unit in the Eastern and Central Taurides. Atakul-Özdemir et al. (2011) recently initiated a study of a well exposed section in the Hadim region of the Central Taurides.

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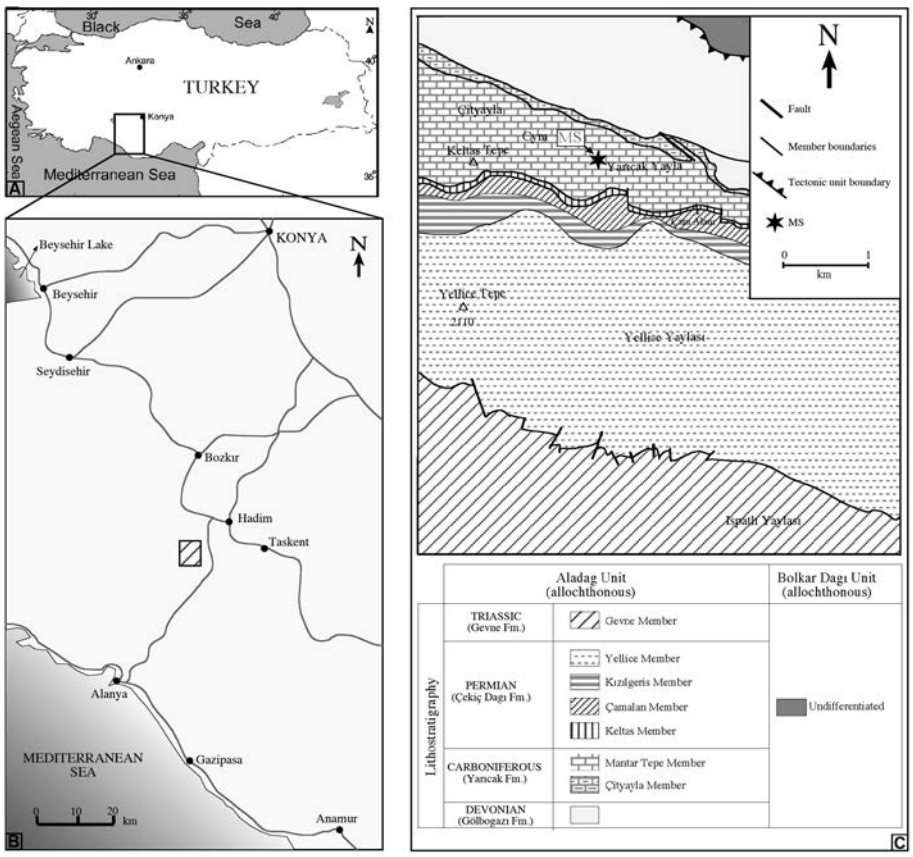


Fig. 1 - Geographic setting (A, B) and geologic map (C) after Altıner and Özgül (2001) and location of the measured section (MS).

Their bed-scale sampling and detailed foraminiferal biostratigraphy led to precise location of the Mid-Carboniferous boundary.

This study aims to describe in detail the conodont succession across the Mid-Carboniferous boundary at the section near Hadim, at which foraminifers from the boundary interval were described by Atakul-Özdemir et al. (2011). Conodont zones recognized at this section are correlated with those at other important Mid-Carboniferous boundary sections around the world. This paper is the first to document the distribution and biostratigraphic significance of conodonts across the Mid-Carboniferous boundary in the Central Taurides, Turkey.

Geologic Setting

The Aladağ Unit is one of the main tectonic units in the Tauride Belt, southern Turkey (Özgül 1976, 1984, 1997). It displays a continuous upper Paleozoic carbonate sequence encompassing the Mid-Carboniferous boundary, and is widely exposed in the Hadim region (Fig. 1). The Carboniferous Yarıcak Formation of the Aladağ Unit (Central Taurides) has been divided into the Çityayla and Mantar Tepe members (Özgül 1997). The Çityayla Member is a succession of dark colored shale interbedded with thin limestones of Tournaisian age. This member was probably deposited in low energy shelf conditions below wave base (Özgül 1997). The upper Tournaisian to Gzhelian Mantar Tepe Member is mainly bioclastic, oolitic and micritic limestones in its lower part, and quartz arenitic sandstones intercalated with limestones in its upper part (Altıner & Özgül 2001). The carbonates of the Mantar Tepe Member were deposited below and above wave base. Limestones grade laterally into quartz sandstones across the Mid-Carboniferous boundary interval, reflecting a considerable influx from land into the shallow shelf environment. The 26 m thick measured section near Hadim is predominantly composed of bioclastic and oolitic grainstones intercalated with quartz arenitic sandstones. It represents a continuous shallow marine succession in the Mantar Tepe Member (Fig. 2).

