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Abstract

The Paleogene carbonate deposits of Pabdeh and Jahrum formations are widespread in the northwest of the Shahrekord region (Dashte Zari area) in the High Zagros Mountains of Iran and record lateral and upward transition from open marine into shallow water environment within the Zagros foreland basin. The Pabdeh Formation shows a succession of open marine pelagic and hemipelagic limestone, argillaceous limestone, and argillaceous chert. It consists of planktonic wackestone, pellet-planktonic wackestone, mudstone with planktonic foraminifera, and radiolarian siliceous wackestone. The planktonic foraminifera are assigned to the Late Paleocene to Late Eocene, and correspond to subtropical to tropical Zones P4b–E15. Only one planktonic biozone (Zone E12), which corresponds to the high level stand of the Bartonian climate optimum (MECO) was not recognized in likely response to a tectonic event.The Jahrum Formation is represented by bioclast-bearing limestone and calcarenite. It consists of benthic foraminiferal wackestone, benthic foraminiferal-red algal packstone, and bioclast-intraclast packstone deposited in a shallow platform environment. The Jahrum Formation is inter-fingered in the upper part of the Pabdeh Formation and finally overlies it conformably during the Bartonian-Priabonian. Shallowing and offlap relationships record basin shrinking, while repeated inter-fingering signals moderate tectonic subsidence. Both formations are disconformably covered by the Late Oligocene-Miocene Asmari Formation.

Keywords

Biostratigraphy, Dashte Zari, Pabdeh and Jahrum formations, Zagros foreland basin, Paleogene foraminifera, West Iran

1. INTRODUCTION

The Iranian ranges long have been considered part of the Alpine-Himalayan System (Stöcklin, 1968, 1977, Sengör *et al.,* 1988, Babazadeh, 2003). This orogenic belt, which resulted from the closure of the Mesozoic Neo-Tethys, extends from western Europe (west Neo-Tethys) to Tibet passing through Turkey, Iran, Afghanistan (central Neo-Tethys), and possibly continues to Burma and Indonesia (east Neo-Tethys) (Sengör *et al*. 1988; Ahmad *et al.,* 2014) (Fig. 1A). Multiple continental blocks were amalgamated and are now separated by ophiolitic complexes (Stöcklin, 1977). During the Late Cretaceous, northeastward subduction beneath the Iranian sub–plate led to the closure of the central Neo–Tethys and ophiolite obduction onto the margin of the Afro-Arabian Plate (Stöcklin, 1977; Berberian & King, 1981; Davoodzadeh & Schmidt, 1981; Stoneley, 1981; Berberian, 1995; Alavi, 2004). Continent–continent collision starting in the Cenozoic led to the formation of the Zagros fold–and–thrust belt and associated Zagros foreland basin, in which Late Cretaceous to Miocene sediments accumulated (Fig. 1B). During the

Paleocene and Eocene, the Pabdeh Formation (pelagic marls and argillaceous limestones) and the Jahrum Formation (shallow marine carbonates) were deposited in the middle part and on both sides of the Zagros basin axis respectively (Motiei, 1993). During the Oligocene–Miocene this basin narrowed gradually and the Asmari Formation, which consists of dolomitized carbonate ramp limestones, calcareous sandstones and evaporites was deposited (e.g. Ehrenberg et al., 2007).

In the study area the lower contact of the Pabdeh Formation with the underlying Upper Cretaceous Gurpi Formation is faulted. The Jahrum Formation is inter-fingered in the upper part of Pabdeh Formation and overlaps it at his top. In the southwestern part of the Zagros basin, the Asmari Formation overlies the Pabdeh Formation, whereas in the Fars and Lurestan regions it covers the Jahrum and Shahbazan formations. Although the lower part of the Asmari Formation is locally interfingered with the Pabdeh Formation, its upper part extends over the entire Zagros basin. The Zagros Mountains include the High Zagros (Internal Zagros), Folded Zagros (Outer Zagros), and Khuzestan plain. In the High Zagros, the Shahrekord region of Chahar-Mahale Bakhtiari Province is subdivided into northeast (Z1), central (Z2), and southwest (Z3) fault-bounded zones. The Central Zone (Z2) is located between the Saman - Fereidoon Shahr thrust (F1) and the Bazoft thrust (F3) (Zahedi & Rahmati Ilkhechi, 2006). This zone is divided into two smaller sub-zones Z2a and Z2b, which are located in the Shahrekord region (Fig. 2A). It consists of the Upper Cretaceous to Paleogene Gurpi, Jahrum, Pabdeh, and Asmari formations. The studied Dashte Zari section (32°25'N; 50°20'E) is located in the sub-zone Z2b of the structural division of northwest Shahrekord city (Fig. 2B).

In the study area, the Pabdeh Formation is subdivided into Lower and Upper units and consists of pelagic carbonate and siliceous sediments, which include a succession of gray thin-bedded limestone, cream argillaceous limestone, and argillaceous chert. In contrast, the Jahrum Formation is composed of shallow marine grey to cream bioclastic limestone and calcarenite (Fig. 3A).

James & Wynd (1965) and Adams & Bourgeois (1967) were pioneers in the study of microfossils and microfacies of the Paleogene carbonate deposits in Zagros basin. They established the benthic foraminiferal biozonation of the Jahrum Formation in southwest and west Iran. Basic works on the Paleogene biostratigraphy of benthic foraminifera in the High Zagros Basin and other basins along the southwestern margin of Iran focused mostly on microfacies and macrofossils (Rahghi, 1976, 1978, 1980, 1983; Kalantari, 1976, 1978, 1980, 1986; Stöcklin & Setudehnia, 1991; Khatibi Mehr & Moalemi, 2009; Babazadeh *et al.,* 2015). The foraminiferal assemblage zones of Jahrum Formation and its equivalents were reported by a few researchers such as James & Wynd (1965) and Hottinger (2007) On the other hand, the Pabdeh Formation was analyzed by several researchers (Kalantari, 1986; Babazadeh *et al.,* 2010; Daneshian *et al.,* 2015; Chegni *et al.,* 2016; Moradian & Baghbani, 2016; Moradian *et al.,* 2017; Hadavandkhani *et al.,* 2018) based on biofacies and stratigraphy of samples from outcrops of the folded Zagros and Khuzestan plain, whereas the analysis of biostratigraphic zonation of planktonic foraminifera are extensively conducted for the first time in the High Zagros of Chahar- Mahale Bakhtiari Province. The purpose of this study is: 1) to document the planktonic and benthic foraminiferal fauna, and 2) to introduce the Paleogene foraminiferal biozonations.

2. MATERIALS AND METHODS

A total of 111 samples of Pabdeh and Jahrum formations from the Dashte Zari section are used in this study. Most of the diagnostic criteria such as the size of the test, the shape of chambers, the thickness of the test, and the number of keels can be recognized in axial and sub-axial sections in thin sections. The thin sections of the specimen samples were prepared in Payame Noor University Laboratory. The Paleogene planktonic zonations were established by many researchers: Toumarkine & Lutertacher (1985); Berggren *et al.* (1995); Olsson *et al.* (1999); Berggren & Pearson (2005), and Wade *et al.* (2011). Besides, the calibration of the first occurrence (FO) and last occurrence (LO) data of planktonic species is based on Berggren *et al.* (1995); and Berggren & Pearson (2005). The identification of Paleogene planktonic foraminiferal species in thin sections is carried out based on the following publications: Postuma (1971); Wernli *et al.* (1997); Konijnenburg *et al.* (1998); Premoli Silva *et al.* (2003); Babazadeh *et al.* (2010); Daneshian *et al.* (2015); Sarigul *et al.* (2017), and Sari (2017) The species identification of benthic foraminifera was made by reference mainly to Ellis & Messina (1940); Le Calvez (1949); Cole & Gravell (1952); Hanzawa (1957); Rahaghi (1980); Loeblich & Tappan (1987); Ozgen (2000); Sirel (2003, 2009); Hottinger (2007); Serra-Kiel *et al.* (2016), and Hayward *et al.* (2021). The biozonal schemes of Berggren *et al.* (1995) and Berggren & Pearson (2005) were correlated with relevant data levels of species found in the study area (Figs. 4A & 4B).

3. STRATIGRAPHY

The excellent exposures of Paleogene carbonate sedimentary rocks of the High Zagros basin of southwest and west Iran have allowed detailed stratigraphical and micropaleontological investigations of these rocks. The Paleocene-Eocene marine deposits of the Pabdeh and Jahrum formations in the Dashte Zari section contain planktonic and larger benthic foraminifera, which provide the basis for regional biostratigraphy. Due to the presence of faults and discontinuous outcrops of Paleogene successions in the Shahrekord region, the planktonic biostratigraphic research was not conducted until today.

3.1. BIOSTRATIGRAPHY

The planktonic foraminiferal zonations of Berggren *et al.* (195); Berggren &Pearson (2005) and Wade *et al* (2011), and the benthic foraminiferal zonations of Serra-Kiel *et al.* (1998) and Hottinger (2007) are adopted for comparison and interpretation. However, a brief evaluation of the depositional setting is also explained in terms of Murray (1991), Hottinger (1983, 1997), and Flugel (1982, 2004). The planktonic and benthic foraminiferal assemblages from hemipelagic and neritic successions of the High Zagros provide the first published biostratigraphic data on this area. A total of 46 planktonic foraminiferal species belonging to 14 different genera, and 19 benthic foraminiferal species belonging to 17 different genera have been identified and led to the recognition of 14 planktonic biozones and 3 benthic associations respectively. The columnar stratigraphic sections are summarized in figures 5 and 6, which show the distribution of selected taxa of planktonic and benthic foraminifera. The micrographs of thin sections of Paleogene planktonic and benthic foraminiferal species are shown in plates 1-4 and plate 5 respectively. The planktonic foraminiferal biozonations enable to correlate with other biostratigraphic scales and to make more precise their age determination (Fig. 7).

Pabdeh Formation

The planktonic foraminiferal biozones are as follows:

Pp1 - *Acarinina subsphaerica* Zone (TRZ)

TRZ: Total Range Zone

Estimated age: 59.2–56.5 Ma (Cande & Kent, 1965) ; 60.0– 57.3 Ma (Luterbacher *et al.,* 2004 ; Middle-Late Paleocene (Wade *et al.,* 2011).

This zone, characterized by the total range zone of *Acarinina subsphaerica* (Subbotina) has a thickness of 9 meters (bed Pl 1 to bed Pl 7) (Fig. 5). It is equivalent to subzone P4a (Globanomalina *pseudomenardii-Acarinina subsphaerica* CRSZ), subzone P4b (*Ac. Subsphaerica-Ac. Soldadensis* ISZ) of Berggren *et al.* (1995), and subzone P4b (*Ac. Subsphaerica* PRSZ) of Berggren & Pearson (2005) and Wade *et al.* (2011), thereby indicating Selandian to Thanetian age for the lowermost part of the Pabdeh Formation in the study area. The associated planktonic fauna is *Acarinina decepta* (Martin), *Acarinina mckannai* (White), and *Acarinina* cf. *nitida* (Martin). The associated foraminiferal taxa are well represented throughout the Late Paleocene to Early Eocene. This zone is assigned to the Late Selandian-Thanetian in the study area.

Pp2-*Morozovella velascoensis* Zone (PRZ)

PRZ: Partial Range Zone

Estimated age: 55.9–55.5 Ma (Cande & Kent, 1995); 56.7– 55.8 Ma (Luterbacher *et al.,* 2004); late Paleocene (Wade *et al.,* 2011).

