

Planktonic foraminifera and dinoflagellate cysts from the Upper Cretaceous Abderaz Formation in the Koppeh-Dagh Basin, NE Iran

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ABSTRACT: Assemblages of planktonic foraminifera and dinoflagellate cysts were studied from the 359 m thick Padeha-Baghak composite section of the Abderaz Formation, eastern Koppeh-Dagh Basin, NE Iran. The formation consists mainly of light grey shales and marls with three chalky limestone beds in the upper part. Nine genera and 44 species of planktonic foraminifera and 39 genera and 85 species of dinoflagellate cysts are identified. Planktonic foraminifera are attributed to four biozones (*Dicarinella primitiva*–*Marginotruncana sigali*, *Dicarinella concavata*, *Dicarinella asymetrica* and *Globotruncanella elevata* zones). Two dinocyst superzones (*Conosphaeridium striatoconum* Superzone and the lower part of the *Odontochitina porifera* Superzone) with seven interval zones are recognized. These biozones suggest a late Turonian–early Campanian age for the Abderaz Formation in this part of the Koppeh-Dagh Basin.

Key words: Planktonic Foraminifera, dinoflagellate cysts, biostratigraphy, Turonian–Campanian, Koppeh-Dagh Basin, Iran.

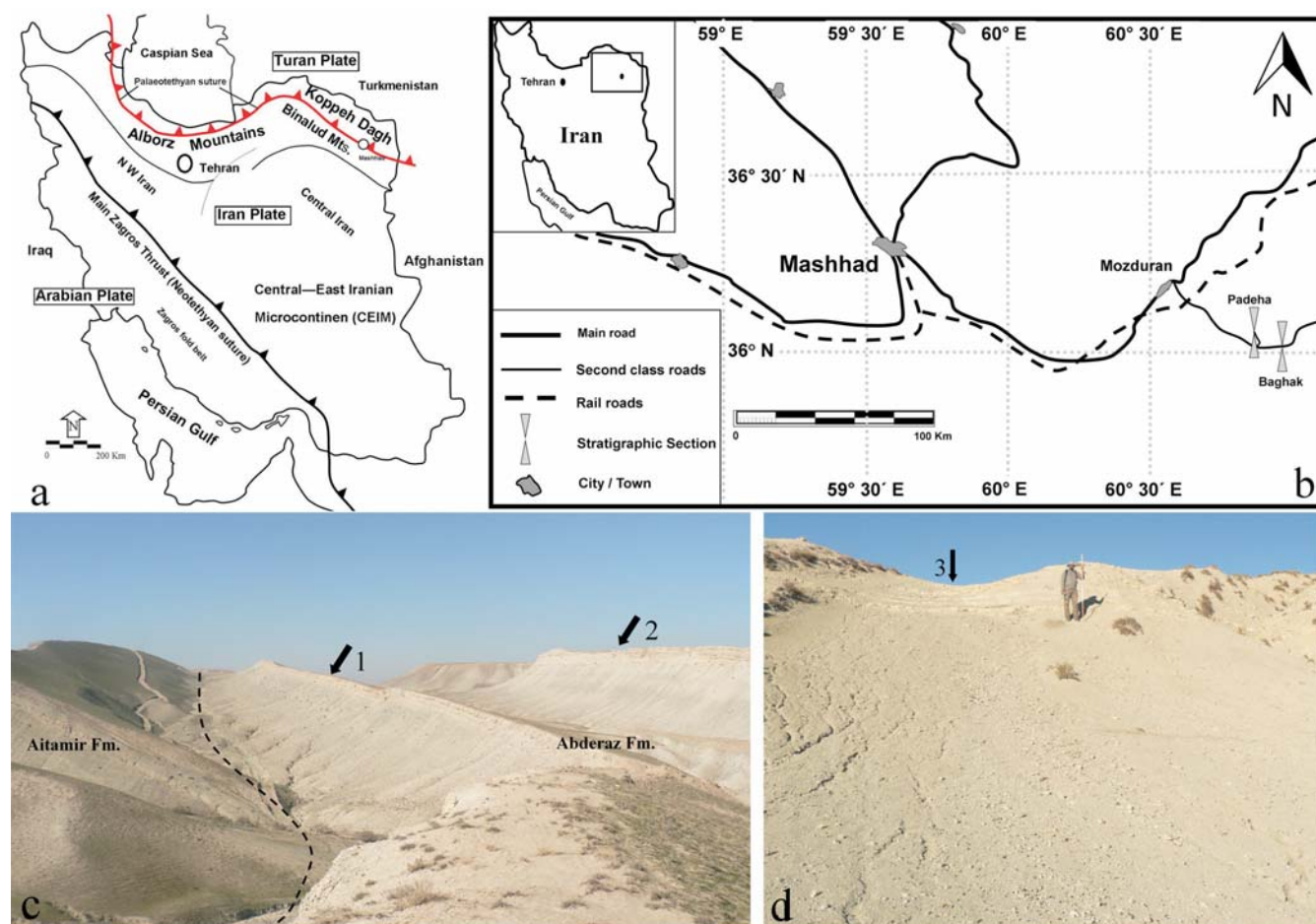
INTRODUCTION

The Koppeh-Dagh Basin is located in northeastern Iran and trends on a WNW to ESE axis. This basin extends through northeastern Iran, southwestern Turkmenistan, and northern Afghanistan (text-fig. 1) and was formed after the closure of the Palaeotethys Ocean in the Late Triassic when the Iranian Plate collided with Eurasia (Turan Plate) producing the Cimmerian Mountain chain (Sengör 1990). The Palaeotethys suture is interpreted to lie between the Alborz, Koppeh-Dagh and Binalud mountains in Iran (text-fig. 1, Berberian and King 1981, Alavi 1992, Alavi et al. 1997, Zanchi et al. 2006) and runs south of the Caspian Sea from northwestern to northeastern Iran. This suture separates the Koppeh-Dagh from the Binalud Mountains. After the mid-Jurassic, the Koppeh-Dagh Basin was inundated by an extensive Mesozoic epicontinental sea. The suture reopened during the Middle Jurassic and a strongly subsiding basin system formed in northern Iran (south Caspian and Kashafrud basins; Brunet et al. 2003; Fürsich et al. 2009a, b). The Kashafrud Basin documents the initial rifting stages of the subsequent Koppeh-Dagh Basin that preserves a very thick succession (more than 10 km) of predominantly marine strata ranging from the Middle Jurassic up to the Mio-Pliocene (Afshar-Harb 1994; Robert et al. 2014). During the Cretaceous, deposition remained largely unaffected by major syn-sedimentary tectonics, but local uplifts in response to the regional-scale modifications of plate slab-coupling in the Neotethys subduction zone to the southwest have been noted (Robert et al. 2014).

The Abderaz Formation is one of the major Cretaceous lithostratigraphic units of the Koppeh-Dagh Basin. Everywhere

in the basin along a regional late Cenomanian–early Turonian disconformity (Afshar-Harb 1994; Mousavinia and Wilmsen 2011), the Abderaz Formation unconformably overlies the glauconite-bearing sandstone and shales of the Aitair Formation (Shafiee Ardestani et al. 2012; Mousavinia et al. 2014) and is in turn overlain conformably and gradationally by softer marls and shales of the Abtalkh Formation. The Abderaz Formation contains highly diverse and abundant micro and macrofossils. Dinoflagellate biostratigraphic analyses together with evaluation of planktonic foraminifera bio-events were conducted in order to precisely date the formation in the present study.

In the section studied, the Abderaz Formation is composed mainly of light grey to greyish white shale and marls with three chalky limestone beds. Due to tectonic activity and the frequency of faulting in the eastern Koppeh-Dagh Basin, it is not possible to find a complete section at a single locality. Based on surveillance of satellite images and palynologic studies of this section, it has been determined that there are repeated strata in the lowermost layers, most likely due to the frequent faulting in this area. For this reason, we have measured two sections in a structurally complex area and compiled a composite section. The lowermost layers of the Abderaz Formation consisting of light grey shales and marls, were sampled to the north of the village of Baghak, located at 36°4'42½" N and 60°46'6½" E (text-fig. 1) where sampling continued to the top of the second chalky limestone bed. The second locality, the Padeha section, is located some 4 km to the west of Baghak and includes the interval above the second chalky limestone up to the top of the formation. The formation has a total thickness of 359 meters in the Padeha-Baghak composite section



TEXT-FIGURE 1

a, Structural and geographic framework of Iran. The suture between Iran and Turan plates is indicated by the red line. Modified from Wilmsen, et al. (2009); b, Location map of the studied section. c, d, field aspects of the Abderaz Formation in Baghak (c) and Padeha (d), black arrows indicate positions of chalky limestones.

The Abderaz Formation has previously been subdivided biostratigraphically using macrofossils (e.g. Tavakoli 2009; Keshavarz 2012; Noorbakhsh Razmi et al. 2013), foraminifera (Kalantari 1969; Vahidinia and Aryai 1998; Foroghi 2004; Bakhshandeh and Khosro-Tehrani 2009; Shafiee Ardestani et al. 2011, 2012, 2013; Vahidinia et al. 2014) and calcareous nannoplankton (Karami 1999) and dinoflagellate cyst assemblages were discussed by Allameh and Moradian (2010), and Yousefi-Moghadam et al. (2015), (text-fig. 2).

