Diversity changes among calcareous nannofossil assemblages across the Paleocene/Eocene Boundary in the Zagros (Southwest Iran)

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Received: 24 November 2013 / Accepted: 08 February 2014 / Published online: 09 February 2014

Abstract

Calcareous nannofossil assemblages of the boundary Paleocene-Eocene deposits (Pabdeh formation) of the Zagros, Dezful Embayment-Mansouri oilfield have been studied in detail. It consists of shale and grey marlstone with inter layers of calcareous argillites and marly claystone. We present a study focused on changes in calcareous nannofossils of the Pabdeh formation during the Paleocene/Eocene Boundary (PEB). As a result of this study, 15 genera and 24 species of nannofossils have been identified for the first time. The abrupt increase in genus Discoaster and Tribrachiatus abundance provide distinct data for quick recognition of the Paleocene/Eocene Thermal Maximum (PETM) warming event. The evolutionary changes among the nannofossils created two distinct biostratigraphic marker zones in PEB, described as nannofloral zones NP9 and NP10. According to these zones, the age of boundary is Late Paleocene (Thanetian)-Early Eocene (Ypresian).

Keywords: Calcareous nannofloras, Biostratigraphy, Late Paleocene-Early Eocene, Iran.

1– Introduction

The Paleocene/Eocene Boundary (PEB) is associated with a global warm event or PETM (Paleocene/Eocene Thermal Maximum). The PETM is characterized by a global increase in temperature and injection of carbon into the ocean (Sluijs *et al*., 2007). The increase in carbon dioxide concentrations affects the saturation state of the oceans, resulting in a decrease of alkalinity (Feely *et al*., 2004). Also, the PEB is associated with a rapid diversification of planktonic foraminifera (e.g. Lu *et al*., 1998) and calcareous nannoplankton (e. g. Perch-Nielsen, 1985; Bralower *et al*., 1995; Aubry *et al*., 1996). The response of calcareous nannofossils to the climate and carbon cycle changes on a global scale was significant, including the in Dezful Embayment, Zagros, Iran. In order to survey calcareous nannofossils, the Paleocene-Eocene interval of the Pabdeh Formation is selected in the Dezful Embayment. In this interval, more detailed sampling was conducted near the PEB. In the present study, only zonal markers and other stratigraphically significant taxa were distinguished and listed. Cenozoic calcareous nannofossil zonation schemes have been established by numerous investigators (Perch-Nielsen, 1985; Young and Bown, 1997; Bown and Young, 1998). In between, the standared zonation of Martini (1971) and the low latitude zonation of Okada and Bukry (1980) are accepted (Perch-Nielsen, 1985). This paper presents diversity changes among calcareous nannofossil and biostratigraphy of Pabdeh formation (Paleocene/Eocene boundary) in SW Iran (Zagros).

2– Geological Setting

The Zagros Mountains is a proposed suture zone between the Arabian plate and Eurasian margin (Dercourt *et al*., 1986; McQuarrie, 2004). The Zagros is generally divided into three zones, the Zagros fold-Thrust belt, the imbricated zone and the suture-thrust zone (Alavi, 2004) (Fig. 1).

