Distribution of *Alveolina* assemblages in the Ypresian (Ilerdian-Cuisian) successions from Iran and Turkey (central and western Tethys): biostratigraphic implications for regional correlation

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ABSTRACT: Benthic foraminiferal assemblages dominated by *Alveolina* species from the Ypresian (Ilerdian–Cuisian) are studied herein from numerous localities of Iran and Turkey. From these successions, highly diversified assemblage of 58 alveolinid species are identified along with their detailed biostratigraphical application, which resulted in the recognition of eight shallow benthic zones (SBZ5–SBZ12). Our findings are based upon the distribution ranges of *Alveolina* from the Ilerdian–Cuisian sediments in Iran (Central Tethys) that are considered to have a strong affinity with their coeval fauna in Turkey (Western Tethys). In this study, the wide expansion ranges of *Alveolina* permit us to achieve a high-resolution biostratigraphy and apply the shallow benthic zones of the peri-Mediterranean region (Western Tethys) to the Ilerdian–Cuisian successions in Iran (Central Tethys). Nevertheless, the distribution of some *Alveolina* species, even the zonal markers consisting of *Glomalveolina lepidula*, *Alveolina ellipsoidalis, A. pisiformis*, *A. laxa*, *A. subpyrenaica*, *A. varians*, *A. fornasinii* and *A. canavarii* are found occurring at younger stratigraphic levels in Iran and/or Turkey than in the western European shallow marine deposits.

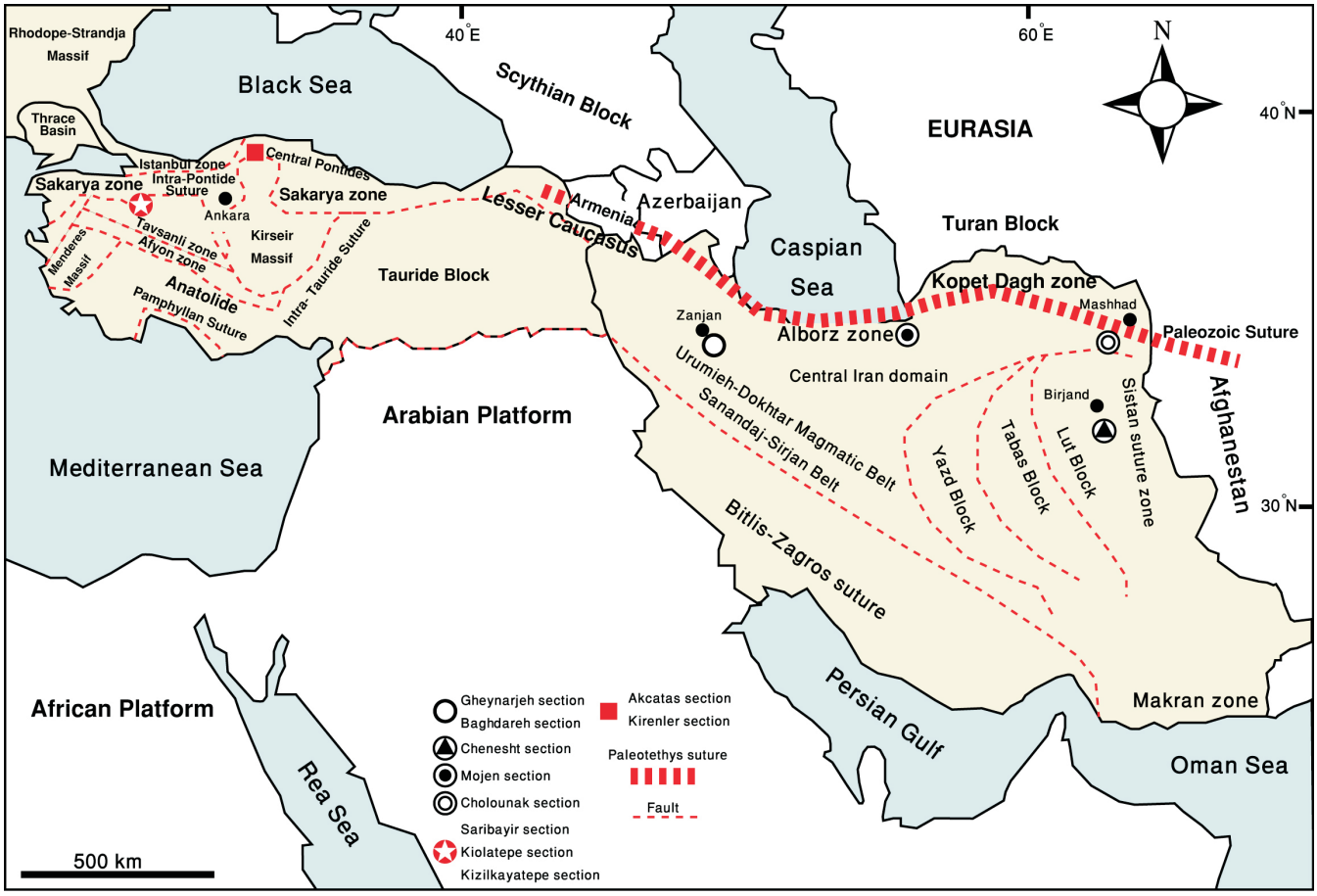
Keywords: *Alveolina*; biostratigraphy; Eocene; Tethys; SBZ

INTRODUCTION

Alveolina is a group of symbiont-bearing larger benthic foraminifera (LBF) occurring from the late Palaeocene (Thanetian) to the late middle Eocene (Bartonian) with a wide geographic distribution in the Tethys (Drobne et al. 2011). They are a powerful tool for biostratigraphic interpretations in the Tethyan realm due to rapid evolutionary changes and high species diversity during the Eocene. The first identification of alveolinids was by d'Orbigny (1826) and after a prolonged period they were described from European sediments (Checchia-Rispoli 1905), northern Africa (Schwager 1883), and the Indo-Pacific region (Somalia, Pakistan and India; Silvestri 1938). In the 1960s to 1980s, the most comprehensive studies of alveolinids from the Eocene shallow-water sections of the Tethys region were carried out by Hottinger (1960, 1974), Scotto di Carlo (1966), Sirel (1976a, b); Drobne (1977) and Rahaghi (1978, 1980, 1983). More recently, with the introduction of the shallow benthic zones by Serra-Kiel et al. (1998), new studies have provided an updated biostratigraphic scheme for the alveolinid species (e.g., Vecchio et al. 2007; Özgen-Erdem 2008; Özgen-Erdem et al. 2007, 2016; Sirel and Acar 2008; Drobne et al. 2011; Deveciler 2014; Papazzoni et al. 2017; Hadi and Vahidinia 2019; Hadi et al. 2019a,b,c). While a perusal of the literature confirms that *Alveolina* from central and eastern Tethyan regions are poorly known, except for a few papers (e.g., Sameeni and Butt 2004; Zhang et al. 2013; Sarkar 2016), there is still a large gap in data regarding the SBZs based on the biostratigraphical distribution of *Alveolina* as a correlation of the eastern and western Tethyan realms. In this paper, we present our results on the biostratigraphy of alveolinids pertaining to the Ilerdian–Cuisian shallow marine sediments from the western central Tethys. Detailed biostratigraphical studies on the widespread spectrum of *Alveolina* permit us to correlate these localities with the SBZs introduced by Serra-Kiel et al. (1998), and make an attempt to determine their coeval assemblage affinities from the Iranian and Turkish platforms.

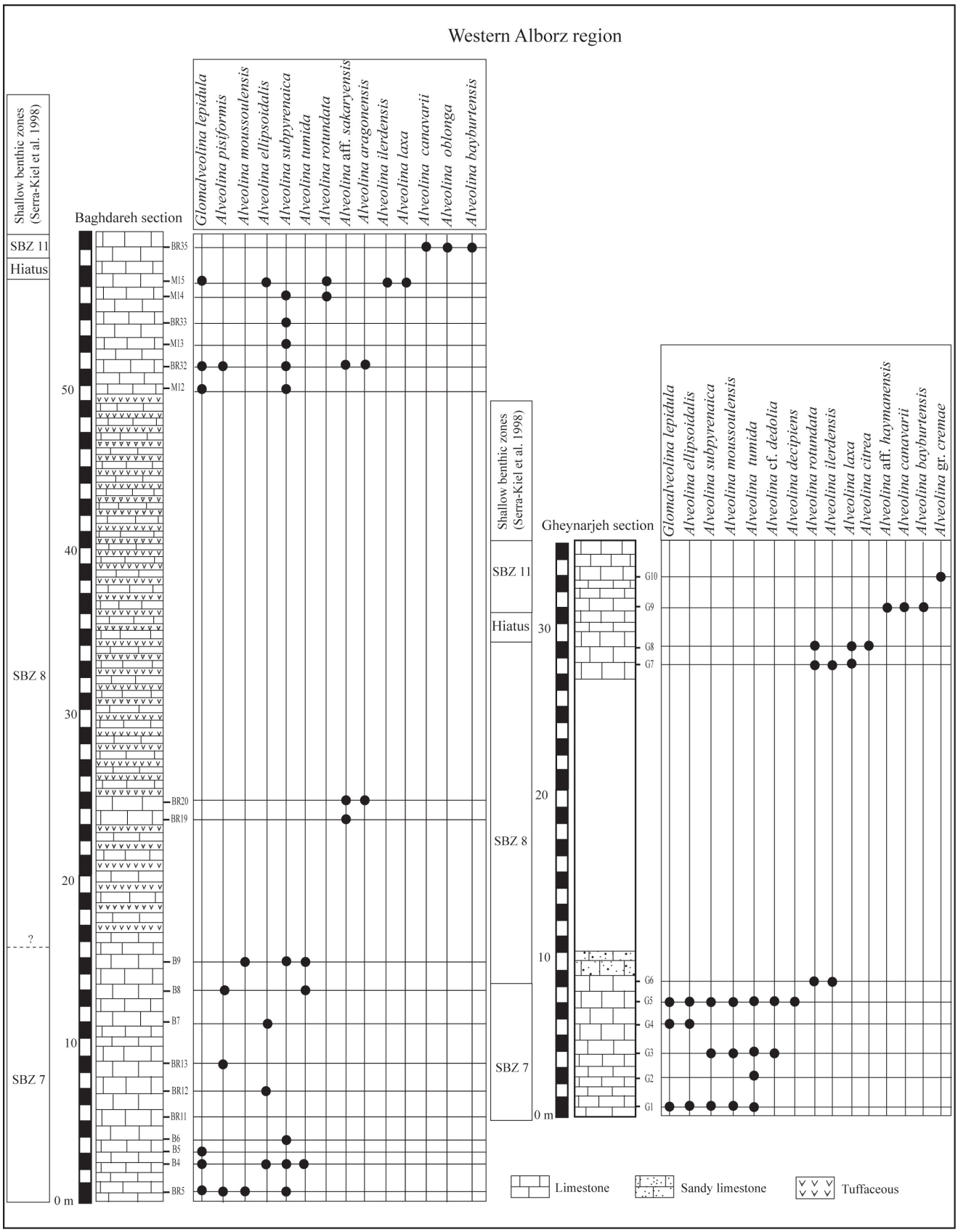
GEOLOGICAL SETTING AND THE ILERDIAN-CUISIAN SUCCESSIONS IN ALBORZ, CENTRAL AND EASTERN IRAN, SEYITGAZI (ESKIŞEHIR) AND TOSYA (KASTAMONU) REGIONS

The Turkish-Iranian Plateau is subdivided into several sedimentary-structural provinces each of which are characterized by different tectonic and sedimentary events (Stöcklin 1968; Okay