Planktonic foraminifera and dinoflagellate cysts have previously been reported from Upper Cretaceous strata in NE Iran, including from the Abderaz Formation in the Koppeh-Dagh Basin (e.g., Vahidinia and Aryai 1998; Allameh and Moradian 2010; Bakhshandeh and Khosro-Tehrani 2009; Yousefi-Moghadam et al. 2015; Shafiee Ardestani et al. 2012, 2013; Vahidinia et al. 2014). Based on Shafiee Ardestani et al. (2012) an early Turonian to earliest Campanian age has been assigned to the Abderaz Formation in the Padeha section. However, the biostratigraphic results have always been controversial and as a result, different ages have been variously assigned to the formation at different times. Due to the importance of the Abderaz

Formation in the Koppeh-Dagh Basin, and also to shed light on some of the discrepancies, we decided to compare dinoflagellate assemblages to established foraminiferal biozonations in order to establish a dinocyst biozonation for use in the region. We compare the palynomorphs from the Abderaz Formation to dinocyst assemblages from New Zealand and Australia because of the similarity in assemblages and because of the proximity of the basins at the time of deposition (Allameh and Ghasemi Nejad 2015) (text-fig. 7).

The purpose of this paper is to correlate the dinocyst and planktonic foraminiferal biostratigraphy of the Baghak-Padeha composite section of the Abderaz Formation in the Koppeh-Dagh Basin, NE Iran. We attempt to show that dinocyst biozonations from New Zealand and Australia can be used.

The section studied for this purpose is near Mozduran road (ca 90 km southeast of Mashhad) in the eastern Koppeh-Dagh Basin (text-fig. 1).

MATERIAL AND METHODS

Fifty-five rock samples were selected for palynologic analysis and 126 for foraminiferal studies. Of the 55 rock samples pre-

Age				Macrofossils				Foraminifera				Nanno.	Dinoflagellate	This study	
Turonian				Coniacian				Santonian				Campanian			
early	mid.	late		early	mid.	late		early	mid.	late		early	mid.	late	
Tavakoli 2009, Abderaz Fm. (Hamam-Ghale section)				Keshavarz 2012, Abderaz Fm. (Sheikh section)				Vahidinia and Aryai 1998, Abderaz Fm. (eastern Koppeh-Dagh)				Noorbakhsh et al. 2013, Abderaz Fm. (Ghaleh-Zoo section)			
Vahidinia 1994, Abderaz Fm. (Muzduran section)				Foroghi 2004, Abderaz Fm. (NE Mashhad)				Bakhshandeh and Khosro-Tehrani, 2009 Abderaz Fm. (Mozdoran section)				Shafiee et al. 2012, Abderaz Fm. (Padeha section)			
Shafiee et al. 2013, Abderaz Fm. (Mazdavad section)				Vahidinia et al. 2014, Abderaz Fm. (Shorab section)				Karami 1999, Abderaz Fm. (Taherabad section)				Allameh and Moradian and 2010, Abderaz Fm. (Hamam-Ghale Section)			
Yousefi-Moghadam et al. 2015 Abderaz Fm. (Sangane section)				Foraminifera				Abderaz Fm. (Padeha-Baghak composite section)				Abderaz Fm. (Padeha-Baghak composite section)			

TEXT-FIGURE 2

Age determination for the Abderaz Formation based on planktonic foraminifera and dinoflagellate cysts and comparison with the existing ages gained from macrofossils, foraminifera, nannofossils and dinoflagellate cysts.

pared for palynologic analysis, 53 were rich in palynomorphs (dinoflagellate cysts, spores and pollen grains). The samples consist predominantly of shale, marl and calcareous marls and were prepared at the Department of Geology of the Ferdowsi University of Mashhad, Iran, where the slides are also housed.

Palynological preparation procedures followed those of Traverse (1988). The first stage of preparation of all palynology samples was the removal of carbonate and silicate material using HCL and HF acid, then sieving the resultant residues with a 200 μm and 20 μm nylon mesh, respectively. The organic residues were separated using zinc chloride (ZnCl_2) to concentrate palynomorphs, and four or five slides were prepared from each sample. The slides were examined and palynological assemblages were identified. Dinoflagellate cysts are the most abundant palynomorphs found in most samples.

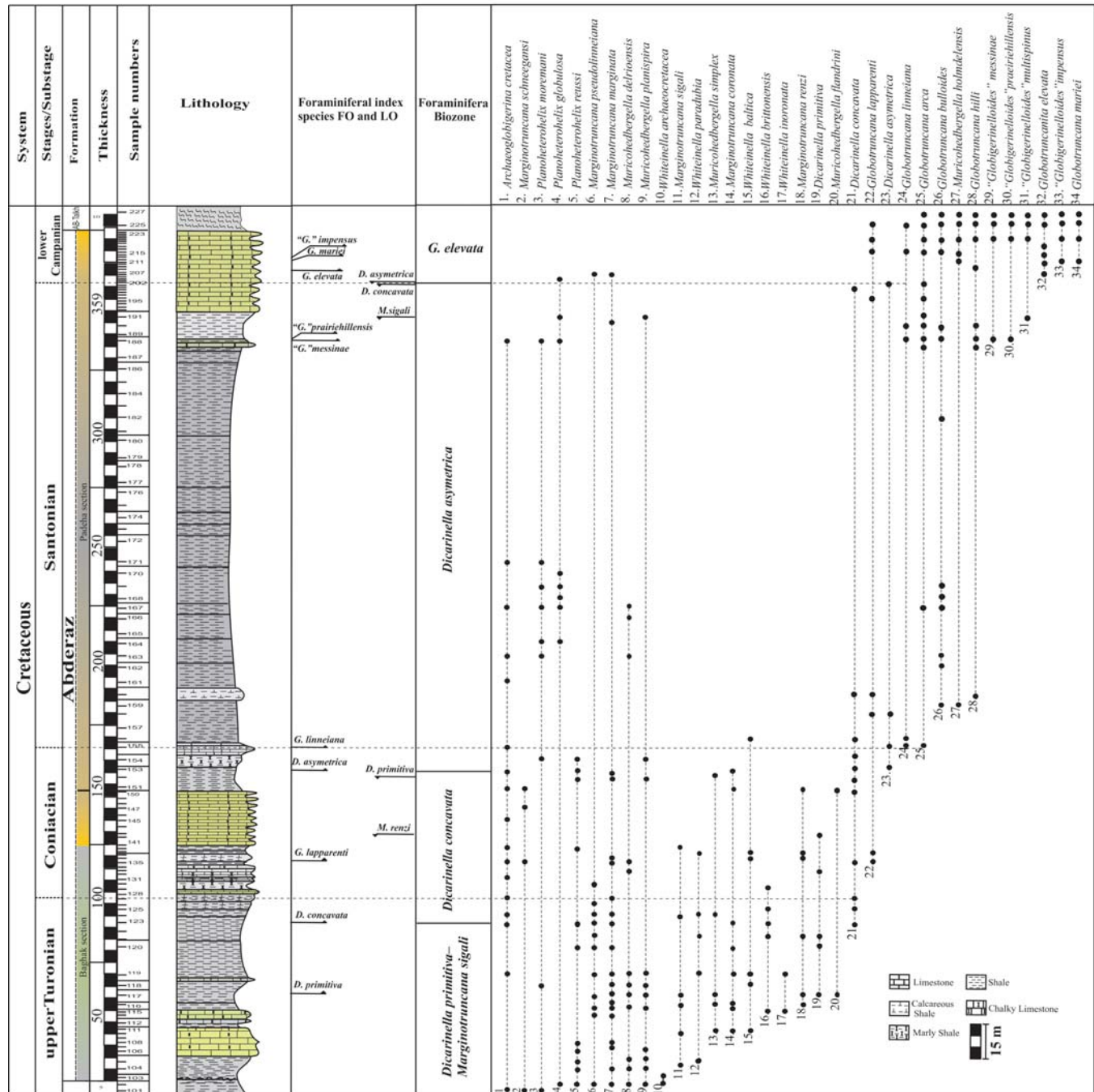
For foraminiferal studies, samples from shale and marl layers were selected and placed in 10% H₂O₂ for one day in order to breaking down more resistant samples. All samples were washed over a 63 µm sieve, and separated into 63–125 µm and

125–250 μm fractions. All specimens were picked, identified and housed in sample cells for permanent storage.

The preservation and diversity of the dinoflagellate cysts is good to very good in the studied samples. The recorded assemblages and the first and last occurrences of index forms allowed for differentiation of the strata into distinct biozones (text-fig. 7) and confirmed a late Turonian to early Campanian age for the formation.