Biostratigraphic interval characterized by the partial range of the nominate taxon between the LO (Last Occurrence) of *Acarinina mckannai* (White) and the first occurrence (FO) of *Morozovella marginodentata* (Subbotina). This zone has a thickness of 3.5 meters and only appears on horizon Pl 8 (Fig. 5). It is comparable to Zone P4c (*Ac. soldadoensis-Gl. pseudomenardii* ISZ); Zone P5 (*M. velascoensis* IZ) of Berggren *et al.* (1995) and subzone P4c (*Ac. soldadoensis-Gl. pseudomenardi* CRSZ), Zone P5 (*M. velascoensis* IZ), Zone E1 (*A. sibaiyaensis* LOZ) and Zone E2 (*P. wilcoxensis-M. velascoensis* CRZ) of Berggren & Pearson (2005), thereby indicating Late Paleocene (Thanetian) to Early Eocene age in this study. This zone also contains *Acarinina nitida* (Martin).

Pp3- *Morozovella marginodentata- Morozovella formosa* Zone (IZ)

IZ: Interval Zone

Estimated age: 54.5–54.0 Ma (Cande & Kent, 1995); 54.9– 54.4 Ma (Luterbacher *et al.,* 2004); Early Eocene (Early Ypresian) (Wade *et al.,* 2011).

This zone, marked by the FO of *Morozovella marginodentata* (Subbotina) and the FO of *Morozovella formosa* (Bolli), extends over a thickness of 2.5 meters (bed Pl 9 to bed Pl 10) (Fig. 5). It corresponds to the *Globorotalia edgari* Zone of Premoli Silva & Bolli, (1973) (in part), the Zone P6a (*Morozovella velascoensis- M. formosa*/ *M. lensiformis* ISZ) of Berggren *et al.* (1995), and the Zone E3 (*Morozovella marginodentata* PRZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). The associated planktonic foraminifera of this biozone are *Morozovella edgari* (Premoli Silva & Bolli), *Morozovella velascoensis* (Cushman), *Morozovella acuta* (Toulmin), *Morozovella marginodentata* (Subbotina) and *Acarinina nitida* (Martin). The stratigraphic range of this zone is Early Eocene (Early Ypresian).

Pp4- *Morozovella formosa - Guembelitrioides lozanoi* Zone (IZ)

Estimated age: 54.0–52.3 Ma (Cande & Kent, 1995); 54.4– 52.3 Ma (Luterbacher *et al.,* 2004); Early Eocene (Ypresian) (Wade *et al.,* 2011).

The biostratigraphic interval is characterized by the FO of *Morozovella formosa* (Bolli) and FO of *Guembelitrioides lozanoi* (Colom). This zone is 5 meters thick (bed Pl 10 to bed Pl 14) (Fig. 5). It corresponds to the Zone P6b (*M. aragonensis- M. formosa*) of Berggren *et al.* (1995) and Zone E4 (*Morozovella formosa* LOZ) of Berggren and Pearson (2005) and Wade *et al.* (2011). The associated planktonic foraminifera of this biozone are *Acarinina* cf. *nitida* (Martin), *Igorina (Pearsonites) broedermanni* (Cushman & Bermudez), *Morozovella velascoensis* (Cushman), *Morozovella marginodentata* (Subbotina), and *Morozovella subbotinae* (Morozova). This associated species ranges within the Early Eocene (Ypresian) age.

Pp5- *Guembelitrioides lozanoi - Acarinina pentacamerata* (IZ)

Estimated age: 52.3–50.8 Ma (Cande & Kent, 1995 and Luterbacher *et al.,* 2004); Early Eocene (Ypresian) (Wade *et al.,* 2011).

This zone, characterized by the FO of *Guembelitrioides lozanoi* (Colom) and the FO of *Acarinina pentacamerata* (Subbotina), extends over a thickness of 2.8 meters (Pl 14 to Pl 18) (Fig. 5). This biozone can be equivalent to the Zone P7 (*M. aragonensis/ M. formosa*) and Zone E5 (*M. aragonensis/ M. subbotinae* CRZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). The associated fauna of this biozone consists of *Igorina broedermanni* (Cushman and Bermudez), *Morozovella subbotinae* (Morozova), *Guembelitrioides lozanoi* (Colom), and Radiolaria and extends throughout the Early Eocene (Ypresian).

Remark: the first radiolarian association occurs in the interval from bed 12 to bed 18 (Fig. 5).

Pp6- *Acarinina pentacamerata - Planorotalites palmerae* Zone (IZ)

Estimated age: 50.8–50.4 Ma (Cande & Kent, 1995); 50.8– 50.3 Ma (Luterbacher *et al.,* 2004); Early Eocene (Ypresian) (Wade *et al.,* 2011).

This zone, marked by the FO of *Acarinina pentacamerata* (Subbotina) and the FO of *Planorotalites palmerae* Cushman and Bermudez, is 2.5 meters thick (bed Pl 18 to bed Pl 20) (Fig. 5). It is equivalent to Zone P8 *(M. aragonensis* PRZ) of Berggren *et al.* (1995) and Zone E6 *(A. pentacamerata* PRZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). This zone also contains *Guembelitrioides lozanoi* (Colom) and *Turborotalia prolata* (Belfoed). The stratigraphic range of this zone is assigned to the Early Eocene (Early Ypresian).

Pp7- *Planorotalites palmerae - Guembelitrioides nuttalli* Zone (IZ)

Guembelitrioides nuttalli is synonymous with *Globigerinoides higginsi*

Estimated age: 50.4–49.0 Ma (Cande & Kent, 1995); 50.3– 48.6 Ma (Luterbacher *et al.,* 2004); Early Eocene (Late Ypresian) (Wade *et al.,* 2011).

This zone, characterized by the FO of *Planorotalites palmerae* Cushman and Bermudez and the FO of *Guembelitrioides nuttalli (*Hamilton), is 2.3 meters thick (bed Pl 20 to bed Pl 22) (Fig. 5). It corresponds to the Zone P9 (*P. palmerae* **–** *G. nuttalli* IZ) of Berggren et al. (1995); Zone E7 (*Acarinina cuneicamerata* LOZ) of Berggren & Pearson (2005) and Zone E7a (*Acarinina cuneicamerata* LOSZ) of Wade *et al.* (2011). This zone also contains *Acarinina collactea*

(Finaly), *Acarinina pentacamerata* (Subbotina), *Guembelitrioides lozanoi* (Colom), *Planorotalites palmerae* Cushman & Bermudez, *Igorina broedermanni* (Cushman & Bermudez) and *Acarinina pseudotopilensis* Subbotina. This species association is assigned to the late Early Eocene (Late Ypresian).

Pp8- *Guembelitrioides nuttalli - Globigerinatheka kugleri* Zone (IZ)

Estimated age: 46.4–44.4 Ma (Cande & Kent, 1995); 45.5– 43.4 Ma (Luterbacher *et al.,* 2004); Middle Eocene (Wade *et al.,* 2011).

This zone, marked by FO of *Guembelitrioides nuttalli* (Hamilton) and FO of *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan 1957), is 14 meters thick (bed Pl 22 to bed Pl 38) (Fig. 5). It corresponds to the Zone P10 (*Hantkenina nuttalli* IZ) of Berggren et al. (1995), Zone E8 (*G. nuttalli* LOZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). The associated fauna consists of *Dentoglobigerina yeguaensis* (Weinzierl & Applin), *Guembelitrioides lozanoi* (Colom), *Truncorotaloides* sp., *Acarinina bullbrooki* (Bolli), *Turoborotalia frontosa* (Subbotina), *Morozovella caucasica* (Glaessner) and *Morozovella aragonensis* (Nuttall). This zone is assigned to Middle Eocene (Early Lutetian).

Remarks: the second radiolarian association occurs in the interval from bed Pl 30 to bed Pl 35 (Fig. 5).

Pp9- *Globigerinatheka kugleri-Morozovella aragonensis* Zone (CRZ)

CRZ: Concurrent Range Zone

Estimated age: 44.4–43.6 Ma (Cande & Kent, 1995); 43.4– 42.6 Ma (Luterbacher *et al.,* 2004); middle Eocene (Wade *et al.,* 2011).

This zone, characterized by the concurrent range of the nominate taxa between the FO of *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan) and the LO (last Occurrence) of *Morozovella aragonensis* (Nuttall), is 8.5 meters thick (bed Pl 38 to bed Pl 45) (Fig. 5). This zone is equivalent to P 11 (*G. kugleri-M. aragonensis* CRZ) of Berggren *et al.* (1995) and Zone E 9 (*G. kugleri-M. aragonensis* CRZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). This zone also contains *Guembelitrioides nuttalli* (Hamilton), *Acarinina bullbrooki* (Bolli), *Dentoglobigerina yeguaensis* (Weinzierl & Applin), *Globigerinatheka senni* (Beckmann), *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan), *Globigerinatheka index* (Finlay), *Turborotalia possagnoensis* (Toumarkine & Bolli), *Turboroatlia frontosa* (Subbotina) and *Morozovella aragonensis* (Nuttall). This association corresponds to the Middle Eocene (Middle Lutetian).

Remarks: the third radiolarian association occurs in the interval from bed Pl 41 to bed Pl 42 (Fig. 5).

Pp10- *Acarinina topilensis* Zone (PRZ)

(PRZ): Partial Range Zone

Estimated age: 43.6–42.3 Ma (Cande & Kent, 1995); 42.6–41.4 Ma (Luterbacher *et al.,* 2004); middle Eocene (Wade *et al.,* 2011).

This zone defined by the LO of *Morozovella aragonensis* (Nuttall) and the LO of *Guembelitrioides nuttalli* (Hamilton), is 5 meters thick (bed Pl 46 to bed Pl 51) (Fig. 5). It is equivalent to the lower part of P 12 (*M. lehneri*, PRZ) of Berggren *et al.* (1995) and Zone E10 (*A. topilensis*, PRZ) of Berggren & Pearson (2005) and of Wade *et al.* (2011). This zone also contains *Acarinina spinuloinflata* (Bandy), *Guembelitrioides nuttalli* (Hamilton), *Globigerinatheka index* (Finlay), *Acarinina topilensis* (Cushman), *Acarinina bullbrooki* (Bolli), *Turboroatlia frontosa* (Subbotina), *Turboroatlia pomeroli* (Toumarkine & Bolli), *Dentoglobigerina yeguaensis* (Weinzierl & Applin), *Morozovella* (*Morozovelloides*) *lehneri* (Cushman and Jarvis), *Globigerina praebulloides* Blow, and *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan). Based on planktonic foraminifera, this horizon can be assigned to the Middle Eocene (Middle Lutetian).

Pp11- *Morozovelloides lehneri* Partial-Range Zone (PRZ)

Estimated age: 42.3–40.5 Ma (as per Cande & Kent, 1995); 41.4– 39.8 Ma (as per Luterbacher *et al.*, 2004); middle Eocene (Lutetian-Bartonian) (Wade *et al.*, 2011).

This zone, characterized by the LO of *Guembelitrioides nuttalli* (Hamilton) and LO of *Acarinina bullbrooki* (Bolli), is 4 meters thick (bed Pl 52 to bed Pl 58) (Fig. 5). It is equivalent to the upper part of P12 (*M. lehneri*, PRZ) of Berggren *et al.* (1995) and E11 (*M. lehneri*, PRZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). The associated planktonic fauna contains *Globigerinatheka kugleri* (Bolli, Loeblich and Tappan), *Acarinina topilensis* (Cushman), *Turoborotalia frontosa* (Subbotina), *Dentoglobigerina yeguaensis* (Weinzierl and Applin), *Acarinina bullbrooki* (Bolli), *Globigerinatheka senni* (Beckmann) and *Hantkenina* sp. This association extends through the Late Lutetian-Bartonian age.