Conodont Biostratigraphy

Conodonts for this study were obtained from approximately 2 kg limestone samples that were crushed and processed using standard acidizing techniques with 10-15% formic and acetic acid solutions. The residues were washed through nested sieves of 63, 125, 250, and 425 microns and the elements were concentrated from the residue by using sodium polytungstate heavy liquid. Unfortunately most of the samples were barren, with

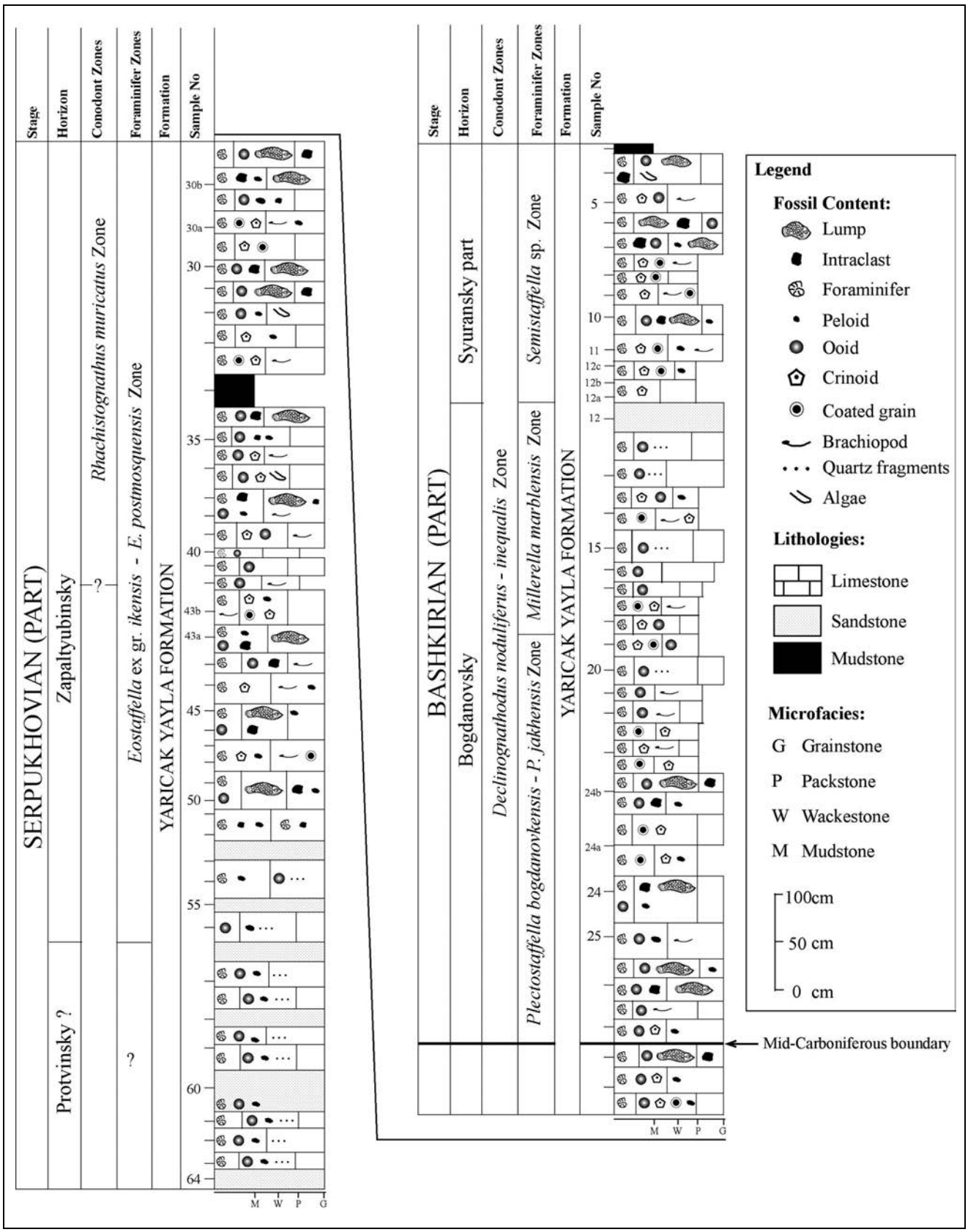


Fig. 2 - Columnar stratigraphic section showing the position of the Mid-Carboniferous boundary in the Aladağ Unit (modified from Atakul-Özdemir 2011). The coordinates of the base of the section is 36445144 E – 4085730 N.