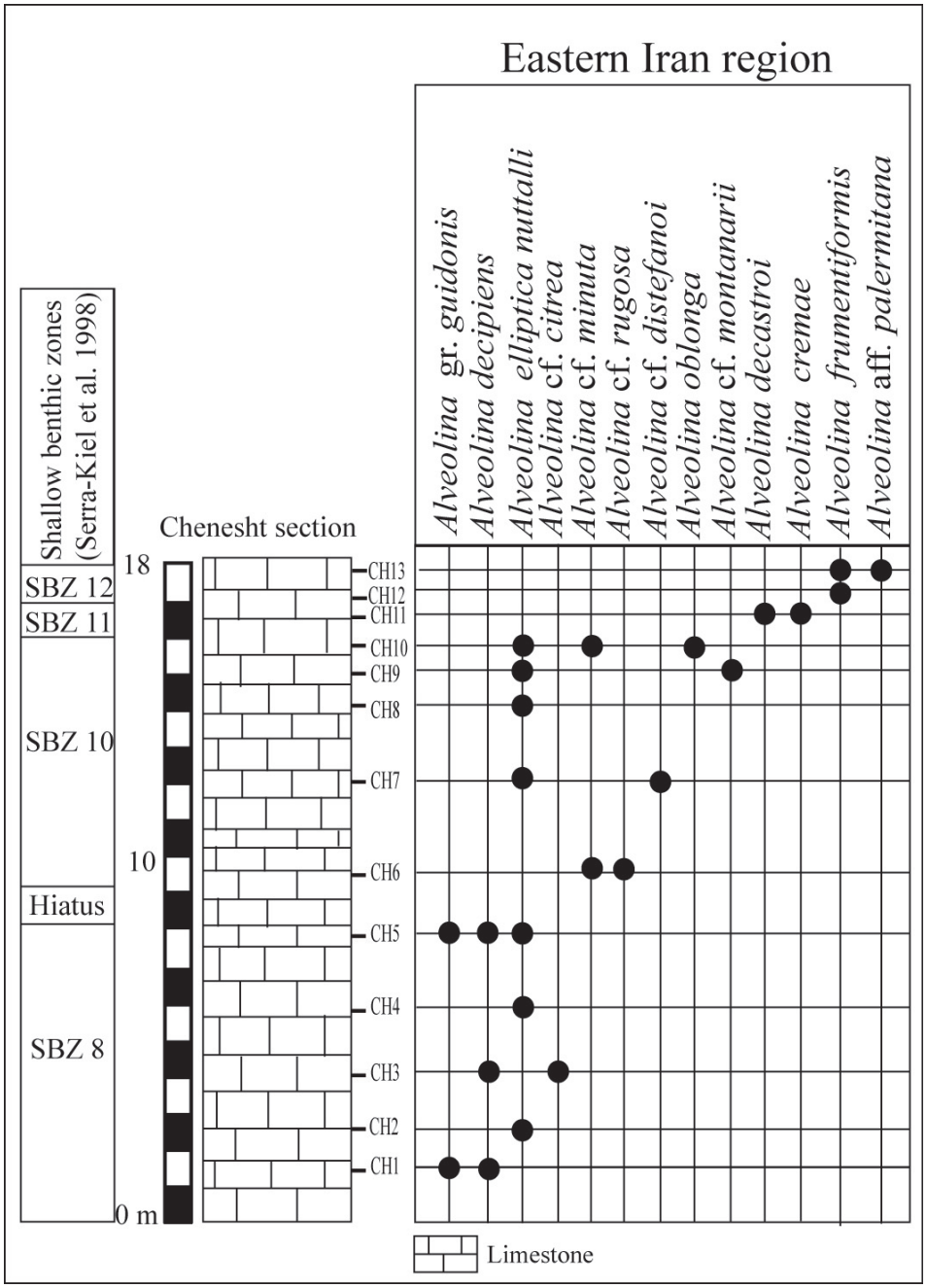


TEXT-FIGURE 1
Geological map of Iran-Turkey and location of the studied outcrops (simplified from Shafaii-Moghadam et al. 2017).

and Tüysüz 1999; Aghanabati 2004; Plunder et al. 2013, text-fig. 1). These regions are as a part of the largest mountain belt of the Alpine-Himalayan system located along 2,800 km between western Turkey and eastern Iran regions. In Iran, the Alborz zone is situated 200–500 km to the north of the Neotethyan suture in the Arabia-Eurasia collision zone (Rezaeian 2009), south of the Caspian Sea and north of the Central Iran zone. In this zone the Eocene shallow marine successions belonging to the Ziarat Fm. lie unconformably on the continental siliciclastic deposits of the Fajan Fm. and is overlain by the Eocene volcano-sedimentary rocks of the Karaj Formation (Hadi et al. 2016, 2019a, 2019b). The Central Iran zone is one of the most important and complicated structural zones in Iran, which is located as a triangle in the middle of Iran. This zone consists of three north–south oriented crustal domains, called the Lut, Tabas and Yazd blocks, which are presently aligned from east to west, respectively (Berberian and King 1981; Masoodi et al. 2013). According to Alavi (1991) the central Iran zone comprises the Sabzevar block and Tabriz-Qom belt (Central Iran domain). In this region, the early-middle Cuisian shallow-water limestones occur within the Sabzevar-Torbate-e-Heydarieh ophiolite belt (Hadi and Vahidinia 2019). Further east, the Eastern Iran region (Sistan ocean zone) extends as a N-S trending belt over more than 700 km along the border area between the Lut block and the Afghan block, which is a result of eastward-directed subduction of a Tethyan ocean basin beneath the Afghan block (Bröcker et al. 2013). The lithostratigraphic units in the Sistan ocean zone are substantially composed of Cretaceous ophiolites and ophiolitic mélanges, overlain by Maastrichtian-Eocene flysch sediments (Babazadeh and De Wever 2004; Fotoohi-Rad et al. 2009), whereas the Ilerdian-Cuisian carbonate successions with distinct stratification occur within the volcanic and flysch deposits (Schlagintweit and Hadi 2018; Hadi et al. 2019b-c). Towards the western parts of Iran and in Turkey, the Ilerdian-Cuisian sedimentary successions from the Seyitgazi (Eskişehir) region are situated into the Tavşanli zone between the Ýzmir-Ankara suture and the Afyon zone (Okay and Tüysüz 1999). This suture zone is remnant of the major Neotethys ocean that separated Laurasia and Gondwana during the middle to late Triassic (Tekin et al. 2002) and then closed in the Late Cretaceous (in the west) or early Palaeogene (in the east; Meijers et al. 2010; Lefebvre et al. 2013). The Tavşanli zone is divided into four tectonostratigraphic units from the bottom to top: 1) Orhaneli group, which encompasses continental origin rocks, forming a regular stratigraphical sequence, 2) Ophiolitic melange, 3) Ophiolite, 4) Eocene sedimentary rocks and granitoids (Okay 1984). The Eocene sediments unconformably overlies the basement rocks and ophiolites comprising shallow-water limestones, sandy-clayey limestones and marls (Özgen-Erdem et al. 2007). Tosya region is located in the central Pontides zone (Okay and Tüysüz 1999; Aygül et al. 2016). The Central Pontides is a part of the



TEXT-FIGURE 2
Stratigraphic distributions of the *Alveolina* species in the Baghdareh and Gheynarjeh sections, western Alborz region (Iran).



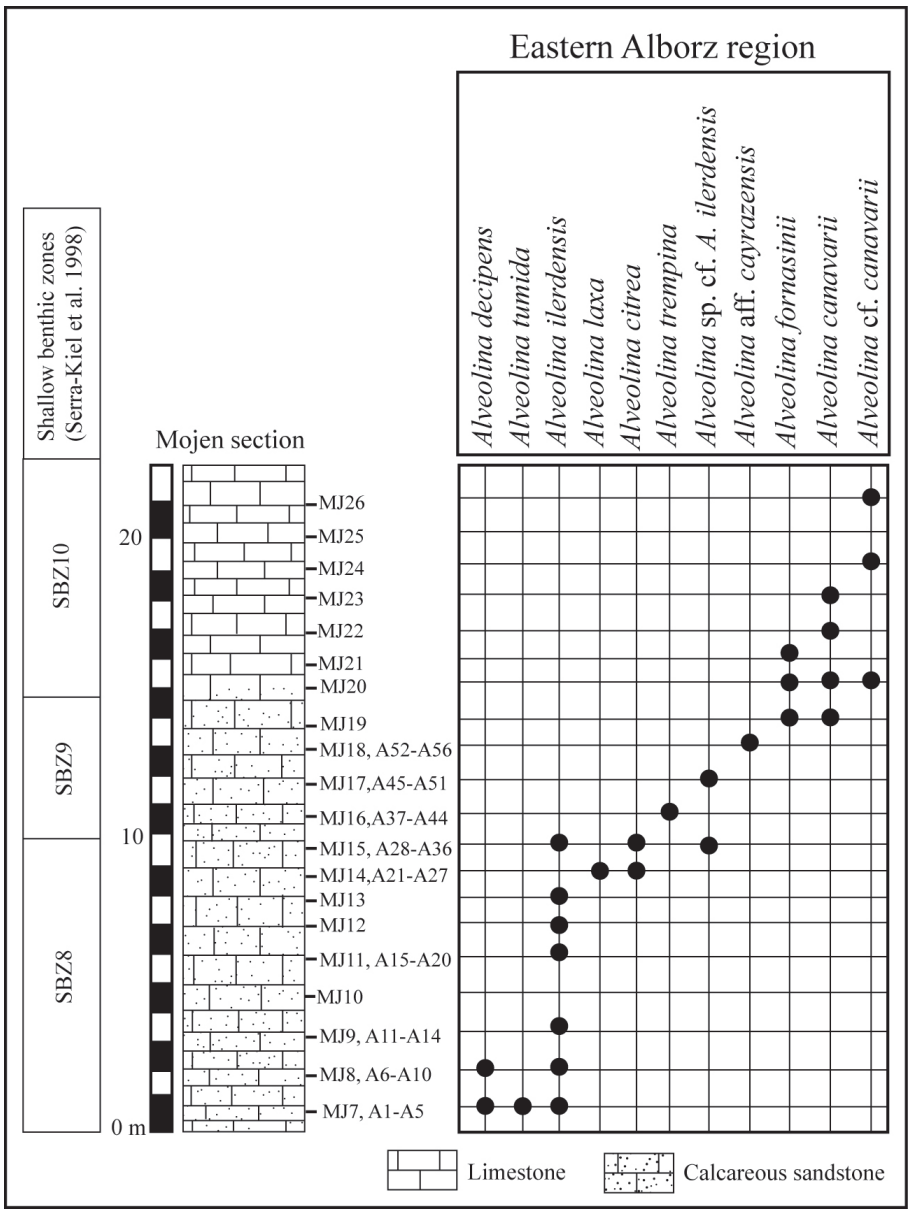
TEXT-FIGURE 3
Stratigraphic distributions of the *Alveolina* species in the Chenesht section, eastern Iran region (Iran).

Sakarya Zone (Tüysüz and Tekin 2007) and bordered by the Black Sea in the north and the İzmir-Ankara-Erzincan Suture in the south (Aygül and Okay 2012). The measured sections in the Tosya region are located in the southeastern part of the Central Pontides. In the studied area, the basement rocks of the Cretaceous metasedimentary and metamorphic sequences (Aygül et al. 2016) are followed by late Maastrichtian shallow-water carbonates (see Consorti and Köroğlu 2019). The Ilerdian carbonates and basalts unconformably overlie the metamorphic sequences and melange. The Ilerdian unit has basal conglomerates and it gradually passes into sandstones, sandy carbonates, and carbonates. The medium-bedded sandy carbonates are composed of yellowish, sporadic grey layers and fossils. Fossiliferous carbonates on top of them are grey to white and sporadic yellowish in color, hard, and medium-bedded. This succession is overlain by Quaternary alluvium sediments.

DESCRIPTION OF SECTIONS

Baghdareh section

The Baghdareh section (36°13'04" N; 48°58'54" E) is about 59-m-thick and was measured ~1.5 km southwest of Baghdareh village, which is ~30 km west of Khoram-dareh town. This section is situated ~150 km southwest of Zanjan city. The lower



TEXT-FIGURE 4
Stratigraphic distributions of the *Alveolina* species in the Mojen section, eastern Alborz region (Iran).

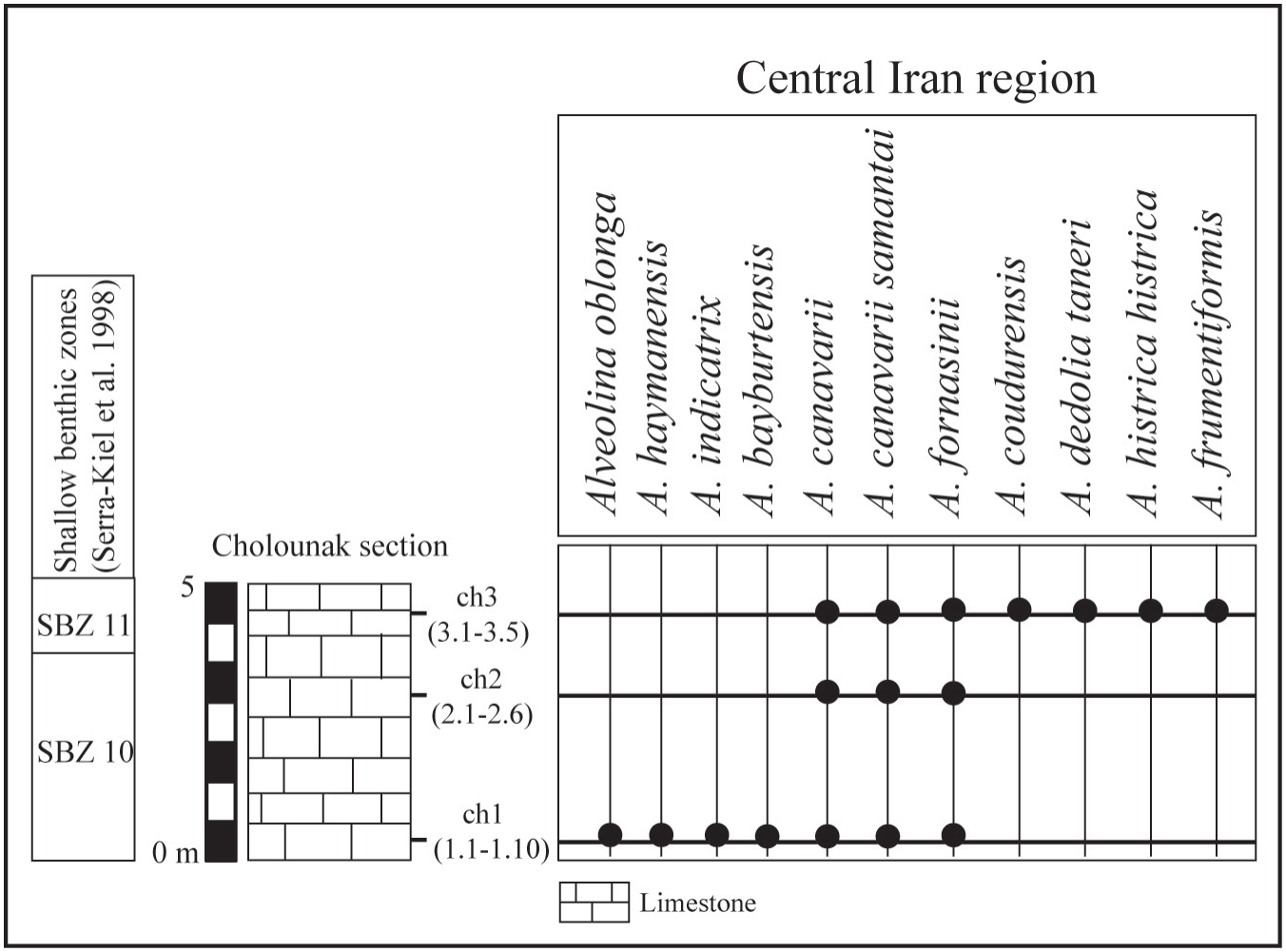
unit is composed of limestone beds containing abundant well-preserved alveolinid species of the middle Ilerdian. The basal part consists of dark-yellow to brown, medium-bedded limestone. The upper unit is composed of light grey to grey, thin-bedded limestone with intercalations of tuffaceous deposits whereas the uppermost part is dominated by medium-bedded limestone with abundant and diverse well-preserved early Eocene alveolinid assemblages (text-fig. 2).