Remarks: The Zone E12 (*Orbulinoides beckmanni* Taxon-range Zone) of Berggren & Pearson (2005) and Wade *et al.* (2011) is absent due to lateral facies change. There, pelagic carbonates of the Pabdeh Fm. corresponding to the planktonic biozone E12, are replaced by an inter-fingered lens of the Jahrum Formation (with benthic foraminifera). This interval has a thickness of 2.5 meters (bed Pl 59 to bed Pl 60) (Fig. 5). The benthic foraminifera consist of *Gyrodinella magna* (Le Calvez), *Neorotalia* spp., *Asterigerina rotula* (Kaufmann), and *Discocyclina* sp. and are assigned to the Bartonian.

Pp12: *Morozovella crassata- Globigerinatheka kugleri* (IZ)

Estimated age: 40.0–38.0 Ma (Cande & Kent, 1995); 39.4– 37.7 Ma (Luterbacher *et al*., 2004); 40.0–38.1 Ma (Pälike *et al*., 20006) ; Middle Eocene (Bartonian) (Wade *et al*., 2011).

This zone, marked by the FO of *Morozovella crassata* (Cushman) and the LO of *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan), has a thickness of 14 meters (bed Pl 61 to bed Pl 76) (Fig. 5). This zone is equivalent to P14 (*Tr. rohri-M. spinulosa* PRZ) of Berggren *et al*. (1995), Zone E13 (*M. crassata* HOZ) of Berggren & Pearson (2005) and Zone E13 (*Morozovelloides crassatus* HOZ) of Wade *et al*. (2011). The biostratigraphic range is assigned to the Bartonian.

The planktonic fauna is as follows: *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan), *Morozovella crassata* (Cushman), *Catapsydrax dissimilis* Cushman & Bermudez, *Dentoglobigerina yeguaensis* (Weinzierl & Applin), *Subbotina eocaenica* (Guembel), *Turborotalia pomeroli* Toumarkine & Bolli, *Turborotalia griffinae* Blow, *Pseudohastigerina micra* (Cole), *Turborotalia increbescens* Bandy, *Globigerinatheka index* (Finlay), *Globigerinatheka Mexicana* (Cushman), *Globigerinatheka lutherbacheri* Bolli, *Turborotalia cerroazulensis* (Cole), *Pseudohastigerina* sp. and *Hantkenina* sp.

In this interval (from bed Pl 61 to bed Pl 76), two inter-fingered lenses of Jahrum Formation containing benthic foraminifera are observed**.** The first lens contains *Gyrodinella magna* (Le Calvez), *Asterigerina rotula* (Kaufmann), *Gypsina marianensis* Hanzawa, *Nummulites fossulata* De Cizancourt, and *Discocyclina* sp. It has a thickness of 3.5 meters and extends from bed Pl 64 to bed 68 (Fig. 6). The second horizon contains *Neorotalia* spp., *Discocyclina* sp., *Gyroidinella magna* (Le Calvez), *Gypsina marianensis* Hanzawa, and *Asterocyclina sireli* Özcan & Less. It presents a thickness of 3.5 meters and extends from bed Pl 72 to Pl 74 (Fig. 6). Based on benthic foraminiferal association, the biostratigraphic range of both lenses is considered Bartonian.

Pp13- *Cribrohantkenina inflata- Globigerinatheka Mexicana* Zone (IZ)

Estimated age: 38.0–35.8 Ma (Cande & Kent, 1995); 37.7– 35.8 Ma (Luterbacher *et al.*, 2004); 38.1–35.8 Ma (Pälike *et al.*, 2006); Middle-Late Eocene (Bartonian-Priabonian) (Wade *et al.*, 2011).

This zone, characterized by FO of *Cribrohantkenina inflata* Howe to LO of *Globigerinatheka Mexicana* (Cushman) is 4.5 meters thick (bed Pl 75 to bed Pl 83) (Fig. 5). It is equivalent to Zone P15 (*Po. semiinvoluta* IZ) of Berggren *et al.* (1995) and Zone E14 (*G. semiinvoluta* HOZ) of Berggren & Pearson (2005) and Wade *et al.* (2011). The associated planktonic fauna contains *Turborotalia cerroazulensis* (Cole), *Turborotalia pomeroli* (Toumarkine & Bolli), *Catapsydrax dissimilis* Cushman & Bermudez, *Globigerinatheka index* (Finlay), *Turborotalia increbescens* Bandy, *Globigerina venezuelana* (Hedberg), and *Cribrohantkenina inflata* Howe.

Pp14: *Globigerinatheka index* Zone (PRZ)

PRZ: Partial Range Zone

This zone, characterized by the partial range of the nominate taxa between the LO of *Globigerinatheka Mexicana* (Cushman) and the LO of *Globigerinatheka lutherbacheri* Bolli, extends over a thickness of 10 meters (bed Pl 83 to bed Pl 99) (Fig. 5). The associated planktonic fauna is *Pseudohastigerina naguewichiensis* (Myatliuk), *Cribrohantkenina inflate* Howe, *Turborotalia cocoaensis* (Cushman), *Turborotalia cerroazulensis* (Cole), *Globigerina (Dentoglobigerina) venezuelana* (Hedberg), *Pseudohastigerina micra* (Cole), *Turborotalia pomeroli* (Toumarkine and Bolli), *Catapsydrax dissimilis* Cushman and Bermudez, *Turborotalia increbescens* Bandy, *Globigerinatheka Mexicana* (Cushman) and *Globigerinatheka lutherbacheri* Bolli.

Two horizons with benthic foraminifera are observed in this biozone. They can be correlated with the zone E15 of Berggren & Pearson (2005) and Wade *et al.* (2011). The first horizon 4.5 meters thick, extends from bed Pl 85 to bed 90 (Fig. 6). It consists of *Fabiania cubensis* (Cushman & Bermudez), *Chapmanina gassinensis* (Silvestri), *Penarchaias* cf. *glynnjonesi* (Henson), *Praebullalveolina afyonica* Sirel & Acar, *Halkyardia* sp., *Silvestriella* cf. *tetraedra* Gumbel, *Discocyclina nandori* Less, *Nummulite*s cf. *fabianii* (Prever), *Borelis* sp., *Gyroidinella magna* (Le Calvez), *Neortalia* spp., *Praerhapydionina* sp., and *Discocyclina* sp. The second horizon presents a thickness of 1.5 meters and extends from bed 94 to bed 97. It contains *Chapmanina gassinensis* (Silvestri), *Nummulite*s cf. *fabianii* (Prever), and *Neorotalia* spp. (Fig. 6). This association is equivalent to E15 of Berggren & Pearson (2005) and Wade *et al.* (2011) and can be assigned to the Priabonian due to the presence of *Nummulite*s cf. *fabianii* (Prever).

The rest of the columnar section (top of section) with a thickness of 22.5 meters (bed 100 to bed 111) is formed by the Jahrum Formation. It contains *Alveolina nuttalli* (Davies), *Discocyclina nandori* Less, *Asterigerina rotula* (Kaufmann), *Macetadiscus incolumnatus* Hottinger, and *Discocyclina* sp. This benthic foraminiferal association is equivalent to E16 of Berggren & Pearson (2005) and Wade et al. (2011). The range of this association is assigned to the Priabonian.

4. **PALEOENVIRONMENT REMARKS**

The lithologic units may change laterally from a continuous to abrupt fashion (Boggs (2006). Facies changes may occur as lateral gradation, pinch out, or inter-tonguing/inter-fingering. The abrupt contacts (inter-tonguing), which are commonly very sharp can distinctly separate two formations with different lithologies a result of fast changes in local depositional conditions. The pelagic and hemipelagic facies of the Pabdeh Formation are deposited in deep-sea (open ocean) environment. They consist of argillaceous limestones, mudstones, and radiolarian cherts. The argillaceous limestones mostly contain planktonic foraminifera such as *Acarinia*, *Morozovella*, *Globigerinatheka*, *Turborotalia*, etc. The stratigraphical analysis of the Pabdeh Formation showed the presence of some inter-fingering layers of the Jahrum Formation containing benthic foraminifera only, which correspond to shallow marine neritic deposits. The occurrence of inter-fingered tongues of benthic facies (Jahrum Formation) within the pelagic facies (Pabdeh Formation) suggests repeated sharp depth changes (Fig. 3B). In addition, the appearance of medium to coarse grain bioclastic limestone with larger benthic foraminifera and large-sized red algae in the top of the section (Jahrum Fm.) suggests shallowing. Hence, the overlapping benthic facies on top of the section recorded regression that could be due to progressive shrinking of the basin and sea-level drop as well. The gradual decline of micrite observed in the Jahrum Formation is likely due to decreasing water depth and increasing energy, which led to the development of bioclastic limestone. Concomitantly, the benthic foraminifers are mainly limited to rotaliids (*Gyroidinella*, *Fabiania,* etc.), orthophragminids (*Discocyclina*), and alveolinids, which indicate restricted platform conditions (Murray 1991; Hottinger 1983, 1997; Flugel 1982, 2004).

5. DISCUSSION

The studied section mainly consists of Pabdeh Formation with some inter-fingered tongues of Jahrum Formation. Based on lithological features, the Pabdeh Formation is subdivided into two lithological units (Lower and Upper Units). The Lower Unit is dominated by pelagic limestone and radiolarian chert, whereas the Upper Unit consists of pelagic limestone, mudstone, and some inter-fingered lenses of bioclastic limestone, which are attributed to the Jahrum Formation. Further up, toward the top of the section, the Pabdeh formation is overlain by the Jahrum Formation represented by a carbonate succession of packstone with abundant red algae, bioclasts, and hyaline/porcellaneous foraminifers.

The presence of marker planktonic foraminifera such as *Acarinina subsphaerica* (Subbotina) confirms the Late Paleocene age of Zone Pp1, because the last occurrence of this species falls in the upper part of Zone Pp1. The species *Morozovella velascoensis* (Cushman) occurs across the Late Paleocene-Early Eocene boundary, therefore its presence help to distinguish the Zone Pp2. During the Early Eocene from the upper part of Zone Pp2 to Zone Pp7, some taxa such as

Morozovella and *Turborotalia* were rare but *Igorina broedermanni* (Cushman and Bermudez) was only sporadic during the Early Eocene (Ypresian).

The Lutetian stage (from Zone Pp8 to Zone Pp10) coincides with the extinction of some species such as *Planorotalites palmerae* Cushman and Bermudez, *Acarinina pseudotopilensis* Subbotina, *Turborotalia prolata* (Belfoed), and *Acarinina pentacamerata* (Subbotina). In contrast, the association of *Acarinina bullbrooki* (Bolli), *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan), *Turborotalia possagnoensis* (Toumarkine & Bolli), *Acarinina topilensis* (Cushman), *Dentoglobigerina yeguaensis* (Weinzierl & Applin), *Globigerinatheka senni* (Beckmann), *Guembelitrioides nuttalli* (Hamilton), *Turboroatlia frontosa* (Subbotina), *Turborotalia possagnoensis* (Toumarkine & Bolli), and *Morozovella aragonensis* (Nuttall) are abundant.

