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Ostracod biostratigraphy and Strontium isotope stratigraphy of the Miocene sequences of the Ayrancı Basin (Karaman/Turkey)

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We investigate the stratigraphy of the Miocene fossil ostracod fauna from the Ayrancı Basin in southern Turkey, based on five key stratigraphic sections. Abundant ostracods belonging to the *Neomonoceratina helvetica-Aurila soummamensis* Biozone were found within the limestones of the Mazı Formation. This formation also records the initial appearance of *Carinocythereis* and *Praeorbulina glomerosa curva-Orbulina suturalis*, which are indicative of the *Orbulina universa* planktonic foraminiferal Biozone. The Divlek Formation, characterized by fossiliferous argillaceous limestones and marls, contains a diverse and well-preserved ostracod assemblage, allowing correlation of this lithological unit with the late appearance of *Cyprideis* during the Miocene. The formation age has been determined to span from the Tortonian, with an age range of 7.1–8.4 Ma based on $^{87}Sr/^{86}Sr$ ratios of two samples.

Key words: Ayrancı Basin, Karaman, Ostracods, Planktonic foraminifera, Strontium isotopes, Anatolia.

INTRODUCTION

The study area encompasses the central part of the Ayrancı Basin, situated in the Karaman Province of southern Turkey (Fig. 1). Previous investigations conducted in the Ayrancı Basin have focused on analyzing the sedimentary sequences of the Middle and Upper Miocene. These studies used the fossil content to determine biostratigraphy and understand the evolution of the basin (Koçyiğit, 1976; Pampal, 1987; Pampal and Meriç, 1990; Murat and Temur, 1995). A thorough geological investigation was undertaken in the Karaman-Ermenek region, with a specific focus on interpreting the Miocene marine succession and the overlying lacustrine limestones (Koçyiğit, 1976; Pampal, 1986, 1987). Previous studies conducted in the Mut-Ermenek region (south of the Ayrancı Basin) by Tanar and Gökçen (1990) have provided detailed information on the Lower and Upper Oligocene, Burdigalian, Langhian, and Serravallian formations, including their respective depositional environments.

In this study, we aim to establish a consistent regional framework for palaeontological and chemostratigraphical investigations of the Divlek and Mazı formations within the Ayrancı Basin. Ostracod biozones are identified and established and are correlated with biozones reported elsewhere in the literature.

STUDY AREA

The oldest rocks exposed in the study area are attributed to the Kıraman ophiolitic unit, situated above the Berendi unit with a tectonic boundary, and emplaced in the region during the Campanian (Murat and Temur, 1995). The Berendi Formation, consisting of Jurassic-Cretaceous limestones, comprises the basal unit in the study area. These limestones were deposited on a shallow and stable carbonate platform (Demirtaşlı et al., 1983). In the Late Miocene, oolitic limestones formed in association with these deposits (Fig. 1).

The Mazı Formation, which is the oldest Miocene unit, unconformably overlies the Kıraman ophiolitic mélange. The formation is characterized by a basal conglomerate composed of serpentinite pebbles, and argillaceous limestone. The Divlek Formation, which overlies the Mazı Formation, represents the uppermost part of the Miocene in the region. It is composed of cream-coloured, fossiliferous limestones that developed within oolitic sediments during the Tortonian Stage (Murat and Temur, 1995). It is overlain by the Hotamıţ Formation characterized by the presence of claystone, siltstone, sandstone, clay, fossiliferous clay and lignite layers. Above the older units, there is an unconformable cover of alluvium consisting of conglomerate and sandstone, contributing to the current geomorphology of the basin (Salman, 2010).

METHODS

The first geological maps of the Karaman (Ayrancı) region were produced between 2018 and 2019.