Gheynarjeh section

The Gheynarjeh section (36°30'42"N; 48°31'46"E) is about 35-m-thick, measured ~1 km north of the Gheynarjeh village (located 19 km southeast of Zanjan). The lower unit is composed of light-grey to grey, medium-bedded limestone with alveolinid horizons of the early Eocene, which in the uppermost part consists of dark-yellow to brown, thinly bedded sandy limestone (text-fig. 1). The upper unit is similar to the uppermost part of the Baghdareh section (text-fig. 2). Both the Baghdareh and Gheynarjeh sections lie unconformably on the Fajan Formation and are conformably overlain by the Karaj Formation.

Chenesht section

The Chenesht section (32°38'22"N; 59°23'54"E) is about 18-m-thick and located ~1 km northwest of the Chenesht village, and ~50 km southeast of Birjand. Limestones are grey- and brown-colored with distinct beds often less than 60 cm in thickness. The base is partly covered or consisting of volcanoclastic sediments. The Eocene carbonates are overlain by sand-



TEXT-FIGURE 5
Stratigraphic distributions of the *Alveolina* species in the Cholounak section, central Iran region (Iran).

stones. The *Alveolina* assemblage in the Chenesht section comprises the early Eocene stratigraphic interval (text-fig. 3).

Mojen section

The Mojen section (36°29'53"N; 54°35'43"E) is ~22-m-thick composed of foraminiferal limestones and located ~4.5 km northwest of Mojen village, which is ~45 km west of Shahroud. The basal part consists of yellow to grey, medium-bedded calcareous sandstone. The middle part is composed of light grey to grey, medium-thick bedded sandy limestone with abundant and diverse, well-preserved, early Eocene *Alveolina* species, whereas the uppermost part is dominated by medium-bedded limestone (text-fig. 4). They lie unconformably on the Fajan Formation and are conformably overlain by the Karaj Formation.

Cholounak section

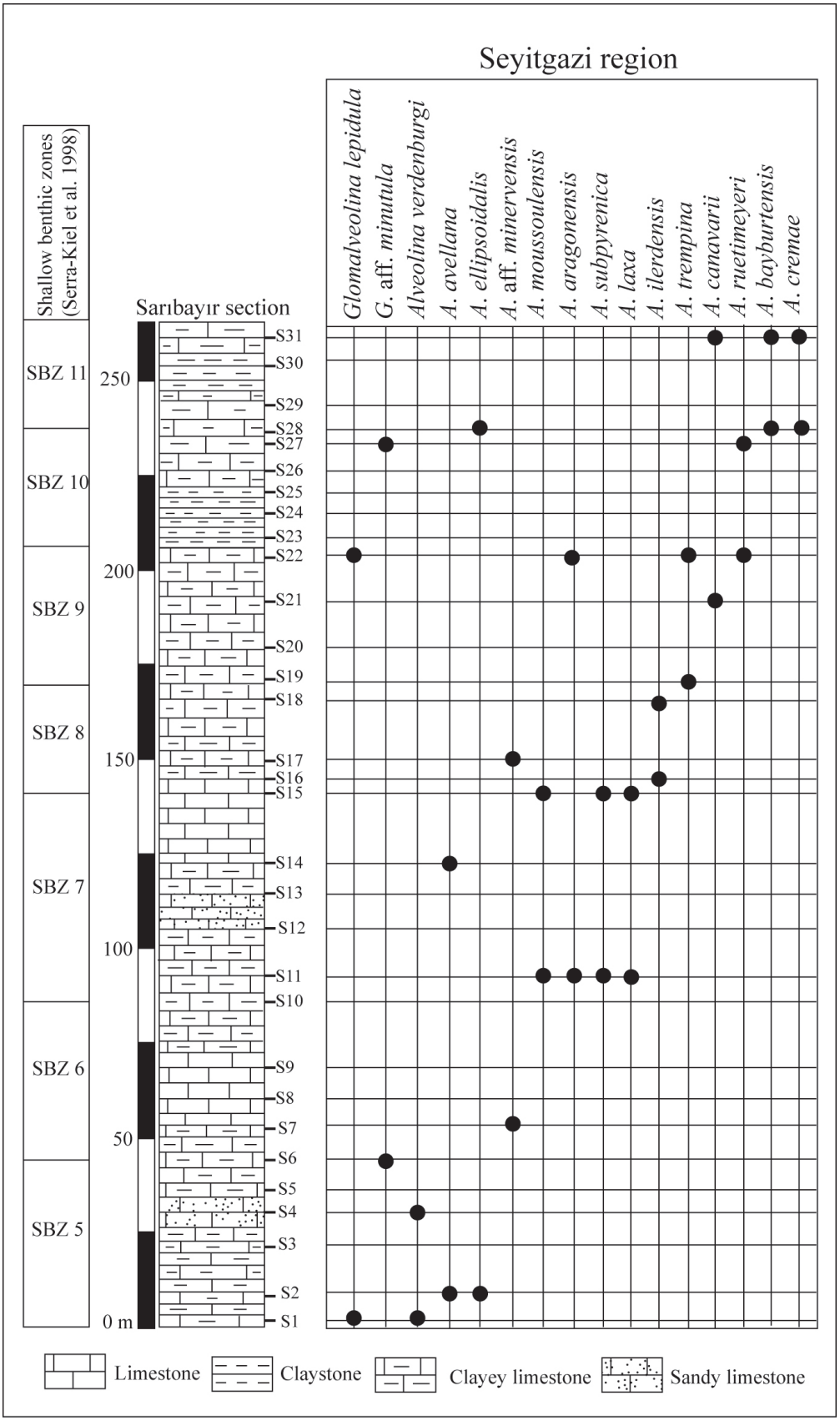
The Cholounak section (35°43'06"N; 58°58'59"E) is ~5-m-thick and situated 1 km south of Cholounak village, which is 20 km northeast of Kadkan and 60 km northwest of Torbat-e-Heydarieh. This unit is composed of bedded detrital limestones containing abundant early Eocene alveolinids (text-fig. 5).

Sarıbayır section

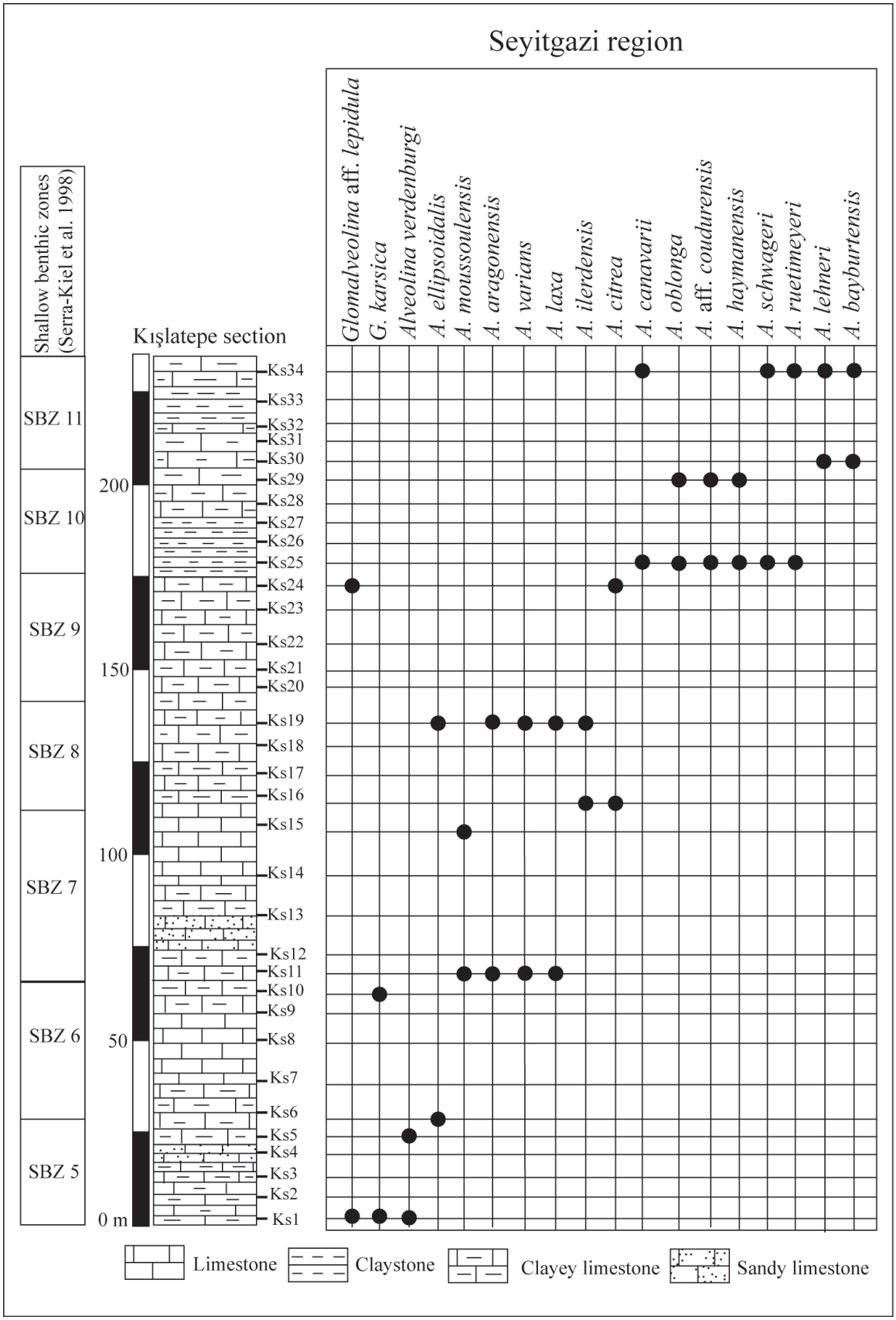
The Sarıbayır section (39°25'38" N; 30°37'05"E) is 260-m-thick and located ~2 km southwest of Sarıbayır village, which is southwest of Seyitgazi. It represents a continuous sequence from the early Ilerdian to middle Cuisian. The lower unit is composed of alternations of dark yellow to greenish sandy limestones, interbedded limestones and clayey limestones. The clayey limestone beds contain abundant, well preserved early Eocene *Alveolina* species. The upper unit is composed of an alternation of multicolored, sometimes reddish claystones and clayey limestones. The claystones and clayey limestones also include abundant, well preserved, and early Eocene *Alveolina* species (text-fig. 6).