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

Planktonic foraminifera are abundant and diverse in most of the samples studied. The well-preserved assemblages recorded here allowed application of standard Tethyan zonation schemes established by Premoli Silva and Bolli (1973), Caron (1985), Premoli Silva and Sliter (1999), Premoli Silva and Verga (2004), Haynes et al. (2015) and Coccioni and Premoli Silva (2015). Four biozones (*Dicarinella primitiva*–*Marginotruncana sigali* Partial Interval Zone, *Dicarinella concavata* Interval Zone, *Dicarinella asymmetrica* Total Range Zone and *Globotruncanella elevata* Interval Zone) were identified that confirm a late Turonian to early Campanian age for the formation (text-figs 3, 5 and 6). The key



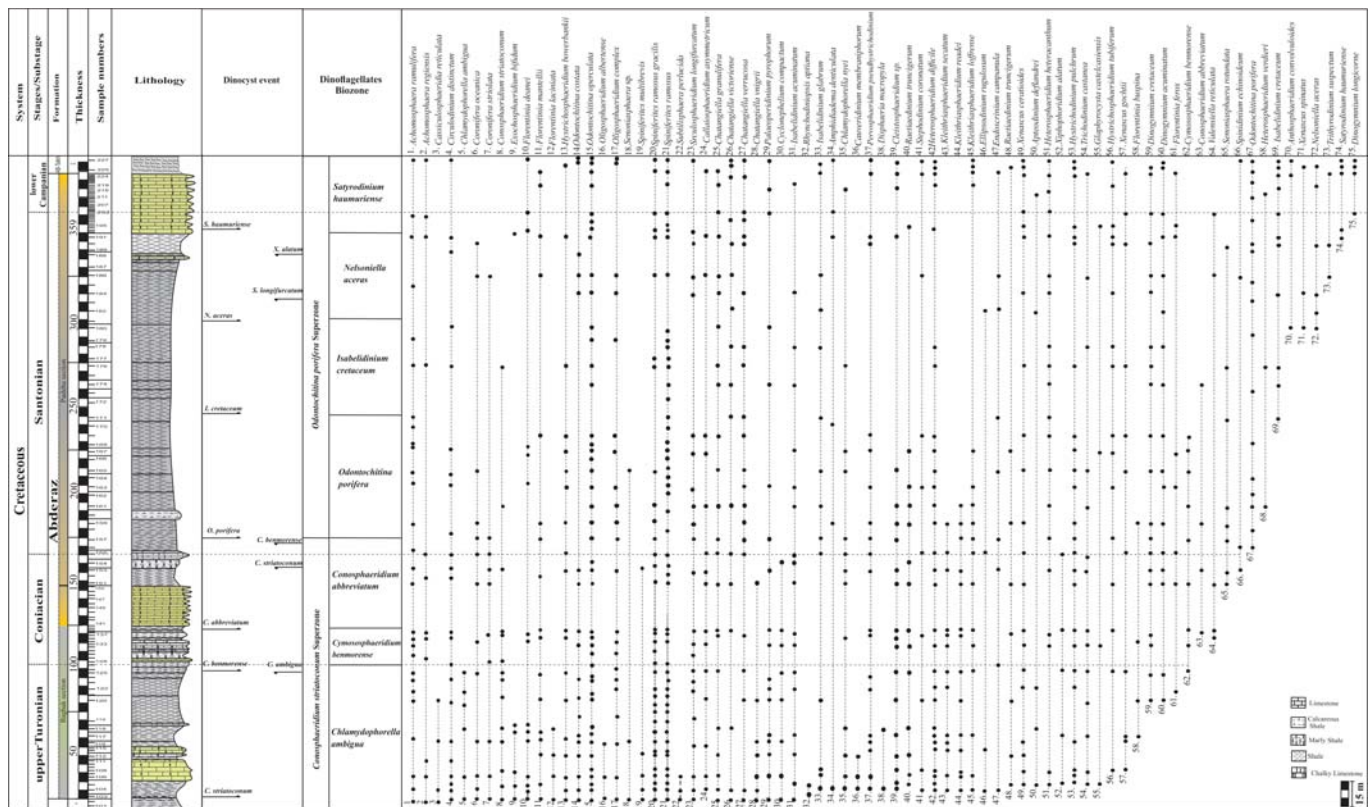
TEXT-FIGURE 3
Distribution of foraminifera in the Abderaz Formation, Baghak-Padeha composite section, NE Koppeh-Dagh Basin. As there are no obvious foraminiferal proxies being used for the Turonian-Coniacian boundary it is based on inoceramid evidence.

species were imaged using a scanning electron microscope (Zeiss (LEO) 1450VP) and illustrated in text-figures 8 and 9. The zonation recorded is summarized below.

Dicarinella primitiva–*Marginotruncana sigali* Partial range Zone of Premoli Silva and Verga 2004 and Coccioni and Premoli Silva 2015

Age. Late Turonian.

Definition. The base of this zone is traditionally defined by the last occurrence (LO) of *Helvetoglobotruncana helvetica* and continues up to the first occurrence (FO) of *Dicarinella concavata* Premoli Silva and Verga (2004), Coccioni and Premoli Silva (2015). As *H. helvetica* is absent in the lower part



TEXT-FIGURE 4

Distribution of dinoflagellate cyst in the Aberdaz Formation, Baghak-Padeha composite section, NE Koppeh-Dagh Basin.

of the formation, this Partial range Zone appears to initiate in the upper part of the underlying Aitamir Formation. The base of this zone is defined here by the occurrence of *Marginotruncana sigali* (Reichel) in our study succession. This indicates an age not older than late Turonian for the lowest studied sample. We recorded the FO of *Dicarinella concavata* at 65 m (sample 122) from the base of the section. This interval range Zone spans samples 103 to 122 (1–65 m). The FO of *Dicarinella primitiva* appears at 60 m (sample 118) from the base of the section a level that indicates an age of late Turonian–early Coniacian (Dimitrova and Valchev 2007).

Associations. The accompanied species recorded in this interval Zone are as follows:

Archaeoglobigerina cretacea, *Dicarinella primitiva*, *Marginotruncana coronata*, *Marginotruncana marginata*, *Marginotruncana pseudolinneiana*, *Marginotruncana sigali*, *Marginotruncana renzi*, *Marginotruncana schneegansi*, *Muricohedbergella delrioensis*, *Muricohedbergella flandrini*, *Muricohedbergella planispira*, *Muricohedbergella simplex*, *Planoheterohelix globulosa*, *Planoheterohelix reussi*, *Whiteinella baltica*, *Whiteinella brittonensis*, *Whiteinella inornata* and *Whiteinella paradubia*.

The first occurrences of *A. cretacea*, *D. primitiva*, *P. globulosa* and *P. reussi* are recorded in this zone.

Dicarinella concavata Interval Zone of Sigal (1955), Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015)

Age. Late Turonian– through late Coniacian

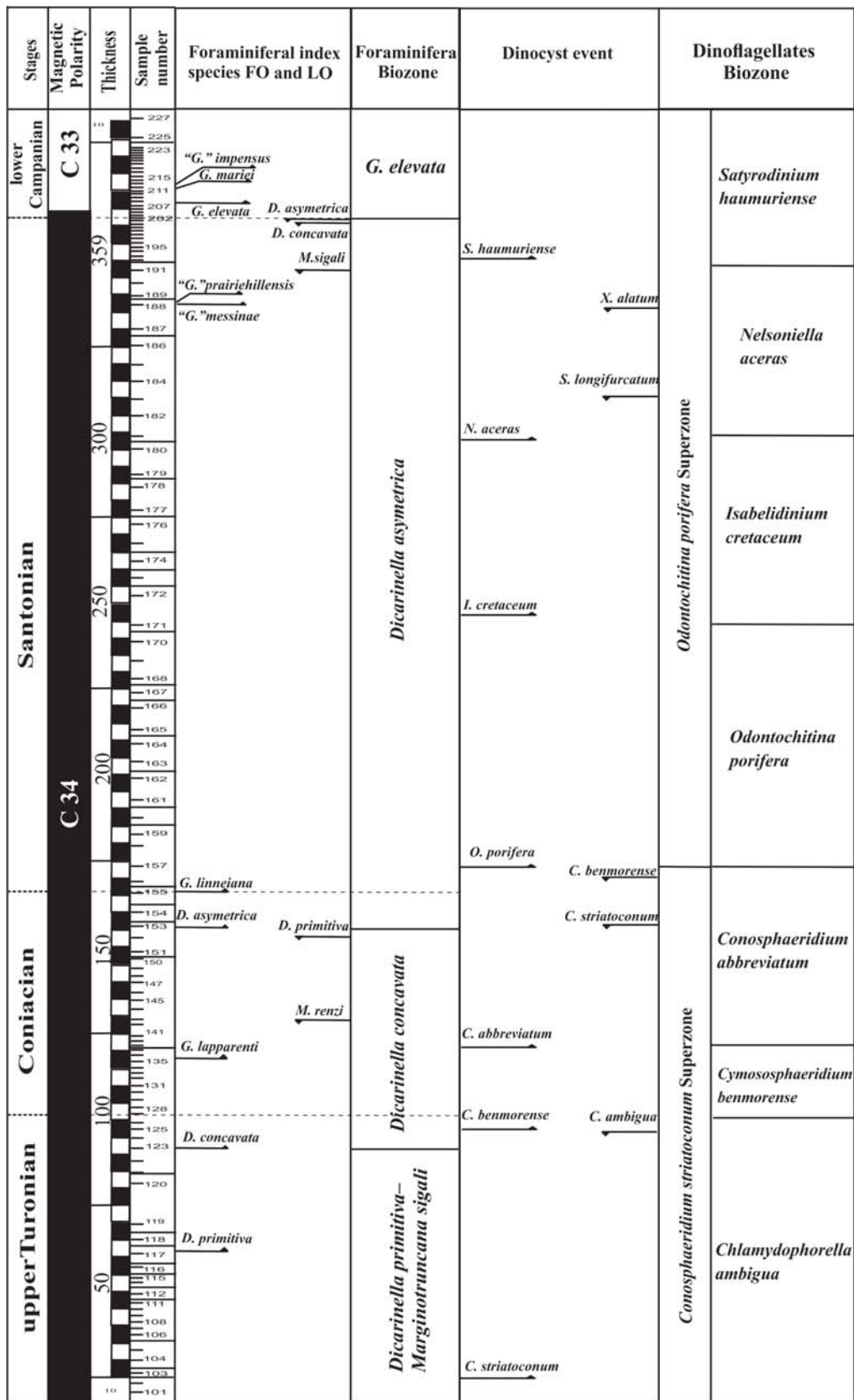
Definition. The base of this zone is defined by the FO of *Dicarinella concavata* and continues up to the FO of *Dicarinella asymetrica* (Caron 1985) and encompasses the 66 m from the base of the section to 135 m. This zone has been reported from the Tethyan realm by Wonders (1980), Premoli Silva and Verga (2004) and Coccioni and Premoli Silva (2015) (text-fig. 6).