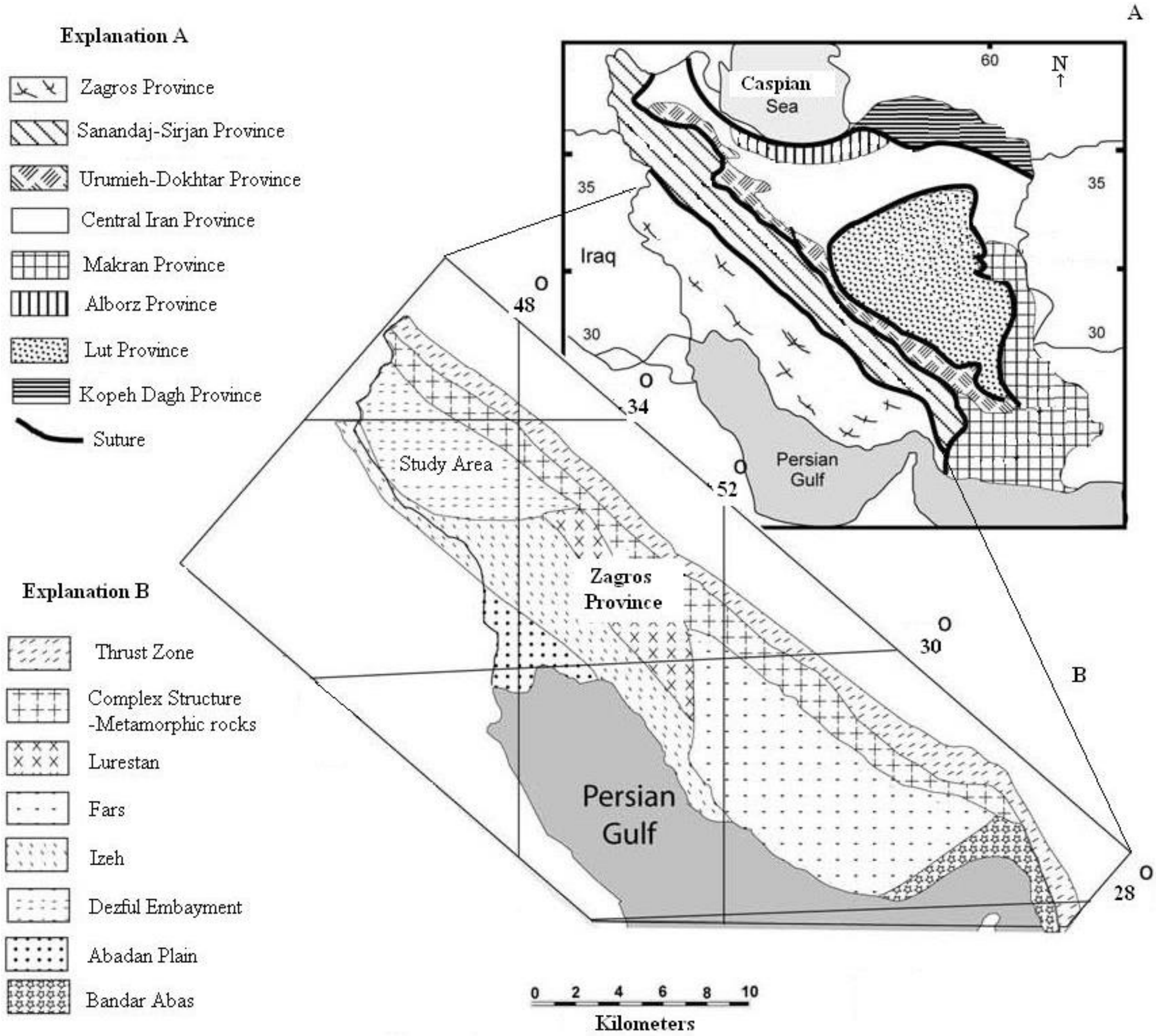

Figure 1) ***A:*** *General map of Iran showing eight geologic provinces.* ***B:*** *Subdivision of the Zagros Province, after Motiei (1993). The Dezful Embayment is located in the Zagros Province.*

The Zagros fold-thrust belt resulted from the continent to continent collision between Arabian and Eurasian plates following the closure of the Neo-Tethys Ocean during the Cenozoic (Falcon, 1974; Stampfli and Borel, 2002). The Northwest-Southeast trending Zagros fold-thrust belt extends for about 1800 km from the Taurus Mountains (NE Turkey) to the strait of Hormus (Haynes and McQuillan, 1974). Also, the Zagros basin is one of biggest oilfields in the world, which the sedimentary succession comprises a 12 km thick of Paleozoic (lower Cambrian) through Cenozoic (Pliocene) strata (Motiei, 1993). The Cenozoic strata characterized by a regional change in sedimentary facies, from an open marine to a continental environment. The study interval (PEB) is part of the Zagros folded belt, which is composed of Cenozoic sediments.