System	Stage	Horizon	Conodont Zones	Sample No / Species	*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															

Fig. 3 - Stratigraphical distribution of conodont species and conodont zonation across the Mid-Carboniferous beds in the Aladağ Unit.

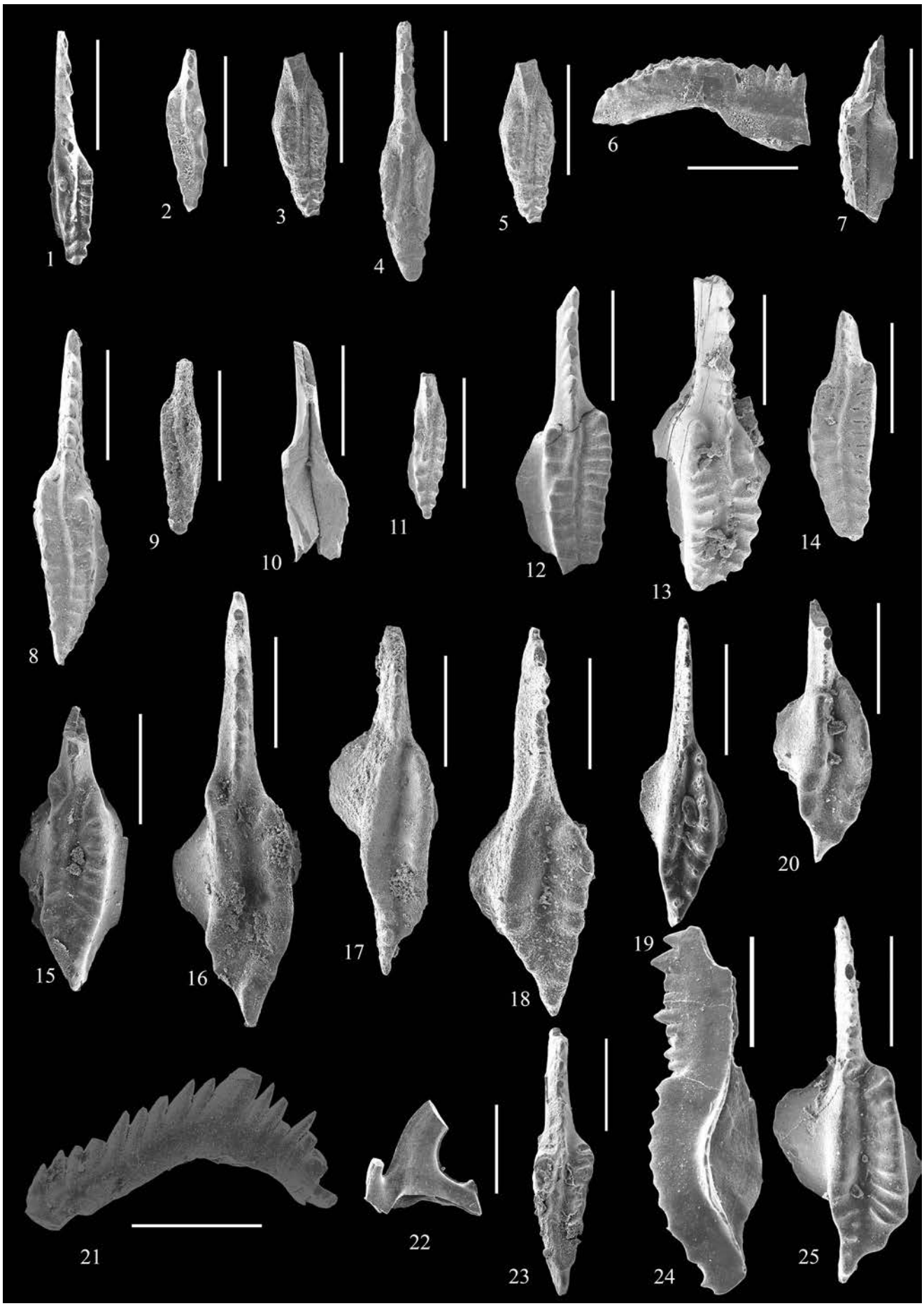
conodont elements recovered from only 7 samples. The distribution and abundance of conodont elements in the measured section is illustrated in Fig. 3. All described and figured specimens are housed in the Department of Geological Engineering, Middle East Technical University, Turkey. Although not abundant, conodonts discovered in this study include important Serpukhovian – early Bashkirian species and the marker taxon for the Mid-Carboniferous boundary. The different morphotypes of the *Declinognathodus noduliferus* group are described as distinct species in this study. Based on the appearance of biostratigraphically significant taxa, the following zones are recognized (Fig. 3):