Kıslatepe section

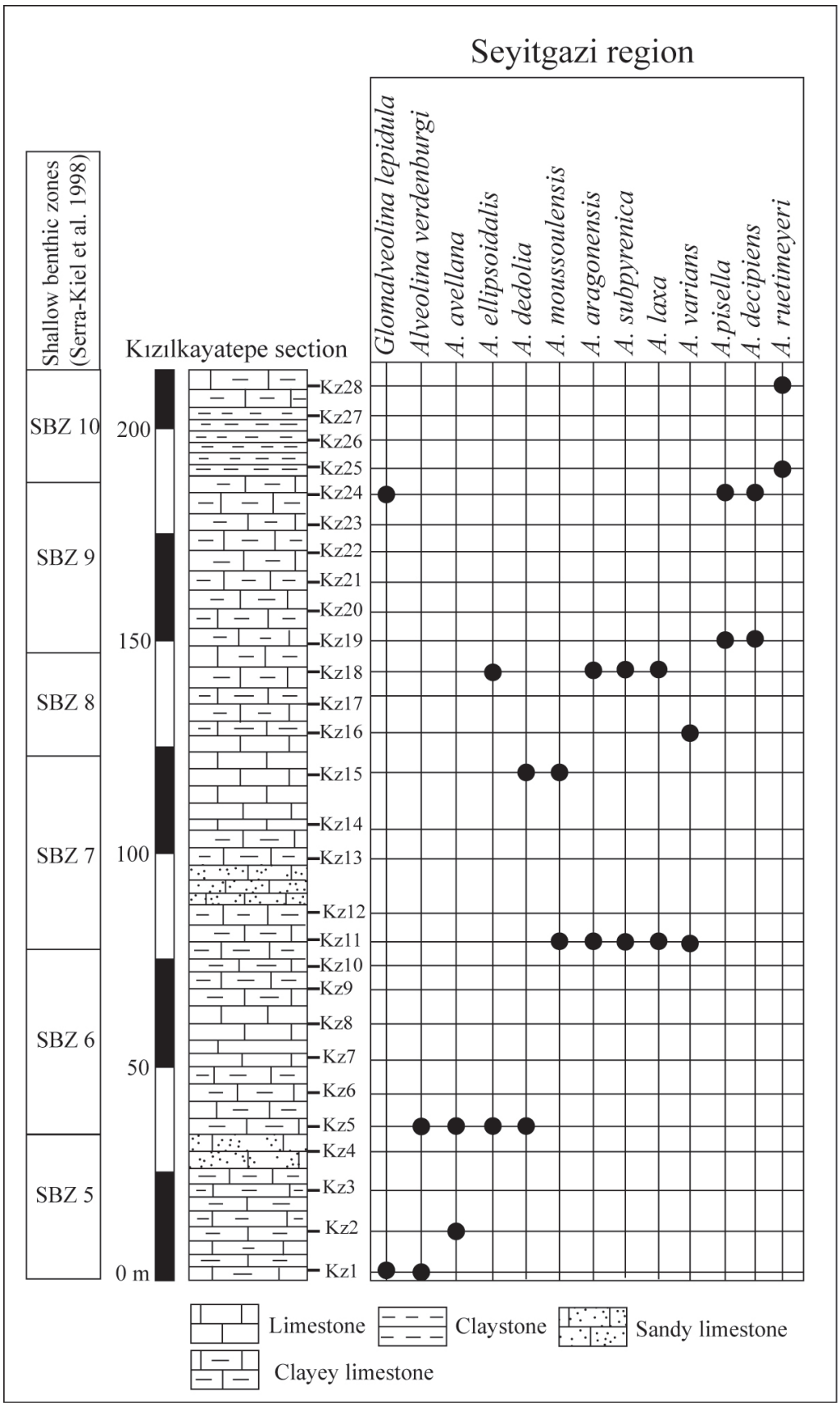
The Kıslatepe section (39°23'27"N; 30°35'58"E) is 235-m-thick and situated ~2 km west of Kiola village, which is southwest of Seyitgazi. The Kıslatepe section also represents a continuous sequence from the early Ilerdian to middle Cuisian (text-fig. 7). The lithological characteristics of the unit are similar to that of the Sarıbayır section (text-fig. 7).



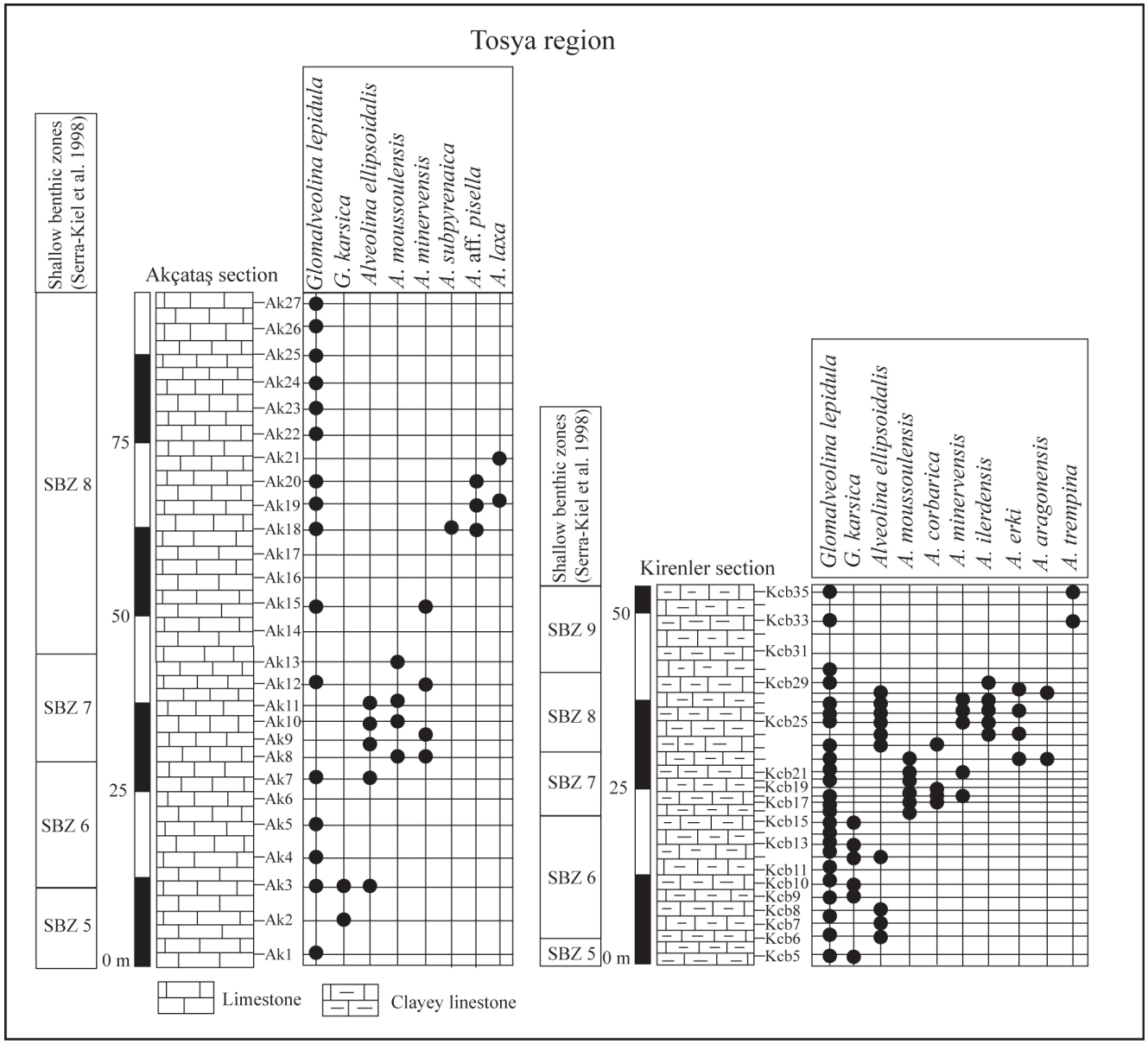
TEXT-FIGURE 6
Stratigraphic distributions of the *Alveolina* species in the Sarıbayır section, Seyitgazi region (Turkey).



TEXT-FIGURE 7
Stratigraphic distributions of the *Alveolina* species in the Kıslatepe section, Seyitgazi region (Turkey).



TEXT-FIGURE 8
Stratigraphic distributions of the *Alveolina* species in the Kızılkayatepe section, Seyitgazi region (Turkey).



TEXT-FIGURE 9
Stratigraphic distributions of the *Alveolina* species in the Akçataş and Kirenler sections, Tosya region (Turkey).

Kızılkayatepe section

The Kızılkayatepe section (39°14'10"N; 30°54'25"E) is 217-m-thick and measured ~4 km east of Iskankuyu village, which is southeast of Seyitgazi. The Kızılkayatepe section is a continuous sequence ranging from the early Eocene (text-fig. 8). The lithological characteristics of the unit are identical to the Sarıbayır section (text-fig. 8).

Akçataş section

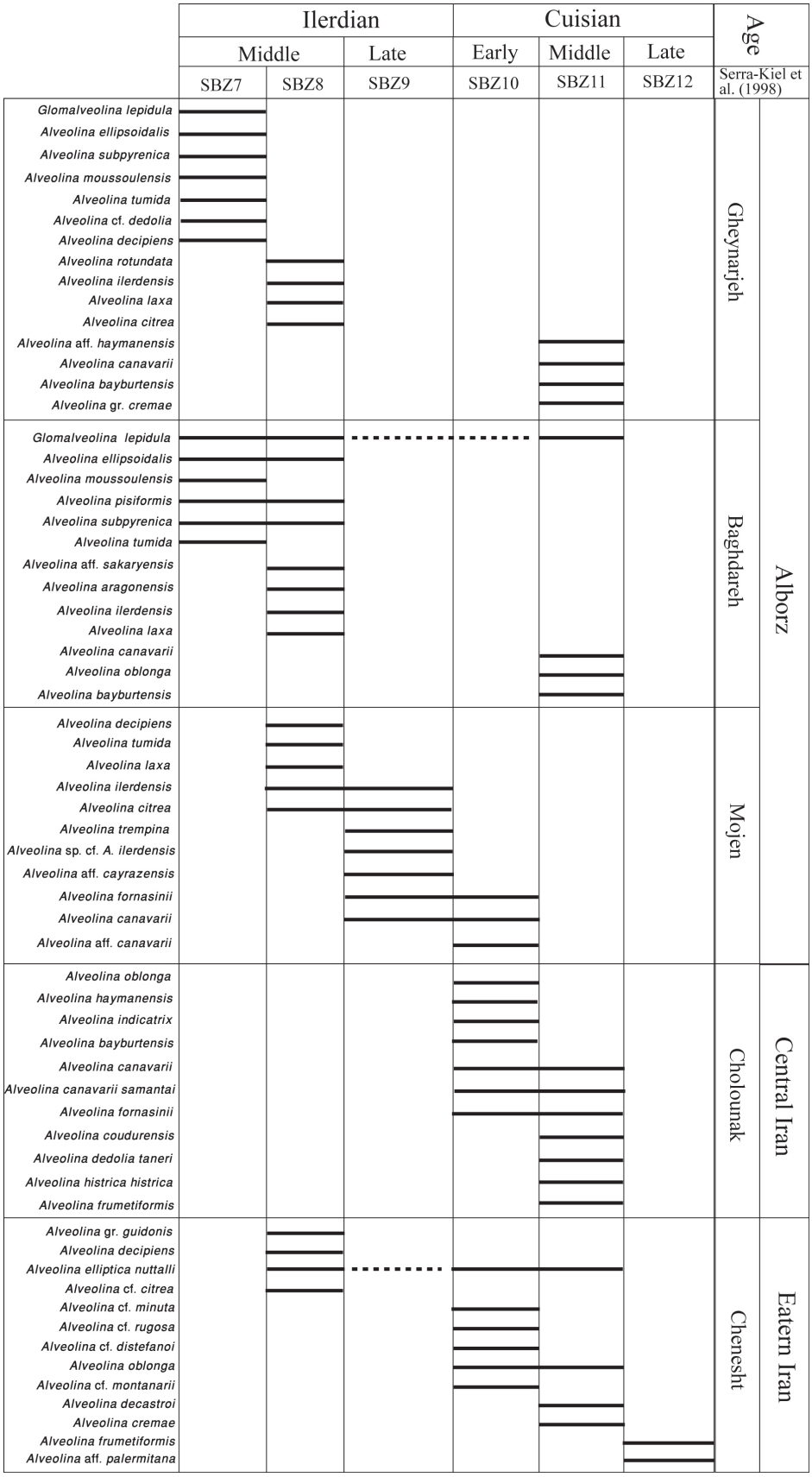
The Akçataş section (41°11'34"N; 34°00'42"E) is 90-m-thick and situated 10 km northwest of Tosya town, within the area of the Akçataş village. This section is mainly represented by limestones including abundant *Alveolina* and *Opertorbitolites* of early Eocene age (text-fig. 9). The lithology comprises gray variegated and thin-dense textured limestones.

Kirenler section

The Kirenler section (41°12'26"N; 34°01'34"E) is 52-m-thick situated 500 m southwest of Çibanköy village, which is ~15 km northwest of Tosya. This section is composed of gray-dark gray to yellowish and thin-bedded limestones with highly abundant, diversified and well-preserved early Eocene *Alveolina* species (text-fig. 9).

MATERIAL AND METHODS

The Ilerdian–Cuisian alveolinids were analyzed from ten sections in Iran and Turkey, including Baghdareh (59 thin-sections, Western Alborz region), Gheynarjeh (26 thin-sections, Western



TEXT-FIGURE 10
Stratigraphic distribution of the Ilerdian-Cuisian *Alveolina* from the Alborz, Central and Eastern Iran regions.

Alborz region), Mojen (68 thin-sections, Eastern Alborz region), Chenesht (20 thin-sections, Eastern Iran region), Cholounak (21 thin-sections, Central Iran region), Sarıbayır (31 thin-sections, Tavşanli region), Kıslatepe (34 thin-sections, Tavşanlı region), Kızılkayatepe (28 thin-sections, Tavşanli region), Akçataş (24 thin-sections, Tosya region) and Kirenler (31 thin-sections, Tosya region). 342 thin-sections were prepared and investigated from these sections. Also, some isolated *Alveolina* were obtained from the marl and clayey limestone beds. The thin-sections (6 cm × 10 cm, 2.5 cm × 7.5 cm, and 2.5 cm × 2.5 cm) were studied and digitally photographed under transmitted light (Olympus BX51 and Leica M125) and binocular microscopes (Nikon-SMZ1).