3– Materials and Methods

The survey of biostratigraphy and diversity changes was on the basis of the study of calcareous nannofossils that originating from 14 samples. The studied samples proceed from the Late Paleocene-Early Eocene sediments of the Pabdeh Formation, consisting of marlstones and calcareous argillites. These were prepared from unprocessed sediment as smear slides for nannofossil analysis, using standard techniques (Bown and Young, 1998).

All sediment samples were prepared for light microscope examination. Smear slides, were analyzed with an optical microscope at ×1000 magnification by both cross-polarized and phase-contrast methods. The Paleocene/Eocene boundary nannofossil species considered in this paper are referenced in Perch-Nielsen (1985) or Bown and Young (1998). The number of calcareous nannofossil species was calculated through semiquantitative analysis, with abundance code defined as follows; R = rare (1 specimen per field of view [FOV] 11-100), F = few (1 specimen per 2-10 FOV), C = common (1-10 specimens per FOV), A = abundant (>10 specimens per FOV).

4– Calcareous Nannofossils

Calcareous nannofossils are an excellent proxy with a number of taxa showing distinct responses to paleoenvironmental change, including to temperature and fertility (Bralower, 2002; Gibbs *et al*., 2006a, 2006b; Dunkley and Bown, 2007). This group due to their fast evolutionary rate, small microscopic size and wide geographic spread provides one of the most complete fossil records for Cenozoic times (Bown *et al*., 2004). Also they are the component of biogenic carbonate sediments and in this research their preservation is moderate throughout of the Paleocene/Eocene boundary interval. The most abundant and diverse assemblages of Cenozoic calcareous nannofossil which permit the most detailed zonation are found in warm water areas at low latitudes and generally in depths less than 4000 m. The species diversity in calcareous nannofossils is controlled by selective dissolution of skeletal elements (Egger *et al*., 2003). Accordingly, several species of calcareous nannofossils from PEB in Dezful Embayment were identification. These zonal schemes are shown in Table 1 and are compared with the other commonly used zonations. The NP (Nannoplankton Paleogene) nannofossil zonation of Martini (1971) and the CP (Coccoliths Paleogene) nannofossil zonation of Okada and Bukry (1980) are used in the present study.

5– Biostratigraphy

As result of this study, 15 genera and 24 species of calcareous nannofossils have been identified for the first time in Zagros (Dezful Embayment), Southwestern Iran. Also, we identified 21 bioevents delineated as last occurrence (LO) and first occurrence (FO) of index species, according to Martini (1971) and Okada and Bukry (1980). These zonal schemes are shown in Table and are compared with the other commonly used zonations, the taxa discussed in this section are illustrated in plate (Fig. 2).

According to these FO and LO of marker species of nannofossils, two calcareous nannofossils biozones were recognized in PEB, ranging in age from Late Paleocene (Thanetian) to Early Eocene (Ypresian). The following proposed biozones are *Discoaster multiradiatus* (NP9) and *Tribrachiatus contortus* (NP10) zones:

*Table 1**)** Nanno-stratigraphic Chart of PEB in Dezful Embayment, SW Iran. Species abundance: R = rare, F = few, C = common, A = abundant.*