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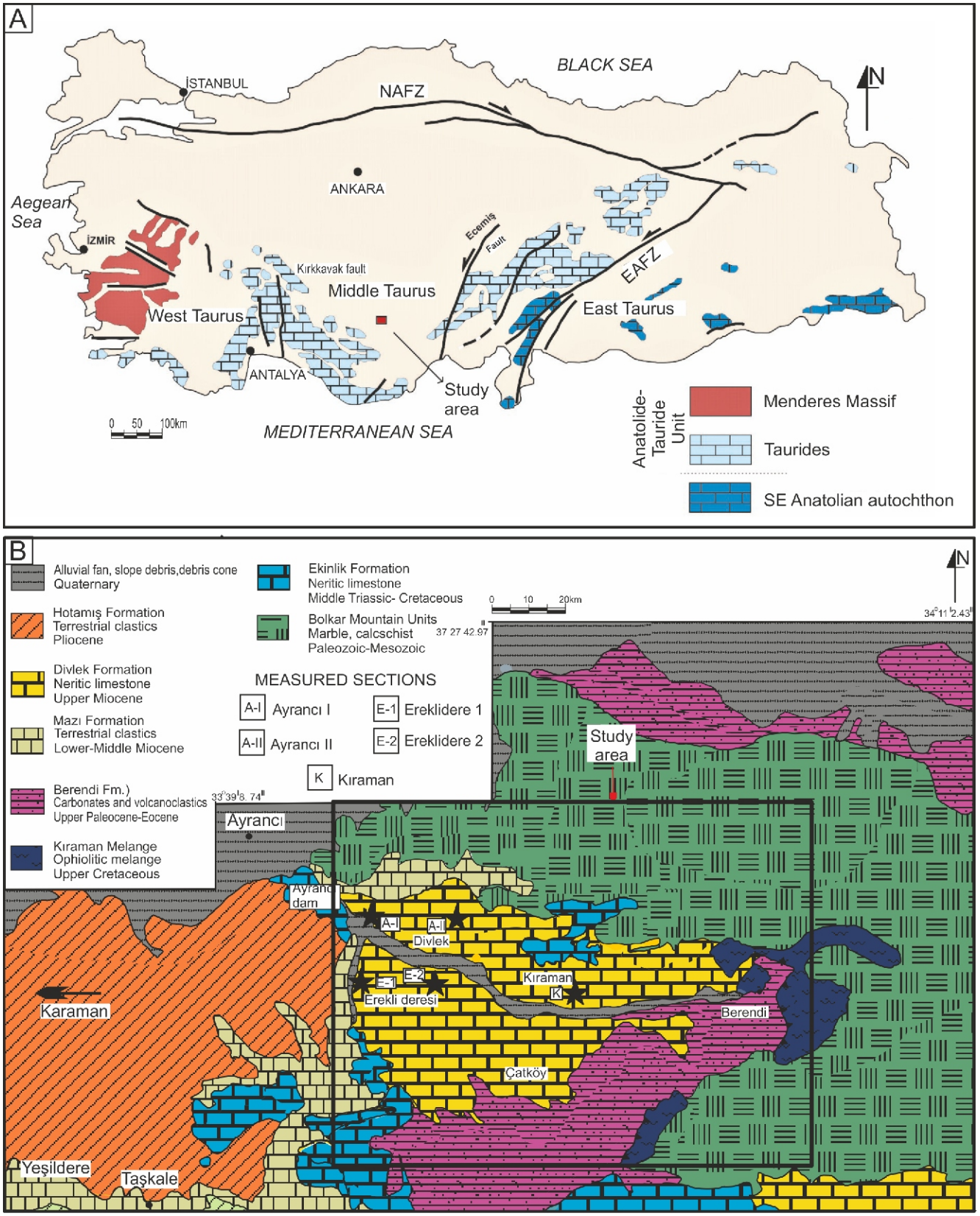

Fig. 1A – the location of the study area in Turkey (Göncüoğlu et al., 1997);
B – geological map of the study area, simplified from MTA (2002)

NAFZ – North Anatolian Fault Zone; EAFZ – East Anatolian Fault Zone

The present study was conducted in the Divle, Kıraman, and Ereklidere sections (map sheets Karaman N31a3, Karaman N31b4 and Karaman N31b3). Fossiliferous levels and lithological data were collected during the measurement of these sections. 73 samples were collected and washed using pressurized water in sieves with mesh sizes of 0.25 mm, 0.50 mm and 1 mm. The washed samples were subsequently dried and stored. From the washed samples, ostracod species and genera were identified. The identified taxa were counted, and the lateral and vertical distributions of the ostracods analyzed. Represention of the frequency of ostracods is as follows: very rare (1–2 valves), rare (3–5 valves), common (6–15 valves), frequent (15–25 valves), and very frequent (more than 25 valves), denoted by the symbol "+". The classification of ostracods was based on Sissingh (1972) and followed the classification by Hartmann and Puri (1974) as well as Frenzel and Viehberg (2004). Palaeoenvironmental analyses and ostracod data interpretation were based on Morkhoven (1963), Doruk (1973), Bassiouni (1979), Tanar (1989), Šafak (1993), Gammudi and Keen (1993), Šafak and Donat (2014), Led and İsmail (2016) and Šafak and Nurlu (2018). Additionally, several genera and species of planktonic foraminifera were identified in the washed samples. The species identified are archived in the Çukurova University Geology-Paleontology Laboratory with collection numbers Ay/1-68. The ostracod zonation established allowed correlations with previously studied successions in nearby basins.