The time interval Lutetian-Bartonian is equivalent to Zone Pp11, which is consistent with Zone E11 of Berggren & Pearson (2005). It is characterized by the partial range zone of *Morozovella lehneri* (Cushman & Jarvis).

Abundant Bartonian planktonic foraminifers are represented in the Zone Pp12 of this study, but some species such as *Turborotalia griffinae* Blow, *Pseudohastigerina micra* (Cole), *Globigerinatheka Mexicana* (Cushman), *Globigerinatheka lutherbacheri* Bolli, *Turborotalia increbescens* Bandy, *Turborotalia cerroazulensis* (Cole), *Pseudohastigerina* sp. and *Hantkenina* sp. are rare in this biozone. In contrast, they are abundant in the Zone Pp13 for the Bartonian-Priabonian time interval. The species *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan) becomes extinct in this biozone, whereas the species *Globigerina (Dentoglobigerina) venezuelana* (Hedberg), and *Cribrohantkenina inflata* Howe are reported for the first time.

Three associations of benthic foraminifera (Fig. 6) are distinguished in the middle and upper parts of the stratigraphic section. They are assigned to the Bartonian and Priabonian stages and can be equivalent with Zone Pp 12 –Zone Pp14.

5. CONCLUSION

- The Pabdeh Formation is mainly composed of hemipelagic and pelagic sediments with intercalations of radiolarian chert, whereas the Jahrum Formation consists of neritic deposits accumulated on a shallow marine platform. Both formations are disconformably covered by the Late Oligocene-Miocene Asmari Formation.

-The Pabdeh Formation consists of Late-Paleocene to Late Eocene planktonic foraminifera (Zone Pp1–Pp14) which correlate mainly to the subtropical to tropical Zones P4b-E15 of Berggren & Pearson (2005). This Formation passes upwards and laterally into the Jahrum Formation and up section. Hence, the abrupt disappearance of the planktonic foraminifera in the Pabdeh Formation coincides with the presence of larger benthic foraminifera (orthophragminids, rotaliids) in the Jahrum Formation.

-The orthophragminids (*Discocyclina*) are mainly associated with rotaliids (*Gyroidinella*, *Asterigerina*, etc), while alveolinids and nummulitids are locally relatively common in the bioclastic facies of Jahrum Formation. The low frequency of *Nummulites* and major changes in the composition of benthic foraminifera with increasing rotalides recorded a change of sedimentary environment.

-The occurrence of Jahrum Formation (bearing benthic foraminifera) within the Pabdeh Formation (bearing planktonic foraminifera) enables benthic foraminifera ranges to be tied to local planktonic foraminiferal biostratigraphy. Therefore, the stratigraphic range of benthic foraminiferal associations in the upper part of the study section is Bartonian-Priabonian.

-Late Paleocene planktonic foraminifera are sparse in the Pabdeh Formation, whereas the Eocene planktonic foraminifers are more abundant and widespread.

-During the Early Eocene, the two genera *Acarinina* and *Morozovella* are abundant but other genera such as *Globigerinatheca, Turborotalia,* etc. gradually become predominant.

-The absence of open marine planktonic foraminifera such as *Orbulinoides beckmanni,* which corresponds to Zone E12 of Berggren and Pearson (2005) in the upper unit of Pabdeh Formation, coincides with the sudden appearance of larger benthic foraminifera coeval with coarsening upwards trend. As this interval coincides with the Middle Eocene Climate Optimum (ca. 40 Ma), which corresponds to a sea level rise of ca. 50 m (e.g. Miller et al., 2020 and references therein), such abrupt shallowing recorded by the absence of planktonic foraminifers must be due to tectonic causes.

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REFERENCES

Adams T. D. & Bourgeois F. 1967. Asmari biostratigraphy, Geological and Exploration Division. *Iranian Oil Offshore Company Report*, 1074 (Unpublished).

Ahmad S., Jalal W., Ali F., Hanif M., Ullah Z., Khan S., Ali A., Jan UI. & Rehman K. 2014. Using larger benthic foraminifera for the paleogeographic reconstruction of Neo-Tethys during Paleogene. *Arabian Journal Geoscience,* 1-18.

Alavi M. 2004. Regional Stratigraphy of Zagros Fold-Thrust Belt of Iran and Its Proforel and Evolution. *American Journal of Science*, 304: 1-20.

Babazadeh S. A. 2003. Biostratigraphie et contrôles paléogéographiques de la zone de suture de l'Iran oriental. Implications sur la fermeture Téthysienne. Thèse de doctorat, Université d'Orléans, France 1-384.

Babazadeh S. A., Baharan S., Parvaneh Nezhad Shirazi & Bahrami M. 2010. Biostratigraphy of Pabdeh Formation in Tange Zahjiran section (southeast Shiraz) based on planktic foraminifera. *Sedimentology and stratigraphy Reserches*, 38(1): 145-158.

Babazadeh S. A., Moghadasi S. J. & Yoosefizadeh Baghestani N. 2015. Analysis of sedimentary basin based on the distribution of microfacies of Jahrom Formation in Dashte Zari, Shahrekord. *18 th geology conference of Iran, Tarbiat Modares University,* 649-655.

Berberian M., 1995, Master "blind" thrust faults hidden under the Zagros folds: active basement tectonics and surface morphotectonics: Tectonophysics, 241(3–4), 193–224.

Berberian M. & King G. C. P. 1981. Towards a Paleogeography and Tectonic Evolution of Iran. *Canadian Journal of Earth Sciences*, 18: 210-265.

Berggren W. A., Kent D. V., Swisher I. C. C. & Aubry M. P. 1995. A revised Cenozoic geochronology and chronostratigraphy. *In:* Berggren W.A., Kent D.V., Aubry M. P. & Hardenbol J. (Eds). *Geochronology, Time Scales and Global Stratigraphic Correlations*: Society of Economic Paleontologists and Mineralogists Special Publication, 54:129-212.

Berggren W. A. & Pearson P. 2005. A Revised Tropical to Subtropical Paleogene Planktonic Foraminiferal Zonation. *The Journal of Foraminiferal Research*, 35: 279- 298.

Berggren W. A, Pearson P. N., Huber B. T. & Wade B.S., 2006. Taxonomy, biostratigraphy, and phylogeny of Eocene *Acarinina*. *Cushman Foundation special publication*, 41: 257-326.

Boggs, S. 2006, *Principles of Sedimentology and Stratigraphy* (third ed.), Pearson Education, p. 676.

Cande S. C. & Kent D. V. 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.,* 100: 6093–6095.

Chegni F., Baghbani D., Vaziri S. H. Mohtat T. & Ghadimvand Kohansal N. 2016. Biostratigraphy of Pabdeh Fm. (Middle-Late Eocene) in south Kuh-e-Mishan and Kuh-e-Eshgar in Izeh, west Kazeron fault. *Earth sciences, Geological Survey of Iran*, 99: 143-156.

Cole W. S. & Gravell D. W. 1952. Middle Eocene Foraminifera from Peñon Seep, Matanzas Province, Cuba. *Journal of Paleontology*. 26(5): 708-727.

Daneshian J., Shariati S. and Salsani A. 2015. Biostratigraphy and planktonic foraminiferal abundance in the phosphate-bearing Pabdeh Formation of the Lar Mountains (SW Iran). *N. Jb. Geol. Paläont. Abh., Stuttgart*, 1-16.

Davoudzadeh M. & Schmidt K., 1981. Contribution to the paleogeography and stratigraphy of the Upper Triassic to Middle Jurassic of Iran. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 162, 137–163.

Ehrenberg S. N., Pickard N. A.H., Laursen G.V., Monibi S., Mossadegh Z. K.,T. Svånå A., Aqrawi A. A.M., McArthur J. M. and Thirlwall M. F. (2007). Strontium isotope stratigraphy of the Asmari Formation (Oligocene - Lower Miocene), SW Iran. Journal of Petroleum Geology, 30(2), 107-128.

Ellis B. F. & Messina A. 1940. *Catalogue of Foraminifera. Micropaleontology Press, American Museum of Natural History, New York.*

Flugel E. 1982. *Microfacies analysis of limestones*. Berlin, Springer-Verlag, 633 p.

Flugel E. 2004. *Microfacies of carbonate rock*, Springer-Verlag, 976 p.

Hadavandkhani N., Sadeghi A., Adabi M. H. & Tahmasbi A. R. 2018. Lithostratigraphy and biostratigraphy of Pabdeh Formation in Chaharda village section (Izeh, Khuzestan). *Earth sciences, Geological Survey of Iran*, 107: 137-150.

Hanzawa S. 1957. Cenozoic Foraminifera of Micronesia. *Geological Society of America*. 66: 163 p.

Hayward B. W., Le Coze F., Vachard D. & Gross O. 2021. World Foraminifera Database, *Fabiania cubensis*. https://marinespecies.org/foraminifera/aphia.

Hottinger L. 1983. Processes determining the distribution of larger foraminifera in space and time. *Utrecht Micropaleont Bull*., 30: 239–253.

Hottinger L. 1997. Shallow benthic foraminiferal assemblages as signals for depth of their deposition and their limitations. *Bulletin de la Société Géologique de France,* 168 (4): 491-505.

Hottinger L. 2007. Revision of the foraminiferal genus Globoreticulina Rahaghi, 1978, and of its associated fauna of larger foraminifera from the late Middle Eocene of Iran. *Carnets de Géologie /Notebooks on Geology*, 51 p.

James G. A. & Wynd J. G. 1965. Stratigraphic Nomenclature of Iranian Oil Consortium Agreement Area. *American Association of Petroleum Geologists Bulletin*, 49: 94-156.

Kalantari A. 1976. Microbiostratigraphy of the Sarvestan Area, Southwestern Iran (Geological Laboratories Publication). *National Iranian Oil Company*, 1-129.

Kalantari A. 1978. Paleocene Biostratigraphy of some parts of Iran (Geological Laboratories Publication). *National Iranian Oil Company*, 1-165.

Kalantari A. 1980. Tertiary Faunal Assemblage of Qum-Kashan, Sabzevar and Jahrum areas (Geological Laboratories Publication), *National Iranian Oil Company*, 1-126.

Kalantari A. 1986. Microfacies of Carbonate Rocks of Iran. *National Iranian Oil Company, Geological Laboratories*, 1-520.

Khatibi Mehr M. & Moalemi A. 2009. Historical sedimentary correlation between Jahrom Formation and Ziarat Formation on the basis of benthic foraminifera. *Journal of Geology of Iran,* 9: 87-102.

Konijnenburg J. H. V., Wernli R. & Bernoulli D. 1998. Tentative biostratigraphy of Paleogene planktic foraminifera in thin-section, an example from the Gran Sasso d'Italia (central Apennines, Italy). *Eclogae Geologicae Helvetiae*, 203-216.

Le Calvez Y. 1949. Révision des foraminifères lutétiens du Bassin de Paris II, Rotaliidae et familles affines. *Mémoires pour servir à l'explication de la carte géologique détaillée de la France*, 1-41.

Loeblich A. R. & Tappan H. 1987. *Foraminiferal genera and their classification*. Van Nostrand Reinhold Co., New York, 970 p.

Luterbacher H. P., Ali J. R., Brinkhuis H., Gradstein F. M., Hooker J., Monechi, S., Ogg J. G., Powell J., Röhl U., Sanphilippo A. & Schmitz B. 2004. The Paleogene Period. *In:* Gradstein F., Ogg J. & Smith A. (Eds.). *A Geologic Time Scale. Cambridge University Press*, 384–408.