Shallow benthic zones (SBZs) were determined according to the *Alveolina* species ranges proposed by Serra-Kiel et al. (1998). The dataset is based on a compilation of published data of the authors (Özgen-Erdem et al. 2007, Özgen-Erdem 2008, Hadi and Vahidinia 2019, Hadi et al. 2015, 2019a, 2019b, 2019c), whereas the biostratigraphic ranges of some species are revised in this study. The taxonomic framework of alveolinids was mainly based on the works of Hottinger (1960, 1974), Sirel (1976a, 1976b, 1998), Sirel and Gündüz (1976), Drobne (1977), Drobne and Trutin (1997) and Sirel and Acar (2008). Specimens are deposited in the Nazire collection at Cumhuriyet University, Faculty of Engineering, Department of Geological Engineering, Sivas (Turkey) and Mehdi collection at Ferdowsi University of Mashhad (Iran).

BIOSTRATIGRAPHY BASED ON ALVEOLINA ASSEMBLAGES

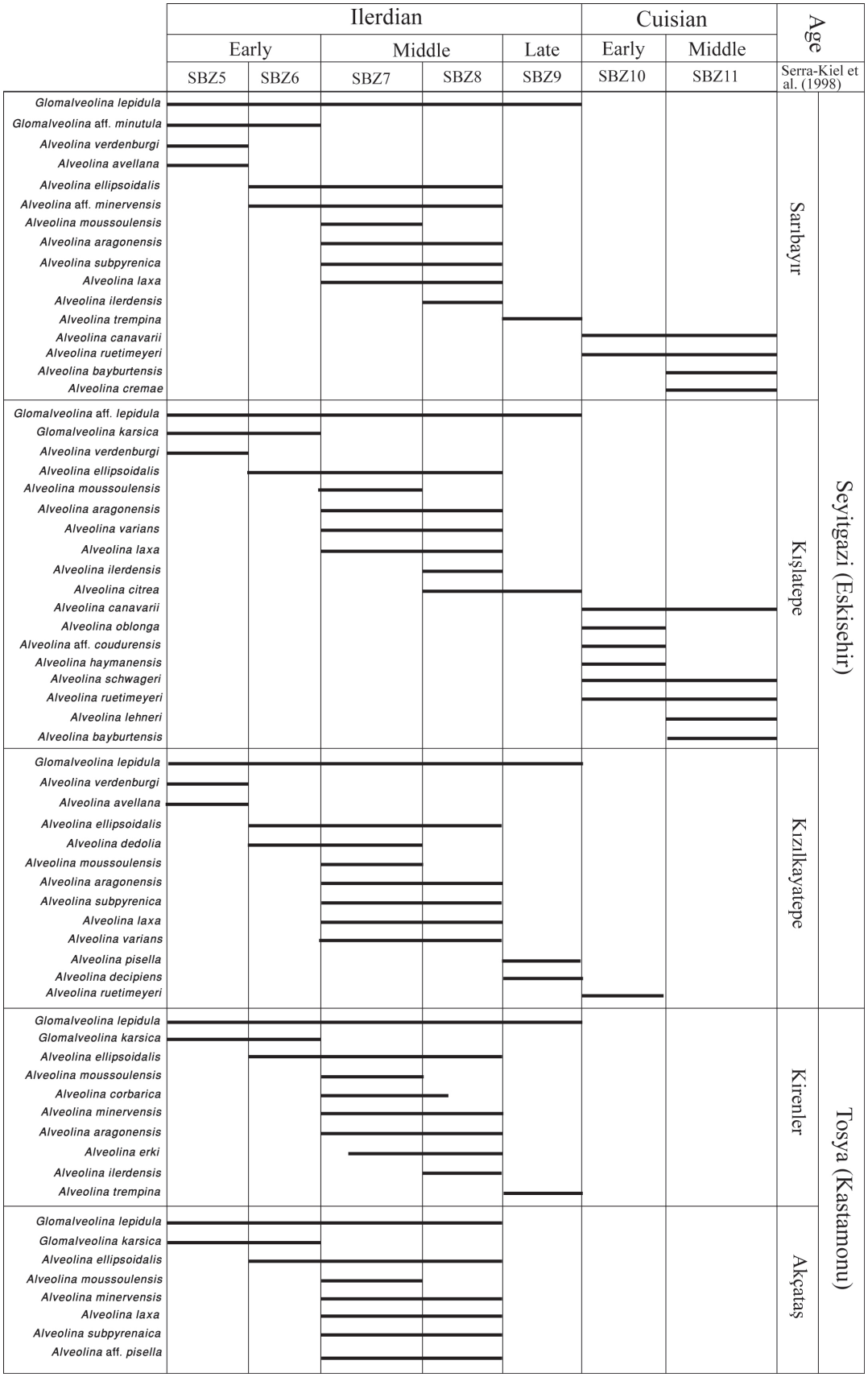
This study presents the Ilerdian-Cuisian biozones SBZ5-SBZ12 based on alveolinid assemblages of the Iran and Turkey basins (text-figs. 10 and 11, plates 1-3). The biostratigraphic data obtained from the alveolinids have been directly correlated with the SBZs from the Mediterranean (western Tethyan province) proposed by Serra-Kiel et al. (1998). On the other hand, Serra-Kiel et al. (1998) erected their biozones on the basis of different groups of larger benthic foraminifera, especially extensive works of Hottinger (1960, 1974) and Drobne (1977). In the last years, some authors (e.g., Özgen-Erdem et al. 2007; Acar and Sirel 2008; Hadi et al. 2019a, 2019b) also recorded the presence of alveolinid associations in older and/or younger strata in comparison to the SBZs of the Tethys. However, the biostratigraphic range of alveolinids in the aforementioned studies is chiefly based on the SBZs from the western Tethys, but the coexistence of some key taxa are tentatively indicative of a minor difference between Iran-Turkey and European (e.g., Pyrenean basin, France, Spain) sediments. However, these data have not been integrated to the nummulitid and/or planktonic groups zonation in a standard yet. Biostratigraphically, eight alveolinid assemblages are identified and explained as follows:

Early Ilerdian (SBZ5-SBZ6)

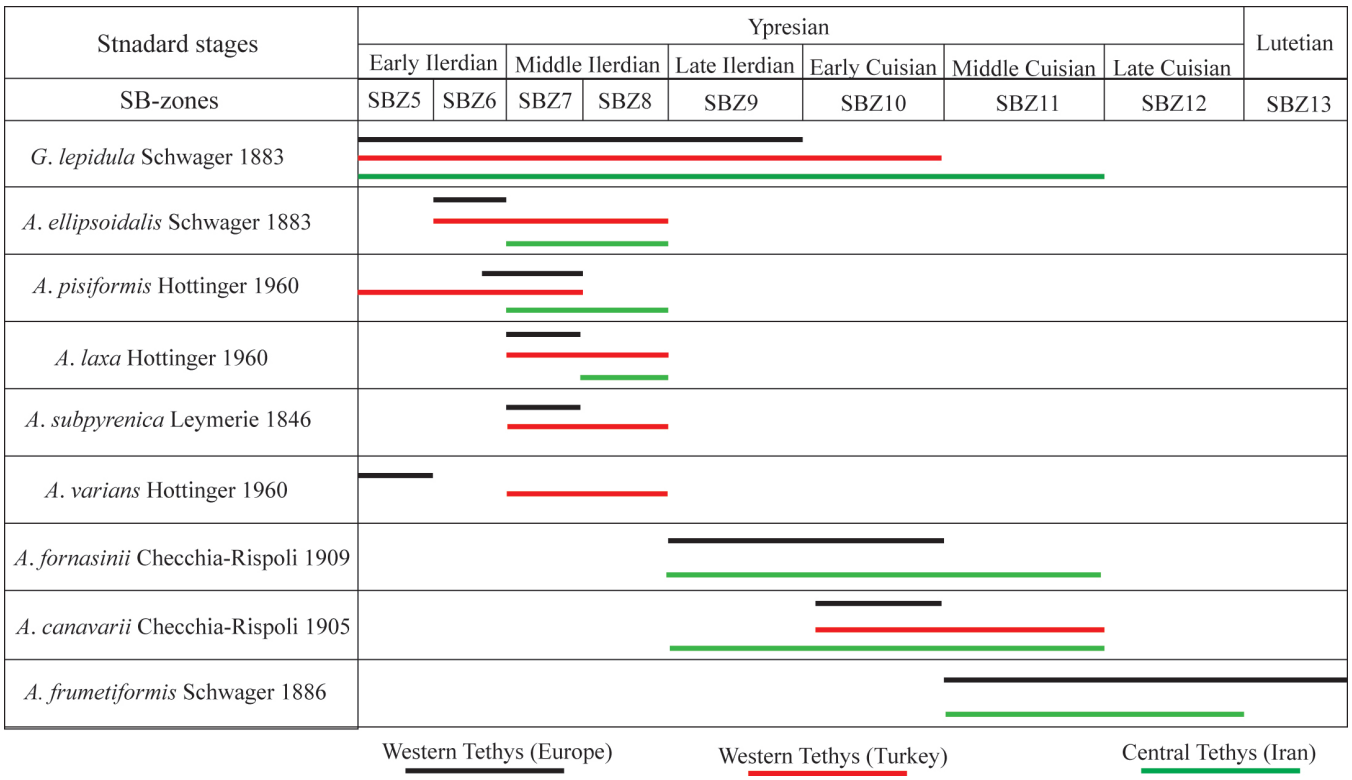
The base of SBZ5 is defined by the first appearance of index zonal marker *A. vredenburgi* in three studied sections (Sarıbayır, Kıslatepe and Kızılkayatepe) from the southern Eskişehir region and by the first appearance of *Glomalveolina lepidula* and *G. karsica* from the southern Kastamonu region in Turkey. Additionally, the co-occurrences of other alveolinid species such as *G. lepidula* and *G.* aff. *minutula* in the Sarıbayır section; *G. lepidula* and *G. karsica* in the Kıslatepe section and *G. lepidula* with *A. avellana* in the Kızılkayatepe section are recognized in this interval. The SBZ5/SBZ6 boundary is marked by the last occurrence of *A. vredenburgi,* which is associated with the first occurrence *A. ellipsoidalis* and *A.* aff. *minervensis*, as well as the upper boundary of this interval is represented by *A. moussoulensis*, *A. aragonensis, A. subpyrenaica* and *A. laxa* in the Sarıbayır section. In the Kıslatepe section, the base of SBZ6 is marked by the last appearance of *A. vredenburgi* and the first appearance of *A. ellipsoidalis*. In addition, the upper boundary of SBZ6 is subsequently defined by first occurrences of *A. moussoulensis*, *A. aragonensis, A. varians* and *A. laxa* and by the last occurrence of *G. karsica* in this section. In the Kızılkayatepe section, the SBZ5/SBZ6 boundary coincides with the last occurrence of *A. vredenburgi* and the first occurrence of *A. ellipsoidalis* and *A. dedolia*. The upper boundary of SBZ6 is represented by the first occurrence of *A. moussoulensis*, *A. aragonensis, A. subpyrenaica, A. laxa* and *A. varians* in this section. In the Kirenler and Akçataş sections, the base and the top of SBZ6 is defined by the first occurrence of *A. ellipsoidalis* and *A. moussoulensis* respectively. In the meantime, it was observed that the biostratigraphic range of *A. ellipsoidalis* started from the late early Ilerdian (SBZ6). The alveolinid assemblage in the early Ilerdian consists of *G. lepidula*, *G.* aff. *minutula*, *A. vredenburgi*, *A. ellipsoidalis*, *A. avellana* and *A.* aff. *minervensis* in the Sarıbayır section; *G .lepidula*, *G. karsica, A. vredenburgi* and *A. ellipsoidalis* in the Kıslatepe section; *A. vredenburgi, A. avellana A. ellipsoidalis* and *A. dedolia* in the Kızılkayatepe section; *G. lepidula*, *G. karsica, A. ellipsoidalis* in the Kirenler and Akçataş sections. This is of great importance because so far no alveolinid data have been assigned to the early Ilerdian age at the stratigraphic levels in the Alborz, central, and eastern Iran basins.

Middle Ilerdian (SBZ7–SBZ8)

The lower part of the middle Ilerdian (SBZ7) has been found in the two studied (Gheynarjeh and Baghdareh) sections. The base of SBZ7 is defined by the occurrence of two index species *A. moussoulensis* and *A. subpyrenaica* while the upper boundary of this interval is marked by the last occurrence of *A. moussoulensis* and *A. tumida.* In addition, the SBZ7 is defined by the first and the last occurrence of *A. moussoulensis* in the Sarıbayır, Kıslatepe, Kızılkayatepe, Kirenler and Akçataş sections. Besides, the lower boundary of SBZ7 is represented by the last occurrence of *G. karsica* in these sections from Turkey, except from the Sarıbayır and Kızılkayatepe sections. Meanwhile, this boundary is recognized by the first occurrence of *A. aragonensis* and *A. laxa* in the Sarıbayır, Kıslatepe, Kızılkayatepe sections, *A. aragonensis, A. corbarica, A. minervensis* in the Kirenler section, and *A. minervensis, A. subpyrenaica* and *A. laxa* in the Akçataş section. The base of SBZ8 is defined by last occurrence of *A. moussoulensis* and *A. tumida* and a little later the appearance of *A. ilerdensis* and *A. rotundata* in the Gheynarjeh section, while *A. ilerdensis* was not observed in the Baghdareh section. The upper boundary of SBZ8 is represented by the last occurrences of *G. lepidula*, *A. ellipsoidalis*, *A. laxa*, *A. rotundata*, and *A. ilerdensis* in the Gheynarjeh section, and *A. laxa*, *A. rotundata* and *A. citrea* in the Baghdareh section. In the Chenesht section, the lower and upper boundaries of SBZ8 are represented by the presence of *A. decipiens, A.* gr. *guidonis*, *A.* cf. *rugosa* and *A.* cf. *minuta, A. elliptica nuttalli* and *A.* cf. *citrea* assemblages. However, the lack of index zonal markers of *Alveolina* does not permit a high-resolution estimation in recognizing this interval. The base of SBZ8 is defined by the first appearance of *A. decipiens*, *A. tumida*, *A. ilerdensis* in association with *A. laxa* and *A. citrea*, while the upper boundary of this in-



TEXT-FIGURE 11
Stratigraphic distribution of the Ilerdian-Cuisian *Alveolina* from the Seyitgazi (Eskişehir) and Tosya (Kastamonu) regions.



