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Reassessment of the age and depositional environments of the Eocene Çayraz Formation, a reference unit for Tethyan larger benthic foraminifera (Haymana Basin, central Turkey)

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ABSTRACT

The Çayraz Formation, a reference unit for Tethyan Ypresian-middle/late Lutetian larger benthic foraminifera (Haymana Basin, central Turkey), is a thick (> 350 m) 'shallow-marine' mixed carbonate-siliciclastic sequence, divided into lower, middle and upper units. The lower and upper units predominantly consist of rhythmic intercalations of limestone and marly/silty beds with abundant larger benthic foraminifera (LBF), and the middle unit is composed of massive fine siliciclastic sediments, mostly barren in LBF and macrofossils. By studying three sections (ÇAYA, ÇAYB, and YEŞ), encompassing the lower unit, we show that the Çayraz Formation (ca. 100 m-thick) displays notable vertical and lateral variability in benthic fauna and facies along an SE-NW transect at its type locality near Çayraz village. The distribution of LBF and facies patterns indicate a general shallowing upward trend, with more open marine environments in the easterly section (ÇAYA) and restricted shallow marine to continental environments with low diversity fauna in the westerly section (YEŞ). A depositional setting ranging from outer to inner-ramp with continental influence only in the westerly section is proposed. Key orthophragminid and alveolinid taxa from the lower unit of the Çayraz Formation indicate shallow benthic zones (SBZ) 9/10 for its lower part, and SBZ 12 for its upper part, suggesting a late Ypresian age. The massive marly/silty section of the middle unit of the Çayraz Formation overlies the *Alveolina*-bearing limestones in all sections and yielded abundant planktonic foraminifera suggestive of P9 Zone. This implies a sharp environmental transition from platform to basin across the Ypresian-Lutetian boundary.

1. Introduction

The Haymana Basin is a thick clastic depocentre of Late Cretaceous to Eocene age in central Anatolia. The Çayraz Formation, the highest stratigraphic unit of the Eocene succession in the basin, is a mostly shallow marine mixed carbonate-siliciclastic sequence, recording the latest phase of the marine sedimentation (Figs. 1 and 2; Ünalan et al., 1976; Özcan, 2002; Özcan et al., 2018). This formation is divided into three parts as lower, middle and upper units mainly based on their lithology and occurrence of macrofossils; lower and upper units, composed of rhythmic intercalations of limestone marly/silty beds, and a middle unit, composed of massive marls, mostly devoid of macrofossils but several limestone beds with larger benthic foraminifera (LBF) at its base. The entire succession, except for the middle marly section, is characterized by a continuous and rock-forming occurrence of LBF, such as nummulitids and orthophragminids; while, alveolinids and rotaliids occur locally (Hottinger, 1960; Dizer, 1968; Schaub, 1981; Sirel, 1992; Özcan, 2002; Sirel and Deveciler, 2017; Özcan et al., 2018). The Çayraz Formation is considered as a reference unit for the Ypresian and Lutetian LBF record in the Tethys, which was used in defining the shallow benthic zonation (SBZ) of the Tethyan deposits by Serra-Kiel et al. (1998). Nummulitid and alveolinid species such as *Nummulites lehneri, Alveolina avellana*, *Alveolina parva*, *Alveolina lehneri*, and *Alveolina pinguis* were described from this unit (Hottinger, 1960; Schaub, 1981; Serra-Kiel et al., 1998). Prior to the present study, a calibration and correlation of the LBF zones to any pelagic datum plane or event

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have never been attempted in the Çayraz Formation due to the presumed absence of pelagic fauna. Previous age assignments to the lower and upper units were also contradictory; the lower unit was considered to be of late Ypresian age in most studies (Hottinger, 1960; Schaub, 1981; Özcan, 2002; Sirel and Deveciler, 2017), although this was misleadingly challenged by Dinçer (2016), who proposed a Lutetian age for the same unit. Age contradictions hamper the accurate evaluation of the stratigraphic ranges of important foraminiferal taxa identified from the Çayraz Formation.

In spite of the numerous studies on the fossil content of the Çayraz Formation, the vertical and lateral faunal changes and depositional conditions were poorly understood. The entire Çayraz Formation was interpreted to be a 'shallow marine' carbonate unit without specific information on depositional setting. Çiner et al. (1996a) subdivided the whole formation into several orders of coarsening-upward and shallowing-upward sequences composed of carbonate mudstones overlain by nummulitic banks, a concept critically evaluated by Papazzoni and Seddighi (2018). Although these banks were considered as allocyclic transgressive-regressive cycles tuned to Milankovitch bands, a combined scheme of stratigraphically integrated facies and fauna is still lacking.

Here, we discuss the vertical and lateral variability in LBF and facies from the lower unit of the Çayraz Formation and reinterpret the depositional environments of the lower and middle units based on paleoecological and sedimentological evidences. For the first time, we also document the occurrence of planktonic foraminifera (PF) from the marly-silty middle unit and reinterpret its age and depositional environments based on faunal content. The significant shift towards deeper conditions within the middle unit and, a newly assigned latest Ypresian/earliest Lutetian age to this unit, are also discussed.

2. Geological setting and general stratigraphy

The Haymana-Polatlı Basin in central Anatolia is an accretionary forearc basin formed by the closure of the Neotethys during the late Cretaceous to middle Eocene time interval (Koçyiğit et al., 1991; Okay and Altıner, 2016). The basin is located close to the suture zone between Anatolide-Tauride Block/Kırşehir Massif and Sakarya Zone (Fig. 1). Basin-fill deposits ranging in age from late Cretaceous to Eocene, are represented by ca. 5 km-thick siliciclastics and fossiliferous carbonates deposited in continental to shallow to deep marine environments (Sirel, 1992, 1998, 1999, 2009, 2015; Sirel and Gündüz, 1976; Özcan, 2002; Özcan et al., 2001; Çolakoğlu and Özcan, 2003; Özcan et al., 2007; Hoşgör and Okan, 2011; Esmeray-Senlet et al., 2015) (Fig. 2). The basement of the Haymana Basin sequence is best observed in the town of Haymana where late Jurassic to late Cretaceous shallow- to deep marine carbonates with calciturbidites crop out at the core of Haymana Anticline (Okay and Altıner, 2016). These units are overlain by Campanian-Maastrichtian flysch sequence of the Haymana Formation consisting of turbidites and debris flow deposits (Yüksel, 1970; Ünalan et al., 1976; Özcan and Özkan-Altıner, 1997; Okay and Altıner, 2016) (Fig. 1).

The Paleocene and Eocene sequence of the Haymana Basin is characterized predominantly by siliciclastics and carbonates deposited in various environments ranging from continental to deep marine setting (Ünalan et al., 1976). The sequence displays remarkable vertical and lateral facies changes that can be traced at outcrop scale. Between Haymana and Polatlı, Paleocene deposits are characterized by continental clastics (Kartal Formation), shallow marine limestone (Çaldağ Formation) and deep marine shales (Yeşilyurt Formation) (Ünalan et al., 1976). In Haymana-Çayraz region, late Paleocene-early Eocene deposits are made up of algal limestone, marl and shale beds (Kırkkavak

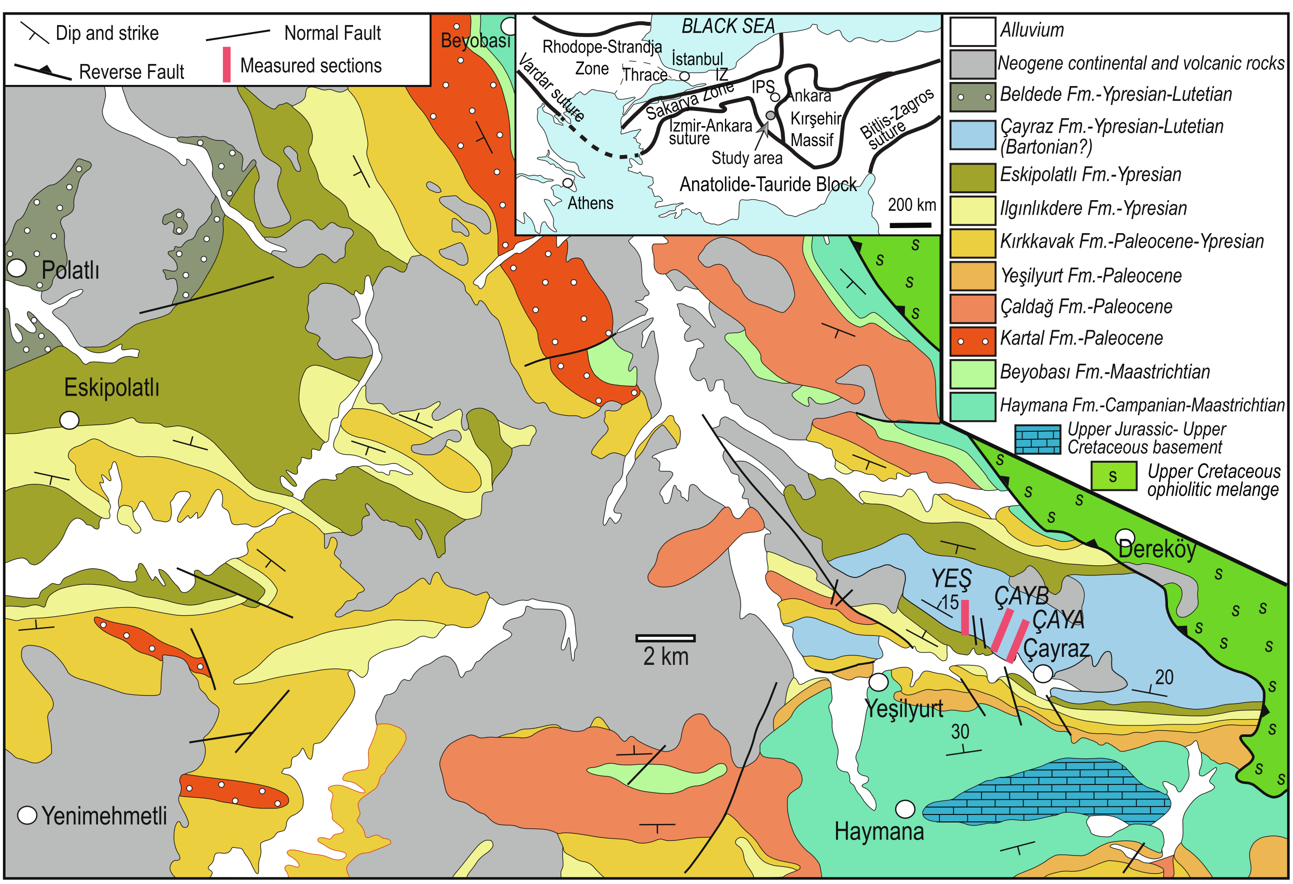

Fig. 1. Tectonic map of central Turkey showing the major sutures and continental blocks and position of the studied sections near Haymana, Ankara (tectonic map simplified from Okay and Tüysüz, 1999 and geological map of the Haymana-Polatlı region after Ünalan et al., 1976). IS: Istanbul Zone, IPS: Intra-Pontid Suture.