In addition, strontium isotopic analysis of two samples of the Divlek Formation was conducted at the METU Central Laboratory, specifically at the Radiogenic Isotope Laboratory within the R&D Training and Measurement Center. The analytical methods and conditions used for the strontium isotopic analysis were in accordance with the protocols described by Köksal et al. (2017). The process involved weighing, chemical dissolution, and chromatographic procedures conducted in a clean laboratory environment that met class 100 cleanroom standards. Ultrapure water and chemicals were used throughout the procedures. The isotopic analysis of $^{87}Sr/^{86}Sr$ for specific sedimentary samples was performed at the Radiogenic Isotope Laboratory of the METU Central Laboratory in Ankara, following the analytical procedures outlined by Köksal and Göncüoğlu (2008).

RESULTS

DESCRIPTION OF THE KEY SECTIONS

EREKLIDERE SECTION 1

This section is shown on the 1/25000 scale topographic map (Karaman, N31b4), with base and top coordinates: X1: 37.154674, Y1: 33.474968, Z1: 1227 m, and X2: 37.154699, Y2: 33.475046, Z2: 1228 m. Argillaceous limestones and yellowish claystones are observed in samples E1-1, E1-2, E1-3, and E1-4 of the Divlek Formation, while alluvial deposits are seen to unconformably overlie the argillaceous and fossiliferous limestones (Fig. 2). Four samples were collected from this 22 metres-thick section.

EREKLIDERE SECTION 2

This is shown on the 1/25000 scale topographic map of Karaman (N31b4). The coordinates of the section's base and top are: X1: 37.154731, Y1: 33.474686, Z1: 1229 m, and X2: 37.154800, Y2: 33.474777, Z2: 1229 m. The basal Divlek Formation, deposited in the Tortonian, consists of fossiliferous argillaceous limestones (samples Er-4, Er-3). The white argillaceous limestone level, from which samples Er-2 and Er-1 were taken, is unconformably overlain by alluvium (Fig. 3). Four samples were collected from this 30 m-thick section.

KİRAMAN SECTION

This section is shown on the 1/25000 scale topographic map (Karaman, N31b3), with base and top coordinates: X1: 37.153529, Y1: 33.515454, Z1: 1191 m, and X2: 37.153411, Y2: 33.515253, Z2: 1174 m. The section comprises pebbly basal conglomerates, brown claystone, argillaceous limestones of the Mazı Formation, and abundant fossiliferous oolitic limestone levels of the Divlek Formation (Fig. 4). Ten samples were obtained from this 42 m-thick section.

AYRANCİ SECTION 1

This section is shown on the 1/25000 scale topographic map (Karaman, N31a3) with base and top coordinates: X1: 37.194218, Y1: 33.443848, Z1: 1169 m, and X2: 37.193910, Y2: 33.443587, Z2: 1171 m of the Ayrancı Basin. Throughout the section, 18 ostracod and 10 foraminifera species were identified (Fig. 5). Twenty-five samples were collected from this 110 m-thick section.

AYRANCİ SECTION 2

This section is shown on the 1/25000 scale topographic map (Karaman, N31a3) with base and top coordinates: X1: 37.191650, Y1: 33.451128, Z1: 1171 m, and X2: 37.191894, Y2: 33.451573, Z2: 1172 m. Within the thirty samples collected throughout the section, 22 ostracod and five foraminifera species were identified. The *Neomonoceratina helvetica-Aurila soummamensis* Zone was defined between 24 and 40 metres of the section (Fig. 6). Thirty samples were obtained from this 130 m-thick section.

A total of 69 ostracod species were identified from the five stratigraphic sections measured in the Ayrancı Basin. Detailed SEM images of 50 selected ostracod species and 4 foraminifer species are shown in Figures 7–9.

LITHOSTRATIGRAPHY

MAZİ FORMATION

The Mazı Formation starts with a basal conglomerate that passes upwards into argillaceous limestone and claystone. The claystones are thinly bedded and range in colour from dark cream to brown. The thin- to medium-bedded argillaceous limestones have a pinkish-cream colour. The Langhian–Serravallian age of this lithological unit is indicated by planktonic and benthic foraminifera, ostracods as well as echinoid species found in the limestones (Pampal, 1987). Figure 10 summarizes the distribution of ostracods and planktonic foraminifera in the Mazı Formation of the study area. The age of the unit was given as Pliocene by previous researchers (Murat and Temur, 1995). This study shows that the formation was deposited from the Burdigalian to the late Serravallian.

