

Sequence and Biostratigraphy of Lower Cenozoic Succession in the Kopet-Dagh Basin, NE of Iran

Batool Rivandi^{1*}, Mohammad Vahidinia¹, Mehdi Nadjafi¹, Assadollah Mahboubi¹, Abbas Sadeghi²

¹Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran

²Department of Geology, Faculty of Science, Shahid Behshti University, Tehran, Iran

Email: *ba_ri730@stu.um.ac.ir

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ABSTRACT

The main purpose of this paper is the sequence stratigraphy and biostratigraphy of lower Tertiary sediments on the base of larger benthic foraminifera in northeast of Iran (Chehel-Kaman Formation). This formation mainly consists of Limestone, dolomite and interbeds of sand, shale and evaporate sediments. Petrographical studies indicate that these sediments may have been deposited on a shallow carbonate platform ramp and consist of 4 carbonate lithofacies (15 subfacies). These lithofacies may have been deposited in open marine, shoal, lagoon and tidal flat environmental conditions. Sequence stratigraphy analysis led to identification of 4 third-order depositional sequences, bounded by type 2 (within the top of the underlying Pestehleigh Formation) and type 1 sequence boundaries (paleosol). Interpreted sea level curve in this basin can be relatively correlated with global curves during Paleocene time and a with a sea-level fall occurred in the latest Paleocene, followed by a rise in the earliest Eocene. Biostratigraphy study led to the identification of 32 larger benthic Foraminifera genera. The Paleocene/Eocene boundary has been probably recorded as a thin red paleosol horizon (~10 - 15 cm).

Keywords: Kopeh-Dagh Basin; Paleogene; Larger Benthic Foraminifer; Sequence Stratigraphy

1. Introduction

This study explores the biostratigraphy and sequence stratigraphy of the Chehel-Kaman Formation by using larger benthic foraminifera and microfacies studies. Larger Benthic Foraminifera (LBF) are photosymbiotic biota lived in warm, oligotrophic, shallow waters within the photic zone [1], thus they can be used to help understanding paleoclimatic and paleoenvironmental conditions in the Paleogene [2,3]. They are major components of many Paleogene carbonate platforms around the world particularly in Paratethys realm. The aim of this paper is to report the diversity of larger benthic foraminifera and correlate them with sequence stratigraphy and sea level change. The peak of larger benthic foraminifera was in late Paleocene. Many works have been done in Paleocene/Eocene boundary, but pre-boundary (Late Paleocene) still needs to be studied more by biostratigraphical concentration.

2. Geological Setting

The Kopet Dagh as an inverted basin [4] was extended

from the east of the Caspian Sea to NE Iran, north Afghanistan and Turkmenistan [5,6]. Following the closure of Palaeo-Tethys in the Middle Triassic [7] and the opening of Neo-Tethys during the Early to Middle Jurassic [6], the Kopet Dagh Basin formed during the Early to Middle Jurassic [8]. Sedimentation took place continuously from the Jurassic through the Neogene times in the Kopet-Dagh Basin [5,9,10] which was recorded by five major transgressive-regressive sequences [11]. Close to the latest Cretaceous period to the early Paleocene epoch, the epicontinental sea regressed toward the northwest and a thick interval of the lower Paleocene redbed siliciclastic sediments were deposited in fluvial environments (Pestehleigh Formation). During the late Paleocene, the sea level raised rapidly. In this transgression the carbonates of the Chehel-Kaman Formation deposited [11,12]. The importance of Kopet-Dagh Basin is due to this fact that it hosts the giant Khangiran and Gonbadli gas fields, what's more upper Paleocene carbonate in this basin constitute one of the producing intervals. Chehel-Kmana Formation is one of the major formation in Kopeh-Dagh basin at northeastern of Iran with upper Paleocene age.

*Corresponding author.

3. Material and Methods

The present study is based on two stratigraphic sections (Padeli and Type locality sections) in Kopet-Dagh Basin which are well exposed (Figure 1). Field and petrographic studies were carried out for facies analysis and paleoenvironmental reconstruction of Chehel-Kaman Formation. Facies identifications were based on microfacies characteristics, including depositional texture, grain size, grain composition and fossil content. The classification of carbonate rocks followed the nomenclature of Dunham (1962) [13] and Embry and Klovan (1971) [14]. The depositional features, microfossils and sedimentary structure led to recognition of 16 subfacies. Microfacies and fossil content of 116 thin-sections were analyzed and 81 samples of shale and marl have been provided during this study. Thin sections were stained using Alizarin red S [15] to detect dolomitization of grains and cements.