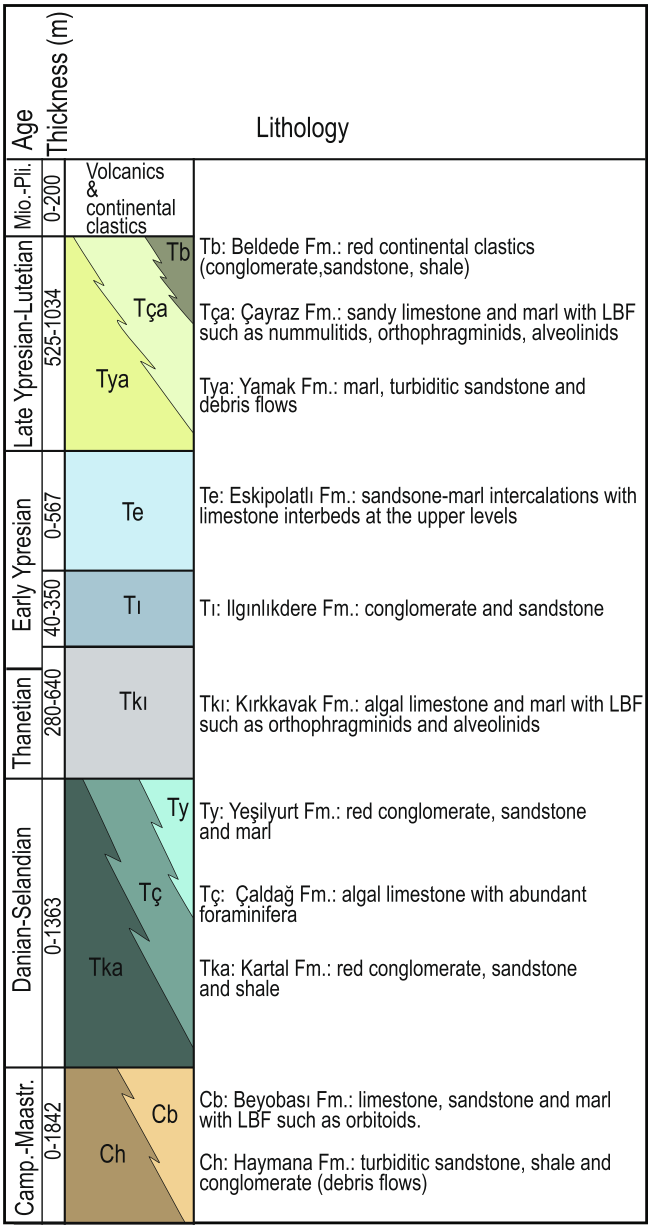

Fig. 2. Stratigraphic setting of the Campanian-Cenozoic deposits in the Haymana-Polatlı Basin (slightly modified from Ünalan et al., 1976).

Formation), which pass into deep marine conglomerate-sandstone-marl-shale intercalations with debris flows (Ilgınlıkdere and Eskipolatlı formations). A regional shallowing is marked by the deposition of fan delta conglomerates and sandstones (Beldede Formation) (Çiner et al., 1993), and shallow marine Çayraz Formation (Çiner et al., 1996a), which laterally grades to the siliciclastic turbidites of the Yamak Formation (Çiner et al., 1996b; Özcan, 2002). The Çayraz Formation consists of lower and upper mixed carbonate-siliciclastic units, ca. 100 and 200 m-thick respectively, separated by a sequence of thick-bedded to massive marl/siltsone unit, almost devoid of LBF, except for its lower levels where allochthonous tests are found within turbidites. The previous studies interpreted these marl/siltstone beds to have deposited in a shallow marine environment, implying almost similar depositional conditions for the whole sequence of the Çayraz Formation (Ünalan et al., 1976; Sirel, 1992; Çiner et al., 1996a; Özcan, 2002). The thickness of the fine siliciclastic deposit, ca. 50 m in the studied section, is highly variable and is sharply reduced towards the east at its exposures near Çayraz village to the north of Haymana town (Fig. 3). Both, lower and upper units contain densely packed LBF in some intervals (Hottinger, 1960; Schaub, 1981; Özcan 2002; Özcan et al., 2007; Deveciler, 2010; Sirel and Deveciler, 2017; Özcan et al., 2018), intercalated with marly/silty interbeds, suggesting a cyclic depositional regime.

3. Materials and methods

Three sections, ÇAYA, ÇAYB, and YEŞ were sampled near Çayraz village (Figs. 1 and 3). We follow Dunham (1962) for the textural classifications of carbonates and Hottinger (1997), Beavington-Penney and Racey (2004), Bassi (2005) and Nebelsick et al. (2005) for the palaeoenvironmental interpretations of the mixed siliciclastic-carbonate sequence. The LBF are described from the equatorial and axial sections of loose specimens collected from the lower unit of the Çayraz Formation. Planktonic foraminifera collected from the pelagic silty-marly beds of the middle unit of the Çayraz Formation are analysed for the first time. The samples, disaggregated by diluted hydrogen peroxide (30%), were washed and screened to obtain residues including isolated planktonic foraminiferal specimens.

Taxonomic classification of planktonic foraminifera is mainly based on the "Atlas of Eocene Planktonic Foraminifera" by Pearson et al. (2006). Biozonal definition follows the standard biostratigraphic schemes of Berggren et al. (1995), Berggren and Pearson (2005) and Wade et al. (2011). The taxonomy of key species of orthophragminids is after Less (1987), Özcan (2002) and Özcan et al. (2007), and alveolinids after Hottinger (1960). The shallow benthic zonation scheme is from Serra-Kiel et al. (1998).

4. Lithostratigraphic succession and new biostratigraphic data

4.1. Description of the sections

Three complete stratigraphic sections, Çayraz A (ÇAYA), Çayraz B (ÇAYB), and Yeşilyurt (YEŞ) covering the lower carbonate unit and the overlying marly/silty-beds of the middle unit, have been studied along SE-NW transects near Çayraz village (Figs. 1, 3–5).

4.1.1. Çayraz A (ÇAYA)

The section, located 1.43 km west of Çayraz village (base of the section: 39°28′36.39″N, 32°31′51.73″E; top of the section: 39°28′45.13″N, 32°31′59.70″E), includes the lower and middle units of Çayraz Formation (Figs. 3 and 4). The pelagic marls of the underlying Eskipolatlı Formation and its boundary with the Çayraz Formation are slightly obliterated by alluvium. The lower 25 m of the section consists of sandy limestone beds intercalated with marly/silty alternations containing predominantly orthophragminids and nummulitids, which are assigned to SBZ 9/10 (early-late Ypresian transition) (Fig. 6A-B). Orthophragminids, represented by *Discocyclina*, *Orbitoclypeus* and *Asterocyclina,* are common wheras the planktonic foraminifera are rare (Fig. 7). The overlying thick limestone bed (samples 8–10) is devoid of clastic material and contains rare alveolinids in addition to common nummulitids (predominantly *Nummulites* and *Assilina*) and rare orthophragminids (Fig. 6C). A lenticular but laterally discontinuous micritic limestone bed (samples 11–13) of ca. 2 m maximum thickness containing corals and bivalves (a coral-bivalve mound) occurs above the thick limestone unit (Fig. 6D). The overlying section (33–58 m) is represented by a monotonous sequence of thick-bedded limestone beds, composed of abundant *Nummulites*, *Assilina* and some *Discocyclina* and *Orbitoclypeus*. In this interval, the dominant facies is *Nummulites-Assilina* packstone. The interval between 58 and 70 m is composed of an alternation of marly/silty beds and nummulitic accumulations (orthophragminid-nummulitid wackestone to packstone) consisting of abundant *Nummulites*, *Assilina*, and some *Discocyclina* and *Orbitoclypeus*. Red algae occur abundantly in sample 17 (Fig. 6E). The interval between 70 and 89 m is characterized by limestone beds, consisting of

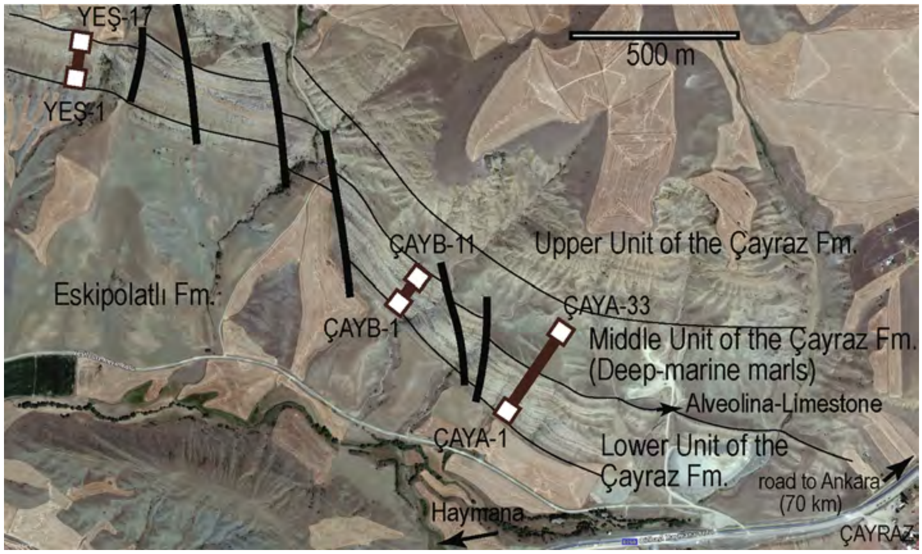

Fig. 3. Aerial photograph of the Çayraz region, showing the positions of the studied sections. Thick lines show the faults and the numbers refer to sample numbers. Note the westward thinning of the pelagic marls overlying the lower unit of the Çayraz Formation.

predominantly *Nummulites, Assilina, Discocyclina* and *Orbitoclypeus*, overlain by a distinct interval made up of several thin-bedded limestone beds (samples 19–22) composed of mudstone facies (Dasycladalean algal-bivalve mudstone). The dominant facies in this interval are *Nummulites-Assilina* packstone and orthophragminid-nummulitid wackestone to packstone. The interval lying between 89 and 101 m is represented by intercalation of marly/silty beds and limestone containing predominantly *Nummulites*, *Assilina* and rare orthophragminids. A significant change in the depositional setting is marked by the appearance of *Alveolina*-limestone beds (samples 26–28) constituting a key-level consistently recorded in all studied sections, at the uppermost part of the lower unit. These beds are situated immediately below the pelagic marls of the overlying middle unit (Fig. 6F). The *Alveolina*-limestone beds, ca. 3 m-thick, are outlined by a nodular to conglomeratic horizon made up of micritic limestone pebbles with alveolinids and nummulitids. The sub-spheroidal nodules (5–15 cm in diameter) contain iron stains, especially at their contacts. Orthophragminids and alveolinids in the upper part of the ÇAYA section suggest SBZ 12, pointing out to latest Ypresian in age. The *Alveolina*-limestone is overlain by a sequence of thick-bedded to massive marl and siltstone section of the middle unit of the Çayraz Formation. Marl/siltstone beds contain planktonic foraminifera consisting of *Acarinina*, *Subbotina,*

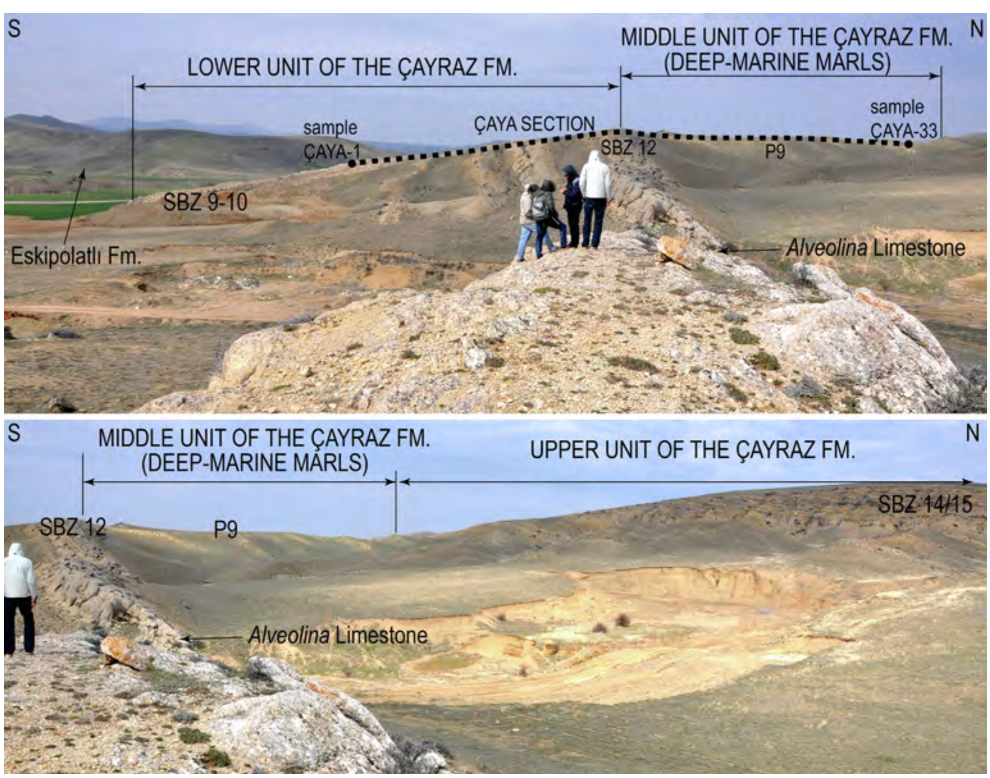

Fig. 4. Field aspects of the Çayraz Formation. Position of ÇAYA section is shown. A sharp facies change just above the *Alveolina*-bed is marked by the deposition of massive marl/siltstone beds with pelagic fauna. SBZ: shallow benthic zones according to Serra-Kiel et al. (1998).