Base of Pabdeh (PEB)										Formation
Paleogene										Period — Calcareous Nannofossils Biozonation
Paleocene				Eocene						Epoch
Late Paleocene				Early Eocene						Age
	NP8		NP9		NP10			NP11		Biozones Martini, 1971
/*Discoaster nobilis*	*Heliolithus riedelii*	*multiradiatus*	*Discoaster*	*contortus*	*Tribrachiatus*		*binodosus*	*Discoaster*		
	CP7	CP8a	CP8b		CP9a			CP9b		Zonation Okada & Bukry, 1980
	NP8		NP9		NP10			NP11		This study
F	F		F		C	F		F		*Braarudosphaera bigelowii*
F		F								*Cruciplacolithus tenuis*
F	R				R					*Chiasmolithus consuetus*
R		R	F		R		F			*Chiasmolithus bidens*
								C		*Coccolithus pelagicus*
R	F	F								*Discoaster araneus*
				F	F	F		F		*Discoaster elegans*
				F	C	C	F			*Discoaster barbadiensis*
								F		*Discoaster pacificusi*
								F		*Discoaster deflandrei*
	F	F	R							*Discoaster mohleri*
		F	F	C	F	R				*Discoaster multiradiatus*
				F	F	R	R			*Discoaster diastypus*
F	F	F		F	F		F			*Ellipsolithus macellus*
F			F							*Ericsonia robusta*
F	F	C	F							*Fasciculithus tympaniformis*
		F	F							*Fasciculithus lillianae*
	F	R								*Heliolithus cantabriae*
F			F	F						*Markalius inversus*
								R		*Micrantholithus excelsus*
	F	R		R				R		*Neococcolithes protenus*
F		R								*Prinsius bisulcus*
		F	R							*Placozygus sigmoides*
		F	C	C	C	F				*Rhomboaster cuspis*
C		F	C	C	F	F				*Sphenolithus anarrhopus*
							F	F		*Sphenolithus editus*
F		C	C	C	C	C	C	F		*Sphenolithus primus*
								C		*Sphenolithus radians*
				F	C	C	C			*Tribrachiatus bramlettei*
				R	C	C				*Tribrachiatus contortus*
							F	F		*Tribrachiatus orthostylus*
								R		*Zygrhablithus bijugatus*