4. Lithostratigraphy and Biostratigraphy

Chehel-Kaman Formation (Paleogene) in the Kopet-Dagh basin is mainly composed of limestone, dolomite and interbeds of marl, shale and evaporate sediments. It conformably overlies siliciclastic sediments of Pestehligh and underlies the olive shale of Khangiran formations. Lithostratigraphic study of Chehel-Kaman Formation shows that this formation is divided into 5 units in Padeli and 4 units in type locality (Chehel-Kaman synclinal). Comparing two lithostratigraphic sections indicates that this formation in eastern part of Kopet-Dagh basin (Padeli section) has more evaporate sediments than locality section. This subject confirms the fact that the basin depth decrease from West to East. After crisis extinction in K/T boundary [extinction of 83% LBFs, 16], the surviving species in the early Paleocene were small and relatively rare [16] but in late Paleocene they became

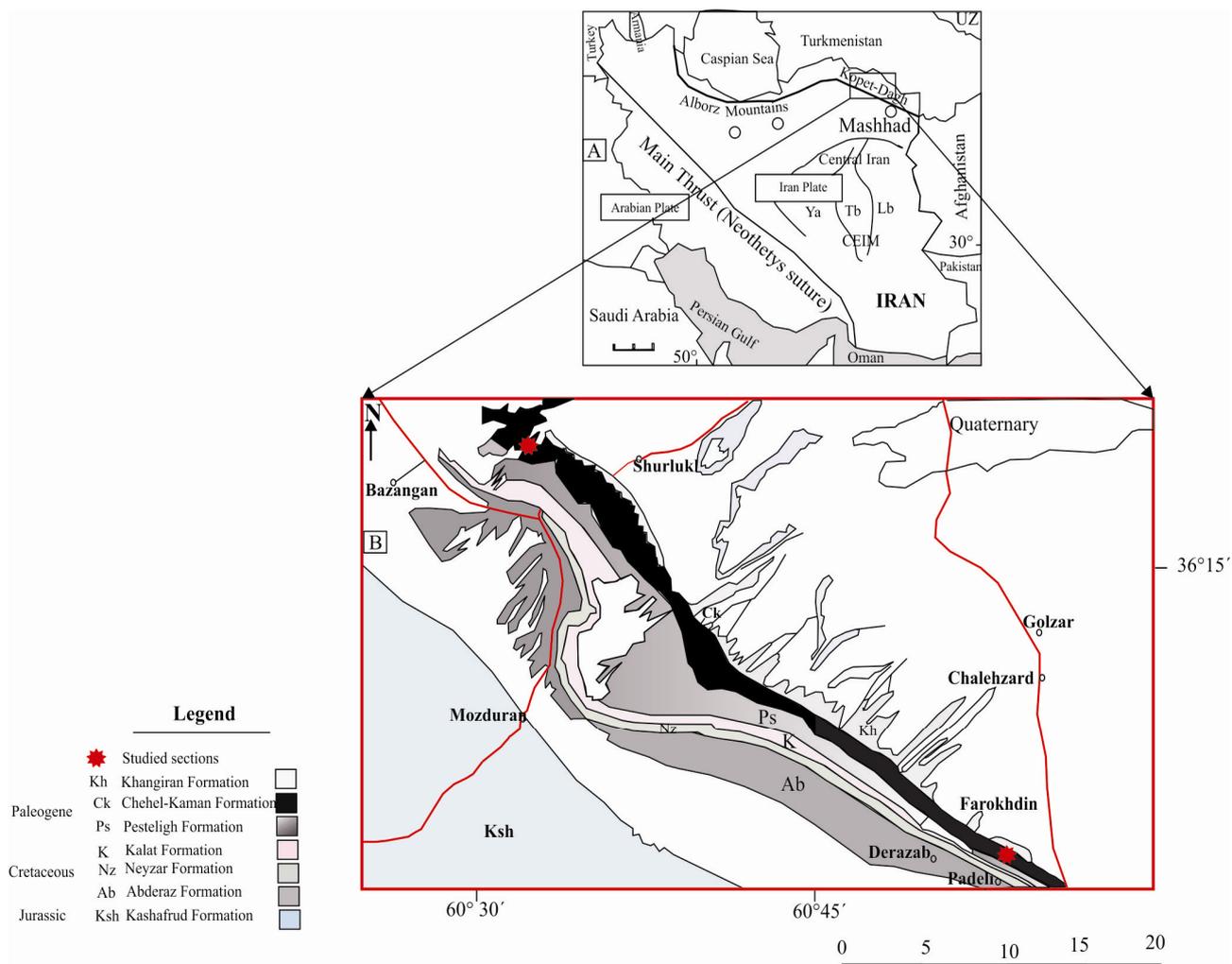


Figure 1. (A) Structural geology and geography map of Iran showing the main sutures, structural units and geographic areas (redrawn from Ghasemi-Nejad *et al.*, 2012). AR: Armenia, AZ: Azerbaijan, UZ: Uzbekistan, Yb: Yazd Block, Tb: Tabas Block, Lb: Lut Block, CEIM: Central-East Iranian microcontinent; (B) Location map of the Chehel-Kaman Formation at Padeli and Locality type sections