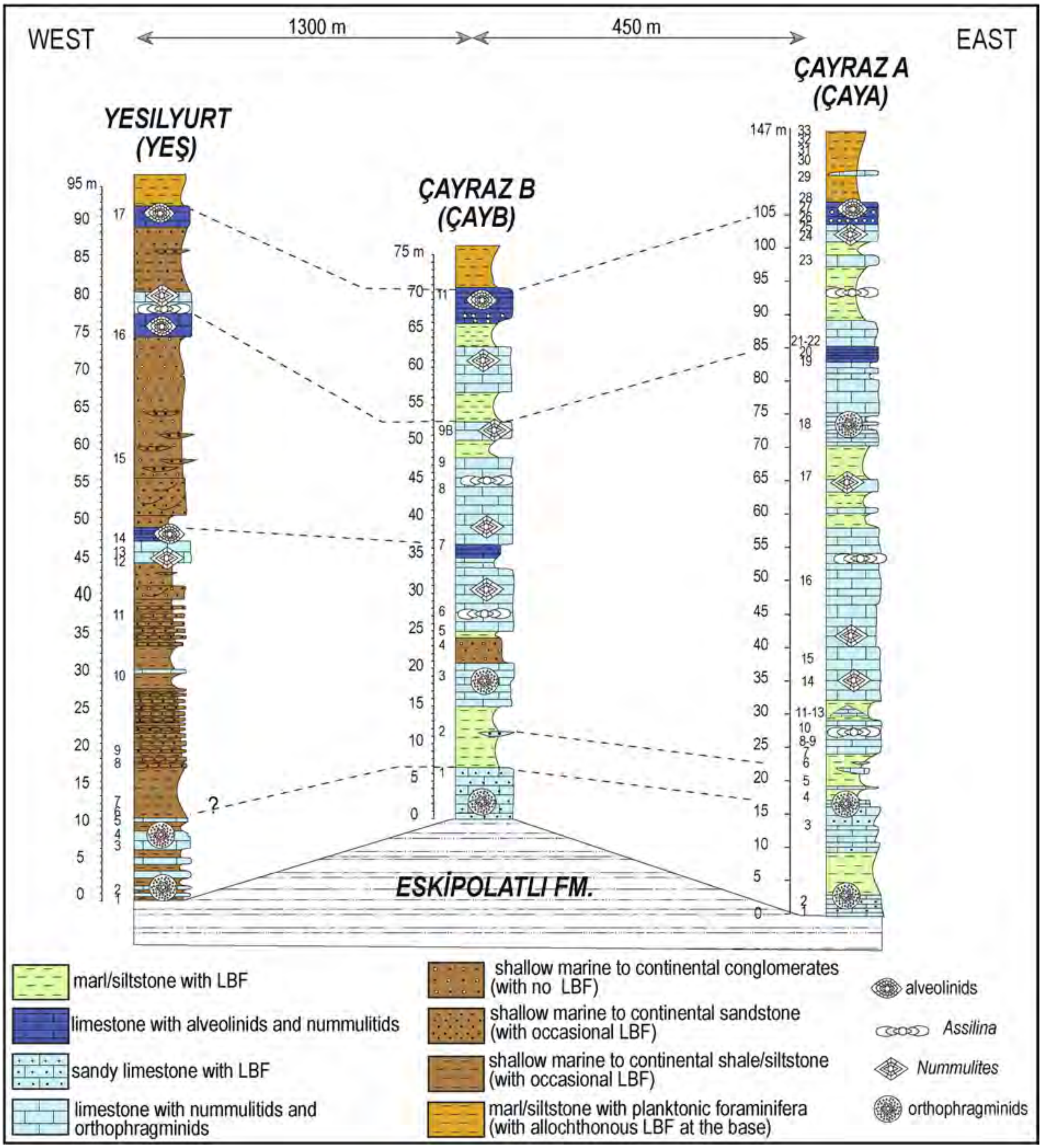

Fig. 5. Columnar sections of the studied profiles and their correlation. A more open marine condition prevails in the deposition of the lower unit of the Çayraz Formation in easterly-located section (ÇAYA) compared to the ÇAYB and YEŞ sections.

Pseudohastigerina, *Igorina, Morozovella* and *Guembelitrioides.* Within the marl/siltsone beds several centimeter- to decimeter-thick limestone beds, containing abundant LBF at their basal parts can be found (Fig. 6G-H).

4.1.2. Çayraz B (ÇAYB)

The section (base of the section: 39°28′46.10″N, 32°31′38.72″E; top of the section: 39°28′50.65″N, 32°31′42.16″E) is located 450 m northwest of ÇAYA section (Figs. 1 and 3). The base of the Çayraz Formation is represented by sandy limestone, dominated by *Discocyclina*, *Nummulites, Assilina* and sporadic *Alveolina*. Planktonic foraminifera occur rarely. Up in the section, a marly/silty interval (9 m-thick) with a limestone intercalation contains *Discocyclina*, *Nummulites* and *Assilina* (Fig. 8). The limestone bed within the marls (sample 2) contains sporadic *Alveolina,* which is followed by several limestone beds with abundant orthophragminids (*Discocyclina* and *Nemkovella*), *Nummulites*, *Assilina* and sporadic *Alveolina*. A sharp change in depositional environment is marked (between 21 and 24 m) by a 3 m-thick conglomerate bed with very sporadic *Nummulites* and *Assilina*. The interval between 25 and 47 m (Fig. 6I-J) is characterized by a monotonous sequence of thick-bedded limestone, composed of abundant *Nummulites*, *Assilina* and some *Discocyclina* and *Orbitoclypeus* and an *Alveolina*-limestone bed (sample 7) in the middle part of the section. In this interval, the dominant facies is *Nummulites-Assilina* (locally with alveolinids) packstone, while *Alveolina*-limestone is characterized by alveolinid-nummulitid wackestone to packstone facies. The interval between

Fig. 6. Field photographs of the lower unit of Çayraz Formation and overlying pelagic sequence. **A:** Quartz-orthophragminid wackestone-packstone facies alternating with marl/siltstone facies consisting of orthophragmids and nummulitids in the lower part of the ÇAYA section. **B:** Close up view of marl/siltstone facies in ÇAYA section, sample ÇAYA-5. **C:** Close-up view of orthophragminid-nummulitid wackestone-packstone beds in ÇAYA section, sample ÇAYA-8. **D:** Coral-bivalve mudstone facies (mud mound) in ÇAYA section, sample ÇAYA-11-13. **E:** Red algae associated with orthophragminids and nummulitids in sample 17 in ÇAYA section. **F:** Limestone pebbles containing alveolinids in the *Alveolina*-limestone at the uppermost part of the lower carbonate unit in ÇAYA section, samples ÇAYA-26, 27. **G–H:** A limestone bed with reworked LBF at the lower part of the pelagic marls in ÇAYA section, sample ÇAYA-29. LBF reworked from the proximal ramp and were transported by turbidity or storm currents into deep-waters. **I–J:** The middle part of the lower carbonate unit of Çayraz Formation in ÇAYB section (samples 5–9) with *Nummulites-Assilina* packstone and grainstone facies. **K–L:** Shallow marine to continental (?) clastic beds (sandstone/siltstone and conglomerate) in the lower carbonate unit in YEŞ section. J: sample YEŞ-11, K: sample just above YEŞ-11. **M:** *Alveolina*-limestone and overlying pelagic unit in YEŞ section.

48 and 66 m is composed of an alternation of marly/silty beds and nummulitic accumulations (*Nummulites-Assilina* packstone) consisting of abundant *Nummulites* and *Assilina*. The *Alveolina*-limestone, 3 m-thick, at the top of the section consists of abundant *Alveolina* and *Nummulites* and is characterized by alveolinid-nummulitid wackestone and packstone facies, overlain by pelagic marls and siltstones of the middle unit.

4.1.3. Yeşilyurt (YEŞ)

The section (base of the section: 39°29′7.97″N, 32°30′52.56″E; top of the section: 39°29′13.21″N, 32°30′51.59″E) is located 1.3 km northwest of ÇAYB section (Figs. 1 and 3). The whole section is predominantly made up of thick clastics with poor or without fauna. Few limestone beds identified in the section (Fig. 9) contain LBF, alveolinids being the most dominant group. At the base of the section, Çayraz Formation is made up of

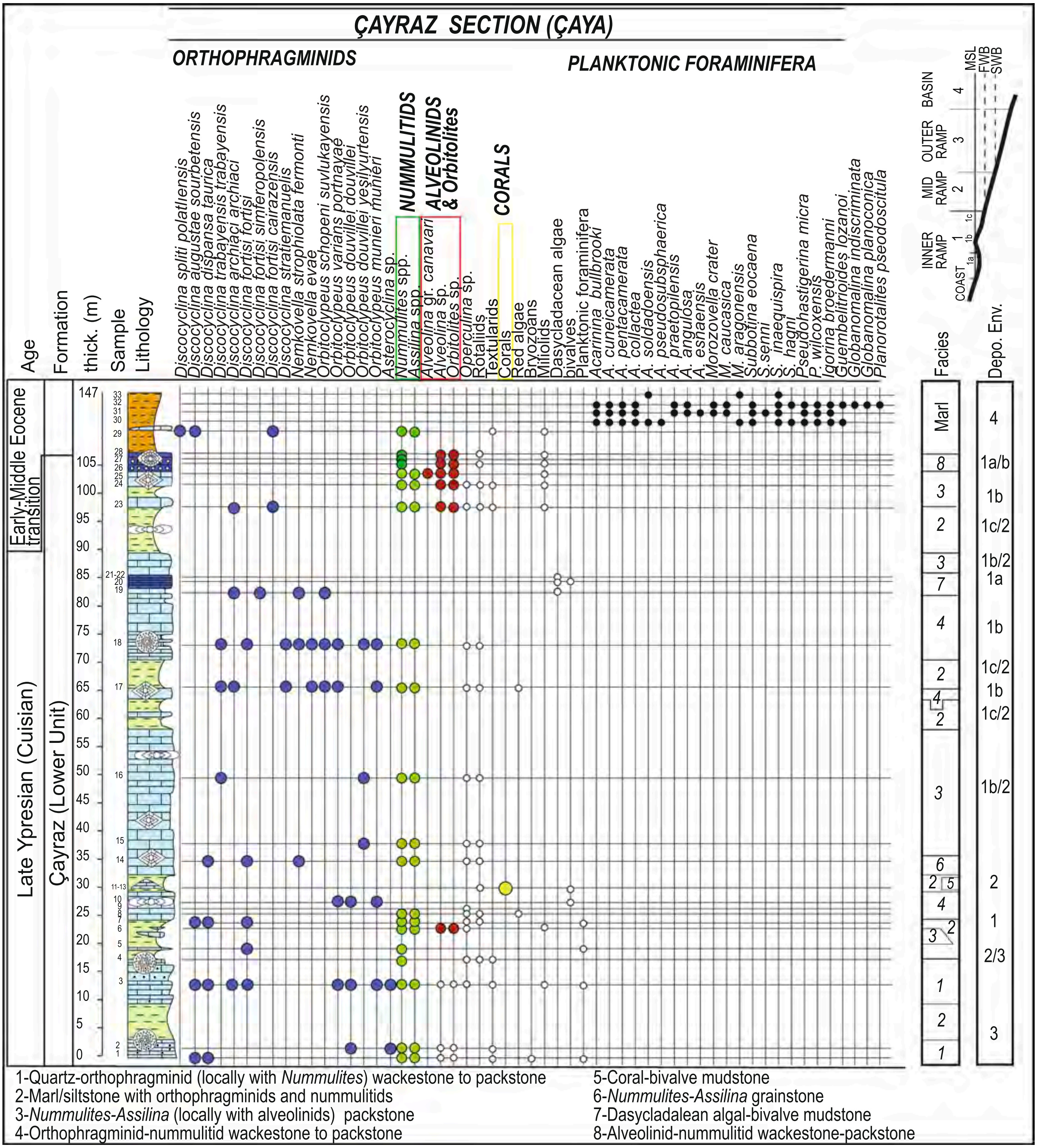

Fig. 7. Distribution of LBF, planktonic foraminifera and other fossil groups and facies distribution and location within the ramp setting in ÇAYA section.