DIVLEK FORMATION

This formation comprises medium- to thick-bedded fossiliferous yellowish cream limestones and is characterized by the strong presence of oolitic limestones. Its chronostratigraphic position is upper Serravallian–Tortonian.

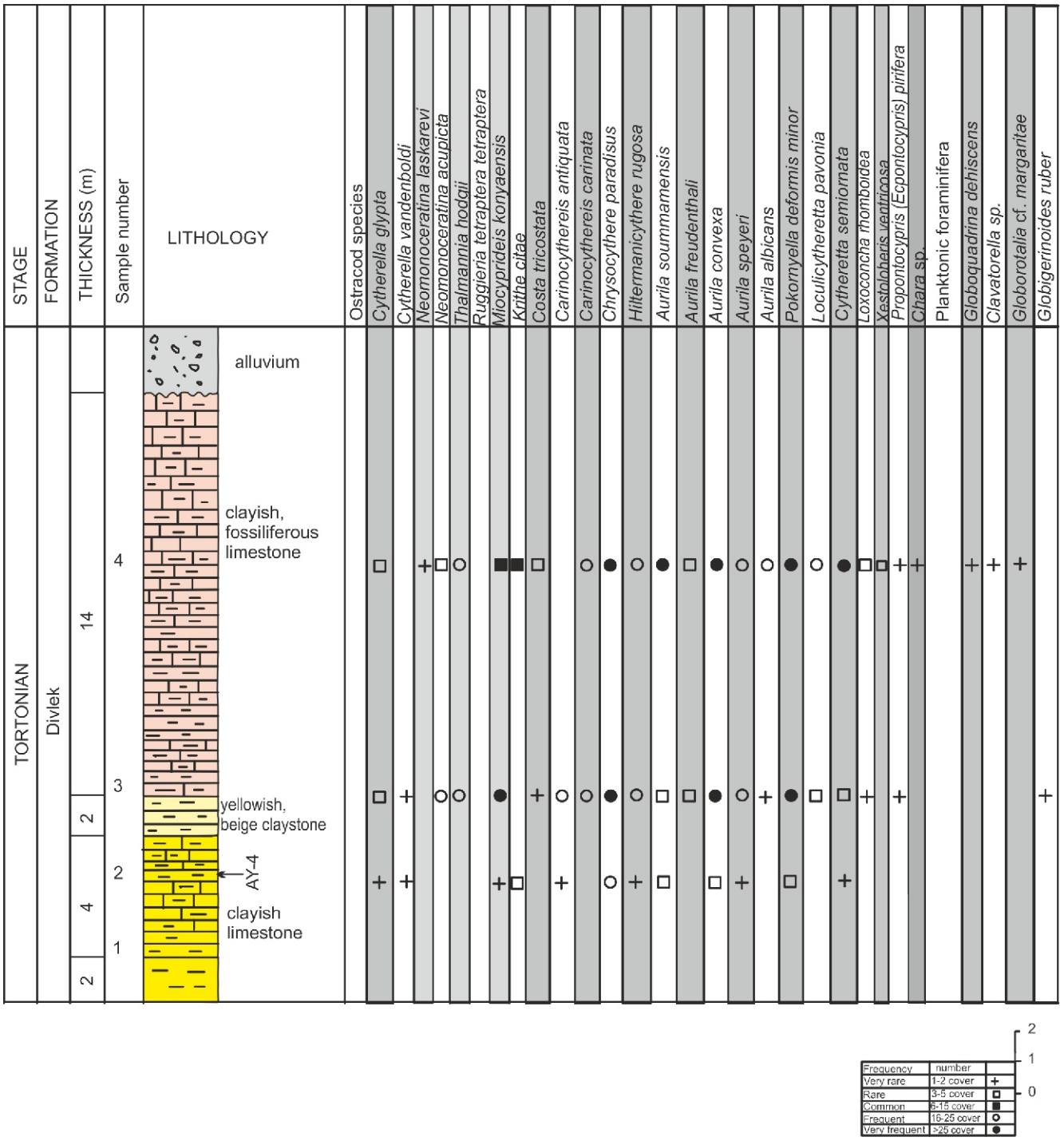

Fig. 2. The distribution of ostracod and planktonic foraminifer species in the Ereklidere 1 measured section