Associations. The accompanying species recorded in this interval zone are as follows:

A. cretacea, *Contusotruncana fornicata*, *D. concavata*, *D. primitiva*, *Globotruncana lapparenti*, *M. coronata*, *M. marginata*, *M. pseudolinneiana*, *M. sigali*, *M. renzi*, *M. pseudolinneiana*, *M. delrioensis*, *M. flandrini*, *Muricohedbergella holmdelensis*, *M. planispira*, *M. simplex*, *P. globulosa*, *P. reussi*, *W. baltica*, *W. brittonensis* and *W. paradubia*.

The first occurrence of *D. concavata* *C. fornicata*, *G. lapparenti* is recorded in this zone.

The Turonian/Coniacian boundary is not clearly specified based on foraminifera in general. Kauffman et al. (1996), Walaszczyk and Wood (1998), Walaszczyk and Cobban (2000), Walaszczyk et al. (2010), and Ifrim et al. (2014) used index inoceramids (specifically the FO of *Cremonoceras deformis erectus*) to mark the base of the Coniacian. In this study, the Turonian/Coniacian boundary is identified in the inoceramid-bearing layer in Sample 128, 82 m from the base of the section (text-fig. 10).



TEXT-FIGURE 5
Summarized foraminiferal and dinocyst biozonation established for the Baghak-Padeha section, Eastern Koppeh-Dagh, Northeast of Iran, Magnetic Polarity from GSSP, 2014 (Lamolda et al. 2014).

Age	Planktonic foraminifera Zonation							
	Wonders 1980 (Western)	Caron 1985 (Generalized)	Robaszynski & Caron 1995 (Paris Basin)	Premoli & Silva & Verga 2004 (Generalized)	Dimitrova & Valchev 2007 (Bulgaria)	Shafiee Ardestani et al. 2012 (NE Iran)	Coccioni & Premoli Silva 2015 (Italy)	This study (NE Iran)
early Campanian	<i>G. elevata</i>	<i>G. elevata</i>	<i>G. elevata</i>	<i>G. elevata</i>	<i>G. elevata</i>	<i>Dicarinella asymetrica</i>	<i>G. elevata</i>	<i>G. elevata</i>
Santonian	<i>G. carinata</i>	<i>D. asymetrica</i>	<i>D. asymetrica</i>	<i>Dicarinella asymetrica</i>	<i>Dicarinella asymetrica</i>		<i>Dicarinella asymetrica</i>	<i>Dicarinella asymetrica</i>
	<i>D. concavata</i>	<i>D. concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>
Coniacian	<i>Dicarinella primitiva</i>	<i>D. concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>	<i>Dicarinella primitiva</i>	<i>M. shneegansi</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>
		<i>Dicarinella primitiva</i>	<i>Dicarinella concavata</i>	<i>Dicarinella concavata</i>			<i>D. primitiva - M. sigali</i>	<i>D. primitiva - M. sigali</i>
late Turonian	<i>M. sigali</i>	<i>M. sigali</i>	<i>M. shneegansi</i>	<i>M. sigali - D. primitiva</i>	<i>M. shneegansi</i>	<i>M. shneegansi</i>	<i>D. primitiva - M. sigali</i>	<i>D. primitiva - M. sigali</i>
middle Turonian	<i>H. helvetica</i>	<i>H. helvetica</i>	<i>H. helvetica</i>	<i>H. helvetica</i>	<i>M. renzi + M. sigali</i>	<i>H. helvetica</i>	<i>H. helvetica</i>	—

TEXT-FIGURE 6

Correlation of the Planktonic foraminifera biozones recognized in the Abderaz Formation with those identified primarily in the Tethys domain.

Dicarinella asymetrica Total Range Zone of Postuma (1971) Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015)

Age. Latest Coniacian through Santonian

Definition. The base of this zone is defined by the FO of *D. asymetrica* and continues up to the LO of *D. asymetrica*, which corresponds to the interval between 136 m to 340 m from the base of the formation. This zone was documented previously in the Tethyan realm (Robaszynski and Caron (1995), Premoli Silva and Verga (2004), Coccioni and Premoli Silva (2015) (text-fig. 6).

Associations. The accompanying species recorded in this interval zone are as follows:

A. cretacea, *D. asymetrica*, *D. concavata*, *Globotruncana arca* (FO in this zone), *Globotruncana linneiana*, *G. lapparenti*, *Globotruncana bulloides*, “*Globigerinelloides*” *bolli*, “*Globigerinelloides*” *prairiehilleinsis*, “*Globigerinelloides*” *messinae*, *M. coronata*, *M. marginata*, *M. pseudolinneiana*, *M. sigali*, *M. renzi*, *M. flandrini*, *M. delrioensis*, *M. planispira*, *M. simplex*, *P. globulosa*, *P. reussi*, *W. inornata* and *W. baltica*.

The first occurrence of *G. bulloides*, *G. linneiana*, “*G.*” *prairiehilleinsis*, “*G.*” *messinae* and the last occurrence of *D. asymetrica* and *D. concavata* (LO end of this zone) is recorded in this zone.

The Coniacian/Santonian boundary can be approximated by using LO of *G. linneiana* (Lamolda et al. 2007; 2014). This species is recognized in sample 155, 135 m from the base of the section.

***Globotruncana elevata* Interval Zone Coccioni and Premoli Silva 2015**

Age. Santonian/Companian boundary though early Campanian

Definition. The base of this zone is defined by the LO of all *Dicarinella* species and continues up to the FO of *Contusotruncana plummerae* and encompasses the interval between 341 m to 359 m. This zone was recognized previously in the Tethyan realm by Robaszynski and Caron (1995), Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015).

Associations: The accompanying species recorded in this interval zone are as follows:

G. arca, *G. bulloides*, *G. linneiana*, *G. lapparenti*, *Globotruncana hilli*, *Globotruncana elevata* (FO in this zone), *Contusotruncana morozovae*, “*G.*” *prairiehilleinsis*, “*Globigerinelloides*” *impensus*, “*G.*” *messinae*, “*Globigerinelloides*” *multispinus*, *Planoheterohelix moremani*, *P. globulosa*, *M. pseudolinneiana* (LO in this zone), *M. delrioensis* and *Muricohedbergella holmdelensis*.

The Santonian/Campanian boundary is not clearly specified but it can be determined based on the extinction of all species of *Dicarinella* (Premoli Silva and Sliter 1995, Petrizzo et al. 2011).

Age	Dinoflagellates Zonation					
	Wilson 1984 (New Zealand)	Helby et al. 1987 (Australian)	SchiÖler & Wilson 1998 (New Zealand)	Cooper 2004 (New Zealand)	Allameh and Moradian 2010 (Iran)	This study (Iran)
early Campanian	<i>Odontochitina porifera</i>	<i>X. australis</i>	<i>S. haumuriense</i>	<i>S. haumuriense</i>	<i>Odontochitina porifera</i> <i>I. cretaceum</i> <i>O. porifera</i>	<i>S. haumuriense</i>
late Santonian		<i>I. cretaceum</i>	<i>Odontochitina porifera</i> <i>I. cretaceum</i>	<i>N. aceras</i>		<i>N. aceras</i>
middle Santonian				<i>I. cretaceum</i>		<i>I. cretaceum</i>
early Santonian		<i>O. porifera</i>	<i>O. porifera</i>	<i>O. porifera</i>		<i>O. porifera</i>
late Coniacian	<i>Conosphaeridium striatoconum</i>	<i>Conosphaeridium striatoconum</i>	<i>C. abbrevia-</i>	<i>C. abbreviatum</i>	<i>Conosphaeridium striatoconum</i>	<i>C. abbreviatum</i>
early Coniacian			<i>C. benmoren-</i>	<i>C. benmorense</i>		<i>C. benmorense</i>
late Turonian			<i>C. ambigua</i>	<i>C. ambigua</i>		<i>C. ambigua</i>