abundant and their size became larger. Here, based on biostratigraphic studies, we investigated the long-term evolutionary patterns of LBF in Para Tethys. SBZ1-SBZ2 biozones are represented by smaller rotaliids genera (*Rotalia* and *Laffitteina*) and miliolids (*Idalina*). *Lockhartia*, *Miscellanea* and *Ornatononion* are commonly reported in this interval however these genera are absent in India and Pakistan in east Tethys [17-20]. *Laffitteina* [21] species are well known foraminifera in Middle Paleocene to Late Paleocene units. The Danian-Selandian boundary (~60 Ma) is characterized by the change of carbonate sedimentation to siliciclastic deposition. This event was observed in the type locality section. Maybe the first appearance of very thin paleosol (5 cm) at the initial sediments of Chehel-Kaman Formation can be considered as a sea level fall and as Danian/Selandian boundary. The D/S boundary at both sections characterized by a glauconit bed. Also the first occurrences of *Laffitteina erki* (Sirel), *Kathina selveri* Smout, *Rotalia trochidiformis* (Lamarck) and *Cuvillierina sireli* İnan, indicate the lower boundary of the Selandian. *Laffitteina bibensis* associated with *Idalina sinjarica*, *Miscellanea primitiva* Rahaghi, *Laffitteina* sp., *Haymanella paleocenica*, *Cuvillierina* sp., Miliolidae and algae indicate Early Thanetian age.

According to Serra-Kiel *et al.* [22], *Laffitteina bibensis* is restricted to the basal Paleocene SBZ1 Biozone. However longer biostratigraphic ranges for *Lf. Bibensis* have been reported from the Paleocene of Iran [23] and the Danian to Thanetian successions of NE Turkey [22,24]. The SBZ3-SBZ4 biozones are characterized by the appearance of many new taxonomic lineages including genera of rotaliids (*Lockhartia* and *Kathina*), miliolids (*Triloculina* and *Quinqueloculina*), pellatispirids (*Miscellanea*), nummulitids (*Ranikothalia*, *Assilina*) and lepidorbitoids (*Daviesina*). Serra-Kiel *et al.* [22] described *Idalina sinjarica* to be ranging from SBZ3 biozone to SBZ6. *Miscellanea miscella* has been reported from Afghanistan [25], northeastern Turkey [26], Iran [27] and India [28] in horizons equivalent to the SBZ5 Biozone. Based on larger benthic foraminifera, three Tethyan foraminiferal biozones (SBZ1-SBZ4) spanning from the late late Danian to late Thanetian interval were identified in Padeli section but they may have the age of early Eocene in the type section. There isn't any evidence showing the presence of *Alveolina*, *Nummulites* and Planktonic foraminifera. So it's difficult to determine exact age of these sediments. Probably the Paleocene/Eocene boundary in the Type locality is characterized by a para disconformity. The following thirty three genera taxa were identified in the studied sections: *Rotalid formilar*, *Daviesina iranica*, *Valvulina* sp., *Cuvillierina sireli inan*, *Laffitteina turcica*, *Laffitteina melona*, *Hottingerina anatolica*, *Sakessaria* sp., *Cidenia soezerii*, *Pseudocuvillierina sireli*, *Lokarthia*

diversa, *Ranikothalia* sp., *Orbitokathina saravensis* Sirel, *Haymanella paleocenica*, *Haymanella elongata*, *Miscellanea juliettae*, *Miscellanea* sp., *Miscellanea miscella*, *Miscellanea primitiva*, *Akbarina primitiva*, *Lokartia* sp., *Lokartia conditi*, *Malatyna dorbnearae*, *Smauyina cruysi*, *Modocia blayensis*, *Kathina selveri*, *Kathina* sp., *Rotalia trochidiformis*, *Idalina sinjarica*, *Astrotrillina eocaenica*, *Raoia indica*, *Quinqueloculina* sp., *Operculina subgranulosa*, *Eorupertia* sp., *Ornatononion moorkensi*, *Rhapydionina* sp., *Triloculina* sp., *Biloculina* sp., *Textularia* sp., *Spirolina* sp., *Rotaliidae indent*, *Assilina granulose*, *Storsella haastersi*.

5. Microfacies and Sequence Stratigraphy

The primary depositional features discernible in thin sections, including textures, microfossils and sedimentary structures led to the recognition of 16 subfacies belong to 5 facies A, B, C, D and E. (A) facies is foraminifera-bryozoan mudstone to packstone. (B) facies is algal-oid-pelloid-echinoderm grainstone. (C) facies is intraclast-miliolid-pelloida-green algae wackestone to grainstone packstone. (D) facies is dolomudstone-mudstone with evaporate component. (E) facies is calcareous shale (marl).

5.1. Foraminifera-Bryozoan Mudstone to Packstone Facies (A)

This facies is divided into 3 subfacies characterized by open marine composition such as bryozoans, echinoderms and fragments of foraminifera (Rotaliids). All these three subfacies are gray to light, thin to medium bedded limestone along the out crop belt. (A1) foraminiferal packstone subfacies contain more than 50% Rotaliidae (range diameter from 0.1 to 0.3 mm) and others benthic foraminifera, bryozoans and brachiopod debris. The matrix consists of dark gray limy mud (**Figure 2(A)**). (A2) Bioclast wackestone subfacies (**Figure 2(B)**) is similar to (A1) subfacies but grains are less than (A1). (A3) Bryozoan Packstone Subfacies contains 30% bryozoan fragments, 10% echinoderm, 5% bivalve fragments and 3% brachiopod fragments (**Figure 2(C)**). The size of fragment is between 0.5 to 2 mm. This facies was deposited in relatively deep water, under low energy environment (open marine).