limestone and sandstone alternations with *Discocyclina*, *Nemkovella*, *Orbitoclypeus*, *Nummulites* and *Assilina* (samples 1–4). The carbonates are characterized by quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone and orthophragminid-nummulitid wackestone to packstone. These carbonates and clastics are overlain by a thick coarsening-upward sequence (10–45 m interval) starting with sandstone and shale alternations passing upwards to conglomerates within poorly defined channels that can be interpreted as mouth bars (Fig. 6K-L). The fauna is poor and only *Nummulites* (and possible *Assilina*) occur sporadically in several beds. The conglomerate contains well sorted, grain supported and moderately rounded mafic and quartz pebbles (Fig. 6L) barren of fossils. Upwards, this is followed by limestone beds (samples 12–13) with abundant *Nummulites*, *Assilina* and few orthophragminids, described as *Nummulites-Assilina* grainstone facies. An *Alveolina*-limestone bed (sample 14) immediately above consists of abundant *Alveolina*, *Orbitolites* and *Nummulites*. The succession continues with a second thick clastic sequence made up of cross-bedded sandstone and conglomerate (between 48 and 75 m) poor in mud/silt and fauna. It contains rare *Nummulites* only in one

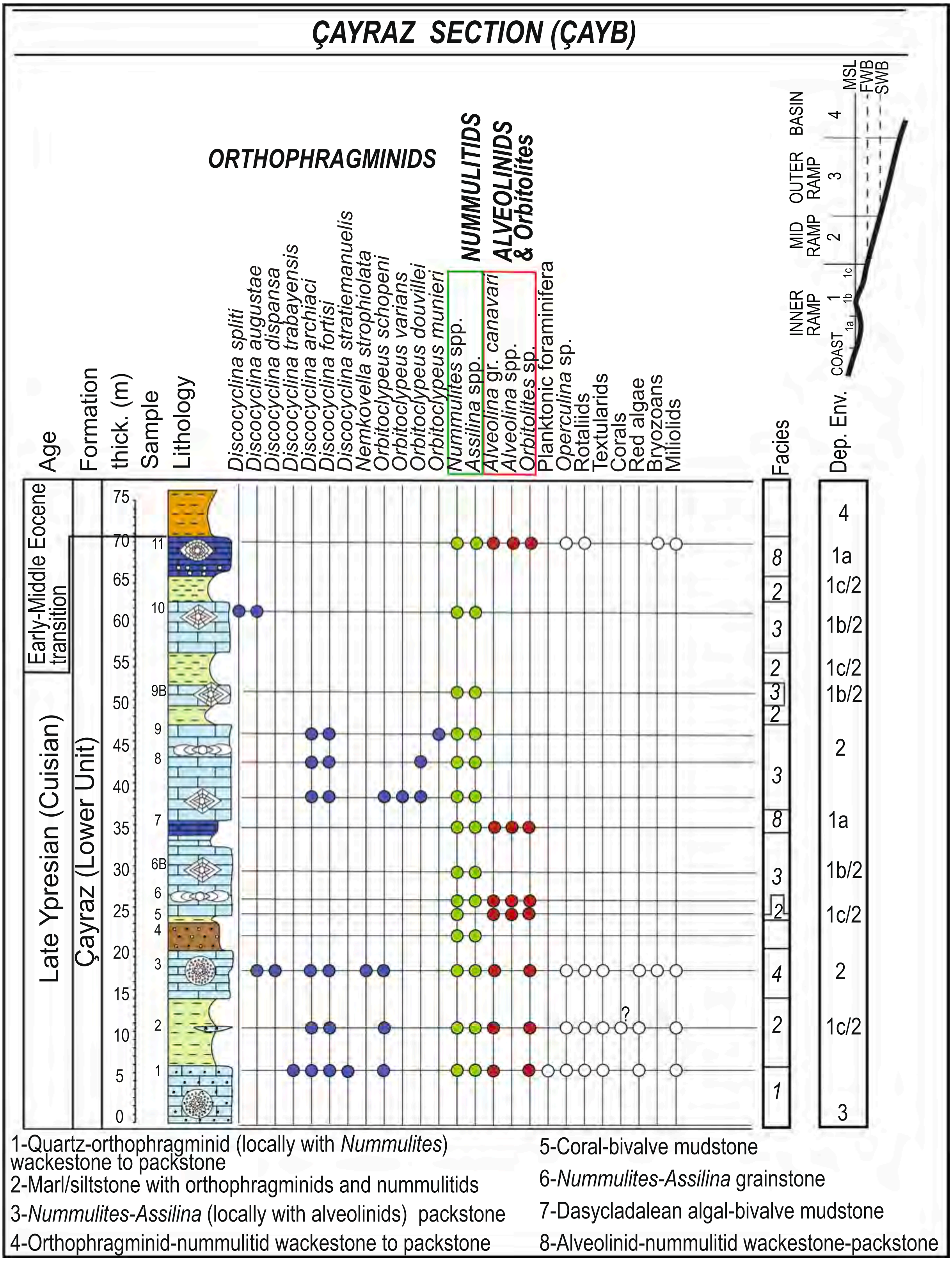

Fig. 8. Distribution of LBF and other fossil groups and interpretation of the facies in ÇAYB section.

level (sample 15). These clastics are overlain by a 5 m-thick interval of limestone beds with abundant *Orbitolites* and few *Alveolina* at its lower (sample 16), and with abundant *Nummulites* and *Assilina* at its upper part. The uppermost part of the lower unit of the Çayraz Formation consists of a sandstone interval without fossils and *Alveolina*-limestone with *Orbitolites*, *Alveolina* and rare *Nummulites* (sample 17). As already well documented in ÇAYA and ÇAYB sections, pelagic marly/silty middle unit overlies the Alveolina-limestone marker bed with thin turbiditic beds containing LBF especially at its lowermost part.

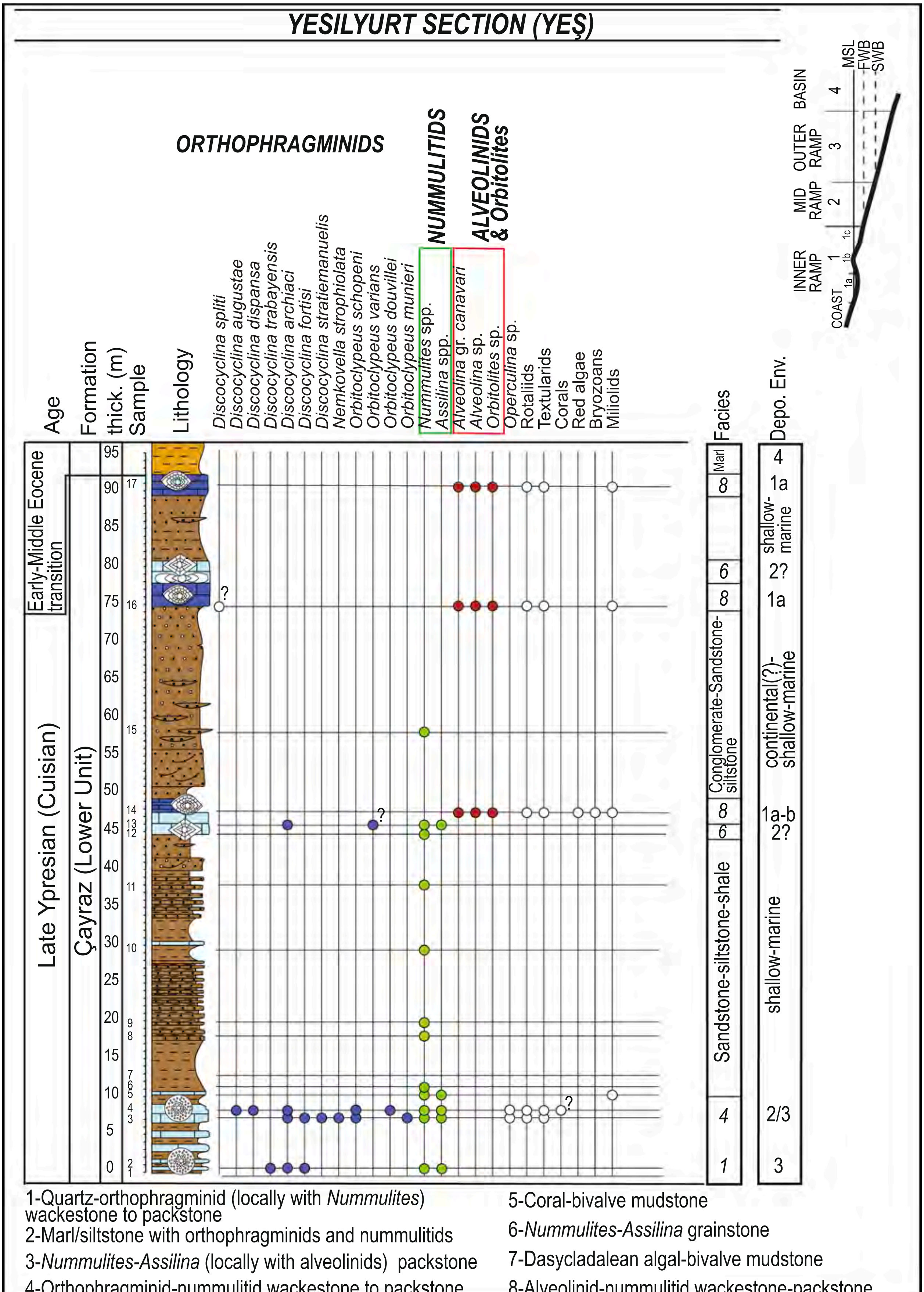

Fig. 9. Distribution of LBF and other fossil groups and interpretation of the facies in YEŞ section.

Table 1
Major LBF groups studied from the Çayraz Formation in the previous works and age assignments. The planktonic foraminiferal data obtained in this study are shown.

Author(s)	*Stratigraphic position*	*Fossil groups*	*Assigned ages*
Hottinger (1960)	Lower unit	Alveolinids	Ypresian
Ünalan et al. (1976)	Lower and upper units	Nummulitids and alveolinids	late Ypresian (Cuisian) (Lower Unit) Lutetian (Upper Unit)
Sirel and Gündüz (1976)	Lower and upper units	Nummulitids and alveolinids	Ypresian (Cuisian)-Lutetian
Schaub (1981)	Upper unit	Nummulitids	(early) Lutetian
Özcan (2002)	Lower unit	Orthophragminids	Late Ypresian
Özcan et al. (2007)	Upper unit	Nummulitids and orthophragminids	Early to middle Lutetian
Deveciler (2010)	Upper unit	Nummulitids	Lutetian to Bartonian
Dinçer (2016)	Lower and upper units	Nummulitids	Lutetian to Bartonian
Sirel and Deveciler (2017)	Lower unit	Rotaliids	(late) Ypresian
Sirel and Deveciler (2018)	Lower and upper units	Nummulitids	Ypresian-Bartonian
Present study	Middle unit	Planktonic foraminifera	Ypresian-Lutetian transition
	Lower unit	Nummulitids and orthophragminids	(late) Ypresian

4.2. Biostratigraphy

4.2.1. Biostratigraphic background: LBF from the lower and middle units of the Çayraz Formation

Hottinger (1960) described several new alveolinid taxa such as *Alveolina avellana* (characteristic for SBZ 5/6- the basal part of the late Ypresian), *A. parva* (characteristic for SBZ 8/9- the early part of the the Ypresian), and *A. lehneri* and *A. pinguis* (characteristic for SBZ 11 and 12 respectively- the middle part of the late Ypresian) from the shallow marine units in the Haymana Basin or same outcrops with the present study (Serra-Kiel et al., 1998). Ünalan et al. (1976) described *Nummulites globulus*, *Alveolina cayrazi*, *A. bayburtenis* and *A. canavari* (all key-species for Ypresian) from the lower Çayraz Formation and *Nummulites laevigatus*, *N. lehneri*, *Assilina spira*, *As. exponens* (all characteristics for Lutetian) from the upper unit of Çayraz Formation. Schaub (1981) introduced *Nummulites lehneri* from the lower part of the upper unit of the Çayraz Formation, suggesting an early Lutetian age (SBZ 13 according to Serra-Kiel et al., 1998) (Table 1). Orthophragminids were studied in detail from the lower unit by Özcan (2002) and many species of *Discocyclina*, *Nemkovella*, *Orbitoclypeus* and *Asterocyclina* were described (see below). The orthophragminid taxa were assigned to SBZ 9/10 at the lower and SBZ 12 at the upper part of lower unit, suggesting an age ranging from early/late Ypresian boundary to Ypresian-Lutetian boundary. The nummulitids in the upper unit of the Çayraz Formation indicate early to middle Lutetian (Özcan et al., 2007). Sirel and Deveciler (2017) described some rotaliids from the lower unit, assigning late Ypresian age to the unit. The Lutetian age recently assigned to the lower unit by Dinçer (2016) is questionable because of the lack of well-documented paleontological data of major faunal groups. In the following sections we present new paleontological findings obtained from newly collected LBF and PF.