Miller K.G., Browning J.V., Schmelz W.J., Kopp R.K., Mountain G.S., & Wright J.D. 2020. Cenozoic sea-level and cryospheric evolution from deep-sea geochemical and continental margin records. *Science Advances* 2020; 6 : eaaz1346

Moradian F. & Baghbani D. 2016. Lithostratigraphy, biostratigraphy of Paleocene-lower Eocene sequences in Dezful embayment, southwest Iran. *Iranian Journal of Earth Sciences,* 8: 135-146.

Moradian F., Baghbani D. & Allameh M. 2017. Microbiostratigrapy of the Paleocene-Lower Eocene Sequences in the Bibi Hakimeh 2 Subsurface Section Located in the SW of Iran. *Open Journal of Geology*, 7: 147-161

Motiei H. 1994. Geology of Iran: Stratigraphy of Zagros. *Geological Survey of Iran Publication*, 583pp.

Murray J.W. 1991. Ecology and Palaeoecology of Benthic Foraminifera. *Longman Science & Technology*, 397 p.

Olsson R. K., Hemleben C., Berggren W. A. & Huber B. T. 1999. Atlas of Paleocene Planktonic Foraminifera. Smithsonian Institution Press, Washington DC, 252 p.

Ozgen N. 2000. *Nurdanella boluensis* n.gen., n.sp., a Miliolid (Foraminifera) from the Lutetian of the Bolu Area (Northwestern Turkey). *Revue de paleobiologie*, 19: 79-85.

Pälike H., Norris R. D., Herrle J. O., Wilson P. A., Coxall H. K., Lear C. H., Shackleton N. J., Tripati A. K., Wade B. S., 2006. The heartbeat of the Oligocene climate system. *Science* 314: 1894–1898.

Postuma S. A. 1971. Manual of Planktonic Foraminifera: Elsevier, Amsterdam, 420 p.

Premoli Silva I. & Bolli H. M. 1973. Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of leg 15, Sites in the Caribbean Sea: *Initial Reports DSDP*, 15: 449–547.

Premoli Silva I., Rettori R. & Verga D. 2003. Practical Manual of Paleocene and Eocene Planktonic Foraminifera: *International School on planktonic foraminifera*, second course, Perugia.

Rahaghi A. 1976. Contribution à l'étude de quelques grands foraminifères de l'Iran. *National Iranian Oil Company,* 6: 1-84.

Rahaghi A. 1978. Paleogene biostratigraphy of some parts of Iran. *National Iranian Oil Company,* 7:1-165.

Rahaghi A. 1980. Tertiary faunal assemblage of Qom-Kashan, Sabzewar and Jahrom area. *National Iranian Oil Company,* 8: 1-126.

Rahaghi A. 1983. Stratigraphy and faunal assemblage of Paleocene and Lower Eocene in Iran. *National Iranian Oil Company,* 10: 1-173.

Sari B. 2017. Lithostratigraphy and planktonic foraminifera of the uppermost Cretaceous–Upper Palaeocene strata of the Tavas nappe of the Lycian nappes (SW Turkey). *Geologia Croatica*, 70 (3): 163-177.

Sarigul V., Hakyemez A., Tuysuz, O., Can Genc S., Yilmaz I. O. & Ozcan E. 2017. Maastrichtian-Thanetian planktonic foraminiferal biostratigraphy and remarks on the K-Pg boundary in the southern Kocaeli Peninsula (NW Turkey). *Turkish Journal of Earth Sciences*, 26: 1-29.

Sengör A. M., Altiner C. Cin D., Ustomer T. & Hsu K. J. 1988. The origin and assembly of the Tethyside orogenic collage at the expense of Gondwana land : *In* : Audley-Charles, M. G. & A. Hallam (eds), Gondwana and Tethys. *Geological Society, Special Publication,* 37 : 119-181.

Serra-Kiel J. S., Hottinger L., Caus E., Drobne K., Ferrandez C., Jauhir A. K., Less G., Pavlovec R., Pignatti J., Samso J. M., Schaub H., Sirel E., Strougot A., Tambareau Y., Toosquella J. & Zakrevskaya E. 1998. Larger foraminiferal biostratigraphy of the Tethyan Palaeocene and Eocene. *Bulletin de la Societe Géologique de France,* 169: 281-299.

Sirel E. 2003. Foraminiferal description and biostratigraphy of the Bartonian, Priabonian, and Oligocene shallow-water sediments of southern and eastern Turkey. *Revue de Paléobiologie,* 22: 269–339.

Sirel E. 2009. Reference sections and key localities of the Paleocene stages and their very shallow/shallow-water three new benthic foraminifera in Turkey. *Revue de Paléobiologie*, 28(2): 413-435.

Stöcklin J. 1968. Structural History and Tectonics of Iran: A Review. AAPG Bulletin (1968) 52 (7): 1229–1258.

Stöcklin, J. 1977. Structural Correlation of the Alpine Ranges between Iran and Central Asia. Mémoires de la Société Géologique de France, 8, 333-353.

Stöcklin J. & Setudehnia A. 1991. *Stratigraphic Lexicon of Iran*, Geological Survey of Iran, 18: 376pp.

Stoneley R., 1981, The geology of the Kuh–e Dalneshin area of Southern Iran, and its bearing on the evolution of Southern Tethys: Journal of the Geological Society, London, 138, 509–526.

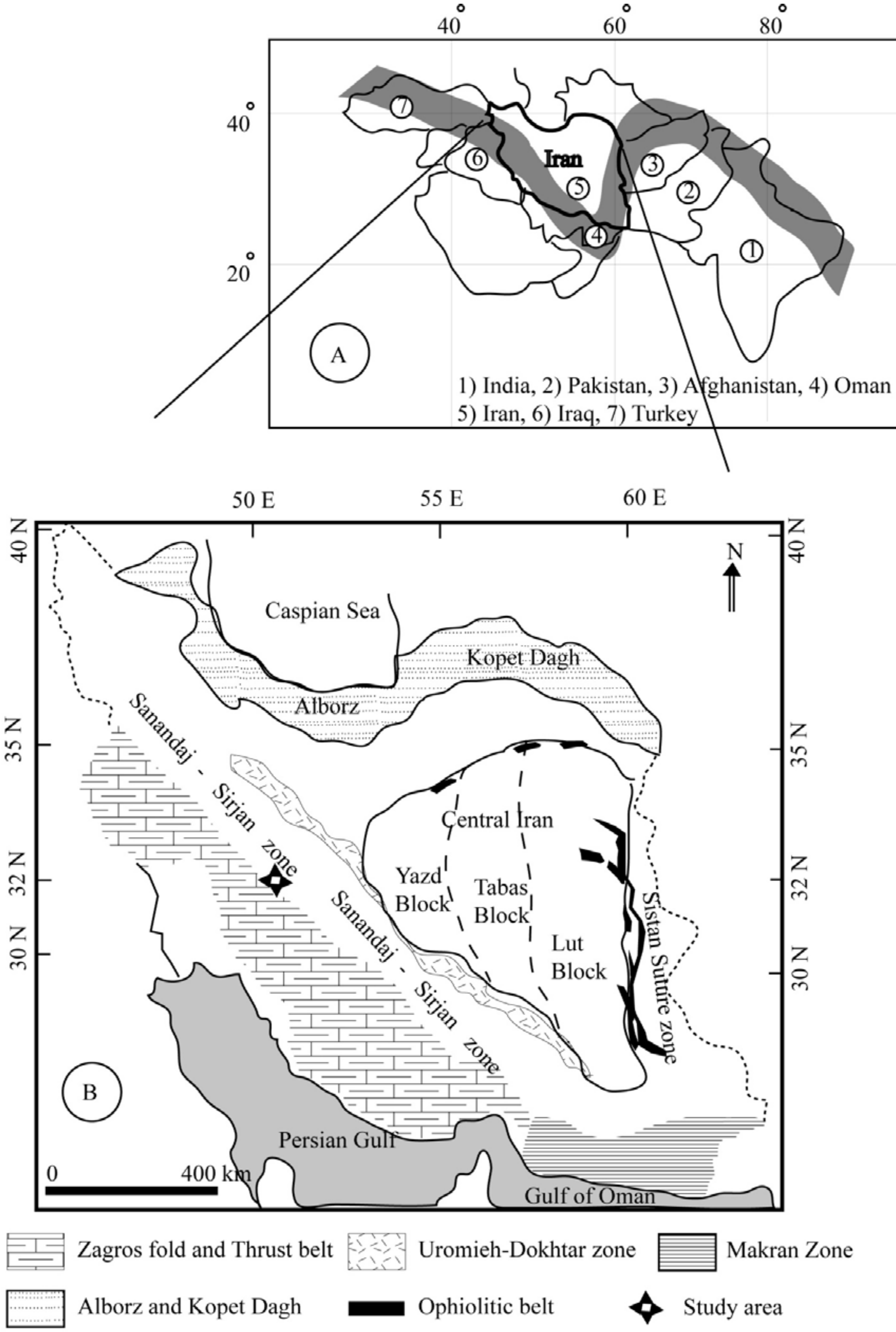
Toumarkine M. & Luterbacher H. P. 1985. Paleocene and Eocene Planktic Foraminifera *In:* Bolli H. M., Saunders J. B. & Perch-Nielsen K. (Eds). *Plankton Stratigraphy*: Cambridge University Press, Cambridge, 87-154

Wade B. S., Pearson P. N., Berggren W. A. & Palike H. 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. *Earth Science Review*, 104: 111-142.

Wernli R., Morend D & Piguet B. 1997. Les foraminifères planctoniques en sections de l'Eocène et de l'Oligocène des Grès de Samoëns (Ultra-helvétique du massif de Platé. Haute-Savoie. France). *Eclogae geol. Helv.,* 90: 581-590.

Zahedi M. & Rahmati Ilkhechi M. 2006. Explanation of Geology of Shahrekord quadrangle, 1: 250000, 194p.