5.2. Ooid-Pelloid-Bioclast Grainstone to Grainstone Packstone Facies (B)

It contains 4 subfacies that consist of ooid, red algae and marine fauna (bivalve, bryozoans, echinoderm, brachiopods and foraminifera). The sizes of sceleta grains are generally coarse. Along the outcrop belt this facies is medium to thick bedded, light gray in color and displays cross bedded and cross laminated. (B1) Quartz bioclast

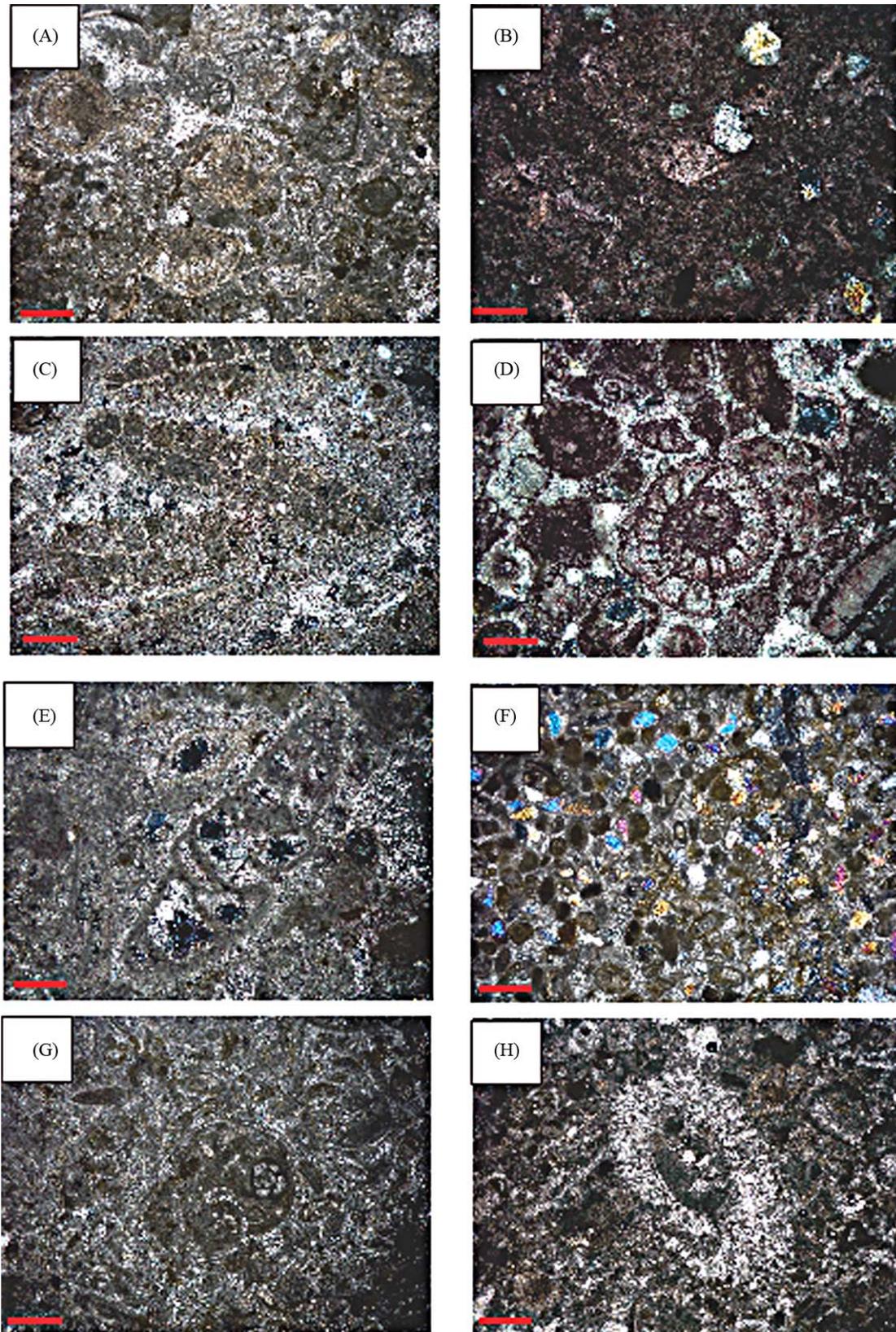


Figure 2. Open marine subfacies: (A) A1, Foraminiferal Packstone (B) A2, Bioclast Wackestone (C) A3, Bryooan Packstone Barrier subfacies: (D) B1, Qz Bioclast Grainstone (E) B2, Bioclast Pelloidal Grainstone (F) B3, Oolitic Grainstone (G) B4, Intraclaats Miliolid Pelloidal Packstone Grainstone Lagoon subfacies: (H) C1, Bioclast Packstone Wackestone Scale: 1 mm.