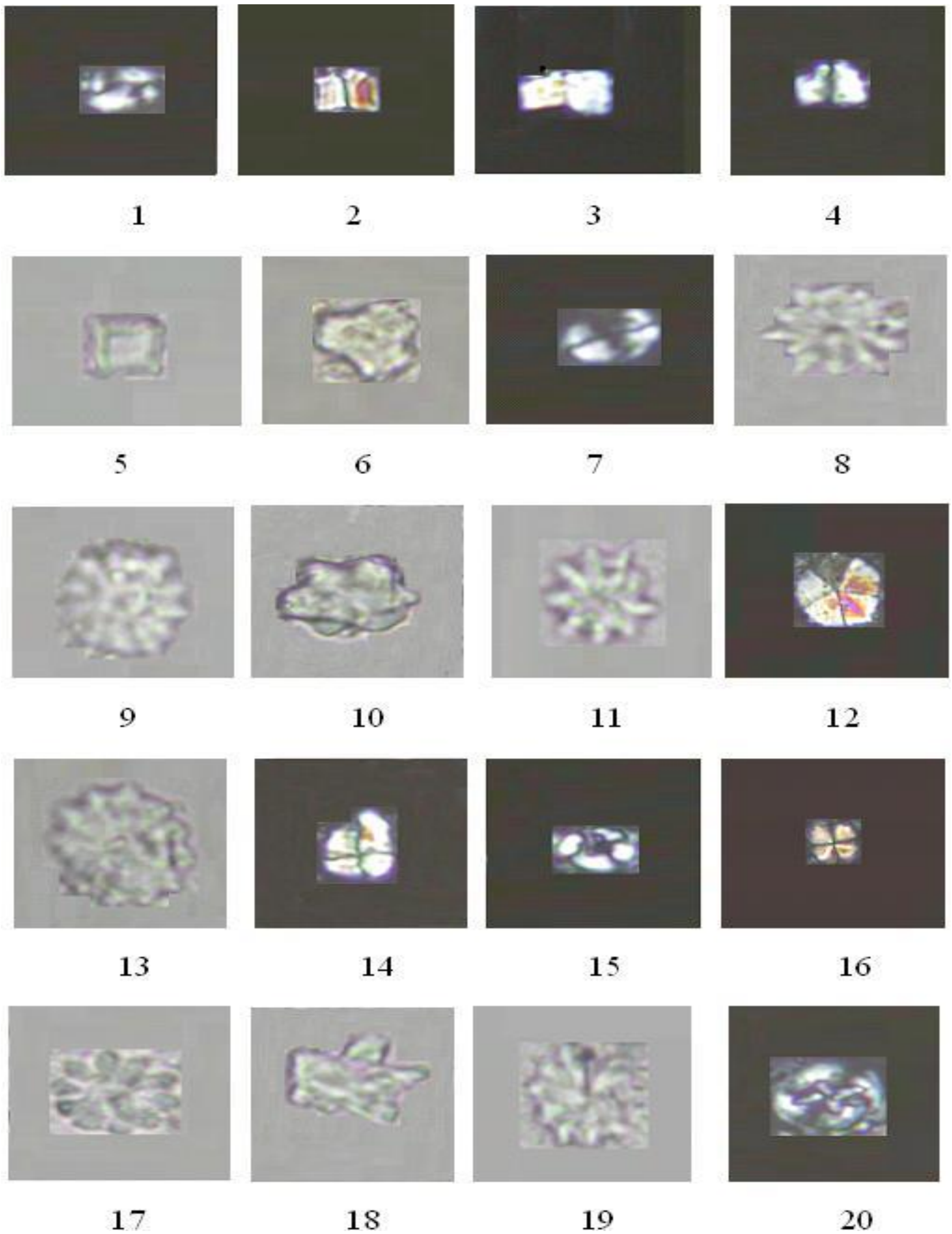

*Figure 2) Plate**:** All figures (XPL-PPL) light microghraphs×1000**;** the taxa considered in the present figure are referenced in Perch-Nielsen (1985).* **1:** *Prinsius bisulcus* (Stradner, 1963) Hay and Mohler, 1967; **2, 3:** *Fasciculithus tympaniformis* Hay and Mohler *in* Hay *et al.*, 1967; **4:** *Fasciculithus lillianae* Perch-Nielsen (1971b); **5:** *Rhomboaster cuspis* Bramlette and Sullivan, 1961**;** **6:** *Tribrachiatus contortus* (Stradner, 1958) Bukry (1972); **7:** *Ellipsolithus macellus* (Bramlette and Sullivan, 1961) Sullivan, 1964; **8:** *Discoaster multiradiatus* Bramlette and Riedel (1954); **9:** *Discoaster diastypus* Bramlette and Sullivan, 1961; **10, 18:** *Tribrachiatus bramlettei* (Brönnimann and Stradner, 1960) Proto Decima *et al*. (1975); **11:** *Discoaster araneus* Bukry, 1971; **12:** *Braarudosphaera bigelowii* (Gran and Braarud 1935) Deflandre 1947; **13, 17:** *Discoaster barbadiensis* Tan, 1927; **14:** *Sphenolithus anarrhopus* Bukry and Bramlette 1969; **15:** *Cruciplacolithus tenuis* (Stradner, 1961) Hay and Mohler *in* Hay *et al*., 1967; **16:** *Sphenolithus primus* Perch-Nielsen, 1971; **19:** *Discoaster mohleri* Bukry and Percival, 1971; **20:** *Chiasmolithus consuetus* (Bramlette and Sullivan, 1961) Hay and Mohler, 1967.