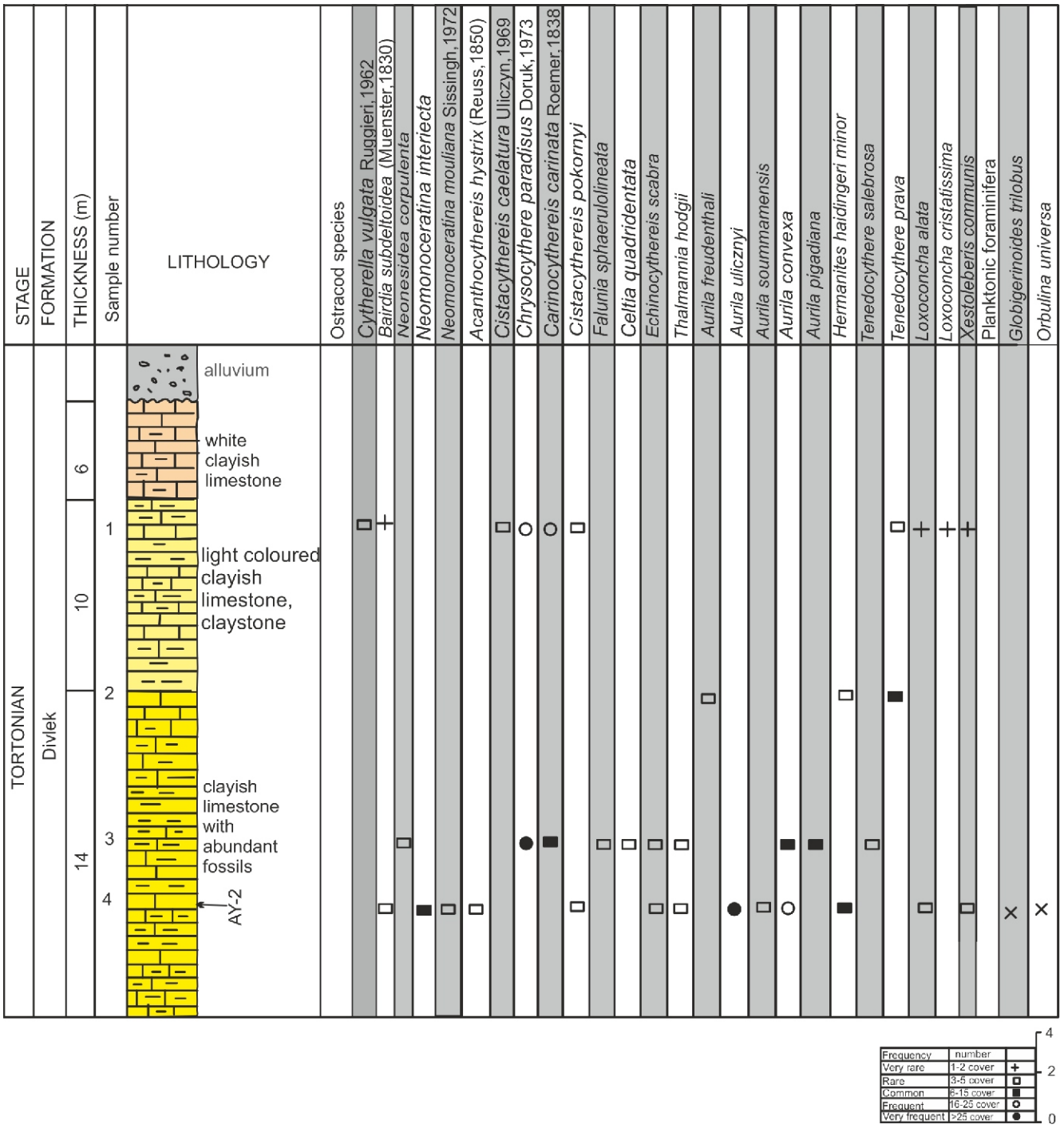

Fig. 3. The distribution of ostracod and planktonic foraminifera species in the Ereklidere 2 measured section