grainstone consists of 25% echinoderm, brachiopods, bryozoans and benthic foraminifera, 20% quartz and a few red algae. The average size of skeletal grains is 2mm (**Figure 2(D)**). (B2) Bioclast Pelloidal grainstone contains of 45% pelloid (0.3 to 0.5 mm), 3% benthic foraminifera (0.5 to 1 mm). Also there is minor amount of echinoids and brachiopods debris in this subfacies (less than 2%) (**Figure 2(E)**). (B3) Oolitic grainstone subfacies (**Figure 2(F)**) is characterized by the abundance of ooid and minor amounts of open marine fauna that are connected by sparite cement. Many ooids have a concentric fabric whereas some have a radial fabric. Ooids Cores are consisting of foraminifera, bivalve, echinoids and quartz grains. The average size of ooid is 0.7 mm. In some grains such as bivalve fragments, micrite envelopes were developed. (B4) Intraclast millolid pelloidal packstone grainstone subfacies (**Figure 2(G)**) comprises of 40% pelloid, 20% milliolids and 10% intraclast. Average diameter of pelloids is 0.1 mm. Intraclast contain a variety of bioclast including bivalves, benthic foraminifera and detrital quartz grains. This facies includes medium bedded succession of gray bioclast calcarenite which have some sedimentary structures (cross bedding, cross lamination). This facies is also mud free that confirms the high energy sedimentary environment (**Figure 3**).

5.3. Intraclast-Miliolid-Pelloidal-Green Algae Wackestone to Grainstone Packstone (C)

This facies consists of 6 subfacies that contains high percentages of grains. In the outcrop belt, this lithofacies were generally light gray to light tan. (C1) Bioclast packstone wackestone subfacies (**Figure 2(H)**) is characterized by the abundance of skeletal grains such as green algae (10%), benthic foraminifera such as textularia and miliolids (35%) and minor amount (2%) of brachiopods and red algae. Also there are non-skeletal grains such as pelloid and detrital quartz. (C2) Bioclast Pelloidal packstone subfacies (**Figure 3(A)**) contains 30% pellet and 5% echinoderm. The diameter of Pellets varied from 0.05 to 0.2 mm. (C3) Pelloidal grainstone packstone subfacies (**Figure 3(B)**) consists of more than 50% pellet and minor amount of bioclast. The average size of the pellets is 0.1 mm. (C4) Quartz bioclast wackestone subfacies (**Figure 3(C)**) consist of bioclast component (green algae, miliolids, Laffitteina sp.) and detrital quartz. Sedimentological evidences assigned that this facies was deposited in restricted lagoon environment.

5.4. Dolomudstone-Mudstone with Evaporate Component (D)

This facies subdivided into 2 subfacies D1 and D2 which are appear to represent the most landward carbonate lithofacies. Field outcrop of this facies contains thin to

medium beds of yellow color limestone. (D1) Dolomudstone (**Figure 3(D)**) contains very fine crystalline of dolomite. There aren't any fossils and the observed non-fossils components have scattered fenestral fabric. Although this subfacies is non-fossiliferous, a few ostracod debris have been observed. (D2) sandy mudstone (**Figure 3(E)**) consists of quartz grain in mud matrix. This subfacies has 15% porosity which is apparently formed by dissolution late-stage diagenesis [29]. The presence of fenestral fabric and evaporate sediments indicates that this facies was deposited in an upper intertidal environment.

5.5. Shale and Calcareous Shale (E)

(E) facies consists of thin to medium intervals of calcareous shale (marl) which are presented in carbonate rocks interval of all sections. This facies can be divided into two subfacies. (E1) subfacies is generally thin to medium green to gray calcareous shale that contains benthic foraminifera and ostracods. (E2) facies contains gray calcareous shale with tiny laminated beds and no fossils content. Moreover in (E2) subfacies association of gypsum crystals and beds has been observed. On base of sedimentological studies gray to green calcareous shale with benthic foraminifera was deposited in an outer ramp setting but gray calcareous shale which contains evaporate sediment but doesn't have any fossils was deposited in a restricted lagoonal inner ramp.

5.6. Calcareous Sandstone and Calcareous Conglomerate Facies (F)

This facies consists of (F1) medium to thin bedded calcareous sandstone (**Figure 3(F)**) that have trace fossils (*Thalassinoides*) and macrofossils (Bivalve) in outcrop belt. The strata are gray to tan and have cross laminated. This facies was formed in a shoreline environment. (F2) subfacies is calcareous conglomerate (**Figure 3(G)**) that includes several grains (Orbitolin and Ooid) of older Formations such as Torgan and Mozduran Formations. Based on field observations and variation of vertical microfacies, depositional sequence and system tracts were identified. The Paleocene interval in this basin consists of four depositional sequences (DS1, DS2, DS3 and DS4), bounded by type 2 and type 1 (**Figure 1**). Depositional sequence 1 (DS1) is the lowest depositional sequence. Base of this sequence lies just beneath the top of the lower Paleocene Pesteligh Formation as a fluvial depositional system [30]. This sequence started with transgressive system tract deposition (TST) which is mostly consists of intertidal lithofacies (shale, gypsum, evaporate deposition) and pass upward into lagoon lithofacies. HST (high stand system tract) deposition is occurred after early eustatic fall. HST described by siliciclastic intervals. In Type locality, first depositional sequence ends to the