TEXT-FIGURE 12
Stratigraphic distribution of the Eocene *Alveolina* from the western and central Tethys regions.

terval nearly coincides with the first occurrence of *A. trempina* and a little later the last occurrence of *A. ilerdensis* and *A. citrea* in the Mojen section. In the Sarıbayır, Kıslatepe and Kirenler sections, the SBZ8 is marked by the first and the last occurrence of *A. ilerdensis*, whereas the lower boundary of this interval is assigned to last appearance of *A. moussoulensis* in the Kızılkayatepe and Akçataş ections. The upper boundary of SBZ8 is recognized by the last occurrence of *A. ellipsoidalis, A. subpyrenaica, A. aragonensis, A. laxa, A. varians* and the first appearance of *A. pisella* and *A. decipiens* in the Kızılkayatepe section and by the last occurrence of *A. ellipsoidalis, A. subpyrenaica, A. minervensis, A. laxa* and *A.* aff. *pisella* in the Akçataş section.

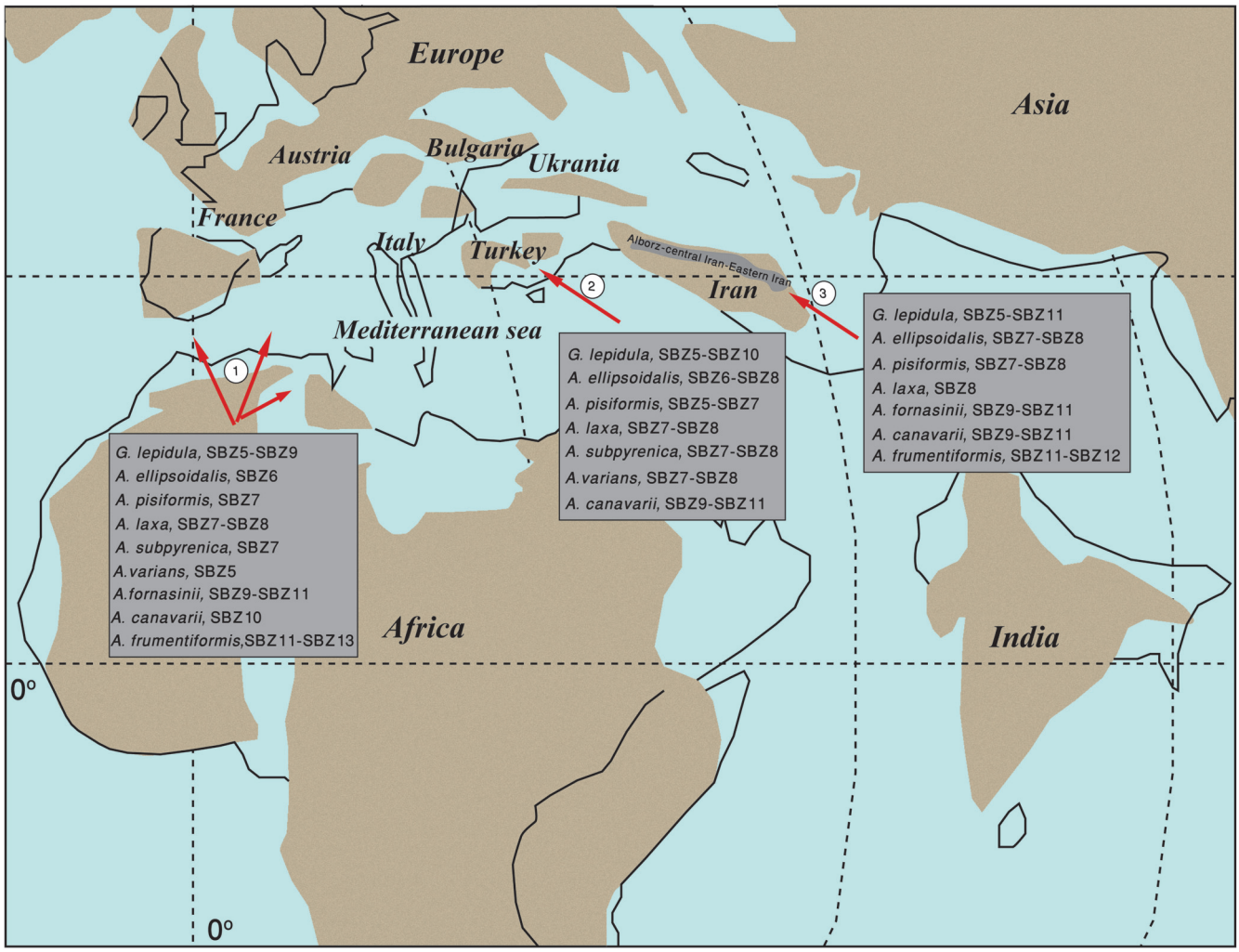
The *Alveolina* assemblages in the middle Ilerdian consists of *G. lepidula*, *A. ellipsoidalis*, *A. moussoulensis*, *A. subpyrenaica*, *A. pisiformis*, *A. tumida*, *A. decipiens*, *A. rotundata*, *A. laxa*, *A. ilerdensis*, *A. aragonensis*, and *A.* aff. *sakaryaensis*, in both sections (Gheynarjeh and Baghdareh), with the exception that *A. citrea* is only observed in the Gheynarjeh section, while the *Alveolina* assemblages of the Chenesht section include *A. decipiens*, *A.* gr. *guidonis*, *A. elliptica nuttalli* and *A.* cf. *citrea*. In the Mojen section, the *Alveolina* species comprise *A. decipiens*, *A. ilerdensis*, *A. tumida*, *A. laxa* and *A. citrea* only in the upper part of the middle Ilerdian. In the Sarıbayır and Kıslatepe sections, the middle Ilerdian is characterized by *G. lepidula*, *A. ellipsoidalis*, *A. minervensis, A. moussoulensis, A. aragonensis, A. subpyrenaica, A. laxa*, *A. ilerdensis* and by *G. lepidula*, *A. ilerdensis*, *A. ellipsoidalis*, *A. moussoulensis, A. aragonensis, A. laxa, A. varians, and A. citrea*. The presence of *G. lepidula, A. ellipsoidalis*, *A. moussoulensis, A. aragonensis, A. subpyrenaica, A. laxa, A. varians* and *A. dedolia* in the Kızılkayatepe section; *G. lepidula*, *A. ellipsoidalis*, *A. minervensis, A. moussoulensis, A. aragonensis, A. corbarica, A. erki, A. ilerdensis* in the Kirenler section; and *G. lepidula*, *A. ellipsoidalis*, *A. minervensis, A. moussoulensis, A. laxa, A. subpyrenaica and A.* aff. *pisella* in the Akçataş section are indicative of the middle Ilerdian.

Late Ilerdian (SBZ9)

The boundaries of the late Ilerdian (SBZ9) are marked by the first and the last occurrence of *A. trempina* in the Mojen, Sarıbayır and Kirenler sections. The upper boundary of SBZ9 is defined by the last appearance of *A. citrea* in the Kıslatepe section. In the Kızılkayatepe section, the appearance of two index *Alveolina* species including *A. pisella* and *A. decipiens* are representative of this interval. The *Alveolina* assemblage in the late Ilerdian consists of *A. ilerdensis*, *A. citrea*, *A.* sp. cf. *A. ilerdensis*, *A.* aff. *cayrazensis*, *A. trempina*, *A. fornasinii*, and *A. canavarii* in the Mojen section; *G. lepidula* and *A. trempina* in the Sarıbayır and Kirenler sections; *G. lepidula* and *A. citrea* in the Kıslatepe section, and *G. lepidula*, *A. pisella* and *A. decipiens* in the Kızılkayatepe section.

Early Cuisian (SBZ10)

The early Cuisian (SBZ10) was not observed in the Gheynarjeh and Baghdareh sections. In the Chenesht section, the lower and upper boundaries are represented by the first and last appearances of *A.* cf. *minuta* and *A. oblonga*, respectively. A little later the upper boundary of this interval is recognized with the first



TEXT-FIGURE 13
Geographical distribution of *Alveolina* in the Ilerdian-Cuisian stages from the western and partly of central Tethys. (1) western Tethyan (N Spain, S France, Italy, Sicily, Greece, Pyrenean basin and Adriatic carbonate platform; Hottinger 1960; Hottinger 1974; Drobne 1977; Hottinger and Drobne 1980; Vecchio et al. 2007; Drobne et al. 2011; Papazzoni et al. 2017). (2) western Tethyan (Turkey; Sirel 1976a, 1976b, 1998; Sirel and Gündüz 1976; Özgen-Erdem et al. 2007; Özgen-Erdem 2008, Sirel and Acar 2008). (3) central Tethyan (Iran, Rahaghi 1978, 1980, 1983; Hadi and Vahidinia 2019; Hadi et al. 2019a, 2019b, 2019c). Simplified palaeogeographic reconstruction of the Mediterranean realm in early Eocene is redrawn from Smith, Smith, and Funnell (1994) and Ozcan et al. (2015).

appearance of *A. decastroi*. The variable stratigraphic range of *A. canavarii* and *A. fornasinii* in association with *A.* cf. *canavarii* with the lack of zonal markers do not allow to reliable determination of this interval in the Mojen section, although the lower boundary is defined by the last occurrence of *A. trempina*. In the Cholounak section, the base of SBZ10 is defined by the first appearance of *A. oblonga* in association with *A. bayburtensis*, *A. haymanensis*, *A. indicatrix*, and *A. canavarii*, while the upper boundary is recognized by the first occurrence of *A. coudurensis*. In the Sarıbayır section, the lower boundary of this interval is defined by the first occurrence of *A. canavarii* and *A. ruetimeyeri* and the last occurrences of *G. lepidula* and *A. trempina* as well as the upper boundary is marked by the first appearance of *A. bayburtensis* and *A. cremae*. The lower and upper boundaries of this interval are defined by the first and the last appearance of *A. oblonga* along with *A. haymanensis* and *A.* aff. *coudurensis* in the Kıslatepe section. Also, SBZ10 is defined by the first occurrence of *A. ruetimeyeri* and the last appearances of *A. pisella* and *A. decipiens* in the Kızılkayatepe section.

In this interval, the *Alveolina* assemblages consist of *A.* cf. *minuta*, *A. oblonga*, *A.* cf. *rugosa*, *A. elliptica nuttalli*, *A.* cf. *distefanoi*, *A.* cf. *montanarii* in the Chenesht section; *A. oblonga*, *A. bayburtensis*, *A. haymanensis*, *A. indicatrix*, *A. canavarii*, *A. canavarii samantai*, and *A. fornasinii* in the Cholounak section; *A. canavarii* and *A. ruetimeyeri* in the Sarıbayır section; *A. oblonga*, *A.* aff. *coudurensis*, *A. haymanensis*, *A. schwageri*, *A. canavarii* and *A. ruetimeyeri* in the Kıslatepe section; *A. ruetimeyeri* in the Kızılkayatepe section.

Middle Cuisian (SBZ11)

The lower boundary of the middle Cuisian (SBZ11) is marked by the first appearances of *A. canavarii*, *A. bayburtensis* and *A.*

aff. *haymanensis* in the Gheynarjeh section, and *A*. *canavarii, A. oblonga* and *A*. *bayburtensis* in the Baghdareh section. In the Chenesht section the first occurrences of *A*. *decastroi*, *A*. *cremae* and last occurrence of *A*. *oblonga* and *A*. cf. *minuta* define the lower boundary of this interval. Also, the upper boundary is defined based on the last appearance of *A*. *canavarii* in the Baghdareh and Gheynarjeh sections. In the Chenesht section, the upper boundary of this interval is defined by first occurrences of *A*. *frumentiformis* and *A*. aff. *palermitana*. In the Cholounak section, the base of SBZ11 is represented by the first occurrence of *A*. *coudurensis* in association with *A*. *canavarii samantai*, *A*. *fornasinii*, *A*. *dedolia taneri*, *A*. *histrica histrica* and *A*. *frumentiformis*. This interval is defined by the first and the last occurrence of *A*. *cremae* and *A. bayburtensis* in the Sarıbayır section. The lower and upper boundaries of this interval are marked by the first and the last appearance of *A. lehneri* and *A. bayburtensis* respectively, in the Kıslatepe section. In addition, the upper boundary of this interval is recognized by the last occurrences of *A. canavarii* and *A. ruetimeyeri* in the Sarıbayır and Kıslatepe sections. The *Alveolina* assemblages include *A*. *canavarii* and *A*. *bayburtensis* in the Gheynarjeh section; *A*. *canavarii*, *A.* aff. *haymanensis*, and *A*. gr. *cremae* in the Baghdareh section; *A*. *decastroi, A. cremae* in the Chenesht section; *A. bayburtensis*, *A. cremae*, *A. canavarii* and *A. ruetimeyeri* in the Sarıbayır section and *A. bayburtensis*, *A. lehneri*, *A. canavarii, A. schwageri* and *A. ruetimeyeri* in the Kıslatepe section.