***Rhachistognathus muricatus* Zone.** This zone is characterized by the presence of *Rhachistognathus muricatus*. The top of the zone is marked by the first ap-

PLATE 1

Selected conodonts from the Aladağ Unit, mostly P1 elements. Scale bar: 300 μm.

Figs 1-2 - *Declinognathodus bernesgae* (Sanz Lopez et al.), HB 28.
Figs 3-7 - *Declinognathodus inaequalis* (Higgins), HB 27.
Figs 8-11 - *Declinognathodus noduliferus* (Ellison & Graves), HB 04.
Figs 12-14 - *Declinognathodus lateralis* (Higgins & Bouckaert), HB 27.
Figs 15-16 - *Rhachistognathus minutus declinatus* (Baesemann & Lane), HB 28.
Figs 17-19 - *Rhachistognathus minutus minutus* (Higgins & Bouckaert), HB 28.
Figs 20 - *Rhachistognathus muricatus* (Dunn), HB 27.
Fig. 21 - P2 element, HB 07.
Fig. 22 - *Kladognathus* sp., HB 24.
Fig. 23 - *Gnathodus girtyi simplex* (Dunn), HB 28.
Figs 24-25 - *Adetognathus lautus* (Gunnell), HB 24.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		Turkey Central Taurides (This Study)	USA Arrow Canyon Section (Lane et al. 1985)	Uzbekistan Aksu-I Section (Nemirovskaya & Nigmadganov 1994)	Japan Hina Limestone (Mizuno 1997)	Ukraine Donets Basin (Nemyrovska 1999)	Southern Urals Kizil Formation (Kulagina et al. 2001)	South China Nashuie Section (Wang and Qi 2003)
Carboniferous	Bashkirian (part)	*Declinognathodus inaequalis - Declinognathodus noduliferus*	*Declinognathodus noduliferus* s.l. - *Rhachistognathus primus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*	*Declinognathodus noduliferus*
				Declinognathodus praenoduliferus	*Declinognathodus inaequalis – Gnathodus bilineatus*			
	Serpukhovian (part)	*Rhachistognathus muricatus*	*Rhachistognathus muricatus*	*Gnathodus bilineatus bollandensis*	*Gnathodus bilineatus*	*Gnathodus postbilineatus*	*Gnathodus bilineatus*	*Gnathodus bilineatus bollandensis*
						Gnathodus bilineatus bollandensis – Adetognahtus unicornis		

Fig. 4 - Correlation of conodont zones of Central Taurides with those of North America, Japan, Southern Urals, Southern China, Ukraine and Uzbekistan.

pearance of *Declinognathodus inaequalis*. The lower boundary cannot be defined because of the absence of conodonts in the underlying levels. Typical Mississippian taxa that occur within this zone include *Rhachistognathus minutus minutus, R. minutus declinatus, Gnathodus girtyi simplex, Declinognathodus bernesgae, Adetognathodus lautus* and *Kladognathus* sp. (Pl. 1). Baesemann and Lane (1985) and Lane et al. (1999) defined this latest Mississippian zone at Arrow Canyon by the appearance of the index species *Rhachistognathus muricatus, Gnathodus bilineatus* and *Cavusgnathus unicornis.*

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.

The *Rhachistognathus muricatus* Zone of the Taurides can be correlated with the Lower and Upper *Rhachistognathus muricatus* zones of the GSSP in Arrow Canyon, Nevada (Lane et al. 1999); the *Gnathodus postbilineatus* Zone and the *Gnathodus bilineatus – Adetognathus unicornis* Zone in 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) (Fig. 4). 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. It further corresponds to the upper part of the *Eostaffella* ex gr. *ikensis-Eostaffella postmosquensis* foraminiferal Zone, to the E2 Zone of Western Europe, and to the Ustsarbaisky Horizon of the Urals (Atakul-Özdemir et al. 2011).