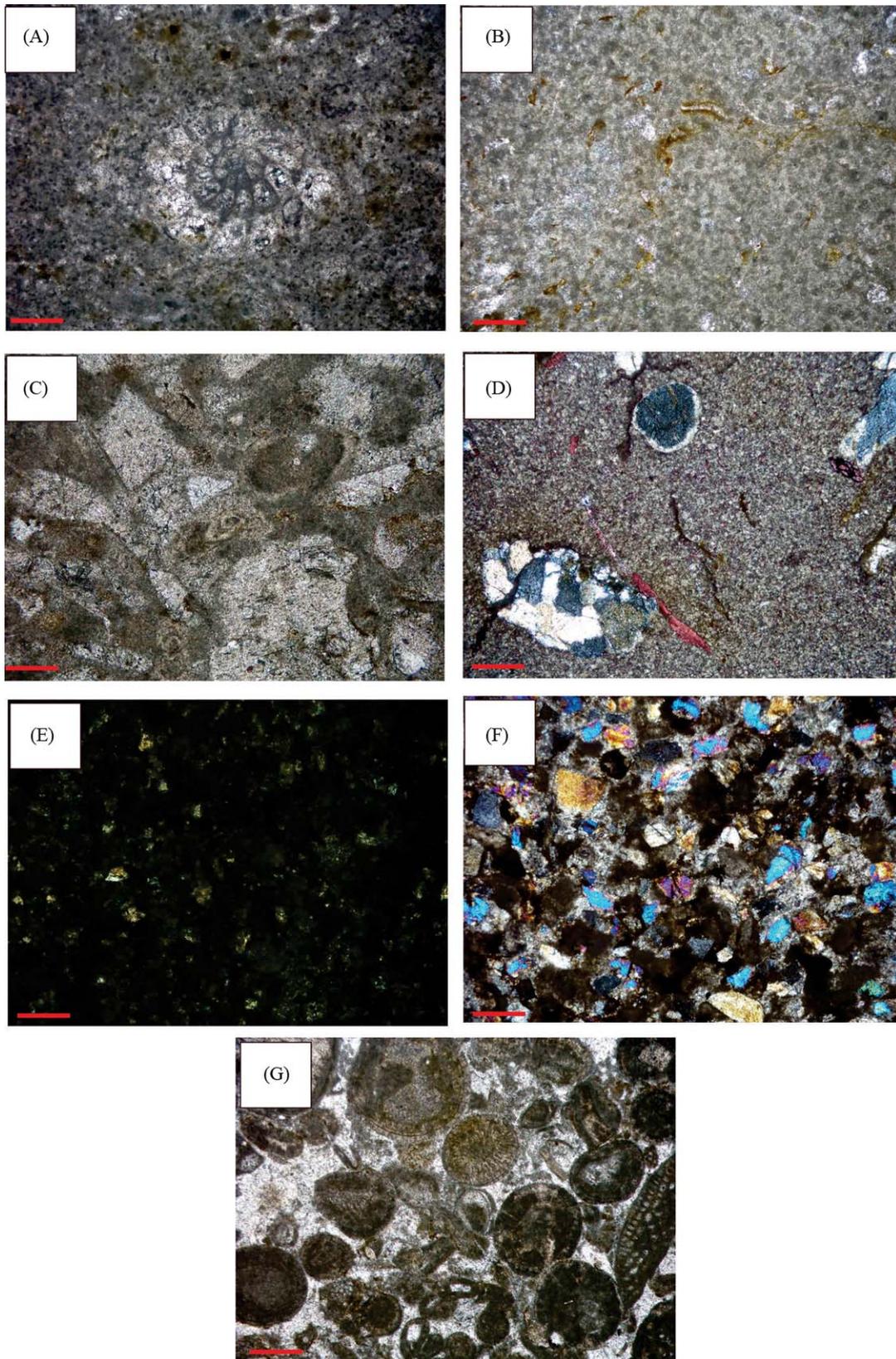


Figure 3. Lagoon subfacies: (A) C2, Bioclast Pelloidal Packstone (B) C3, Pelloidal Grainstone Packstone (C) Qz Bioclast Wackestone Tidal Flat subfacies: (D) D1, Dolomudstone (E) D2, Sandy Mudstone; (F) F1, Calcareous Sandstone (G) Calcareous Conglomerate Scale: 1 mm.