5.1- *Discoaster multiradiatus* Zone (NP9)

The uppermost Paleocene *D. multiradiatus* zone was proposed by Bramlette and Sullivan (1961) and Martini (1971) (Perch-Nielsen, 1985). In section, this zone is identified from the first occurrence (FO) of *Discoaster multiradiatus* to FO of *Tribrachiatus bramlettei* or *Discoaster diastypus*. This interval is similar to CP8 (zone of Okada and Bukry, 1980), that was detected in the Late Paleocene. In other words, the FO of *D. multiradiatus* defines the NP8/NP9 boundary of this study and zonation of Martini (1971) or the CP7/CP8a boundary of zonation of Okada and Bukry (1980). The age of this zone is Late Paleocene (Thanetian).

In this zone, calcareous nannofossils are good diversified, low abundance with a moderate preservation. The species *Campylosphaera eodela* was not observed and therefore, is not distinguished CP8a/CP8b boundary. In this zone, in addition to the marker taxa, the other species are *Braarudosphaera bigelowii, Cruciplacolithus tenuis, Chiasmolithus bidens, Discoaster mohleri, Ericsonia robusta, Fasciculithus tympaniformis, Fasciculithus lillianae, Markalius inversus, Neococcolithes protenus, Placozygus sigmoides, Prinsius bisulcus, Sphenolithus primus, Sphenolithus anarrhopus, Rhomboaster cuspis* and *Ellipsolithus macellus.*

The species *Rhomboaster cuspis, Fasciculithus lillianae, Discoaster multiradiatus* have its FO within zone NP9. Against, the species *Placozygus sigmoides, Heliolithus cantabriae, Prinsius bisulcus, Fasciculithus tympaniformis, Ericsonia robusta, Discoaster mohleri, Discoaster araneus, Cruciplacolithus tenuis* and also *Fasciculithus lillianae,* have its last occurrence within zone NP9. At the basal of *Discoaster multiradiatus* zone (NP9) occurrences of calcareous nannofossils are impoverished and show low abundances of *Chiasmolithus* (i.e. *Chiasmolithus consuetus*), *Ericsonia* (i.e. *Ericsonia robusta*) and *Cruciplacolithus* (i.e. *Cruciplacolithus tenuis*). In other words, coccoliths are extremely rare in the base of PEB.

5–2. *Tribrachiatus contortus* Zone (NP10)

The *T. contortus* zone was proposed by Hay (1964) and Bukry (1973) (Perch-Nielsen, 1985). In this study, this zone is identified from the FO of *Tribrachiatus bramlettei* or *Discoaster diastypus* and *Tribrachiatus contortus* to last occurrence (LO) of *T. contortus*. The first occurrence of *T. bramlettei* is used in the classification of Martini (1971) to define the base of NP10 zone. The LO of *T. contortus* defines the NP10/NP11 boundary of Martini (1971) or the CP9a/CP9b boundary of Okada and Bukry (1980). This interval (NP10) is similar to CP9 zone of Okada and Bukry (1980) zonation, distinguished in the Early Eocene (Ypresian). The FO of *Discoaster diastypus* is used by Okada and Bukry (1980) to define CP8/CP9 boundary, of course this species is rare in this interval. Other species have a high abundance. The age of this zone is Early Eocene (Ypresian). In the samples from this zone, in addition to the marker species (i.e. *Discoaster diastypus, Tribrachiatus bramlettei, Tribrachiatus contortus*), other taxa such as: *Braarudosphaera bigelowii, Chiasmolithus bidens, Chiasmolithus consuetus, Discoaster multiradiatus, Discoaster elegans, Discoaster barbadiensis, Ellipsolithus macellus, Markalius inversus, Neococcolithes protenus, Rhomboaster cuspis, Sphenolithus anarrhopus* and *Sphenolithus primus* have also been found. Also, the species *Discoaster elegans, Discoaster* *barbadiensis*, *Discoaster diastypus*, *Tribrachiatus bramlettei*, *Tribrachiatus contortus* have its FO within zone NP10. A sharp abundance increase in the warm water genus, (i.e. *Discoaster multiradiatus*, *Tribrachiatus bramlettei*, *Tribrachiatus contortus*, *Sphenolithus primus*, *Sphenolithus anarrhopus*) was found in NP10 zone in the Dezful Embayment. In contrast, the abundance *Fasciculithus tympaniformis* to decreases in throughout the NP9 to NP10.