4.2.2. Key LBF (mainly orthophragminids and alveolinids) from the lower and middle units of the Çayraz Formation

Distribution of LBF in the studied sections, represented mainly by orthophragminids, nummulitids, and partly by alveolinids and rotaliids, is shown in Figs. 7–9. In the absence of a systematic study of nummulitids from the lower unit of the Çayraz Formation, we here present only some key orthophragminid and alveolinid foraminiferal taxa, used to constrain the age of the unit (Figs. 10, 11). The stratigraphic ranges of these LBF species/subspecies are shown in Fig. 12. The stratigraphically most important orthophragminids in the lower unit are characterized by *Discocyclina fortisi* (d'Archiac) and *Orbitoclypeus douvillei* (Schlumberger) lineages, which are especially very common in section ÇAYA (Fig. 7). These are accompanied by other orthophragminids such as *Discocyclina archiaci* (Schlumberger), *D. dispansa* (Sowerby) and *Orbitoclypeus varians* (Kaufmann). Among these, *Discocyclina fortisi* is the most common species in the sections and three successive subspecies were identified based on biometry of embryo in equatorial sections. *Discocyclina fortisi fortisi* occurs in the lower and middle part (Figs. 7 and 10A), *Discocyclina fortisi simferopolensis* in the middle part and most advanced subspecies *Discocyclina fortisi cairazensis* (Fig. 10B-D) at the upper part of the section. The associated key-species and subspecies include *D. dispansa taurica* Less (Fig. 10F), *Discocyclina archiaci archiaci* (Schlumberger) (Fig. 10K), *Orbitoclypeus munieri munieri* (Schlumberger) (Fig. 10E) and *Orbitoclypeus varians* (Kaufmann) *portnayae* Less (Fig. 10G). *Orbitoclypeus douvillei* is represented by two subspecies, *Orbitoclypeus douvillei douvillei* (Schlumberger) in the lower and *Orbitoclypeus douvillei* (Schlumberger) *yesilyurtensis* Özcan (Fig. 10H-J) in the upper part of ÇAYA section. The diversity of orthophragminids is sharply reduced both vertically and laterally along the studied sections while *Alveolina* and *Orbitolites* become abundant towards the top of the lower unit. In the lower part of ÇAYA section, where it rests upon the deep marine marls of the Eskipolatlı Formation, orthophragminid assemblages consist of diverse associations of *Discocyclina, Nemkovella, Orbitoclypeus* and *Asterocyclina*, whereas at the upper part of the section, only *Discocyclina* occurs associating with nummulitids and alveolinids. The consistent occurrence of genus *Discocyclina* in levels dominated by *Nummulites* and *Assilina* (and partly *Alveolina*) is noteworthy, a feature previously reported from the very shallow Eocene deposits in Turkey (Özcan et al., 2007, 2020) and Oman (Erbay et al., 2018). Nevertheless, in these deposits, *Discocyclina* is either monospecific or it is represented by only a few species. This shows that among all orthophragminid genera, *Discocyclina* is the most tolerant genus to a wide spectrum of environmental conditions from inner to outer-ramp environments. *Asterocyclina* occurs only in the lower part of the Çayraz Formation (ÇAYA section, Fig. 7) and appears to be confined only to relatively deeper marine environments in the outer ramp. Alveolinids and orbitolitids (accompanied by dasycladalean algae) are the most common groups in the upper part of the lower unit in the studied sections and they occur in many levels of the same unit in YEŞ section. *Alveolina* gr. *canavari* is a diagnostic diagnostic species for late Ypresian (Fig. 11A-C). This species is characteristic for SBZ 10/11 (Serra-Kiel et al., 1998). In spite of reports on genera *Nummulites* and *Assilina* from the Çayraz Formation (e.g. Ünalan et al., 1976; Schaub, 1981; Sirel, 1992; Deveciler, 2019), a systematic study is missing. Several beds with abundant LBF also occur in the lower part of the pelagic marls/siltstones of the middle unit. These allochthonous taxa are represented by *Discocyclina* (*D. spliti polatlıensis*, *D. augustae sourbetensis* and *D. fortisi cairazensis*), *Nummulites* spp. and *Assilina* spp. (Figs. 7 and 12).

4.2.3. Planktonic foraminifera from the middle unit of the Çayraz Formation

The samples from ÇAYA section contain diversified assemblage of well-preserved planktonic foraminifera, reported for the first time from the middle unit of the Çayraz Formation (Fig. 13). The assemblages are characterized by a dominant group of *Acarinina* consisting of *A.*

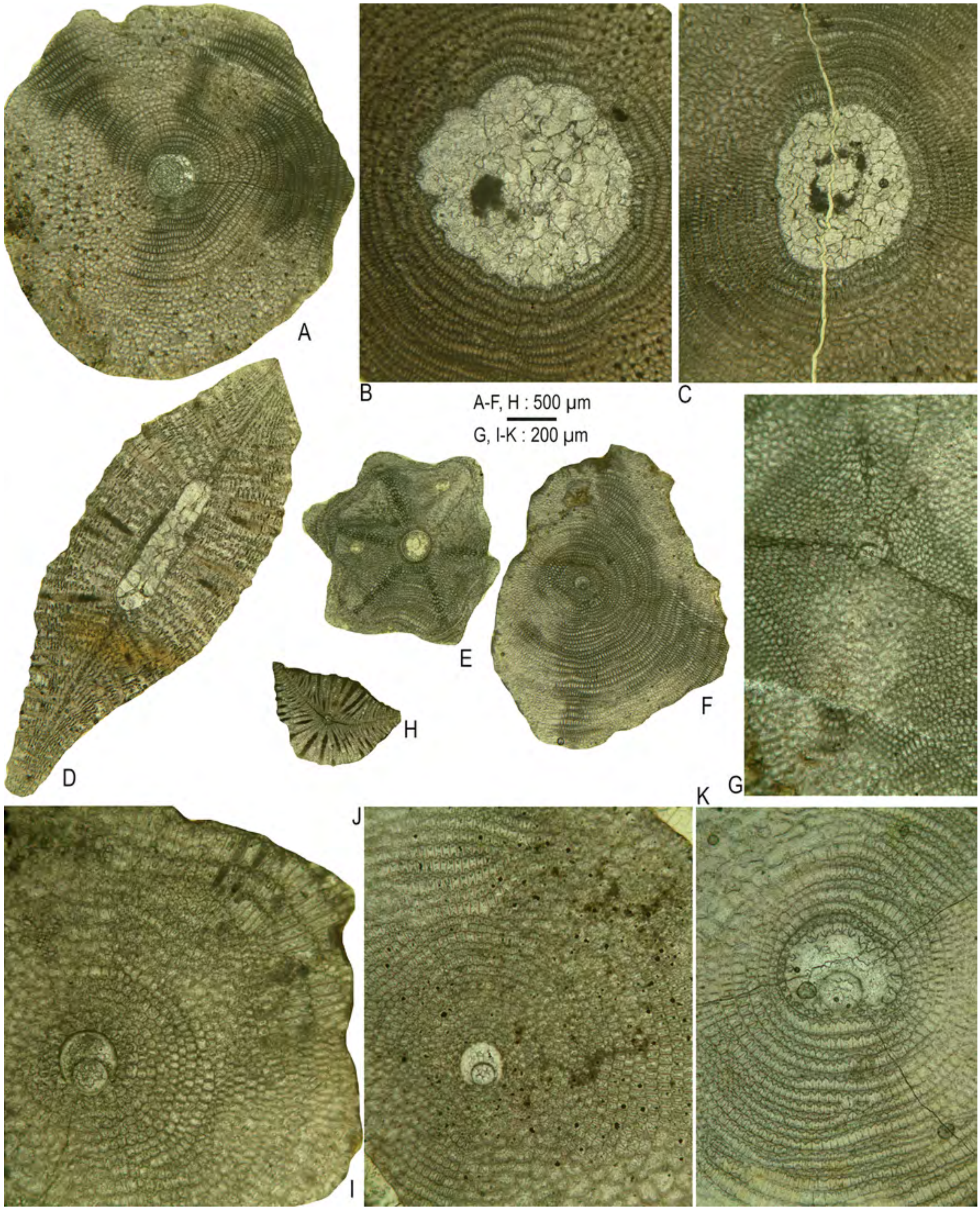

Fig. 10. Equatorial and axial sections of stratigraphically important orthophragminids in the lower unit of the Çayraz Formation. **A:** *Discocyclina fortisi fortisi* (d'Archiac), ÇAYA-5. **B–D:** *Discocyclina fortisi cairazensis* Özcan, ÇAYA-23. **E:** *Orbitoclypeus munieri munieri* (Schlumberger), ÇAYA-3. **F:** *D. dispansa taurica* Less, ÇAYA-7. **G:** *Orbitoclypeus varians portnayae* Less, ÇAYA-3. **H–J:** *Orbitoclypeus douvillei* (Schlumberger) *yesilyurtensis* Özcan, ÇAYA-18. **K:** *Discocyclina archiaci archiaci* (Schlumberger), ÇAYA-17.

cuneicamerata, A. pentacamerata, A. bullbrooki, A. collactea and *A. praetopilensis. Acarinina soldadoensis*, *A. angulosa,* while *A. pseudosubsphaerica* is subordinate. They are associated with scarce *Igorina broedermanni, Subbotina senni, S. inaequispira* and *S. eocaena. Morozovella crater*, *M. aragonensis* and *M. caucasica*. This planktonic foraminiferal assemblage represents the most characteristic elements of the P9 Zone (E7 Zone) of latest Ypresian (Berggren et al., 1995; Berggren and Pearson 2005) or the E7 Zone (Wade et al., 2011) of the late Ypresian-early Lutetian transition. The P9 Zone (E7. *Acarinina cuneicamerata* Zone) defines the biostratigraphic interval between the FO (First Occurrence) of *Acarinina cuneicamerata* and the FO of *Guembelitrioides nuttalli* (Berggren and Pearson 2005; Wade et al., 2011). The occurrences of the zonal marker, *A. cuneicamerata* and *A. pentacamerata* in typical and abundant specimens together with the assemblage above in the samples provide that the marly-silty unit of the ÇAYA section correlates well with the P9 Zone of the standard biostratigraphic schemes (Berggren and Pearson 2005; Wade et al., 2011). The two species were not reported from the Spanish stratigraphic sections where the GSSP for the base of the Lutetian stage is formally defined (Molina et al., 2011; Payros et al., 2011). On the other hand, *Globanomalina planoconica, G.*