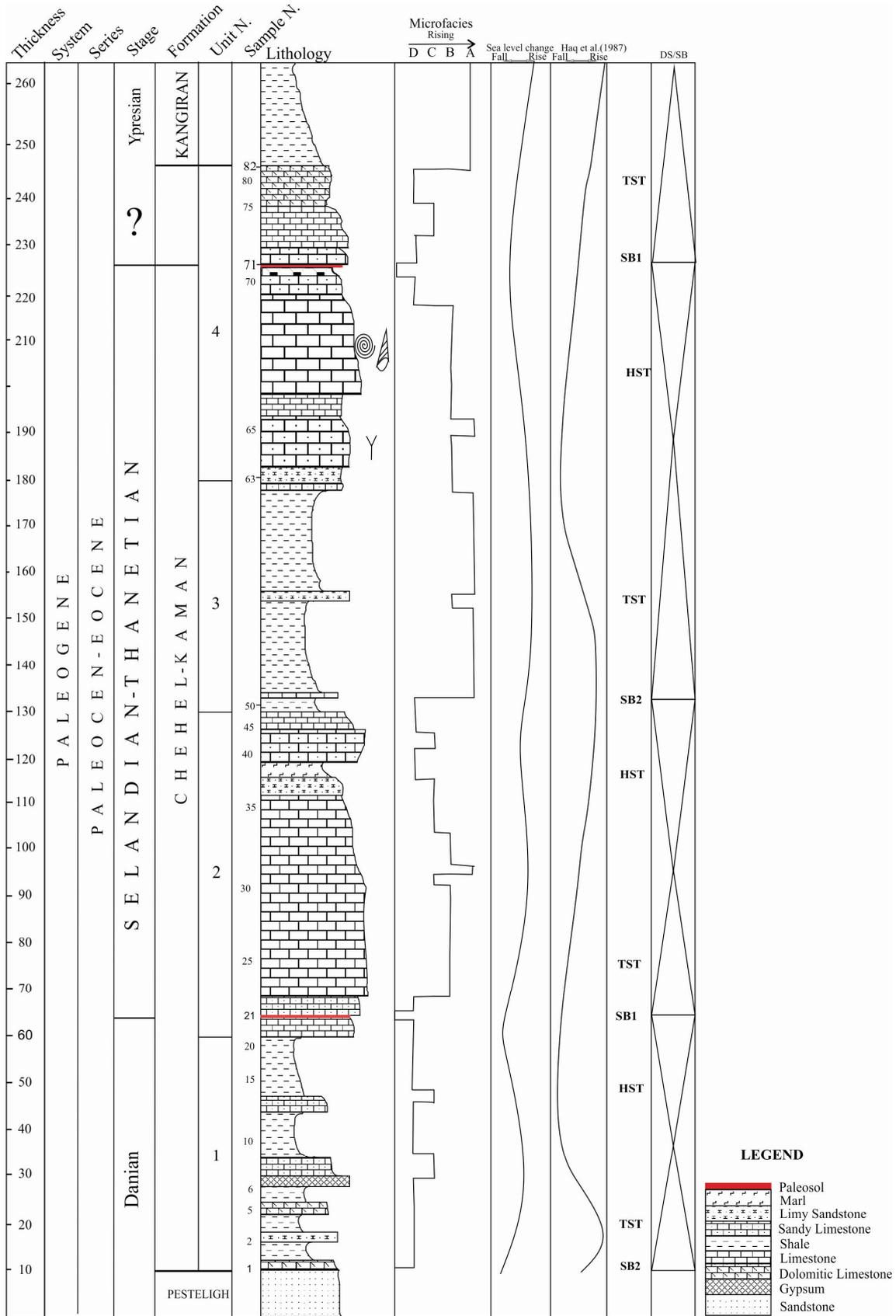


Figure 4. Lithostratigraphy and Sequence stratigraphy of Chehel-Kaman Formation in Type locality.