621 Fig. 1 is below.



621 Fig. 1

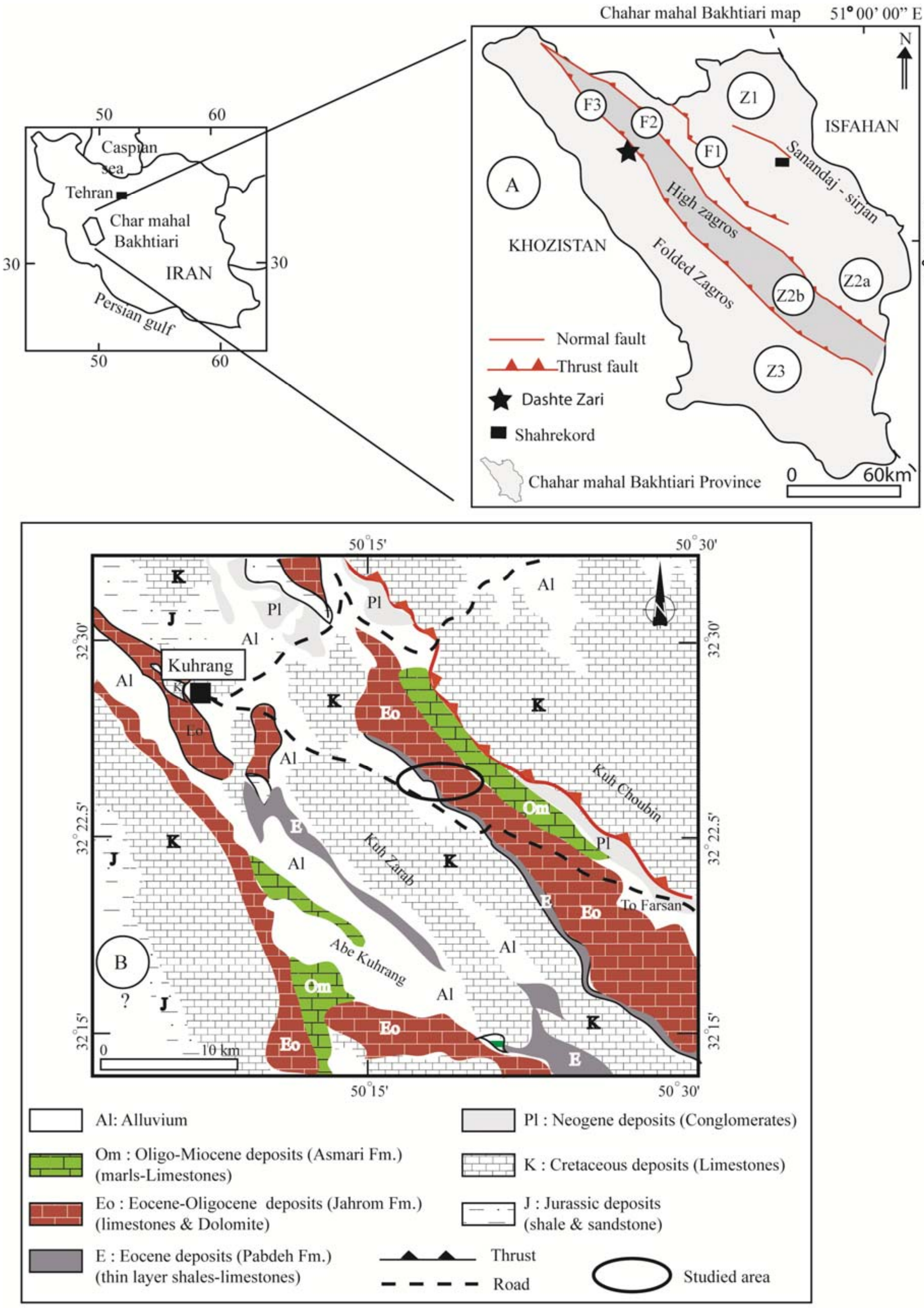
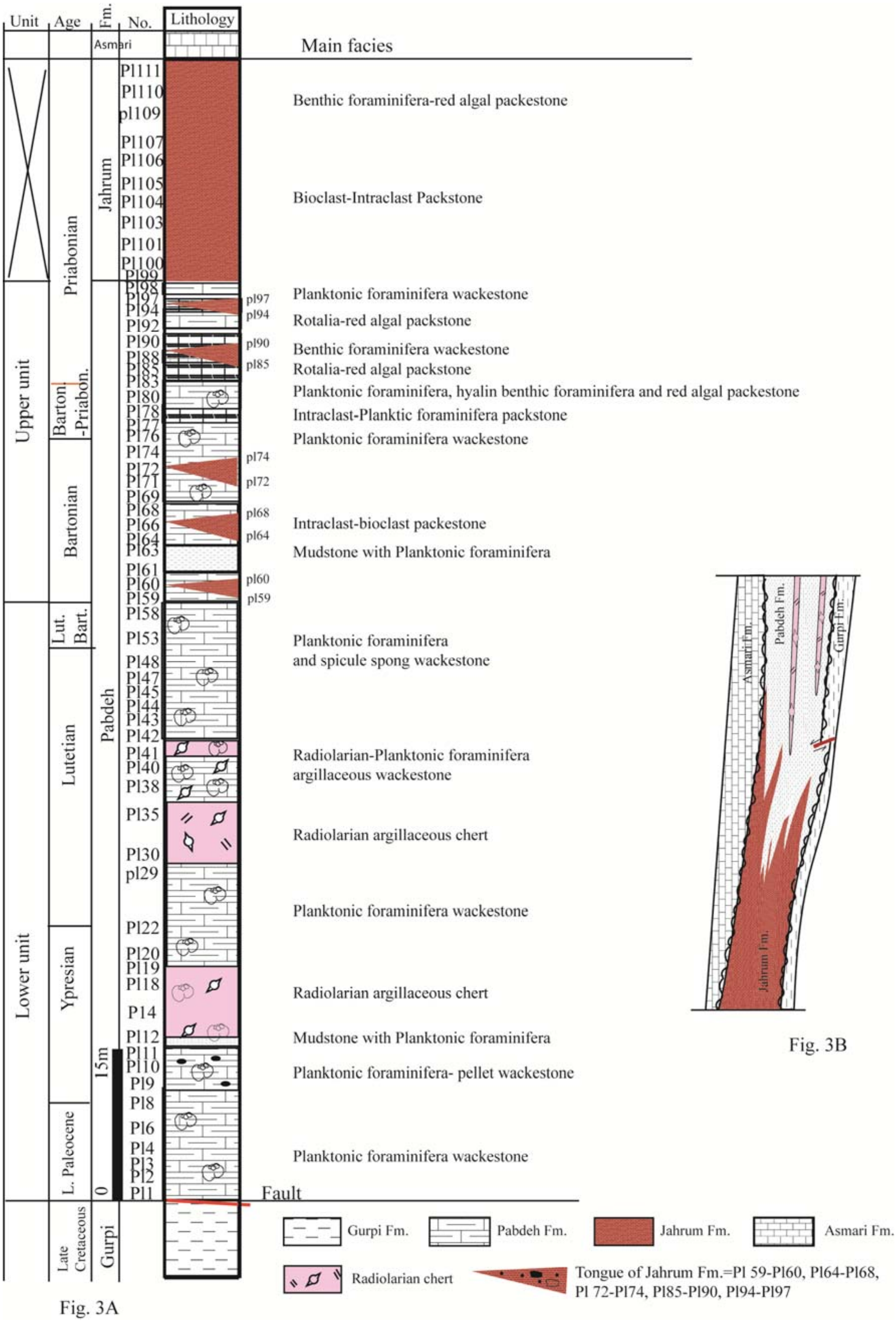

Chahar mahal Bakhtiari map
51° 00' 00" E
32° 00' 00" N
Caspian sea
Tehran
Char mahal Bakhtiari
IRAN
Persian gulf
A
F1
F2
F3
Z1
Z2a
Z2b
Z3
ISFAHAN
KHOZISTAN
High zagros
Folded Zagros
Sanandaj - sirjan
Normal fault
Thrust fault
Dashte Zari
Shahrekord
Chahar mahal Bakhtiari Province
0
60km
B
Kuhrang
Kuh Choubin
Kuh Zarab
Abe Kuhrang
To Farsan
10 km
Al: Alluvium
Om : Oligo-Miocene deposits (Asmari Fm.) (marls-Limestones)
Eo : Eocene-Oligocene deposits (Jahrom Fm.) (limestones & Dolomite)
E : Eocene deposits (Pabdeh Fm.) (thin layer shales-limestones)
Pl : Neogene deposits (Conglomerates)
K : Cretaceous deposits (Limestones)
J : Jurassic deposits (shale & sandstone)
Thrust
Road
Studied area

Fig. 2



Unit
Age
Fm.
No.
Lithology
Main facies
Asmari
Upper unit
Lower unit
Priabonian
Barton.-Priabon.
Bartonian
Lut. Bart.
Lutetian
Ypresian
L. Paleocene
Late Cretaceous
Jahrum
Pabdeh
Gurpi
15m
0
Benthic foraminifera-red algal packstone
Bioclast-Intraclast Packstone
Planktonic foraminifera wackestone
Rotalia-red algal packstone
Benthic foraminifera wackestone
Rotalia-red algal packstone
Planktonic foraminifera, hyalin benthic foraminifera and red algal packstone
Intraclast-Planktic foraminifera packstone
Planktonic foraminifera wackestone
Intraclast-bioclast packestone
Mudstone with Planktonic foraminifera
Planktonic foraminifera
and spicule spong wackestone
Radiolarian-Planktonic foraminifera
argillaceous wackestone
Radiolarian argillaceous chert
Planktonic foraminifera wackestone
Radiolarian argillaceous chert
Mudstone with Planktonic foraminifera
Planktonic foraminifera- pellet wackestone
Planktonic foraminifera wackestone
Fault
Gurpi Fm.
Pabdeh Fm.
Jahrum Fm.
Asmari Fm.
Radiolarian chert
Tongue of Jahrum Fm.=Pl 59-Pl60, Pl64-Pl68,
Pl 72-Pl74, Pl85-Pl90, Pl94-Pl97
Asmari Fm.
Pabdeh Fm.
Gurpi Fm.
Jahrum Fm.