Late Cuisian (SBZ12)

This interval was only observed in the Chenesht section so that the last occurrences of *A*. *decastroi* and *A*. *cremae* and the first occurrences of *A*. *frumentiformis* and *A*. aff. *palermitana* indicated the boundary between SBZ11 and SBZ12. The *Alveolina* assemblages of this interval are dominated by two species *A*. *frumentiformis* and *A*. aff. *palermitana.* This might need some justification but on basis of simultaneous occurrence of other taxa such as *Nummulites polygyratus*, *N*. cf. *campesinus*, *N*. cf. *praelorioli*, *Asterocyclina* cf. *schweighauseri*, *Discocyclina archiaci* cf. *staroseliensis* and *D*. cf. *archiaci bartholomei* (Schlumberger) SBZ12 could be deciphered.

DISCUSSION AND CONCLUSIONS

Detailed studies on the biostratigraphic assessments of the alveolinids during the Ilerdian-Cuisian (SBZ5-SBZ12) show a relative affinity between Iranian and Turkish fauna, for example, Hadi and Vahidinina (2019) and Hadi et al. (2019c) noted that the stratigraphic distribution of some species such as *A*. *ellipsoidalis*, *A*. *pisiformis*, *A*. *laxa*, *A*. *canavarii, A. bayburtensis* and *A*. *dedolia taneri* are more consistent with coeval fauna on the Turkish platform (see Özgen-Erdem et al. 2007, Sirel and Acar 2008) when compared with the western Mediterranean regions (e.g., PgAdCP, Paris basin, Spain, France and Italy; Serra-Kiel et al. 1998). However, some of them have been considered as cosmopolitan species (*A*. *ellipsoidalis*, *A*. *pisiformis*, *A*. *laxa*, *A*. *canavarii*) (see Drobne et al. 2011). Additionally, we consider other species, including *A*. *bayburtensis*, *A*. aff. *sakaryensis*, *A*. aff. *haymanensis*, *A*. *dedolia taneri* and *A*. aff. *cayrazensis* endemic to Iran and Turkey. Likewise, some key cosmopolitan species (e.g., *A*. *ellipsoidalis*, *A*. *subpyrenica*, *A*. *frumentiformis*) were found in younger and/or older stratigraphic levels in this time interval, while they were mainly known as index zonal markers from the western Tethys (i.e., *Alveolina* zones; Hottinger 1960; Serra-Kiel et al. 1998). Additionally, the most comprehensive work from Turkey on the Paleocene–Eocene *Alveolina* assemblages (Sirel and Acar 2008) provides reliable data based on their biostratigraphy and distribution that were determined according to the SBZs of Serra-Kiel et al. (1998). They showed that the alveolinid associ-

PLATE 1

Axial sections of key *Alveolina* species from the Iran and Turkey basins in this study.

SBZ5-SBZ6

1 *Alveolina vredenburgi* Davies and Pinfold, Kıslatepe section (Ks4).

2 *A*. *dedolia* Drobne, Kızılkayatepe section (Kz10).

3 *A*. *avellana* Hottinger, Kızılkayatepe section (Kz6).

4 *A*. *ellipsoidalis* Schwager, Gheynarjeh section (B4-5).

SBZ7-SBZ8

5 *A*. *mousoulensis* Hottinger, Gheynarjeh section (G5-3).

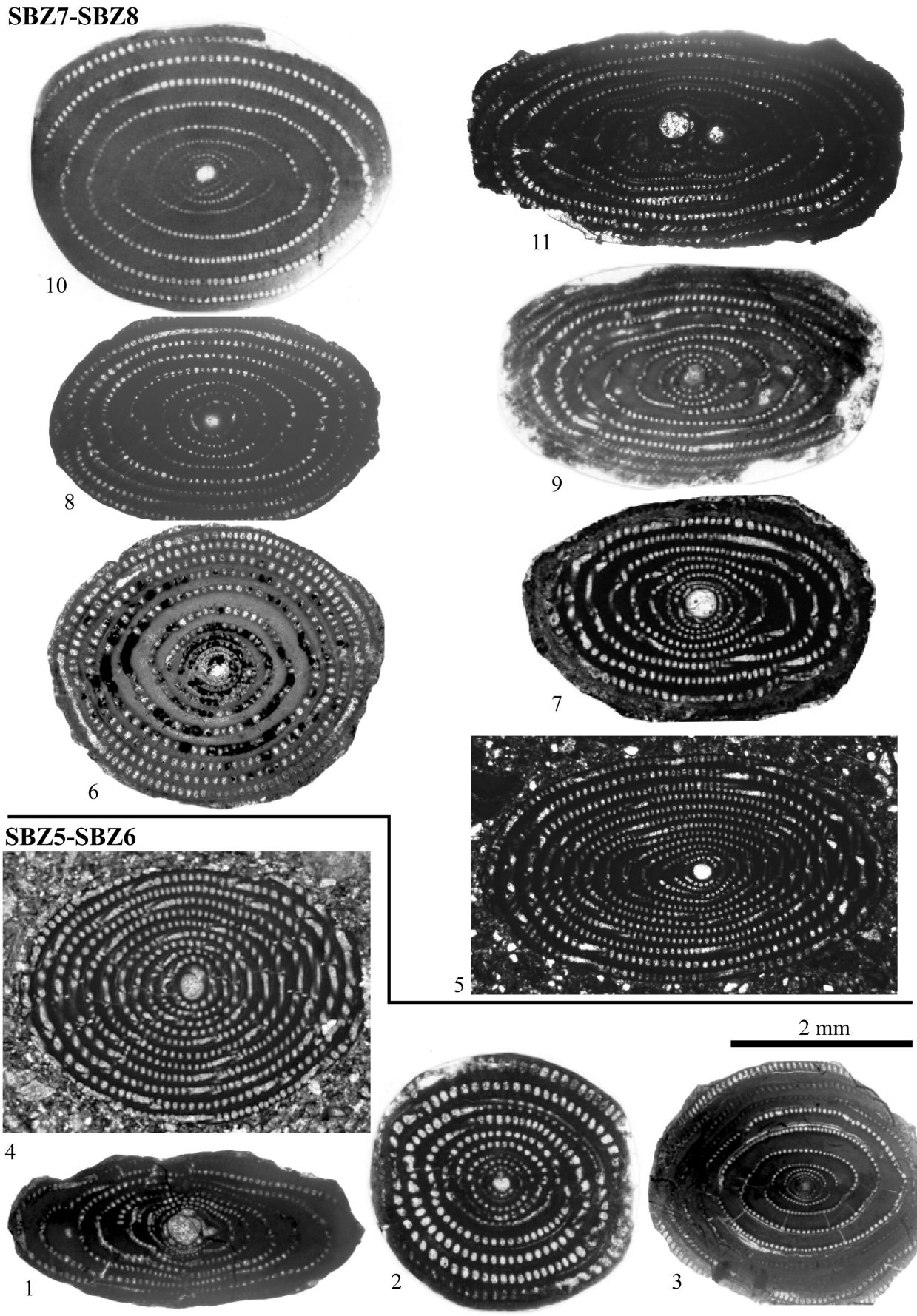
6 *A*. *aragonensis* Hottinger, Kirenler section (Nçb33).

7 *A*. *subpyrenaica* Leymerie, Baghdareh section (BR32-6).

8 *A. citrea* Drobne, Mojen section (A30).

9 *A. decipiens* Schwager, Kızılkayatepe section (Kz.23).

10 *A. laxa* Hottinger, Kızılkayatepe section (Kz.12). *A. ilerdensis* Hottinger, Mojen section (A14).


SBZ7-SBZ8
10
11
8
9
6
7
SBZ5-SBZ6
5
2 mm
4
1
2
3

ation is very diverse along the different stratigraphic ranges in comparison to the coeval faunas of western areas from the Mediterranean Tethys. More details pertaining to the biostratigraphic range distribution of some *Alveolina* species suggest a migration pathway into Tethys throughout the Alpine-Himalayan belt. It seems that the alveolinid assemblages sometimes appeared in younger strata from Iran and Turkey in comparison to similar associations of the western Tethyan basins. The biostratigraphical analysis of *Glomalveolina lepidula* indicates a distribution range of the early Ilerdian to late Ilerdian (SBZ5-SBZ9) from the more western parts of the Mediterranean realm (Serra-Kiel et al. 1998), whereas Sirel and Acar (2008) and Hadi et al. (2019c) showed the latest occurrence of this species from SBZ9 and SBZ10 in Turkey and Iran, respectively (text-fig. 12). The species *A. ellipsoidalis* represents the SBZ6 in the western parts of Tethyan region (Serra-Kiel et al. 1998; Drobne et al. 2011), while the occurrence of this species was reported from SBZ6–SBZ8 in Turkey (e.g., Özgen-Erdem et al. 2007, Sirel and Acar 2008) and SBZ7–SBZ8 in Iran (Hadi et al. 2019c) (text-fig. 12). *A. pisiformis* represents SBZ6–SBZ7 in the western Tethyan region (Serra-Kiel et al. 1998), whereas Sirel and Acar (2008) and Hadi et al. (2019c) reported this species from SBZ5–SBZ7 and SBZ7–SBZ8 in Turkey and Iran respectively (text-fig. 12). *A. laxa* represents SBZ7 in the western Tethys (Serra-Kiel et al. 1998; Drobne et al. 2011), but the species was recognized in SBZ7–SBZ8 within the easternmost part of the Mediterranean region by Sirel and Acar (2008) (text-fig. 12). In Iran, *A. laxa* was recorded in SBZ8 from the Alborz zone (Hadi et al. 2019b-c) (text-fig. 12). *A. subpyrenica* as a typical species was reported from SBZ7 in the western Tethyan region (Serra-Kiel et al. 1998; Drobne et al. 2011), while this species was also referred to SBZ8 in Turkey (for details see Özgen-Erdem et al. 2007; Sirel and Acar 2008) (text-fig. 12). *A. varians* was reported from SBZ5 of the westernmost part of the Tethyan region (Serra-Kiel et al. 1998), while they were found throughout the Middle Ilerdian (SBZ7–SBZ8) in Turkey (see Özgen-Erdem et al. 2007; Sirel and Acar 2008) (text-fig. 12). *A. fornasinii* represents SBZ9–SBZ10 in the western Tethyan region (Serra-Kiel et al. 1998; Drobne et al. 2011) (text-fig. 12). This species is found in younger stratigraphic levels (SBZ9–SBZ11) from the Alborz and central Iran regions of the central Tethys (see Hadi and Vahidinina 2019; Hadi et al. 2019c) (text-fig. 12). *A. canavarii* was considered to be representative of SBZ10 (see Serra-Kiel et al. 1998; Drobne et al. 2011), whereas the occurrence of this species was shown in the younger stratigraphic levels (SBZ10–SBZ11) by Özgen-Erdem et al. (2007), and Sirel and Acar (2008) in Turkey (text-fig. 12). In the central Tethys, Hadi et al. (2019c) reported the range of *A. canavarii* to span SBZ9–SBZ11 (text-fig. 12). The biostratigraphic range of *A. frumentiformis* was reported in SBZ12–SBZ13 (Serra-Kiel et al. 1998) while in a recent report (Papazzoni et al. 2017) it is ascribed to SBZ11 in Italy. In Iran, the occurrence of this species was reported from SBZ11 and SBZ12 (Hadi and Vahidinia 2019; Hadi et al. 2019c) (text-fig. 12).

According to all the above-mentioned explanations, with emphasis on the distribution and expansion of the alveolinids that were controlled by similar environmental conditions, therefore, establish evidence of a close marine connection between the Iranian and Turkish basins by a seaway during the Ilerdian–Cuisian (text-fig. 13), and this also suggests a migra-

PLATE 2

Axial sections of key *Alveolina* species from the Iran and Turkey basins in this study.

SBZ7-SBZ8

1 *A. corbarica* Hottinger, Kirenler section (Nçb17).

2 *A. rotundata* Hottinger, Baghdareh section (BR19).

SBZ9

3 *A. trempina* Hottinger, Sarıbayır section (S20).

4 *A. fornasinii* Checchia-Rispoli, Cholounak section (ch3-4).

5 *A. pisella* Drobne, Kızılkayatepe section (Kz.23).