TEXT-FIGURE 7

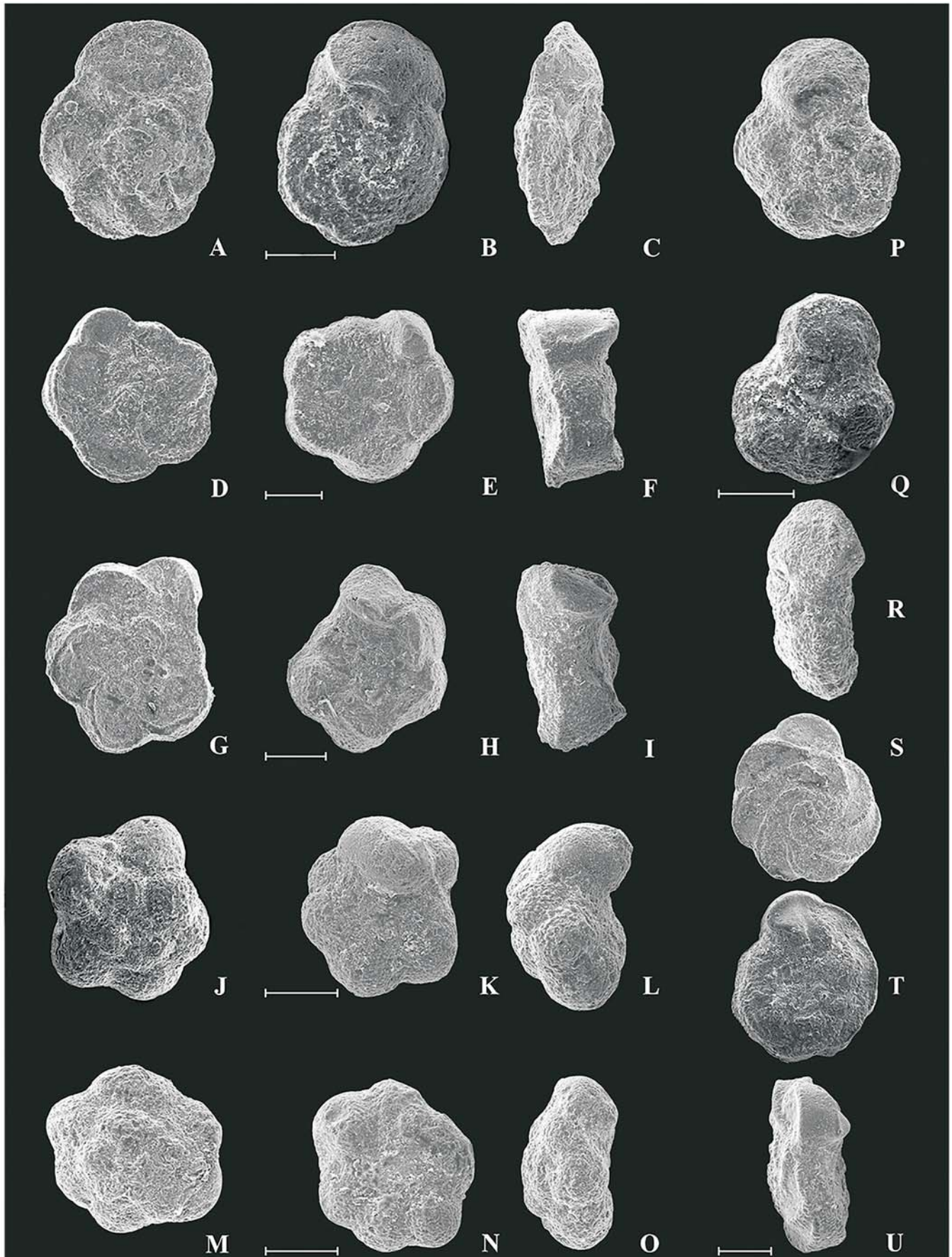
Dinoflagellate cyst zonation scheme erected for the Abderaz Formation and correlation with those erected for, New Zealand and Australia.

TEXT-FIGURE 8

Scale bar = 200 µm.

A,B,C *Dicarinella primitiva* (Dalbiez 1955), sample no. 117;
D,E,F *Dicarinella asymetrica* (Sigal 1952), sample no. 153;
G,H,I *Dicarinella asymetrica* (Sigal 1952) sample no. 153;
J,K,L *Whiteinella brittonensis* (Loeblich and Tappan 1961),
sample no. 115;

M,N,O *Whiteinella paradubia* (Sigal 1952), sample no. 105;
P,Q,R *Whiteinella inornata* (Bolli 1957), sample no. 115;
S,T,U *Marginotruncana coronata* (Bolli 1945), sample no.
111.



This extinction occurs in Sample 202, 336 m from the base of the section.

DINOFLAGELLATE CYST BIOSTRATIGRAPHY

Late Cretaceous dinoflagellate cyst zonations have been proposed for parts of New Zealand, Australia, Iceland, and England by various researchers (e.g., Wilson 1984; Helby et al. 1987; Schiøler 1992; Schiøler and Wilson 1998; Roncaglia and Schiøler 1997; Roncaglia et al. 1999; Riding et al. 1992; Riding and Crame 2002; Crampton et al. 2000; 2001; Schiøler et al. 2001a; 2001b; Raine and Schiøler 2012). As there are few studies of dinocysts from the Middle East (for example: Schrank & Ibrahim 1995; Deaf et al. 2014) and there are many similarities between our dinocysts and those are from New Zealand and Australia, in this study, the dinoflagellate assemblages from Iran were compared and correlated with the Upper Cretaceous dinoflagellate zonations from New Zealand (Wilson 1984; Schiøler and Wilson 1998; Roncaglia et al. 1999) and Australia (Helby et al. 1987). Our comparison and correlation resulted in recognition of two superzones and seven interval zones. The superzones are the *Conosphaeridium striatoconum* superzone of late Turonian–Santonian age and the lower part of the *Odontochitina porifera* superzone of Santonian–early Campanian age according to Helby et al. (1987), Wilson (1984) and Schiøler and Wilson (1998). The zonation scheme is discussed below (text-figs 4, 5, 7, 11 and 12).

Conosphaeridium striatoconum Interval Superzone of Schiøler and Wilson 1998

This interval superzone has been subdivided into three dinoflagellate cyst zones (*Chlamydomorphella ambigua* Interval Zone, *Cymosphaeridium benmoreense* Interval Zone, and *Conosphaeridium abbreviatum* Interval Zone) by Schiøler and Wilson (1998). The two key dinoflagellate events, the first occurrence of *Conosphaeridium striatoconum* and FO of *Odontochitina porifera*, define the base and top of this superzone, respectively. The base of this superzone correlates with the base of the formation and spans 150 m of section.

Based on planktonic foraminifera, deposition of the Abderaz Formation began in the late Turonian and this is corroborated

by the presence of *Conosphaeridium striatoconum* (Deflandre and Cookson 1955) in the lowermost samples. Thus, in the Koppeh-Dagh region, the base of this superzone is similar to what is recorded from New Zealand.

Age. Late Turonian– early Santonian

This superzone is correlated to the planktonic foraminiferal *Dicarinella primitiva*–*Marginotruncana sigali* and *Dicarinella concavata* interval zones.

Chlamydomorphella ambigua Interval Zone of (Deflandre 1937) Stover and Helby 1987

Age. Late Turonian to middle Coniacian

Definition. The base of this zone is defined by the FO of *C. striatoconum* (Deflandre and Cookson 1955) and continues up to the last occurrence of *Chlamydomorphella ambigua* (Deflandre 1937), (Stover and Helby 1987). This interval zone spans samples 103 to 125 (5–75 m). *Chlamydomorphella ambigua* was recorded from the late Turonian to middle Coniacian in New Zealand by Schiøler and Wilson (1998) and Raine and Schiøler (2012) and in Australia by Helby et al. (1987) and McMinn (1988). In the eastern Koppeh-Dagh Basin we recorded this zone from the late Turonian (text-fig. 7).

Associations. Additional species recorded in this interval zone include:

C. striatoconum, *Cauveridinium membraniphorum*, *Florentina laciniata*, *Heterosphaeridium difficile*, *Isabelidinium glabrum*, *Isabelidinium acuminatum*, *Isabelidinium cooksoniae*, *Chatangiella victoriense*, *Chatangiella verrucosa*, *Chatangiella granulifera*, *Xenascus gochti* and *Stephodinium coronatum*.

This Interval Zone is correlated with the *Dicarinella primitiva*–*Marginotruncana sigali* Partial range Zone and lowermost part of the planktonic foraminiferal *Dicarinella concavata* Interval Zone.

TEXT-FIGURE 9 Scale bar = 200 µm.