6– Discussion

The following Late Paleocene epoch (NP9), warming trend ensued and culminating at the Paleocene/Eocene Boundary (PETM event). The Eocene began with an extreme and rapid warming event during the Paleocene-Eocene Thermal Maximum (Kennett and Stott, 1991). In this regard, calcareous nannofossil assemblage can be altered because of dissolution and different degrees of preservation. Dissolution can occur in the water and sediment, eventually resulting in a poor fossil record (Steinmetz, 1994). Thus, the composition of the calcareous nannofossils in the sediments is an effect of carbonate dissolution because, with rapid warming event and increasing carbonate, the calcareous nannofossil assemblage shows higher diversity and better preservation. For example, genus *Sphenolithus* is considered to be an indicator of oligotrophic and warm water conditions (Bralower, 2002; Gibbs *et al*., 2004). Also, Gibbs *et al*., (2006a, 2006b) was proposed a direct link between the nutrient control and increase in temperature during the PETM, and concluded that paleo-fertility is the primary factor controlling the distribution and abundance of this taxon. Another expected finding at this low latitude, deep sea section, is the presence of *Tribrachiatus bramlettei* and *Tribrachiatus contortus*. Genus *Tribrachiatus* is considered to be an indicator of warm water conditions. Although these forms along continental margins and open ocean environments appear, but will not be preserved in deep sea sediments. Bukry (1971) proposed that specimens of the genus *Discoaster* are the most dissolution resistant genus among the Cenozoic genera. Genus *Discoaster* is considered warm water taxa and also thought to have been influenced by the nutrient regime of surface waters preferring oligotrophic conditions (Villa *et al*., 2008). In this reaserch, the first specimens of the genus *Rhomboaster* (*R. cuspis*) with species of *Discoaster* (i.e. *D. mohleri, D. multiradiatus*) occur in the calcareous argillites, which represent the base of the NP9.

7– Conclusions

Considering the results of the studied section the following conclusions can be made:

1- As result of this study, 15 genera and 24 species of calcareous nannofossils have been identified for the first time in Zagros (Dezful Embayment), Southwestern Iran.

2- High salinity and warm waters of the Late Paleocene-Early Eocene is confirmed by the appearance of massive warm water *discoaster* (e.g. *Discoaster multiradiatus, Discoaster diastypus, Discoaster barbadiensis, Discoaster elegans, Discoaster mohleri*), *Sphenolithus* (e.g. *Sphenolithus primus, Sphenolithus anarrhopus*), *Tribrachiatus* (e.g. *Tribrachiatus bramlettei, Tribrachiatus contortus*) and *Rhomboaster cuspis*.

3- A direct link was proposed between the increase in temperature and carbonate content with diversity and preservation of calcareous nannofossils. The high abundant of *Rhomboaster cuspis* and species of *Discoaster* in the PEB assemblages are most probably an effect of selective dissolution and indicating has a similar resistance to dissolution.

4- The evolutionary changes among the nannofossils created two distinct biostratigraphic marker zones in PEB, described as biohorizons NP9 and NP10. According to these zones, the age of the interval studied is Late Paleocene (Thanetian)/Early Eocene (Ypresian).

5- The Paleocene/Eocene boundary is marked by the FO of *Tribrachiatus bramlettei* and *Discoaster diastypus*, which marks the NP9/NP10 boundary of Martini (1971) and the CP8b/CP9a boundary of Okada and Bukry (1980), respectively.

6- The NP8/NP9 boundary is marked by the FO of *Discoaster multiradiatus*.

Acknowledgments:

The authors would like to thank Dr. L. Bakhshandeh and Dr. M. Bahrammanesh for their kind and careful comments that made the manuscript improved.

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