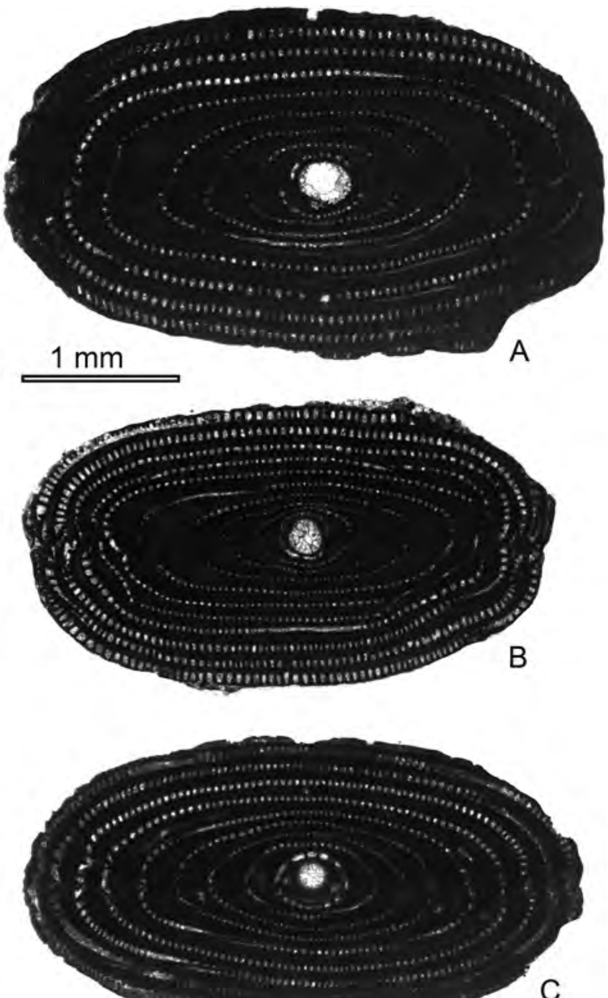

Fig. 11. *Alveolina* gr. *canavari*, a key-species for SBZ 10/11 (late Ypresian), from the ÇAYB section, sample ÇAYB-5.

indiscriminata, Planorotalites pseudoscitula, Pseudohastigerina micra, P. wilcoxensis and *Guembelitrioides lozanoi* in the Lutetian Stratotype (Molina et al., 2011) are also recorded in the ÇAYA section. The concurrent ranges of both *A. bullbrooki* and *Pseudohastigerina micra* (FOs) and *A. pentacamerata* (LO) suggest that the studied marly-silty unit is assignable to the upper part of the P9 Zone (Pearson et al., 2006). This biostratigraphic interval is supported by the occurrence of some specimens in a few numbers, similar to the lowest morphotypes of *Turborotalia frontosa* with smaller size and lower aperture than that of typical specimens whose FO is just below to the Lutetian GSSP and at the base of E7b Subzone (Molina et al., 2011; Wade et al., 2011). Similarly, some atypical specimens of *Guembelitrioides nuttalli,* which can be regarded as initial representatives of the species with small-sized, indistinctly highspired and multiapertured test are rarely recorded in the samples. *G. nuttalli* is the zonal marker with its relatively large-sized, loose coiled and highspired specimens with secondary apertures whose FO defines the lower boundary of the P10 Zone and E8 Zone, respectively (Berggren et al., 1995; Wade et al., 2011).

5. Facies description and depositional environments

Facies distribution and interpretation of depositional environments are illustrated in Figs. 7–9. We distinguished eight facies on the basis of biogenic composition and depositional texture. Facies 1, Quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone;

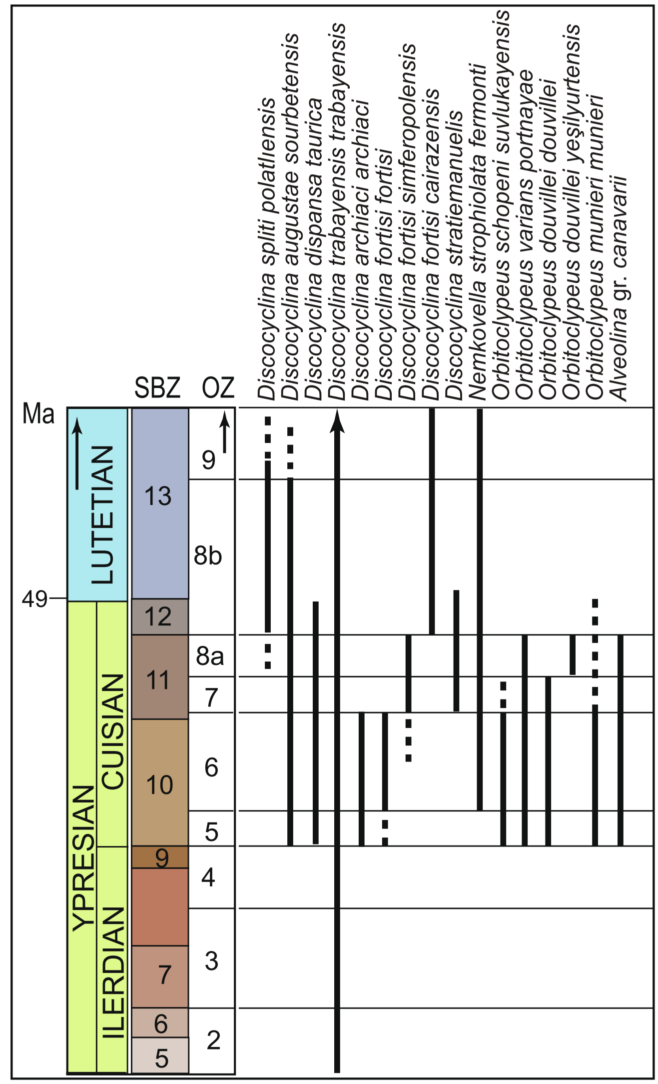

Fig. 12. Stratigraphic distribution of some key Ypresian orthophragminid and alveolinid species/subspecies in the Tethys, identified from the lower unit of the Çayraz Formation (after Less, 1987; Özcan, 2002; Özcan et al., 2007; Zakrevskaya et al. 2011). Shallow benthic zones are from Serra-Kiel et al. (1998) and orthophragminid zones from Özcan et al. (2007).

Facies 2, Marl/siltstone with orthophragminids and nummulitids; Facies 3, *Nummulites-Assilina* (locally with alveolinids) packstone; Facies 4, Orthophragminid-nummulitid wackestone to packstone; Facies 5, Coral-bivalve mudstone; Facies 6, *Nummulites-Assilina* grainstone; Facies 7, Dasycladalean algal-bivalve mudstone, and Facies 8, Alveolinid-nummulitid wackestone-packstone.

Most of the identified taxa are useful for the palaeobathymetric reconstructions and environmental interpretations in the neritic environment (Racey, 1995; Hottinger, 1997; Nebelsick et al. (2005); Beavington-Penney et al., 2006; Erbay et al., 2018). A model showing the associations of major Eocene foraminiferal groups on an idealised carbonate ramp by Beavington-Penney et al. (2006), which is slightly modified here by integrating the orthophragminid data after (Less, 1987; Özcan et al. 2007; Erbay et al., 2018), is shown in Fig. 14. These faunal associations are adopted for environmental interpretations.

5.1. Facies 1: Quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone

Facies 1 exhibits decimeter- to meter-scale quartz-orthophragminid wackestone to packstone (locally with nummulitids) intercalated with

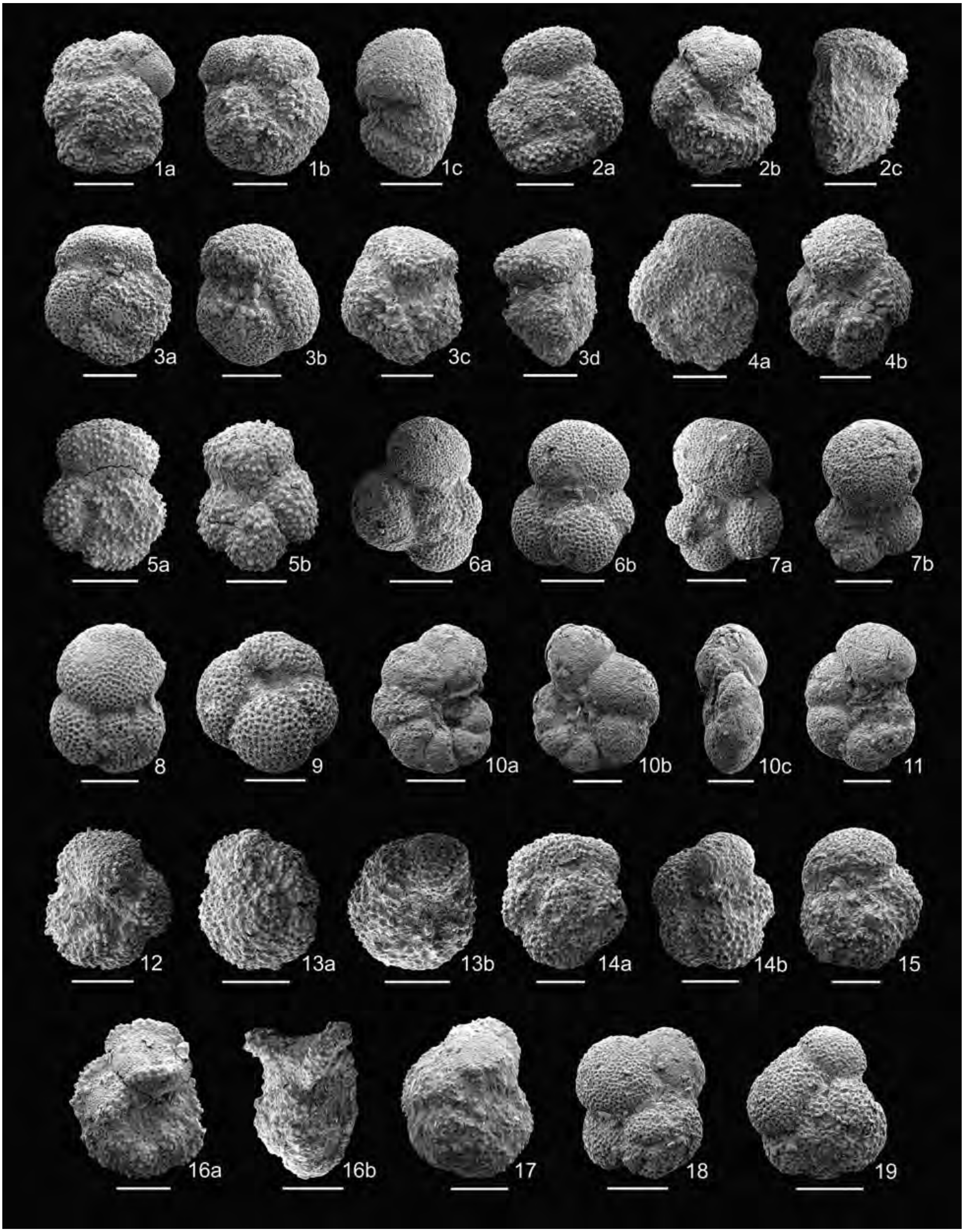

Fig. 13. SEM photographs of planktonic foraminifera from the middle pelagic marly/silty unit of the Çayraz Formation. **1a-c.** *Acarinina pentacamerata* (Subbotina), a- spiral view, b- umbilical view, c- side view, CA31; **2a-c, 4a, b.** *Acarinina cuneicamerata* (Blow), 2a, 4a- spiral view, 2b, 4b- umbilical view, 2c- side view, CA31; **3a-d.** *Acarinina bullbrooki* (Bolli), a- spiral view, b- umbilical view, d- side view, CA31 c- umbilical view, CA32; **5 a, b.** *Acarinina praetopilensis* (Blow), a- spiral view, b- umbilical view, CA31; **6a, b.** *Subbotina eocaena* (Gümbel), a- spiral view, b- umbilical view CA31; **7a, b.** *Subbotina inaequispira* (Subbotina), a- spiral view, b- umbilical view CA31; **8.** *Subbotina* sp., spiral view, CA32; **9.** *Subbotina* sp., umbilical view, CA32; **10a-c.** *Pseudohastigerina micra* (Cole), CA32; **11.** *Pseudohastigerina wilcoxensis* (Cushman and Ponton), CA32; **12.** *Acarinina* sp., umbilical view, CA30, **13.** *Igorina broedermanni* (Cushman and Bermudez), a- spiral view, b- umbilical view, CA31; **14.** *Acarinina collactea* (Finlay), a- spiral view, b- umbilical view, CA30; **15.** *Acarinina soldadoensis* (Brönnimann), umbilical view, CA30; **16a, b.** *Morozovella caucasica* (Glaessner), a- spiral view, b- umbilical view, CA31; **17.** *Morozovella aragonensis* (Nuttall), umbilical view, CA32; **18.** *Guembelitrioides* cf. *nuttalli* (Hamilton), spiral view, CA32; **19.** *Guembelitrioides lozanoi* (Colom), spiral view, CA32. Scale bars: 1–9, 18, 19: 150 µm; 10–15: 100 µm; 16–17: 200 µm.