A,B,C cf. *Marginotruncana pseudolinneiana* (Pessagno 1967) sample no. 102;

D,E,F *Marginotruncana renzi* (Gandolfi 1942), sample no.116;

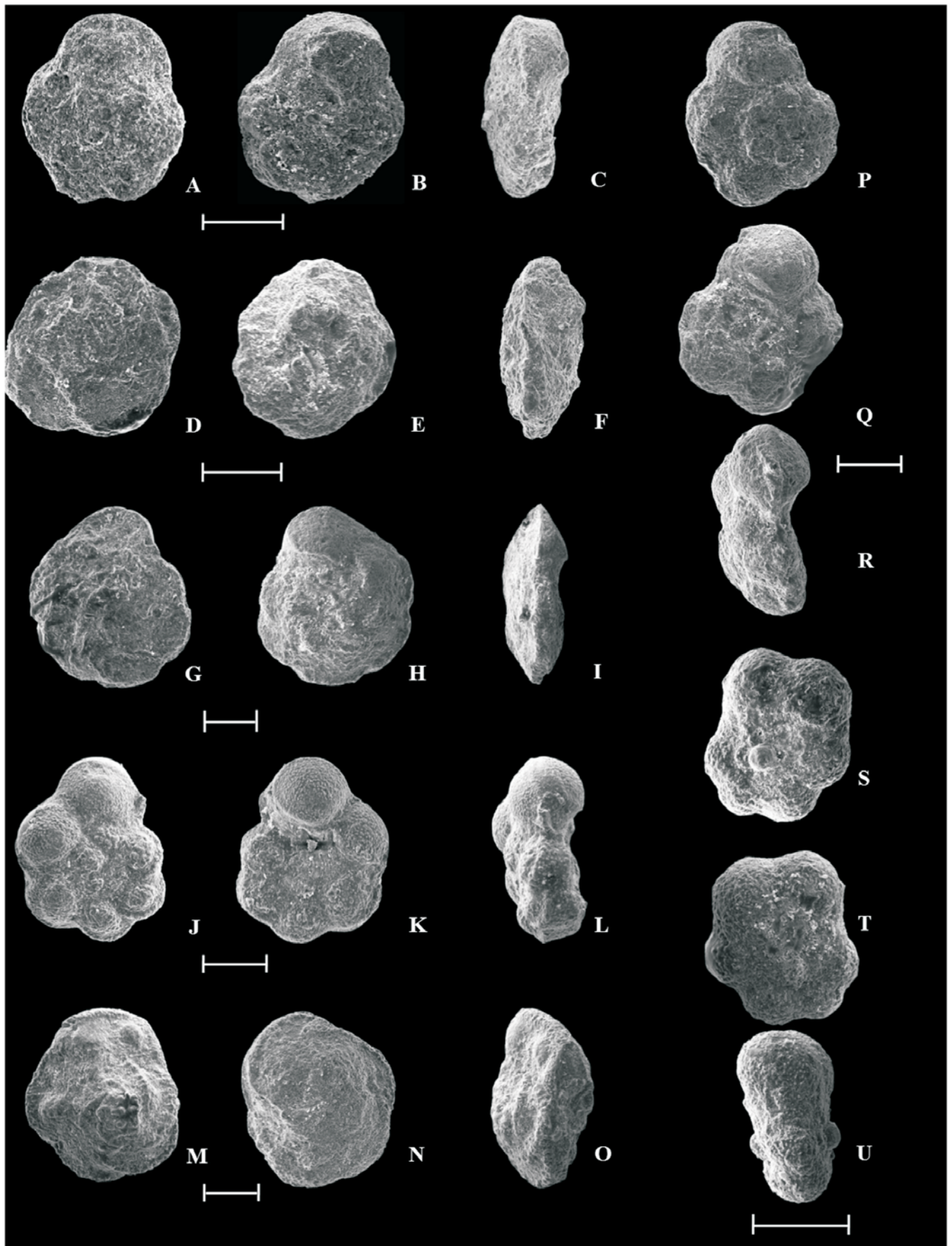
G,H,I *Marginotruncana sigali* (Reichel 1950), sample no.116;

J,K,L *Globotruncana bulloides* (Vogler 1941), sample no.159;

M,N,O *Contusotruncana morozovae* (Vasilenko 1961) sample no. 210;

P,Q,R *Archaeoglobigerina cretacea* (d'Orbigny 1840), sample no. 101;

S,T,U “*Globigerinelloides*” *prairiehillensis* (Pessagno 1967) sample no. 191.



***Cymosphaeridium benmorense* Interval Zone of Schiøler and Wilson 1998**

Age. Middle Coniacian

Definition. The base of this zone is defined by the LO of *C. ambigua* and continues up to the FO of *Conosphaeridium abbreviatum*. This zone is from samples 126 to 137 (76 to 95 m) and is 19 m thick. *Cymosphaeridium benmorense* was recorded from the middle Coniacian of New Zealand by Schiøler and Wilson (1998), and Raine and Schiøler (2012) (text-fig. 7).

Associations. Accompanying species recorded in this interval zone include:

Chlamydophorella nyei, *C. striatoconum*, *Cyclonephelium compactum*, *Odontochitina costata*, *Dinogymnium* sp., *H. difficile*, *I. glabrum*, *Florentinia buspina*, *Kleithriasphaeridium readii*, *Kleithriasphaeridium secatum*, *Kleithriasphaeridium tubulosum*. This interval zone correlates to the middle part of the planktonic foraminiferal *Dicarinella concavata* Interval Zone.

***Conosphaeridium abbreviatum* Interval Zone of Schiøler and Wilson 1998**

Age. Late Coniacian to early Santonian

Definition. The base of this zone is defined by the FO of *C. abbreviatum* (Wilson 1984) and continues up to the FO of *O. porifera* (Cookson 1956). This zone encompasses 54 m of the Abderaz Formation, from 96 m to 150 m (samples 138–157). This interval zone was recorded from the late Coniacian to early Santonian of New Zealand. *Conosphaeridium abbreviatum* was recorded from the late Coniacian of New Zealand by Schiøler and Wilson (1998) and Raine and Schiøler (2012) (text-fig. 7).

Associations. Further species recorded in this interval zone include:

Cymosphaeridium benmorense, *C. striatoconum*, *K. readii*, *K. secatum* and *K. tubulosum*, *Senoniasphaera rotundata*, *Spinidinium echinoideum*.

This interval zone can be correlated with the uppermost part of the planktonic foraminiferal *Dicarinella concavata* Interval Zone.

***Odontochitina porifera* Interval Superzone of Schiøler and Wilson 1998**

This superzone is defined as the interval between the FO of *O. porifera* and the FO of *Isabelidinium korojonense* and has been divided into four dinoflagellate zones in Australia and New Zealand (viz., the *Odontochitina porifera* Interval Zone, *Isabelidinium cretaceum* Interval Zone, *Nelsoniella aceras* Interval Zone and *Satyrodinium haumuriense* Interval Zone, Wilson 1984; Helby et al. 1987). The major components of this interval superzone have been identified in the Abderaz Formation, but the uppermost parts of the *Odontochitina porifera* Interval Superzone occur in the overlying Ab-Talkh Formation. The base of the superzone is at 151 m from the base of the formation. The superzone *Odontochitina porifera* succeeds the *Conosphaeridium abbreviatum* Zone and extends up to 359 m from the base of the Abderaz Formation (samples 158 to 224).

Age. Early Santonian–early Campanian. This superzone correlates with the planktonic foraminiferal *Dicarinella asymetrica*

Total Range Zone and the *Globotruncanita elevata* Interval Zone.

***Odontochitina porifera* Interval Zone of Helby et al. 1987**

Age. Early Santonian

Definition. The base of this zone is defined by the FO of *O. porifera* and its top is delimited by the FO of *Isabelidinium cretaceum* (Cookson 1956). This zone encompasses 65 m of the Abderaz Formation between 151 m and 215 m (samples 158 to 171). The *Odontochitina porifera* zone was assigned an early Santonian age in Australia by Helby et al. (1987) and in New Zealand by Schiøler and Wilson (1998) (text-fig. 7).

Associations. The accompanying species recorded in this interval zone are as follows:

Amphidiadema denticulata, *C. benmorense*, *C. striatoconum*, *Chatangiella tripartita*, *Chatangiella victoriensis*, *Heterosphaeridium verdieri*, *O. porifera*.

This interval zone can be correlated to the base of the *Dicarinella asymetrica* Total Range Zone of planktonic foraminifera.

***Isabelidinium cretaceum* Interval Zone of Evans 1971**

Age. Middle Santonian–late Santonian.

Definition. The base of this zone is defined by the FO of *I. cretaceum* (Cookson 1956) and the top by the FO of *Nelsoniella aceras* (Cookson and Eisenack 1960b). The zone encompasses 54 m of strata between 216 m and 270 m (samples 172 to 181) and was assigned a middle Santonian–late Santonian age in Australia (Helby et al. 1987) and New Zealand (Schiøler and Wilson 1998; Raine and Schiøler 2012).

Associations. Additional species recorded in this interval zone include:

A. denticulata, *C. benmorense*, *C. striatoconum*, *C. tripartita*, *C. victoriensis*, *O. porifera* and *Valensiella reticulata*.

This interval zone is correlated with the middle part of the planktonic foraminiferal *Dicarinella asymetrica* Total Range Zone.