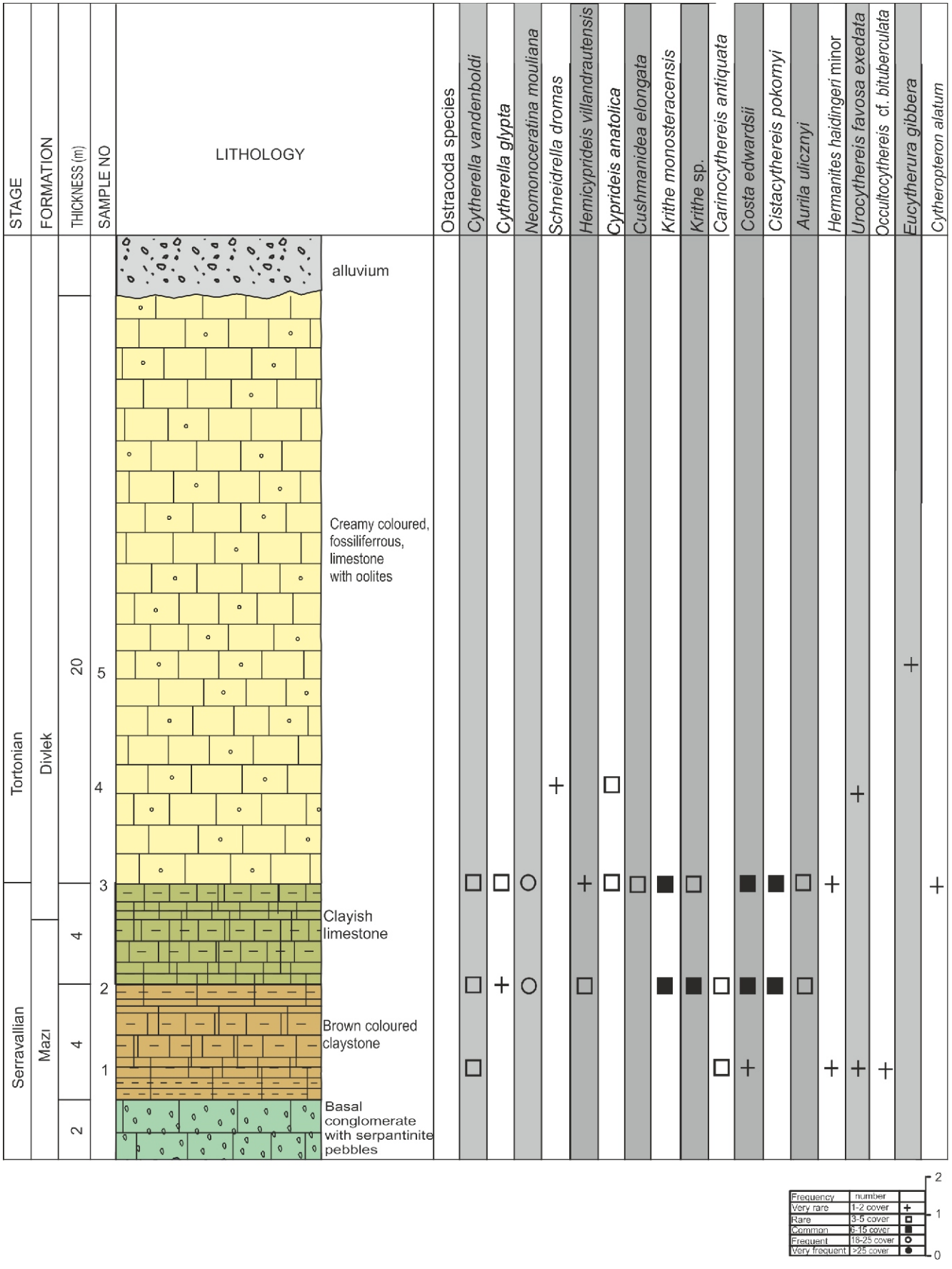

Fig. 4. The distribution of ostracod species in the Kıraman measured section

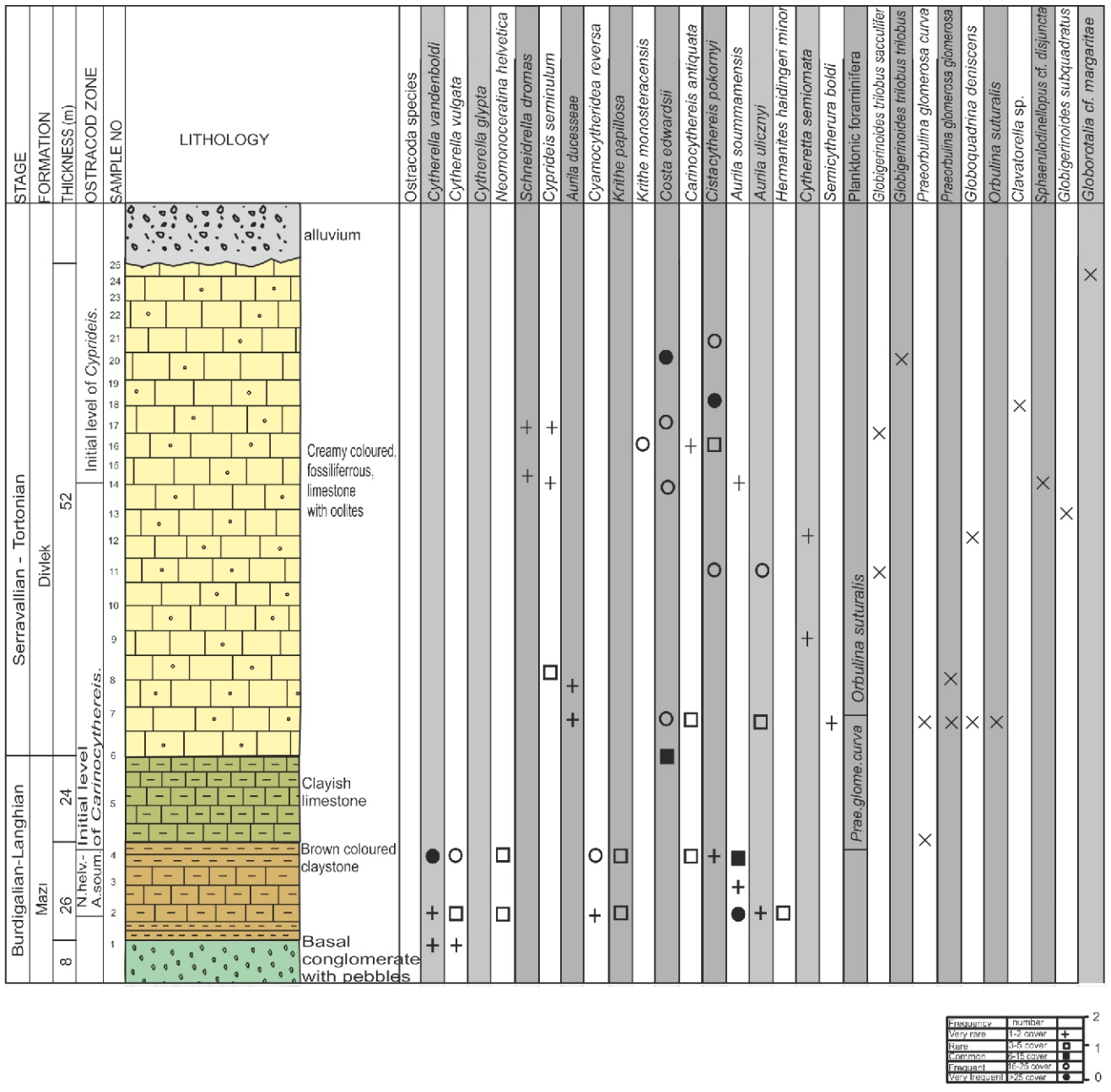

Fig. 5. The distribution of ostracod species in the Ayrancı 1 measured section

The deposition of the Divlek formation, marked by the first appearance and continued range of *Cyprideis*, starting from the upper Serravallian and continuing into the Tortonian, was primarily determined based on ostracods along with planktonic foraminifera (Fig. 10).

STRONTIUM ISOTOPE STRATIGRAPHY

The two calculated $^{87}Sr/^{86}Sr$ ratios in the Divlek Formation range from 0.708926 to 0.708951. These values indicate that two carbonate samples of the Divlek Formation show ages of 7.1 and 8.4 Ma based on these ratios (Fig. 11).

BIOSTRATIGRAPHY

The *Neomonoceratina helvetica-Aurila soummamensis* Biozone (Gökçen, 1984) and first appearances of *Carinocythereis* and *Cyprideis* have been identified in the argillaceous limestones of the Mazı formation.

NEOMONOCERATINA HELVETICA-AURILA SOUMMAMENSIS BIOZONE

D e s c r i p t i o n. – The zone is limited by the first appearance of *Aurila soummamensis* Coutella and Yassini, 1974 and the first appearance of *Carinocythereis* (Fig. 12).

Z o n e d e f i n e d b y: Gökçen (1984)