Fig. 3A

Fig. 3B

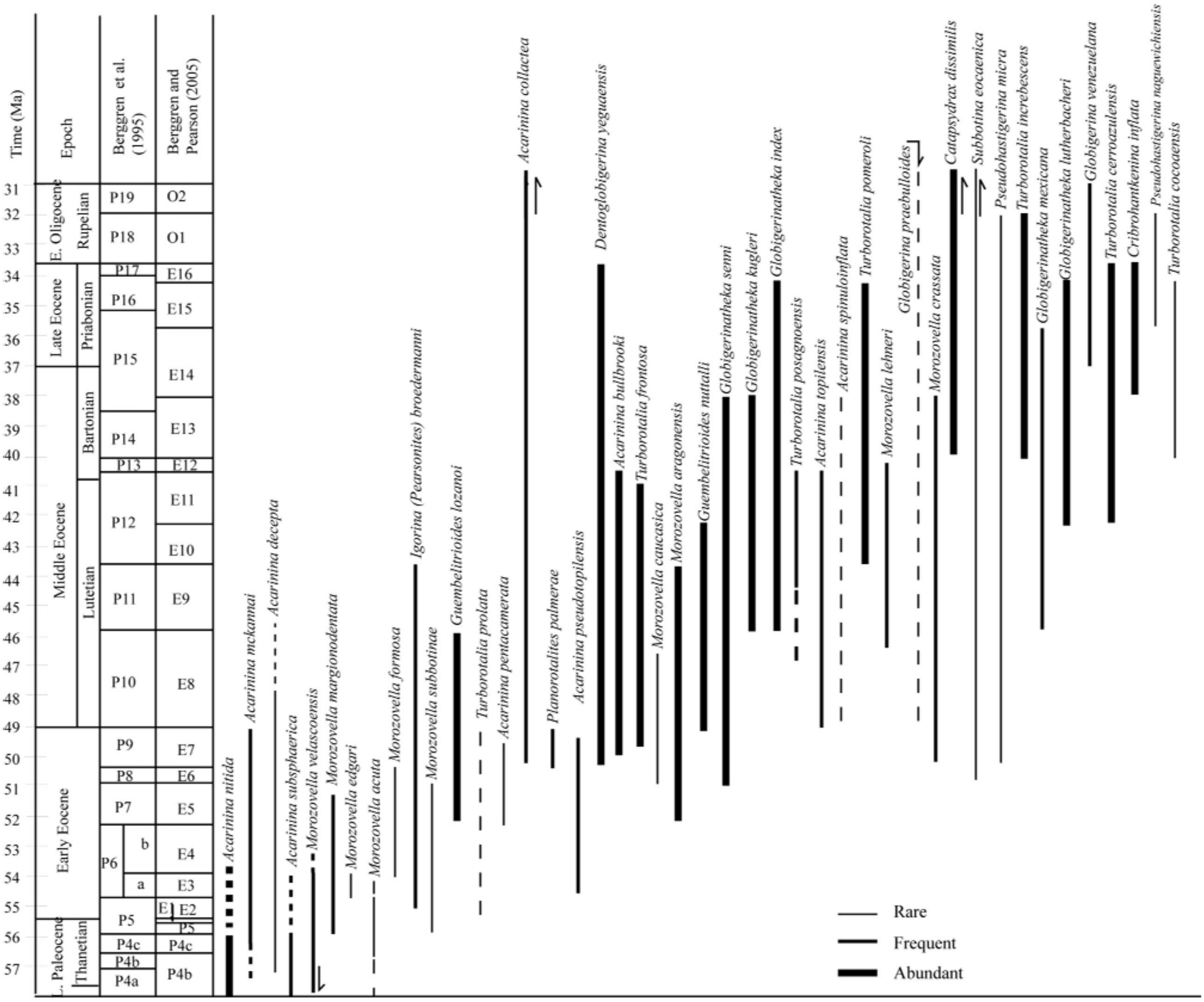
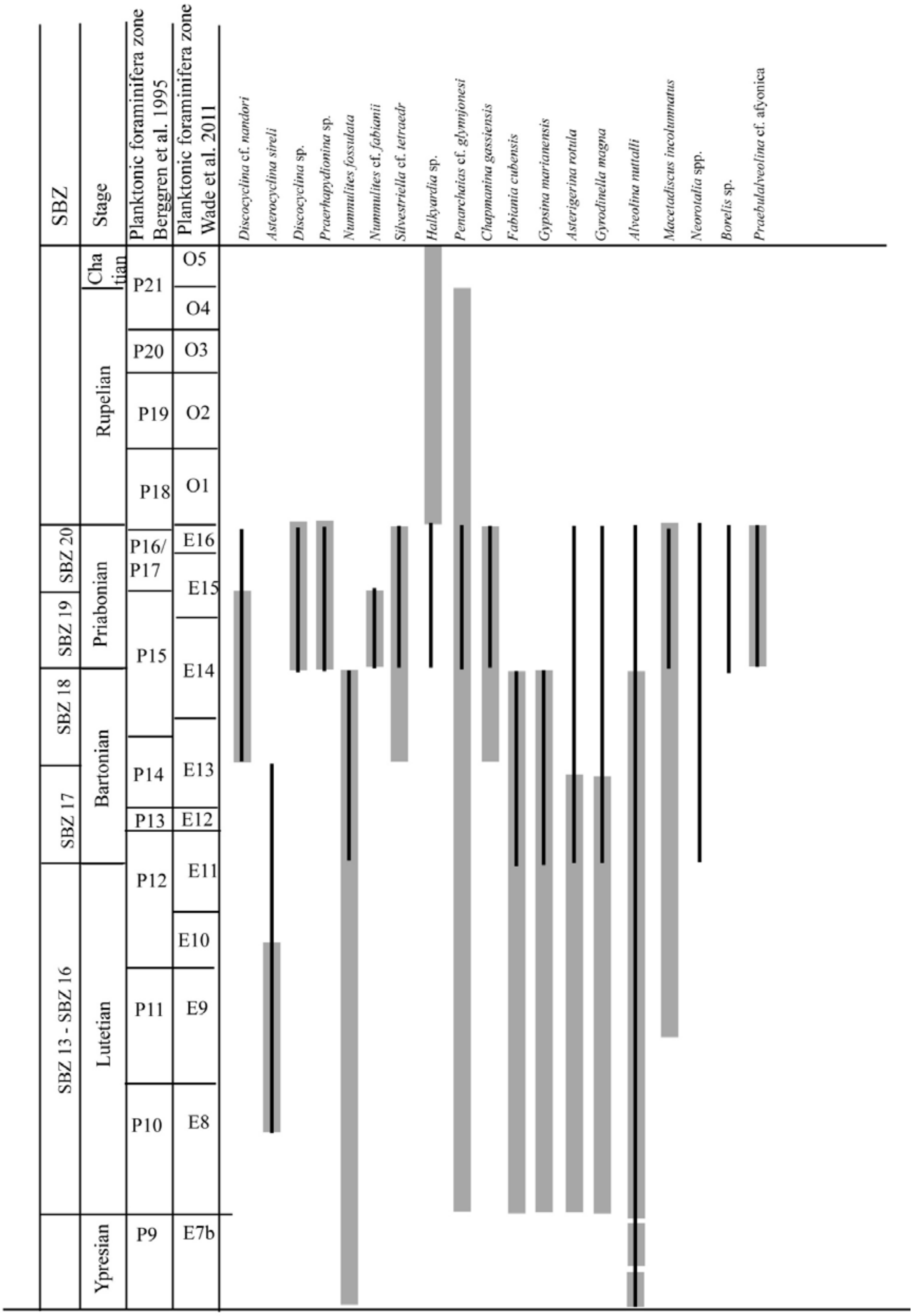

Time (Ma)
Epoch
Berggren et al. (1995)
Berggren and Pearson (2005)
E. Oligocene
Rupelian
Late Eocene
Priabonian
Middle Eocene
Bartonian
Lutetian
Early Eocene
L. Paleocene
Thanetian
P19
P18
P17
P16
P15
P14
P13
P12
P11
P10
P9
P8
P7
P6
a
b
P5
P4c
P4b
P4a
O2
O1
E16
E15
E14
E13
E12
E11
E10
E9
E8
E7
E6
E5
E4
E3
E2
E1
P5
P4c
P4b
Acarinina nitida
Acarinina mckannai
Acarinina decepta
Acarinina subsphaerica
Morozovella velascoensis
Morozovella margionodentata
Morozovella edgari
Morozovella acuta
Morozovella formosa
Igorina (Pearsonites) broedermanni
Morozovella subbotinae
Guembelitrioides lozanoi
Turborotalia prolata
Acarinina pentacamerata
Acarinina collactea
Planorotalites palmerae
Acarinina pseudotopilensis
Dentoglobigerina yeguaensis
Acarinina bullbrooki
Turborotalia frontosa
Morozovella caucasica
Morozovella aragonensis
Guembelitrioides nuttalli
Globigerinatheka senni
Globigerinatheka kugleri
Globigerinatheka index
Turborotalia posagnoensis
Acarinina topilensis
Acarinina spinuloinflata
Turborotalia pomeroli
Morozovella lehneri
Globigerina praebulloides
Morozovella crassata
Catapsydrax dissimilis
Subbotina eocaenica
Pseudohastigerina micra
Turborotalia increbescens
Globigerinatheka mexicana
Globigerinatheka lutherbacheri
Globigerina venezuelana
Turborotalia cerroazulensis
Cribrohantkenina inflata
Pseudohastigerina naguewichiensis
Turborotalia cocoaensis
Rare
Frequent
Abundant