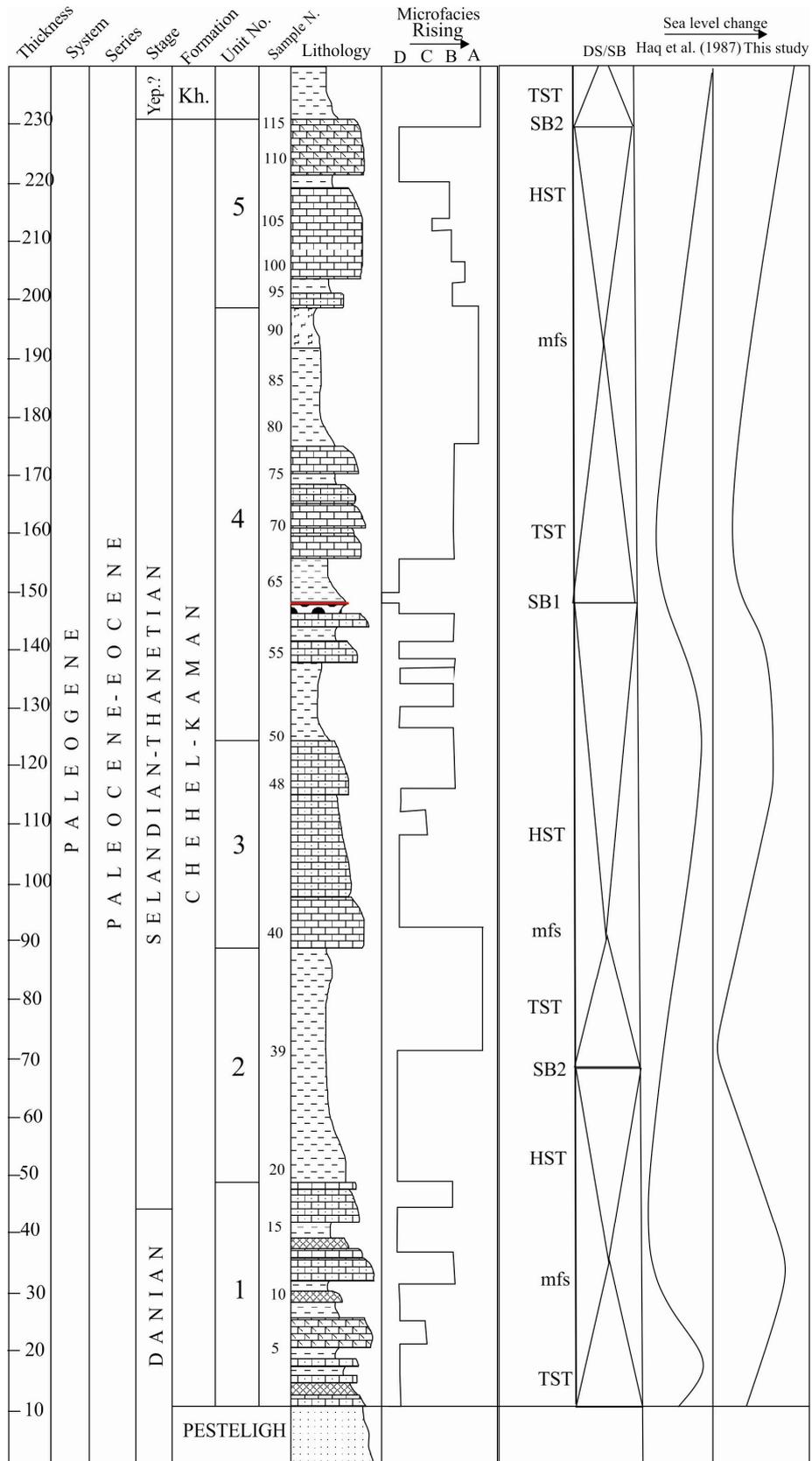


Figure 5. Lithostratigraphy and Sequence stratigraphy of Chehel-Kaman Formation in Padeli section in eastern part of Ko-pet-Dagh Basin.

type 1 sequence boundary. In depositional sequence 2 (DS2) a rapid rise led to the deposition of carbonate intervals in transgressive system tract. In Type locality Maximum flooding surface is characterized by Quartz Bioclastic Packstone. This surface is indicated by Bioclast Grainstone Packstone in Padeli section in eastern part of Kopet-Dagh basin. HST in this sequence occurred with deposition of Shale and Marl along with Cretaceous foraminifera and evaporate sediments. Depositional sequence 3 (DS3) contains TST with the deposition of Shale, Marl and planktonic foraminifera. In this sequence HST interpreted as interval sandstone and sandy carbonate. The low stand system tract of DS4 (LST) is interpreted as a major sea level fall in latest Paleocene. At the base of this depositional sequence there are paleosol and channel sediments (conglomerate) that marks the type sequence 1 boundary at the base of DS4. This conglomerate was deposited as a channel-fill. DS4 is started by deposition of olive open marine shale of Khangiran Formation. Sea level changes during the middle to late Paleocene in the Kopet-Dagh basin are comparable to global changes proposed by Haq *et al.* [31], although some differences related to local and regional geological events have been seen. Most important diagenetic processes affected the limestones of Chehel-Kaman Formation are micritization, cementation, compaction (physical & chemical), neomorphism, dissolution, fracturing, formation of calcite veins, silicification and dolomitization. Sequence stratigraphy, microfacies and sequence boundary is shown in **Figures 4** and **5**.

6. Conclusion

The LBFs of the Kopet-Dagh Basin (NE of Iran) can be used for the biostratigraphy of late early to late Paleocene sediments (SBZ2-SBZ4). Danian/Selandian boundary is shown to be a transition from carbonate to siliclastic sediments. There is bryozoan limestone in the upper Danian and there is a drop in sea level in the starting Selandian interval. Petrographical studies indicate that these sediments may have been deposited on a shallow carbonate platform ramp type and they consist of 4 carbonate lithofacies (15 subfacies). These lithofacies indicate that these sediments have been deposited in open marine, shoal, lagoon and tidal flat environmental conditions. Sequence stratigraphy analysis led to the identification of 4 third-order depositional sequences, bounded by type 2 and 1 sequence boundaries. Comparison of interpreted sea level change of the study area and of two measured sections in the Type locality and Eastern Part of the basin indicated that the depth of basin decrease toward east and south east.

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