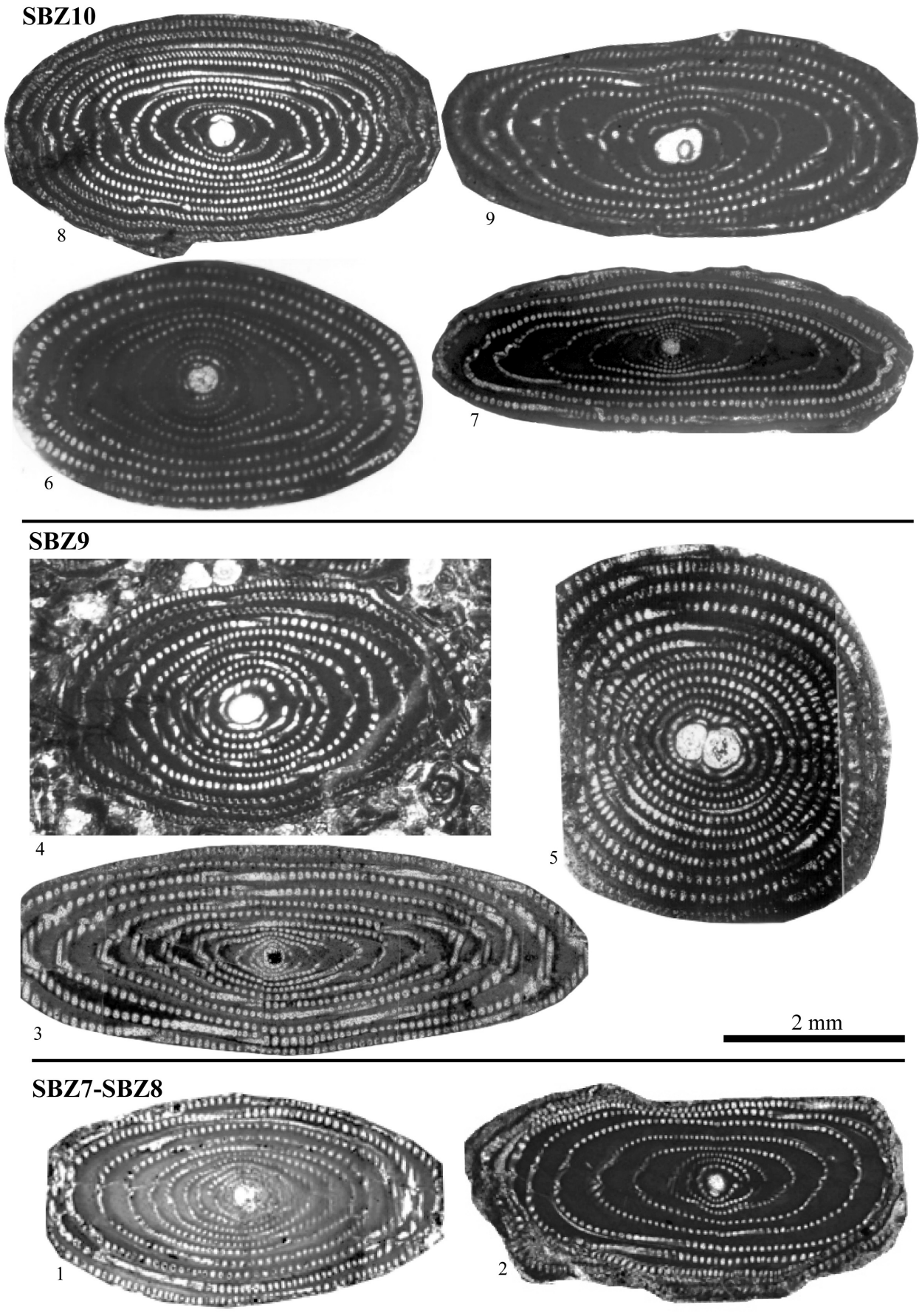
SBZ10:

6 *A. schwageri* Checchia-Rispoli, Kıslatepe section (Ks25).

7 *A. ruetimeyeri* Hottinger, Sarıbayır section (S23).

8 *A. oblonga* d'Orbigny, Cholounak section (ch1-2).

9 *A. canavarii* Checchia-Rispoli, Cholounak section (ch1-2).


SBZ10
8
9
6
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SBZ9
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2 mm
SBZ7-SBZ8
1
2

tion pathway from the western to the central Tethys. However, the early Ilerdian (SBZ5–SBZ6) shallow-marine successions were not so far reported in detail from Iran, it could be the result of uplift and folding activities, i.e., the deposition of the Fajan Formation (Paleocene–early Eocene) in the Alborz region. Further studies of stratigraphic and biogeographic aspects on the Ilerdian–Cuisian *Alveolina* assemblages need to be carried out at a global scale for better datasets regarding the SBZ implications from the central and even eastern Tethys, where available knowledge on the paleobiogeography of *Alveolina* is still inadequate.

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PLATE 3

Axial sections of key *Alveolina* species from the Iran and Turkey basins in this study.

SBZ10

1 *A. haymanensis* Sirel, Kıslatepe section (Ks.27).

2 *A. indicatrix* Hottinger, Cholounak section (ch1-1).

SBZ11-SBZ12

3 *A. histrica histrica* Drobne, Cholounak section (ch3-5).

4 *A. lehneri* Hottinger, Kıslatepe section (Ks.33).

5 *Alveolina bayburtensis* Sirel, Gheynarjeh section (G9-2).

6 *Alveolina cremae* Checchia-Rispoli, Chenesht section (CH11-3).

7 *A. frumentiformis* Schwager, Chenesht section (CH12-1).

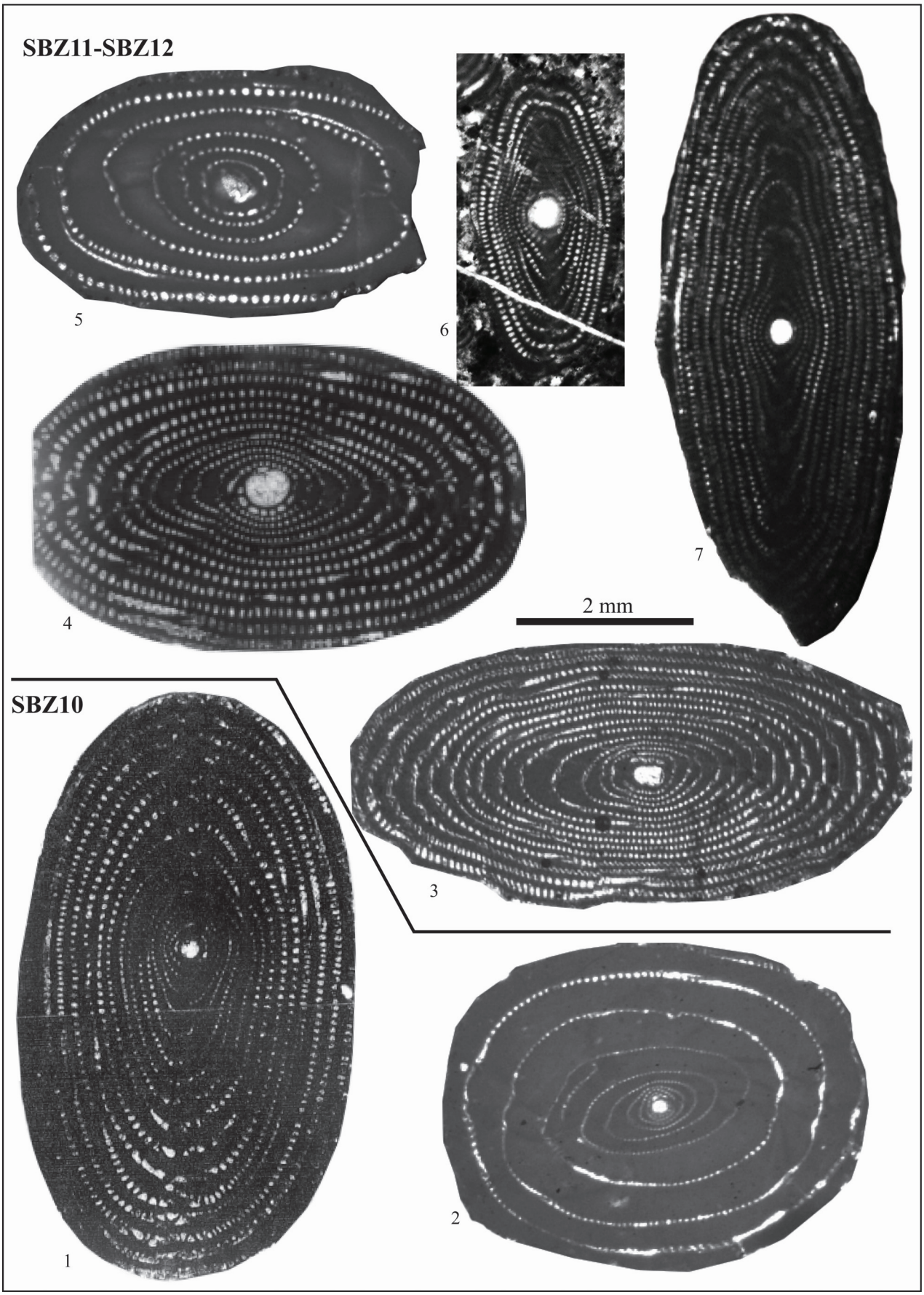
SBZ11-SBZ12
5
6
7
4
2 mm
SBZ10
3
1
2

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PLATE 4

Axial section of megalospheric *Alveolina* specimens from the Iran and Turkey:

1-2 *Glomalveolina lepidula* Schwager, Sarıbayır and Baghdareh sections (S12 and BR32-2).

3 *Alveolina ellipsoidalis* Schwager, Baghdareh section (G1).

4 *A. pisiformis* Hottinger, Baghdareh section (BR5).

5 *A. laxa* Hottinger, Gheynarjeh section (G8-2).

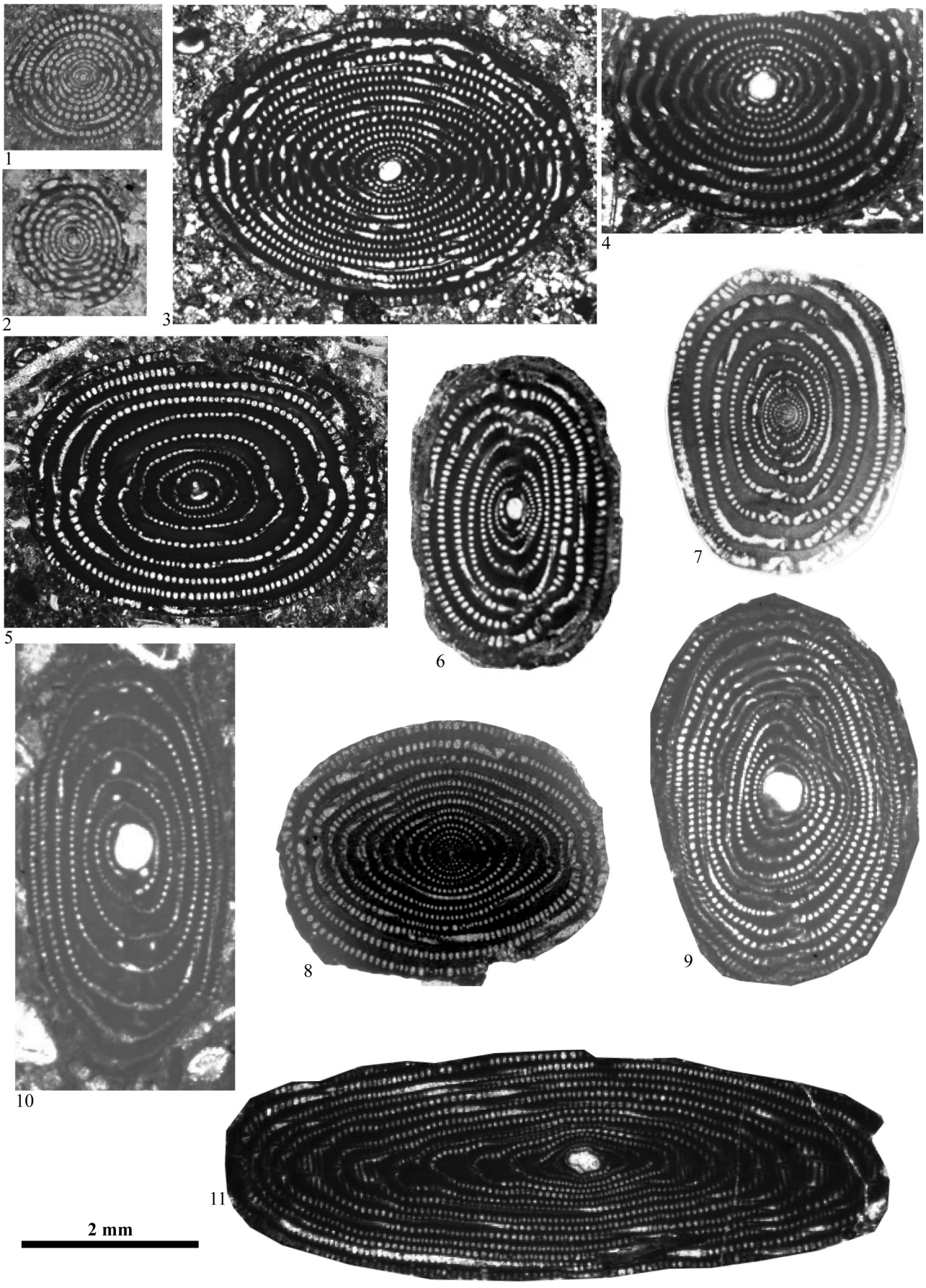
6-7 *A. subpyrenaica* Leymerie, Baghdareh and Kızılkayatepe sections (BR32-6 and Kz13).

8 *A. varians* Hottinger, Kızılkayatepe sections (Kz12).

9 *A. fornasinii* Checchia-Rispoli, Cholounak section (ch1-5).

10 *A. canavarii* Checchia-Rispoli, Cholounak section (ch1-3).

11 *A. frumentiformis* Hottinger, Chenesht section (CH12-1).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