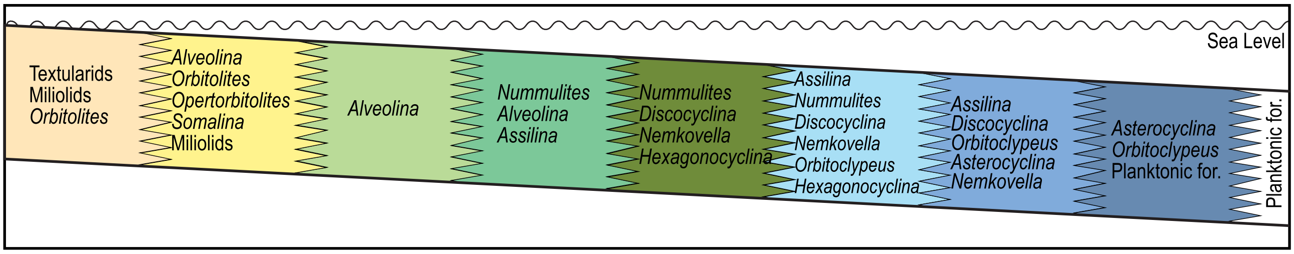

Fig. 14. Foraminiferal associations on idealised carbonate ramp during Eocene (with some modifications by integrating the orthophragminid genera, after Beavington-Penney and Racey, 2004).

marly/silty beds at the lower part of the Çayraz Formation. Quartz and mafic sand grains are angular to sub-angular. Common in this facies are *Discocyclina, Nemkovella, Orbitoclypeus* and *Asterocyclina*, and subordinate *Nummulites* and *Assilina* (Figs. 15A and 16A). The planktonic foraminifera occur sporadically. Orthophragminids including both large robust and small thin forms are the most diverse in this facies compared to those in the upper part of the lower unit in which only *Discocyclina* occurs dominantly and *Orbitoclypeus* is subordinate. LBF in this facies indicate deposition in relatively deeper water, suggestive of outer-ramp environment for the lowermost part of the lower unit (Fig. 7).

5.2. Facies 2: Marl/siltstone with orthophragminids and nummulitids

The medium- to thick-bedded marl/siltsone facies is a prominent part of shallow marine deposition in the lower unit. The marly/silty beds are mostly interbedded with *Nummulites-Assilina* packstone facies (Facies 3). The fauna is characterized predominantly by orthophragminids and nummulitids and other benthic foraminifera (Figs. 7–8). Planktonic foraminifera occur sporadically (Fig. 15C). The fine siliciclastic material suggests deposition in low-energy environment. The intercalation of marls (Facies 2) and coarse-grained limestones (Facies 3, 4 and 6) in ÇAYA section may suggest rhythmic sea-level fluctuations causing the deepening and shallowing of the depositional environment. The transition from marl/silt beds into Facies 3, 4 and 6 records shallowing-upward cycles. The fauna and facies suggest deposition in low-energy environment, either below fair-weather wave base or in deep inner-ramp setting (1c) at the seaward side of the shoals.

5.3. Facies 3: Nummulites-Assilina (locally with alveolinids) packstone

Facies 3 exhibits meter-scale bedding and is most commonly interbedded with Facies 2. It consists of coarse-grained packstone, dominated by abundant *Nummulites* and *Assilina*, and locally subordinate *Alveolina* (Figs. 7 and 8). LBF biofabric includes linear accumulation and chaotic stacking indicative of wave and current reworking (Fig. 15B). The linear accumulations (the tests aligned concordantly with the bedding) represent a parautochthonous wave/current winnowed accumulation (Beavington-Penney et al., 2006). High-energy conditions are also indicated by the abundance of LBF debris including *Nummulites* and *Assilina* (Fig. 15I). This is the most dominant facies in the middle and upper part of the lower unit in ÇAYA and YEŞ sections. The biofabric and texture suggest a shoal environment or parautochthonous shoal formed close to fair-weather wave base (transitional environments shown as 1b/2 in Figs. 7 and 8).

5.4. Facies 4: Orthophragminid-nummulitid wackestone to packstone

Facies 4 is observed within the meter-scale limestone beds and is commonly interbedded with Facies 2. It is characterized by the dominant occurrence of orthophragminids (*Discocyclina* and *Orbitoclypeus*) and nummulitids (*Nummulites* and *Assilina*) (Fig. 15D, G). It is essentially very similar to *Nummulites-Assilina* packstone facies (Facies 3) in many aspects but differs mainly by the occurrence of orthophragminids. The tests of orthophragminids show extensive abrasion and are mostly broken at the edges (Fig. 15D). LBF biofabric includes chaotic stacking indicative of wave and current reworking within this facies (e.g. Nebelsick et al., 2005; Bassi et al., 2013). The biofabric and texture suggest a shoal environment (Figs. 7 and 8).

5.5. Facies 5: Coral-bivalve mudstone

Facies 5 is found within the lenticular micritic limestone body of ca. 2 m-thick (Fig. 7, 29-31 m; samples 11–13). It extends ca. 15 m laterally and pinches out to marl/siltstone beds. This facies occurs only at the lower part of the basal unit in ÇAYA section (Figs. 6D and 15E). The fauna includes only rare corals and bivalves. Deposition in low-energy regime may be suggested by the abundance of micrite. This facies may be interpreted as a low relief carbonate mud-mound (Riding, 2002). Considering the composition of the beds situated immediately above and below this lenticular coral-bivalve mudstone body as well as the internal architecture and composition, it is thought that the latter corresponds to a true mud-mounds *sensu* Riding (2002) and represents an environment situated above the storm weather wave base marking therefore the transition from middle to outer ramp settings.

5.6. Facies 6: Nummulites-Assilina grainstone

Facies 6 is characterized by the thick-bedded limestones and corresponds to a coarse-grained *Nummulites-Assilina* grainstone in ÇAYA section (Fig. 15F). The dominant nummulitids such as *Nummulites, Assilina,* and subordinate *Discocyclina* and *Nemkovella, Operculina,* and rotaliids indicate a typical shallow marine assemblage. LBF tests are concordantly aligned with the bedding (linear accumulation), representing a parautochthonous wave/current concentration or an allochthonous accumulation (Beavington-Penney et al., 2006). This facies represents deposition of an allochthonous grainstone in a high-energy, shallow marine environment, probably in a shoal setting in the inner-ramp.

5.7. Facies 7: Dasycladalean algal-bivalve mudstone

The decimeter-scale beds (samples 19–22) of ÇAYA section encompass the Facies 7, which is interbedded with Facies 3 and 4 at the upper part of ÇAYA section. It contains dominantly dasycladalean algae and subordinate bivalve shells (Fig. 15H). Other bioclasts including miliolids and rotaliids are also present in this facies. A low-energy depositional environment is indicated by the high lime mud content. Presence of dasycladalean algae, miliolids, and rotaliids is suggestive of very shallow or partly restricted conditions (inner-ramp), implying shallowing trends during the deposition.

5.8. Facies 8: Alveolinid-nummulitid wackestone-packstone

Facies 8 occurs within decimeter- to meter-scale limestone bedding and is most commonly associated with Facies 3. It is observed only in

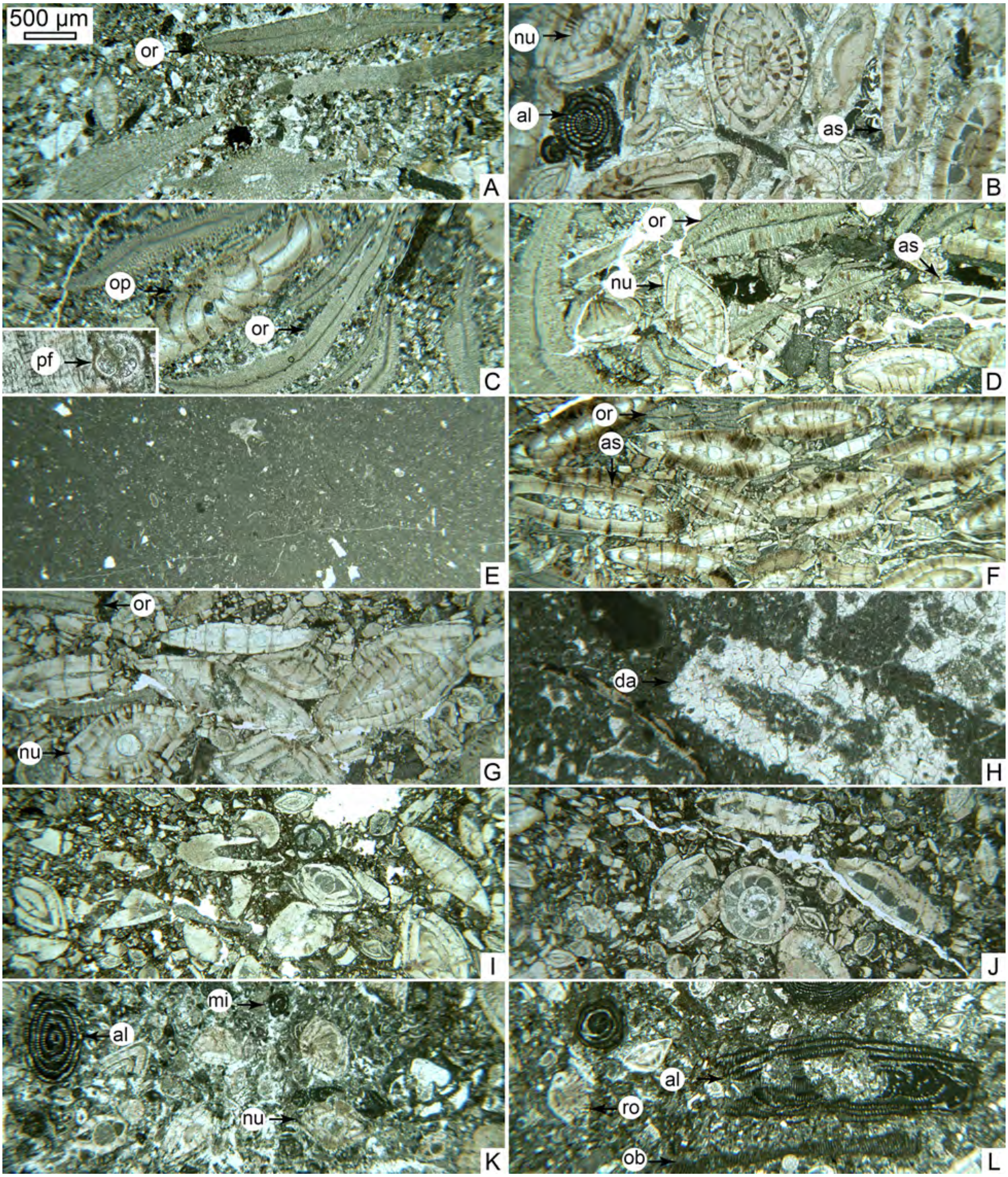

Fig. 15. Photomicrographs of thin sections showing facies in ÇAYA section. **A:** Facies 1, Quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone, sample ÇAYA-1, **B:** Facies 3, *Nummulites-Assilina* (locally with alveolinids) packstone, sample ÇAYA-6, **C:** Facies 2, Marl/siltstone with orthophragminids and nummulitids, planktonic foraminifera (lower left corner) occur sporadically, sample ÇAYA-5, **D:** Facies 4, Orthophragminid-nummulitid wackestone to packstone, sample ÇAYA-10, **E:** Facies 5, Coral-bivalve mudstone, sample ÇAYA-12, **F:** Facies 6, *Nummulites-Assilina* grainstone, sample ÇAYA-14, **G:** Facies 4, Orthophragminid-nummulitid wackestone to packstone, sample ÇAYA-17, **H:** Facies 7, Dasycladalean algal-bivalve mudstone, sample ÇAYA-19, **I–J:** Facies 3, *Nummulites-Assilina* (locally with alveolinid) packstone. I, sample ÇAYA-23, J, sample ÇAYA-25, **K–L:** Facies 8, Alveolinid-nummulitid wackestone to packstone. K, sample ÇAYA-27, L, sample ÇAYA-28. or: orthophragminids, nu: *Nummulites*, as: *Assilina*, al: *Alveolina*, ob: *Orbitolites*, op: *Operculina*, mi: miliolids, ro: rotaliids, pf: planktonic foraminifera, se: serpulids, da: dasycladalean algae.

the uppermost part of ÇAYA section (Fig. 15K-L), and recorded in more levels in westerly sections (Fig. 16C, F, and K-L). This serves as a key facies at the top of lower unit of the Çayraz Formation. This facies contains *Alveolina, Orbitolites, Nummulites, Assilina, Operculina*, rotaliids, miliolids and textularids. The presence of high lime mud in this facies with *Orbitolites*, *Alveolina*, miliolids, textulariids, and rotaliids indicate that sedimentation took place in a very shallow environment (inner-ramp).