***Declinognathodus inaequalis – Declinognathodus noduliferus* Zone.** 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*.

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. (Pl. 1).

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.

The *Declinognathodus inaequalis – Declinognathodus noduliferus* Zone of the Taurides can be correlated with the *D. noduliferus* s.l. zone at Arrow Canyon, Nevada (Lane et al. 1999); the *D. noduliferus* Zone in the Donets Basin, Ukraine (Nemyrovska 1999), in the Kizil Formation, Southern Urals (Kulagina et al. 2001) and in the Nashui Section, South China (Wang & Qi 2003); the *D. inaequalis – Gnathodus bilineatus* Zone and *D. noduliferus* Zone in the Hina Limestone, Japan (Mizuno 1997); and the *D. praenoduliferus* zone and *D. noduliferus* Zone in the Aksu Section, Uzbekistan (Nemirovskaya & Nigmadganov 1994) (Fig. 4). This zone is equivalent to the Bogdanovsky and lowest Syuransky horizons of the Bashkirian Stage in its type area in the South Urals.

The *Declinognathodus inaequalis – Declinognathodus noduliferus* Zone corresponds to three foraminiferal zones of Atakul-Özdemir et al. (2011): *Plecto-*

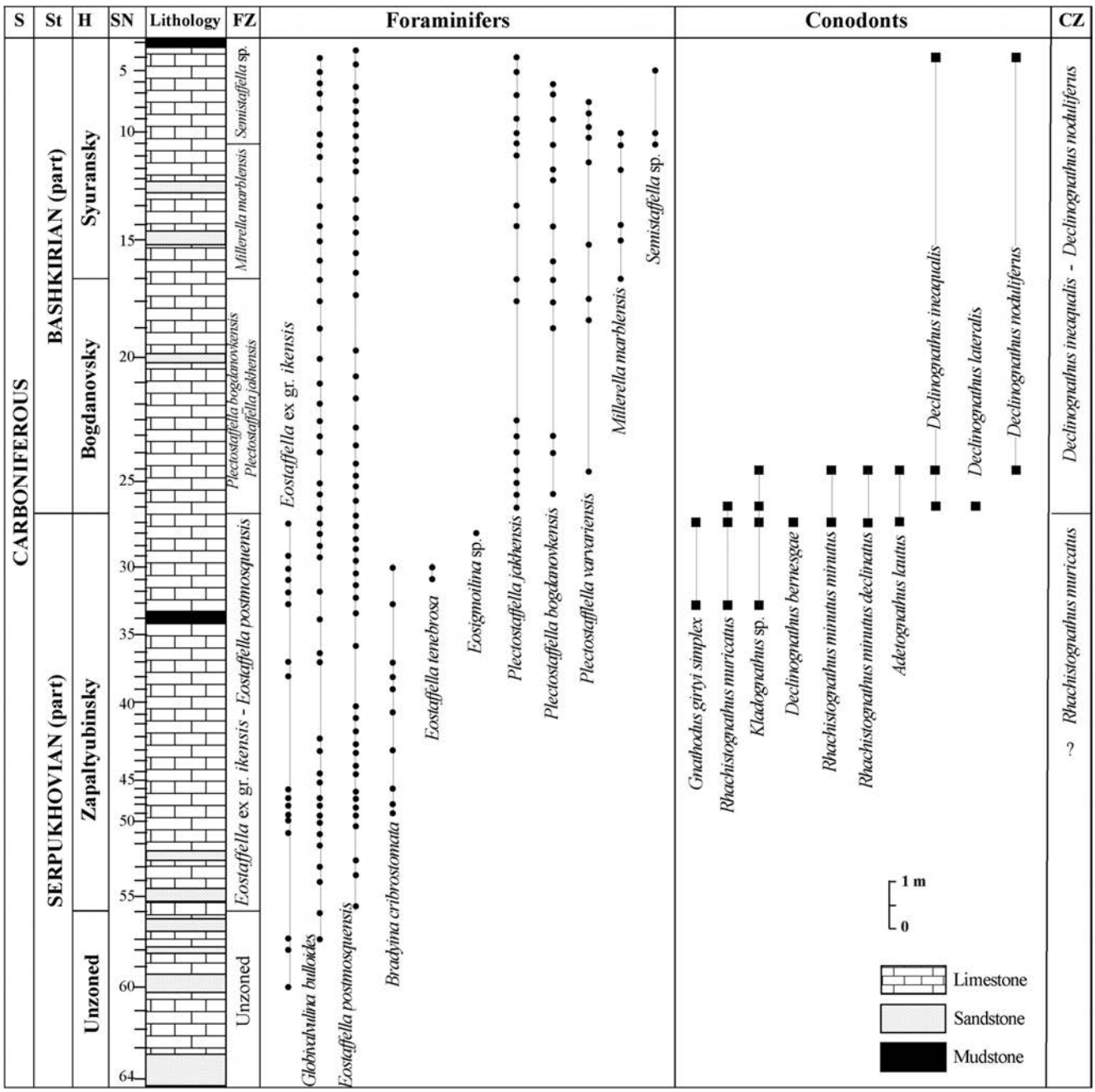

Fig. 5 - The Mid-Carboniferous boundary delineated by the foraminiferal and conodont occurrences in the Aladağ Unit (S: System, St: Stage, H: Horizon, SN: Sample Number, FZ: Foraminiferal Zones, CZ: Conodont Zones).

staffella bogdanovkensis – P. jakhensis, *Millerella marblensis* and *Semistaffella* sp. This interval is correlated with the *Homoceras* Zone in Western Europe, the lower Voznesensky to Krasnopolyansky horizons of the Russian Platform, and the Feninsky Horizon in the Donets Basin (see Atakul-Özdemir et al. 2011).

Mid-Carboniferous boundary in Central Taurides

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 time 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, the International Subcommission on Carboniferous Stratigraphy selected the Arrow Canyon section, Nevada (USA) to be the GSSP for Mid-Carboniferous bound-

ary. The first appearance of the index conodont taxa *Declinognathodus noduliferus* sensu lato, including the subspecies *D. noduliferus noduliferus*, *D. noduliferus inaequalis*, *D. noduliferus lateralis* and *D. noduliferus japonicus,* was 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). 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 & Blanco-Ferrera 2009). In addition to *D. inaequalis*, the first occurrences of *D. lateralis* and *D. noduliferus* sensu stricto are also indicative of earliest Bashkirian time.