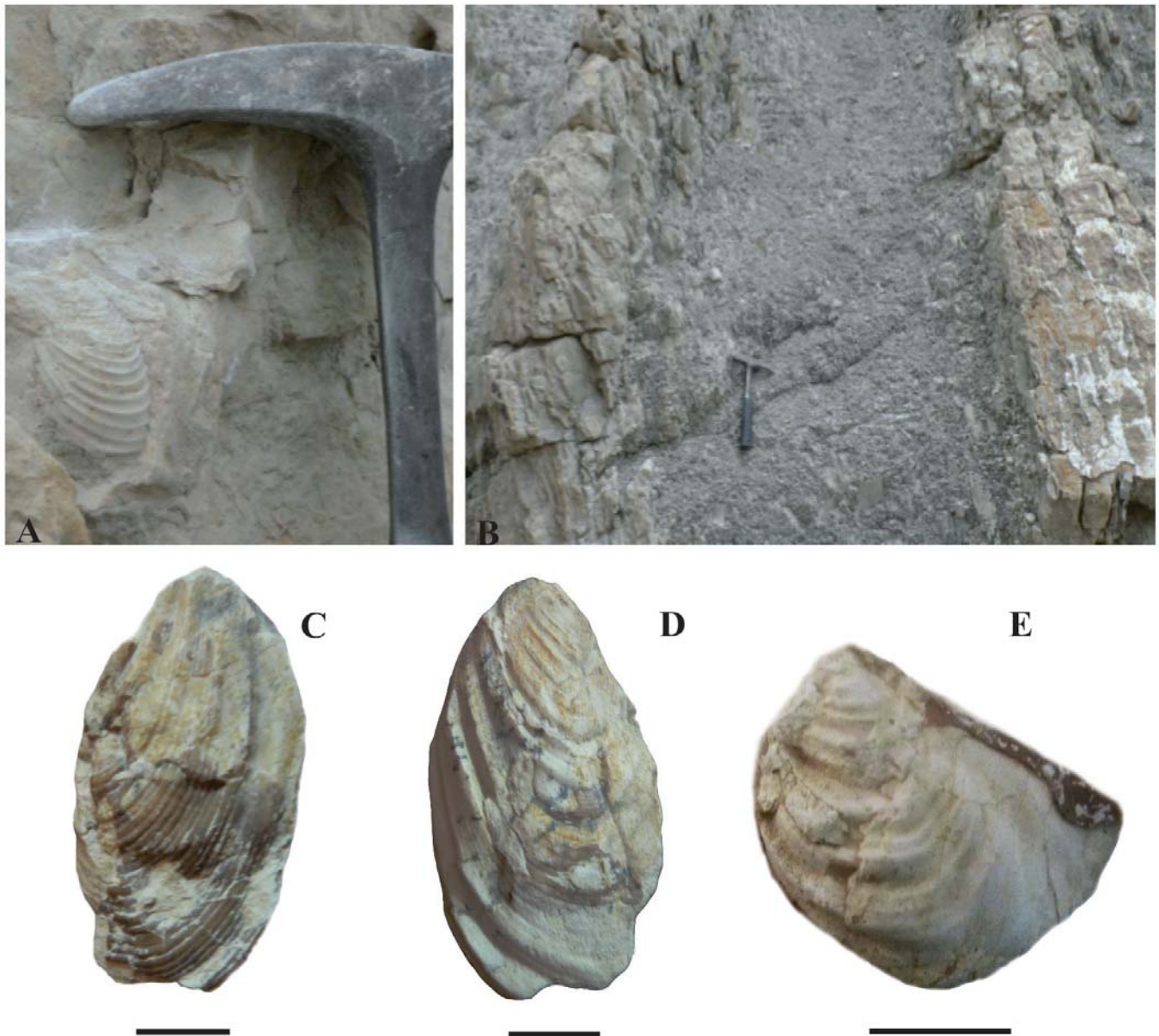
***Nelsoniella aceras* Interval Zone of Evans 1971**

Age. Late Santonian–early Campanian

Definition. The base of this zone is defined by the FO of *N. aceras* (Cookson and Eisenack 1960a) and the top by the FO of *Satyrodinium haumuriense* (Schiøler and Wilson 1998). The zone encompasses 55 m of the Abderaz Formation between 271 m and 325 m (samples 182 to 191). The index species (*N. aceras*) was recorded from upper Santonian–lower Campanian sediments in Australia (Helby et al. 1987) and in New Zealand (Schiøler and Wilson 1998; Raine and Schiøler 2012) (text-fig. 6).

Associations. Other species recorded in this interval zone include:

A. denticulata, *Anthosphaeridium convolvuloides*, *C. tripartita*, *C. victoriensis*, *Dinopterygium alatum*, *Eucladinium* Sp., *I. cretaceum*, *N. aceras*, *O. porifera*, *Spinidinium echinoideum*, *Trithyrodinium suspectum* and *Xenascus spinatus*.



TEXT-FIGURE 10

- A *Inoceramid* in situ, approximately 82 m from the base of the section;
 B *Inoceramid* bearing layer in sample 128, 82 m from the base of the section;

- C,D *Cremonoceramus waltersdorfensis waltersdorfensis* (Andert 1911);
 E *Cremonoceramus deformis erectus* (Meek 1877) scale = 1 cm.

This interval zone is correlated with the uppermost part of the planktonic foraminiferal *Dicarinella asymetrica* Total Range Zone.

***Satyrodinium haumuriense* Interval Zone of Marshall 1990**

Age. Early Campanian.

Definition. The base of this zone is defined by the FO of *Satyrodinium haumuriense* and the top by the FO of *Isabelidinium korojonense*. The index species *I. korojonense* was not recorded in the uppermost beds of the studied section, thus the top of this Interval Zone most likely extends up in to the Ab-Talkh Formation. The interval zone encompasses 34 m of the Abderaz Formation from 326 m to 359 m (samples 192 to 224). This zone has been assigned an early Campanian age in southeastern Australia (Marshall 1990) and New Zealand (Schiøler and Wilson 1998).

Associations. Additional species recorded in this interval zone are as follows:

A. denticulata, *A. convolvuloides*, *Ca. tripartita*, *C. victoriensis*, *D. alatum*, *I. cretaceum*, *N. aceras*, *O. porifera*, *T. suspectum*, *S. haumuriense* and *S. echinoideum*.

This interval zone correlates to the planktonic foraminiferal *Globotruncanita elevata* Interval Zone.

DISCUSSIONS AND CONCLUSIONS

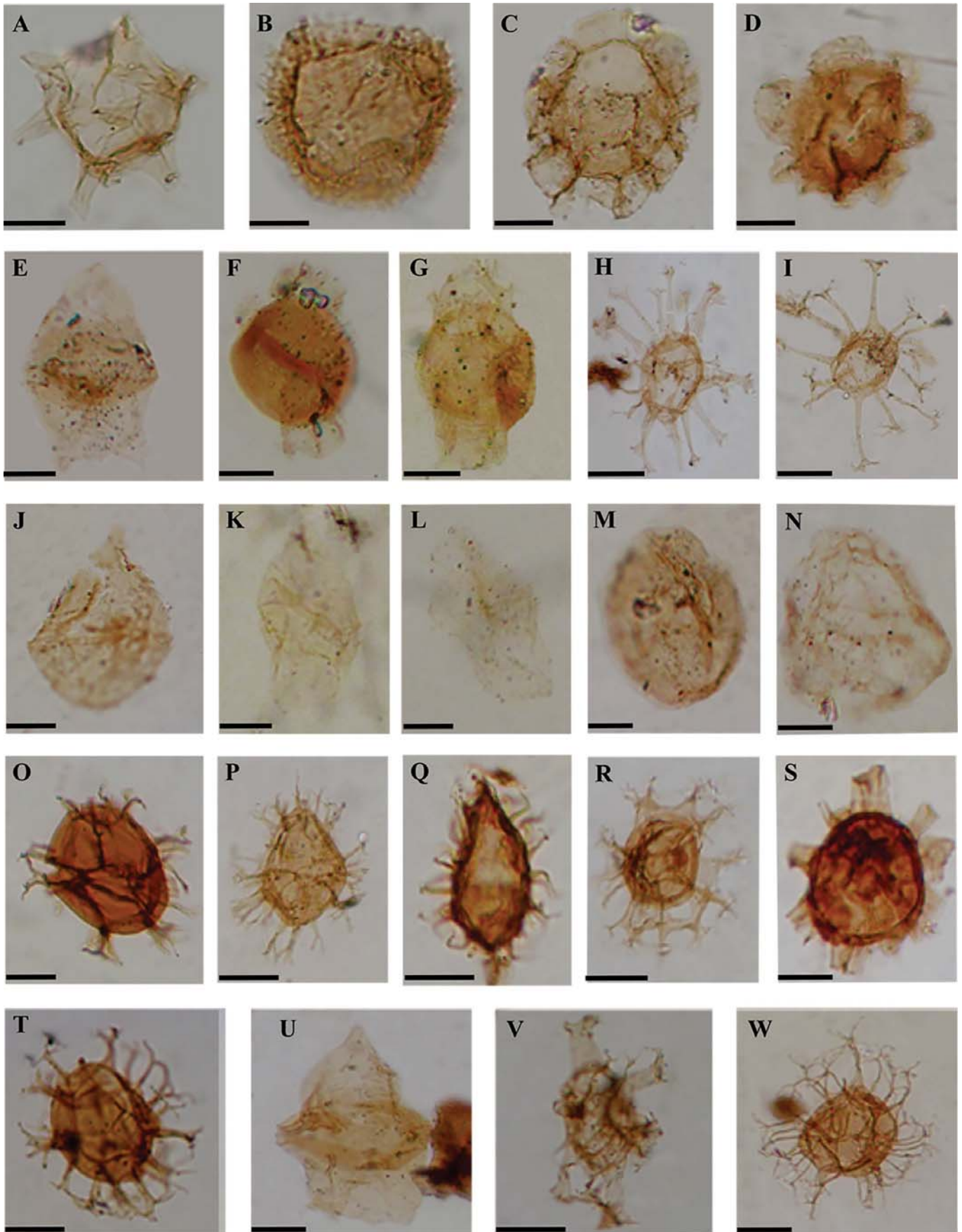
Examination of planktonic foraminifera and dinocysts has resulted in the identification of four planktonic foraminiferal biozones, two dinocyst superzones, and seven interval zones. The identified biozones confirm a late Turonian–early Campanian age for the Abderaz Formation.