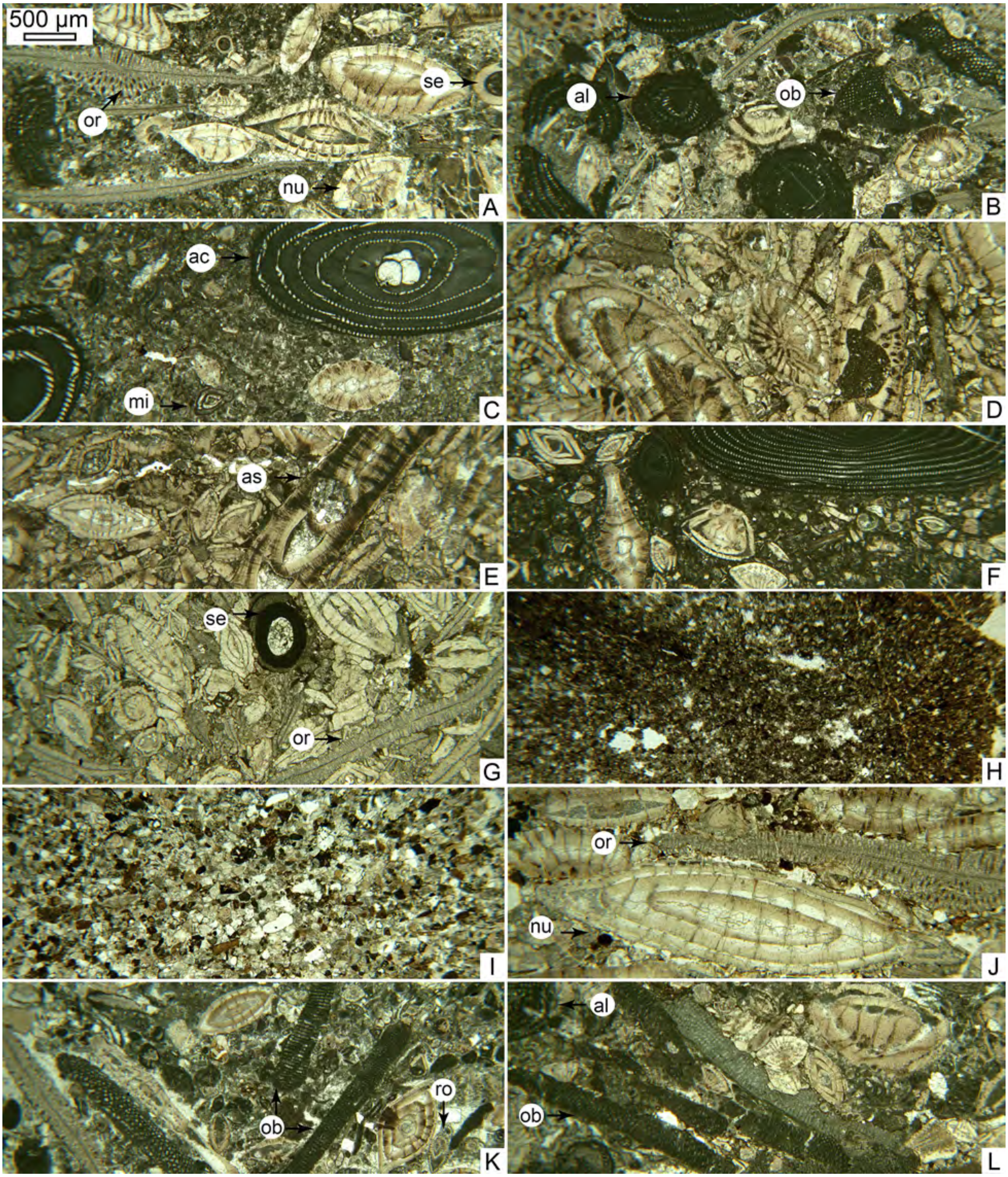

Fig. 16. Photomicrographs of thin sections showing microfacies in ÇAYB (A-F) and YEŞ (G-L) sections. **A:** Facies 1, Quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone, sample ÇAYB-1, **B:** Facies 3, *Nummulites-Assilina* (locally with alveolinids) packstone, sample ÇAYB-6, **C:** Facies 8, Alveolinid-nummulitid wackestone to packstone, sample ÇAYB-7. Alveolinid species at the upper right corner, *Alveolina* gr. *canavari* (ac), is a key species for SBZ 10/11, **D–E:** Facies 3, *Nummulites-Assilina* (locally with alveolinids) packstone, D: sample ÇAYB-8, E: sample ÇAYB-9, **F:** Facies 8, Alveolinid-nummulitid wackestone to packstone, sample ÇAYB-11, **G:** Facies 4, Orthophragminid-nummulitid wackestone to packstone, sample, YEŞ-3, **H:** Siltsone/shale facies with sporadic *Nummulites*, sample YEŞ-10, **I:** Sandstone facies with sporadic *Nummulites*, sample YEŞ-11, **J:** Facies 6, *Nummulites-Assilina* grainstone, sample YEŞ-13, **K–L:** Facies 8, Alveolinid-nummulitid wackestone to packstone. K: sample YEŞ-14, L: sample YEŞ-17. See Fig. 15 for fossil abbreviations.

6. Discussion

The Çayraz Formation, composed of both shallow and deep-marine deposits, has a more complex stratigraphic development than previously suggested. This formation consists of three lithologically distinct subunits, which were previously combined and treated under a single lithostratigraphic unit at ‘Formation' rank. We also follow this scheme since lower and upper units are lithologically very similar by the dominance of LBF accumulations in many levels, and the succession displays a monotonous development, except for the pelagic middle part of the sequence. Subdivision of the Çayraz Formation into three members is also possible, which requires formal description of all units, necessitating also the study and description of the upper unit.

The lower unit, in general, is a regressive unit, dominated by quartz-orthophragminid (locally with *Nummulites*) wackestone to packstone facies at its base and, alveolinid-nummulitid wackestone-packstone facies at its top immediately below the pelagic marls. Thus, the whole sequence records the stratigraphic development from outer to inner ramp setting. Abundant orthophragminids (represented by *Discocyclina*, *Orbitoclypeus* and *Asterocyclina*) and sporadic planktonic foraminifera at the basal beds of the lower unit suggest open marine depositional conditions such as middle to outer-ramp. Coral-bivalve mound in the lower part suggest a depositional environment above the storm weather wave base and marks the transition from outer and middle ramp settings. The middle part of the lower unit is mostly characterized by cyclic deposits of LBF deposits, of various LBF wackestone-packstone facies characterizing shallowing-up cycles and deposited in middle to inner ramp settings. Moreover, the lower unit presents notable lateral facies and faunal changes westward and is characterized by a siliciclastic sequence (sandstone and conglomerate) with very poor fauna (only rare tests of *Nummulites* or *Assilina*). The predominance of *Alveolina* in most levels in westerly section (YEŞ), alveolinid-nummulitid wackestone-packstone and *Nummulites-Assilina* grainstone facies, also shows that the lower unit has been deposited in a shallower palaeoenvironment (inner-ramp) compared to easterly sections (ÇAYB and ÇAYA). The upper part of the lower unit is dominated by Dasycladalean algal-bivalve mudstone and Alveolinid-nummulitid wackestone-packstone facies. The dominant occurrence of *Alveolina, Orbitolites* and dasycladalean algae below the pelagic marls of the middle unit is very characteristic feature for the development of succession. These beds are interpreted to have deposited in an inner-ramp setting. A sharp environmental shift is marked by the initiation of the deposition of the marly/silty beds containing abundant LBF in several limestone beds at its basal part. Limestone beds contain graded test of LBF and are interpreted as allochthonous. Nummulitids and orthophragminids are most common. The LBF, indicative of SBZ 9/10 at the basal beds and SBZ 12 at the upper part of lower unit suggest an upper Ypresian age. The planktonic foraminifera in middle unit belonging to P9 zone constrain the upper part of the lower unit to Ypresian-Lutetian transition, which is consistent with the ages obtained by LBF. The planktonic foraminiferal data obtained from the middle member of the Çayraz Formation provide the establishment of a precise chronologic framework for the lower and middle parts of the Çayraz Formation and transition from shallow-to deep-marine environment in the Haymana Basin for the first time. This further enables the reinterpretation of the stratigraphic ranges of LBF, common in the lower and upper members.

7. Conclusion

The Çayraz Formation, the youngest marine Cenozoic unit in central Turkey, is subdivided into three units based on their lithological features and fossil content. The lower and upper units are mostly dominated by LBF accumulations, while the middle unit consists of thick-bedded to massive marl and siltstone beds with pelagic fauna, and limestone with allochthonous LBF at its basal part. The lower unit displays significant lateral and vertical variability in the composition of LBF and facies along SE-NW transect near Çayraz village. This unit is interpreted as a major shallowing-upward sequence dominated by orthophragminids and rare planktonic foraminifera characteristics of a deep setting in outer-ramp at its base, and LBF (mainly species of *Alveolina* and *Orbitolites*) characteristic of inner ramp at its upper part. The lowermost part of the first unit is dominated by orthophragminids accompanied by abundant nummulitids and rare alveolinids. We interpreted that *Alveolina*, and probably some *Nummulites* and *Assilina* in this part of the sequence were resedimented. The fluctuations in relative sea level during the deposition of lower unit are evidenced by the rhythmic alternations of LBF marl/siltsone beds and limestone. The middle part of the unit usually lacks fine clastic interbeds, and is pedominantly represented by repetitive, thick-bedded limestone beds of *Nummulites*, *Assilina* and sporadic *Discocyclina*. The transition from marly/silty beds to *Nummulites-Assilina* packstone and grainstone facies records a shallowing-upwards cyles in the lower unit of the Çayraz Formation. Eight facies within the lower unit of the Çayraz Formation indicate a depositional spectrum ranging from inner, middle to outer-ramp. Several shallowing-upward cycles within a general shallowing-upward trend are recognized. The shallow marine deposition ends abruptly after the *Alveolina*-bed at the top of the lower unit and deeper pelagic sedimentation starts with marly/silty beds.

The marly/silty beds of the middle unit of the Çayraz Formation contain planktonic foraminifera, suggestive of the P9 Zone, and imply a transitional age across the Ypresian-Lutetian boundary. The dating of the middle marly unit by pelagic fauna clarifies the stratigraphy of the lower and middle units for the first time. The age obtained from planktonic foraminifera unequivocally constrains the age of the lower unit to the Ypresian.

CRediT authorship contribution statement

Ercan Özcan: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Aynur Hakyemez:** Investigation, Writing - original draft. **Attila Çiner:** Investigation, Writing - original draft, Writing - review & editing. **Aral I. Okay:** Investigation, Writing - original draft, Writing - review & editing. **Mohamed Soussi:** Investigation. **Kamel Boukhalfa:** Investigation. **Ali Osman Yücel:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jseaes.2020.104304.

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