The occurrence of *D. bernesgae* together with the last occurrence of *Gnathodus girtyi simplex* indicates a latest Serpukhovian age for sample HB28, just below the Mid-Carboniferous boundary. 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 *D. bernesgae* and *D. praenoduliferus* occur together with *D. inaequalis* at the Mid-Carboniferous boundary (Nemyrovska et al. 2008; Nemyrovska 2009). However, the first occurrences of *D. bernesgae* and *D. praenoduliferus* predate the first appearance of *D. 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 *D. 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 *D. inaequalis*.

The location of the Mid-Carboniferous boundary at the base of the sample 27 in the studied section coincides with that proposed by Atakul-Özdemir et al. (2011) on the basis of foraminiferal occurrences. The boundary separates the last occurrence of *Eostaffella* ex gr. *ikensis,* below, and the first occurrences of *Plectostaffella bogdanovkensis* and *P. jakhensis* above (Fig. 5).

Conclusions

A section in the Yarıcak Formation of the Aladağ Unit (Hadim region, Central Taurides, Turkey) exhibits a biostratigraphically complete upper Serpukhovian – lower Bashkirian succession which is mainly composed of carbonate rocks with intercalations of sandstones. Although conodonts are not abundant, an important assemblage of conodont taxa includes *Rhachistognathus minutus minutus, R. minutus declinatus* and *Kladognathus* sp. The first *Declinognathodus bernesgae* are present together with the last occurrence of *Gnathodus girtyi simplex* at the top of the Serpukhovian. The Mid-Carboniferous boundary is placed at the base of the bed where the first appearance of *Declinognathodus inaequalis* occurs. This agrees with the boundary level recognized using foraminifers by Atakul-Özdemir et al. (2011). In our opinion, the Mid-Carboniferous boundary should be recognized by the first apperance of *Declinognathodus inaequalis*, whereas the other *Declinognathodus* taxa provide a biostratigraphic framework for the correlation of Mid-Carboniferous beds between different basins in the world.

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