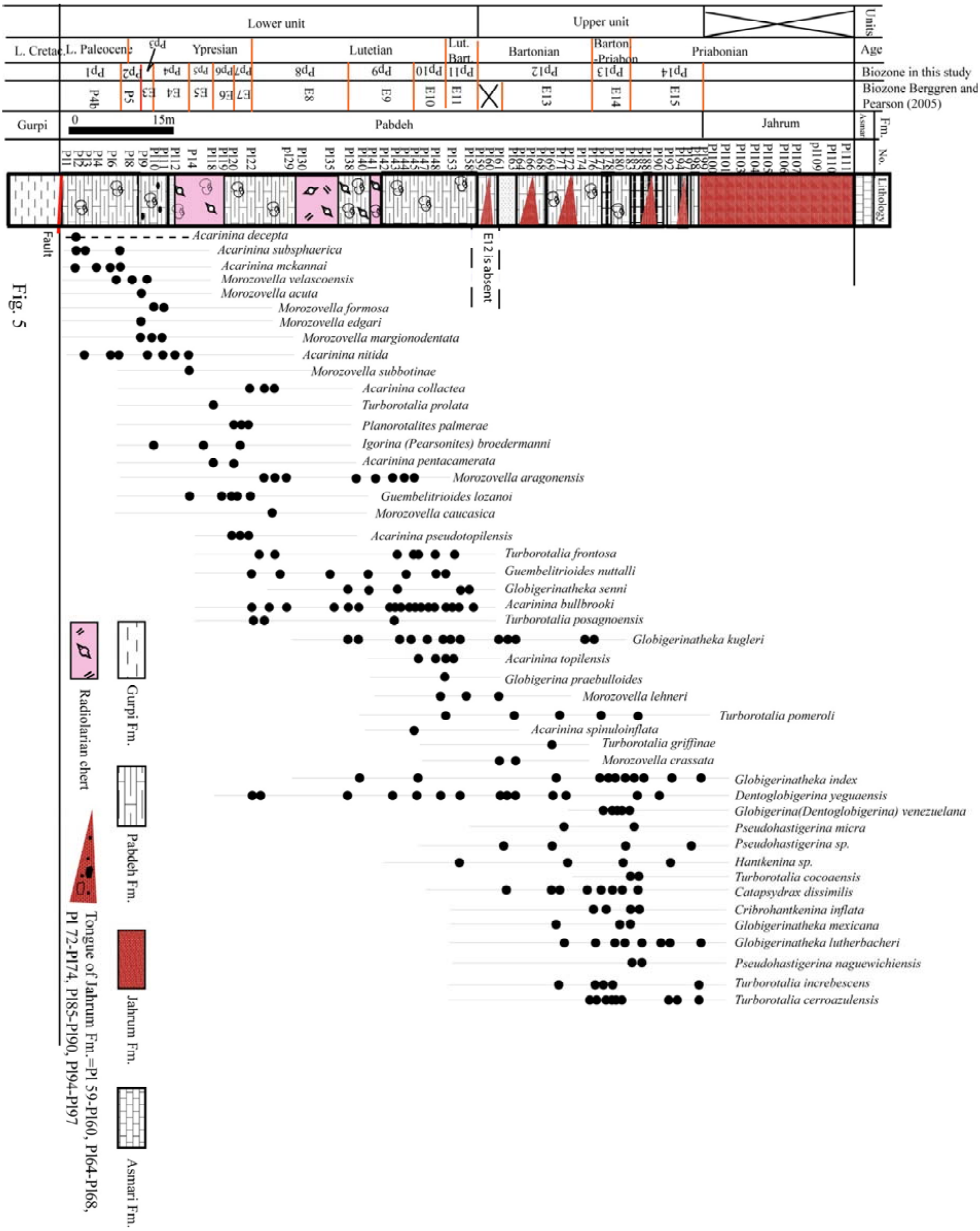
Fig. 4 A

624



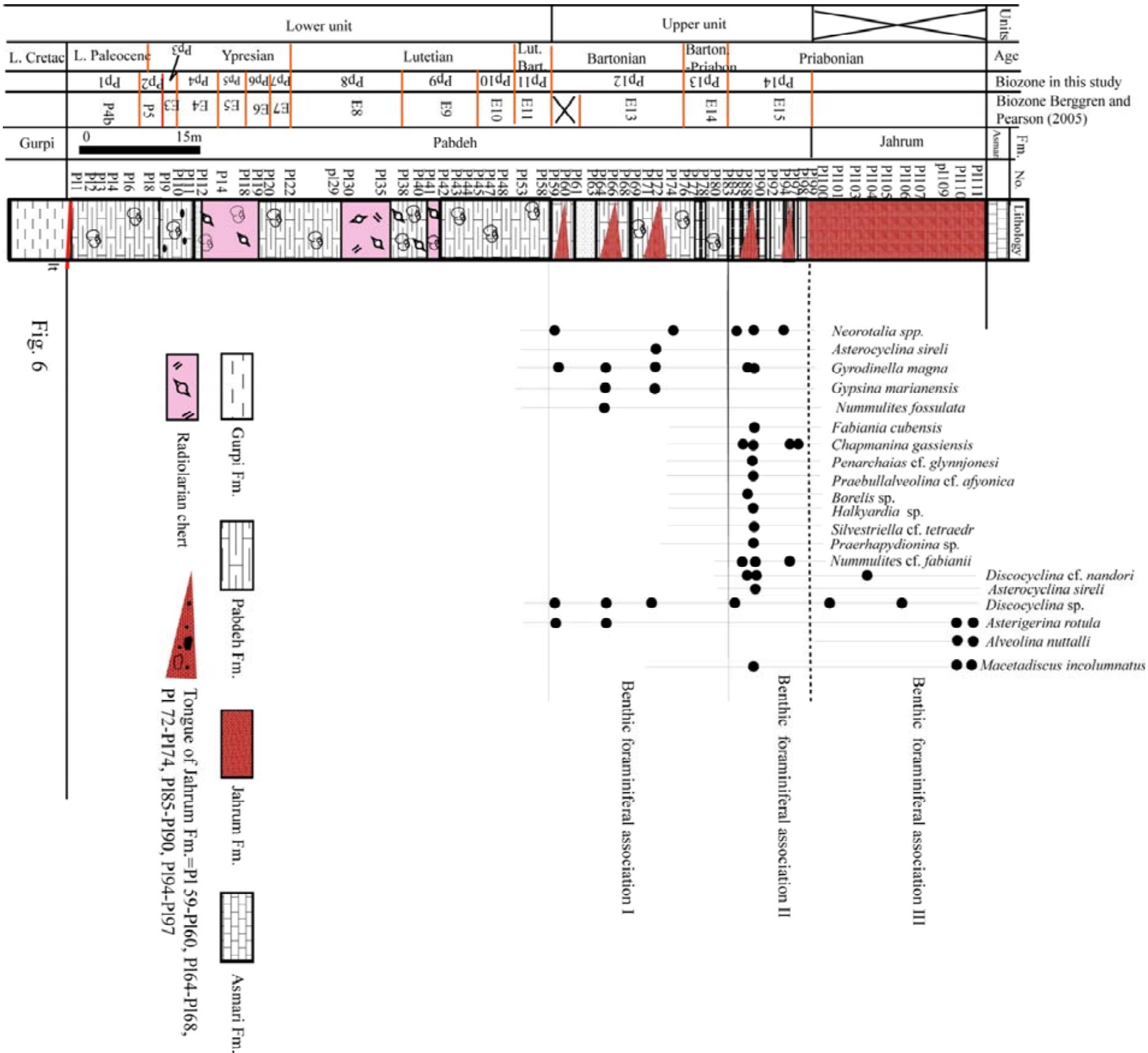
SBZ
Stage
Planktonic foraminifera zone Berggren et al. 1995
Planktonic foraminifera zone Wade et al. 2011
Discocyclina cf. nandori
Asterocyclina sireli
Discocyclina sp.
Praerhapydionina sp.
Nummulites fossulata
Nummulites cf. fabianii
Silvestriella cf. tetraedr
Halkyardia sp.
Penarchaias cf. glynnjonesi
Chapmanina gassiensis
Fabiania cubensis
Gypsina marianensis
Asterigerina rotula
Gyrodinella magna
Alveolina nuttalli
Macetadiscus incolumnatus
Neorotalia spp.
Borelis sp.
Praebulalveolina cf. afyonica
Cha tian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
SBZ 20
SBZ 19
SBZ 18
SBZ 17
SBZ 13 - SBZ 16
P21
P20
P19
P18
P16/ P17
P15
P14
P13
P12
P11
P10
P9
O5
O4
O3
O2
O1
E16
E15
E14
E13
E12
E11
E10
E9
E8
E7b

Fig. 4B



Lower unit
Upper unit
Units
L. Cretac.
L. Paleocene
Ypresian
Lutetian
Lut. Bart.
Bartonian
Barton -Priabon
Priabonian
Age
Biozone in this study
Biozone Berggren and Pearson (2005)
Gurpi
Pabdeh
Jahrum
Asmari
Fm.
No.
Lithology
0
15m
Fault
E12 is absent
Acarinina decepta
Acarinina subsphaerica
Acarinina mckannai
Morozovella velascoensis
Morozovella acuta
Morozovella formosa
Morozovella edgari
Morozovella margionodentata
Acarinina nitida
Morozovella subbotinae
Acarinina collactea
Turborotalia prolata
Planorotalites palmerae
Igorina (Pearsonites) broedermanni
Acarinina pentacamerata
Morozovella aragonensis
Guembelitrioides lozanoi
Morozovella caucasica
Acarinina pseudotopilensis
Turborotalia frontosa
Guembelitrioides nuttalli
Globigerinatheka senni
Acarinina bullbrooki
Turborotalia posagnoensis
Globigerinatheka kugleri
Acarinina topilensis
Globigerina praebulloides
Morozovella lehneri
Turborotalia pomeroli
Acarinina spinuloinflata
Turborotalia griffinae
Morozovella crassata
Globigerinatheka index
Dentoglobigerina yeguaensis
Globigerina(Dentoglobigerina) venezuelana
Pseudohastigerina micra
Pseudohastigerina sp.
Hantkenina sp.
Turborotalia cocoaensis
Catapsydrax dissimilis
Cribrohantkenina inflata
Globigerinatheka mexicana
Globigerinatheka lutherbacheri
Pseudohastigerina naguewichiensis
Turborotalia increbescens
Turborotalia cerroazulensis
Gurpi Fm.
Pabdeh Fm.
Jahrum Fm.
Asmari Fm.
Radiolarian chert
Tongue of Jahrum Fm.=Pl 59-Pl60, Pl64-Pl68, Pl 72-Pl74, Pl85-Pl90, Pl94-Pl97

Fig. 5


Units
Lower unit
Upper unit
Age
L. Cretac
L. Paleocene
Ypresian
Lutetian
Lut. Bart.
Bartonian
Barton. -Priabon
Priabonian
Biozone in this study
Biozone Berggren and Pearson (2005)
Fm.
Gurpi
Pabdeh
Jahrum
Asmari
0
15m
No.
Lithology
Neorotalia spp.
Asterocyclina sireli
Gyrodinella magna
Gypsina marianensis
Nummulites fossulata
Fabiania cubensis
Chapmanina gassiensis
Penarchaias cf. glynnjonesi
Praebullalveolina cf. afyonica
Borelis sp.
Halkyardia sp.
Silvestriella cf. tetraedr
Praerhapydionina sp.
Nummulites cf. fabianii
Discocyclina cf. nandori
Asterocyclina sireli
Discocyclina sp.
Asterigerina rotula
Alveolina nuttalli
Maetadiscus incolumnatus
Benthic foraminiferal association I
Benthic foraminiferal association II
Benthic foraminiferal association III
Gurpi Fm.
Pabdeh Fm.
Jahrum Fm.
Asmari Fm.
Radiolarian chert
Tongue of Jahrum Fm.=Pl 59-Pl60, Pl64-Pl68, Pl 72-Pl74, Pl85-Pl90, Pl94-Pl97
Fig. 6

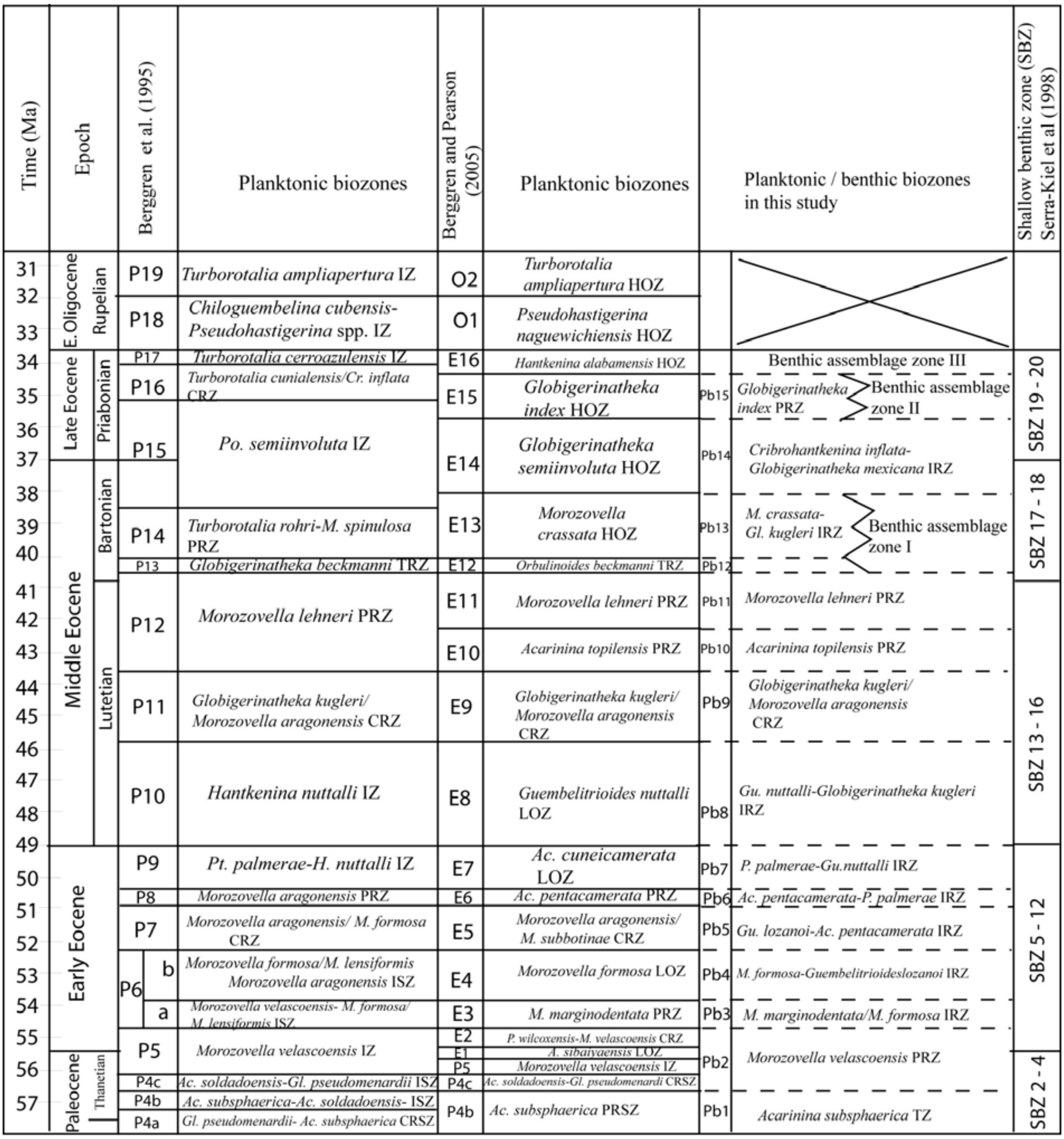


Fig. 7

Ac: Acarinina, Gl. Globigerinatheka, Gu:Guembelitrioides, M: Morozovella, P: Planorotalites, Ps: Pseudohastigerina