The *Chlamydochorella ambigua* Interval Zone at the base of the formation is correlated with the planktonic foraminiferal *Dicarinella primitiva*–*Marginotruncana sigali* Zone that is dated as late Turonian (Coccioni and Premoli Silva 2015). The *Cymosphaeridium benmoreense* and *Conosphaeridium abbreviatum* interval zones of middle–late Coniacian to early Santonian age are correlated to an interval within the planktonic foraminiferal *Dicarinella concavata* Zone that is dated late Turonian through Coniacian (Coccioni and Premoli Silva 2015). Thus, deposition of sediments from 1 m to 150 m must have occurred during the Coniacian. The following *Odontochitina porifera* Zone (early Santonian to middle Santonian), *Isabelidinium cretaceum* Zone (middle Santonian)

TEXT-FIGURE 11

Scale bar = 20 µm.

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| <p>A <i>Conosphaeridium striatoconum</i> (Deflandre and Cookson 1955) Cookson and Eisenack 1969, sample no. 103;</p> <p>B <i>Chlamydochorella ambigua</i> (Deflandre 1937) Stover and Helby 1987, sample no. 102;</p> <p>C <i>Cyclonephelium membraniphorum</i> Cookson and Eisenack 1962, sample no. 115;</p> <p>D <i>Conosphaeridium abbreviatum</i>, Wilson 1984, sample no. 137;</p> <p>E <i>Chatangiella spectabilis</i> (Alberti 1959b) Lentin and Williams 1976, sample no. 138;</p> <p>F <i>Amphidiadema denticulata</i> Cookson and Eisenack 1960a, sample no. 106;</p> <p>G <i>Triblastula utinensis</i> Wetzel 1933b, sample no. 153;</p> <p>H, I <i>Cymosphaeridium benmoreense</i> Schiøler and Wilson 1998, sample no. 124;</p> <p>J <i>Cribopteridinium orthoceras</i> (Eisenack 1958a) Davey 1969a, sample no. 115;</p> <p>K, L <i>Satyrodinium haumuriense</i> (Wilson 1984) Lentin and Manum 1986, sample no. 191;</p> | <p>M, N <i>Nelsoniella aceras</i>, Cookson and Eisenack 1960a, sample no. 181;</p> <p>O <i>Spiniferites ramosus</i> var. <i>ramosus</i>, Ehrenberg 1838, sample no. 103;</p> <p>P <i>Exochosphaeridium striolatum</i>. (Deflandre 1937b) Davey 1969a, sample no. 137;</p> <p>Q <i>Protoellipsodinium</i> Sp., sample no. 119 R, <i>Glaphyrocysta</i> sp., sample no. 157;</p> <p>S <i>Kleithriasphaeridium tubulosum</i> Cookson and Eisenack 1969, sample no. 106;</p> <p>T <i>Achomosphaera ramulifera</i> (Deflandre 1937) Evitt 1963, sample no. 137;</p> <p>U <i>Chatangiella tripartita</i>, Cookson and Eisenack 1960a. Lentin and Williams 1976, sample no. 115;</p> <p>V <i>Xenascus sarjeantii</i> (Corradini 1973) Stover and Evitt 1978, sample no. 152;</p> <p>W <i>Spiniferites</i> Sp., sample no. 105.</p> |
|--|--|



and *Nelsoniella aceras* Zone (middle Santonian to earliest Campanian) dated by Helby et al. (1987) and Schiøler and Wilson (1998) and Raine and Schiøler (2012) correlates to an interval within the planktonic foraminiferal *Dicarinella asymetrica* Zone (latest Coniacian through Santonian) (Coccioni and Premoli Silva 2015). The *Satyrodinium haumuriense* Interval Zone, with an age of early Campanian (Schiøler and Wilson 1998; Raine and Schiøler 2012), is entirely coeval with the planktonic foraminiferal *Globotruncanita elevata* Zone (Coccioni and Premoli Silva 2015). The Turonian/Coniacian boundary is interpreted to occur at the inoceramid bearing layer (FO of the *Cremonoceras deformis erectus*) and the Coniacian/Santonian boundary can be approximated using the LO of the *Globotruncana linneiana* (Coccioni and Premoli Silva 2015). The Santonian/Campanian boundary was determined based on the extinction of *Dicarinella* spp. (Premoli Silva and Sliter 1995; Petrizzo et al. 2011).

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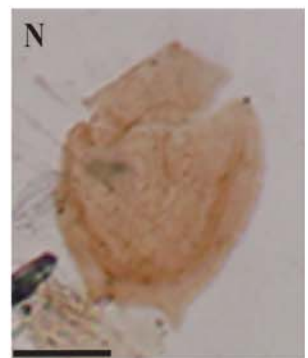
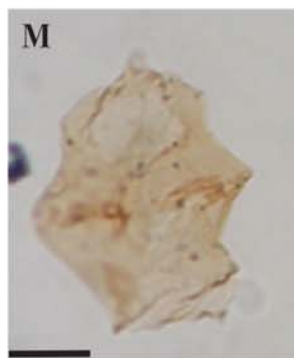
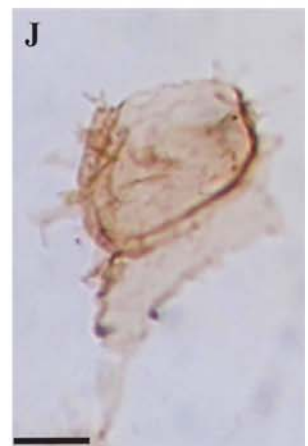
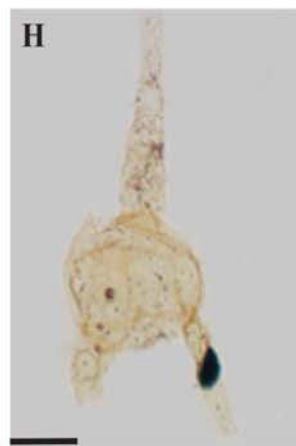
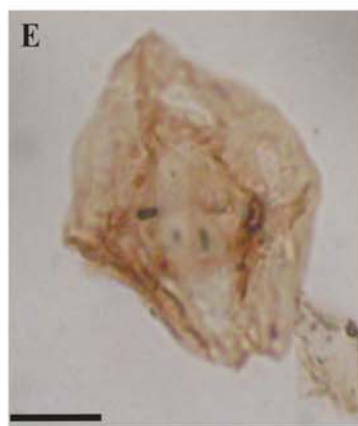
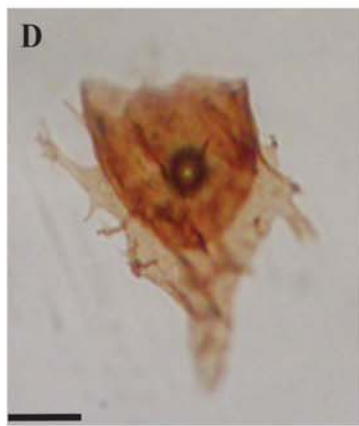
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TEXT-FIGURE 12

Some dinoflagellate cysts recorded in the samples studies. Scale bar = 20 µm.

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| <p>A <i>Odontochitina costata</i>, Alberti 1961, sample no. 106;</p> <p>B,I,C <i>Odontochitina operculata</i> (Wetzel 1933a) Deflandre and Cookson 1955, sample no. 101;</p> <p>D,J <i>Xenascus ceratioides</i> (Deflandre 1937b) Lentin and Williams 1973, sample no. 161;</p> <p>E <i>Endoscrinium campanula</i>, (Gocht 1959), sample no. 101;</p> <p>F <i>Dinogymnium sibiricum</i> (Vozzhennikova 1967), sample no. 163;</p> <p>G <i>Palaeocystodinium golzowense</i> (Alberti 1961), sample no. 191;</p> | <p>H <i>Odontochitina porifera</i>, (Cookson 1956), sample no. 157;</p> <p>K <i>Palaeoperidinium pyrophorum</i> (Ehrenberg 1838 ex Wetzel 1933a) Sarjeant 1967b, sample no. 137;</p> <p>L <i>Isabelidinium glabrum</i> (Cookson and Eisenack 1969) Lentin and Williams 1976 sample no. 133;</p> <p>M <i>Chatangiella victoriense</i> Cookson and Manum 1964, sample no. 119;</p> <p>N <i>Senoniasphaera rotundata</i> subsp. <i>rotundata</i> (Clarke and Verdier 1967), sample no. 137.</p> |
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