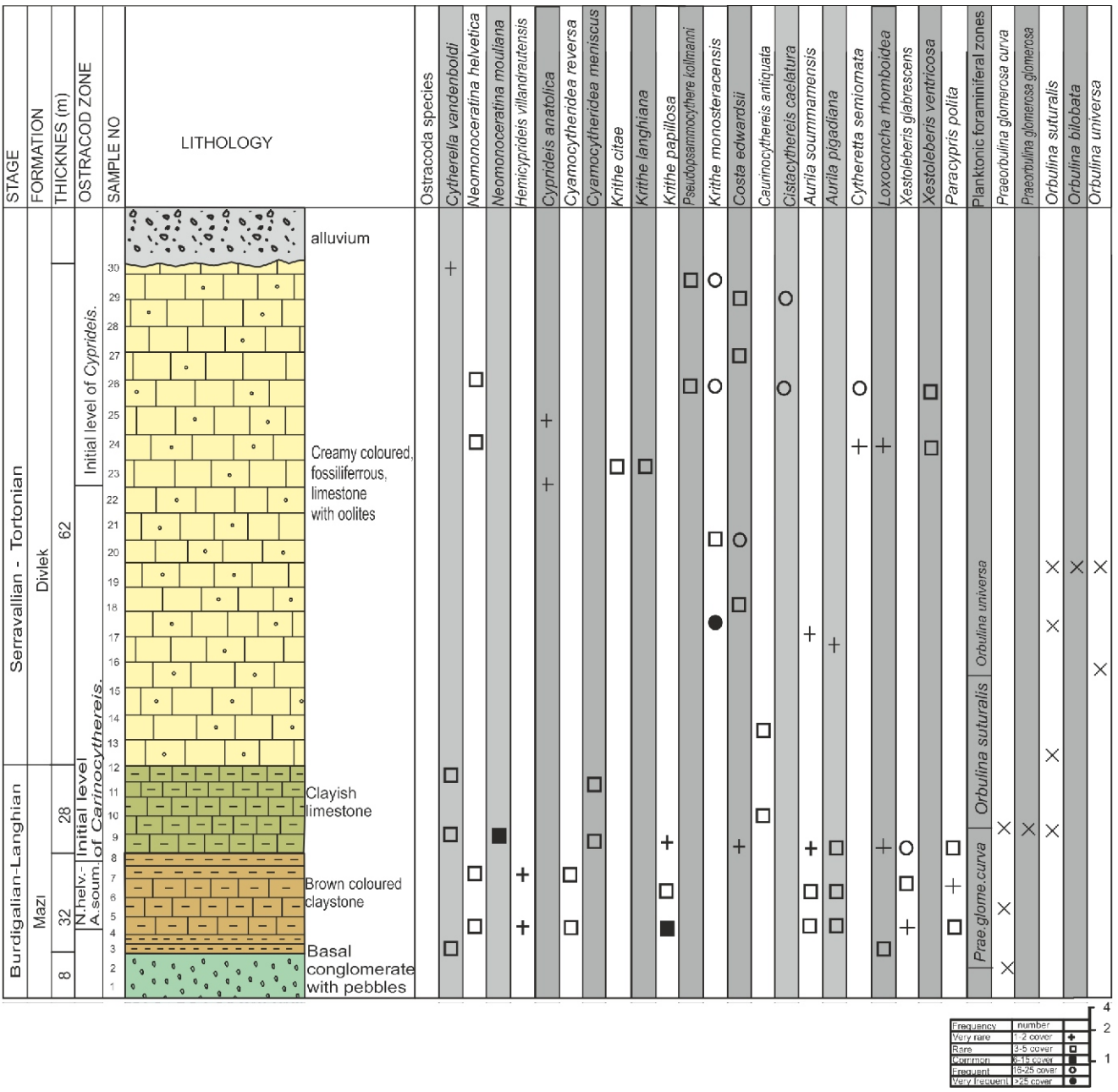

Fig. 6. The distribution of ostracod species in the Ayrancı 2 measured section

A g e. – Burdigalian–early Langhian

L o c a l i t y. – Fossils of this zone were detected in samples 2–4 of the Ayrancı 1 section and samples 4–8 of the Ayrancı 2 section taken from the Mazı Formation in the study area.

C o m m o n s p e c i e s. – *Aurila soummamensis* Coutella and Yassini, 1974, *Neomonoceratina helvetica* Oertli, 1958, *Hemicyprideis villandruensis* (Moyes, 1965) *Cyamocytheridea reversa* (Egger,1858), *Krithe papillosa* Bosquet, 1852, *Hermanites haidingeri minor* (Reuss, 1850).

CARINOCYTHEREIS FIRST APPEARANCE

D e s c r i p t i o n. – This occurs in the argillaceous limestone beds within the Mazı Formation. This level comprises the first appearance of *Carinocythereis*, as well as ostracod species such as *Neomonoceratina mouliana* Sissingh, 1972, *Costa edwardsii* (Roemer, 1838), *Aurila ulicznyi* Sissingh, 1972 and assemblage.

A g e. – Langhian–Serravallian

L o c a l i t y. – The fossils of this interval were obtained from the Mazı Formation, and observed in samples 5–9, 11 and 12 of the measured section of Ayrancı 1 and samples 8–12, 15, 17–19 of the measured section of Ayrancı 2.

CYPRIDEIS FIRST APPEARANCE

D e s c r i p t i o n. – This level begins in the argillaceous limestone-oolitic limestone of the Divlek Formation. In addition to the first appearance of *Cyprideis* at this level, the ostracod species and distinctive fossil assemblage contain *Cytherella glypta* Doruk, 1977, *Neomonoceratina acupicta* Bonaduce,

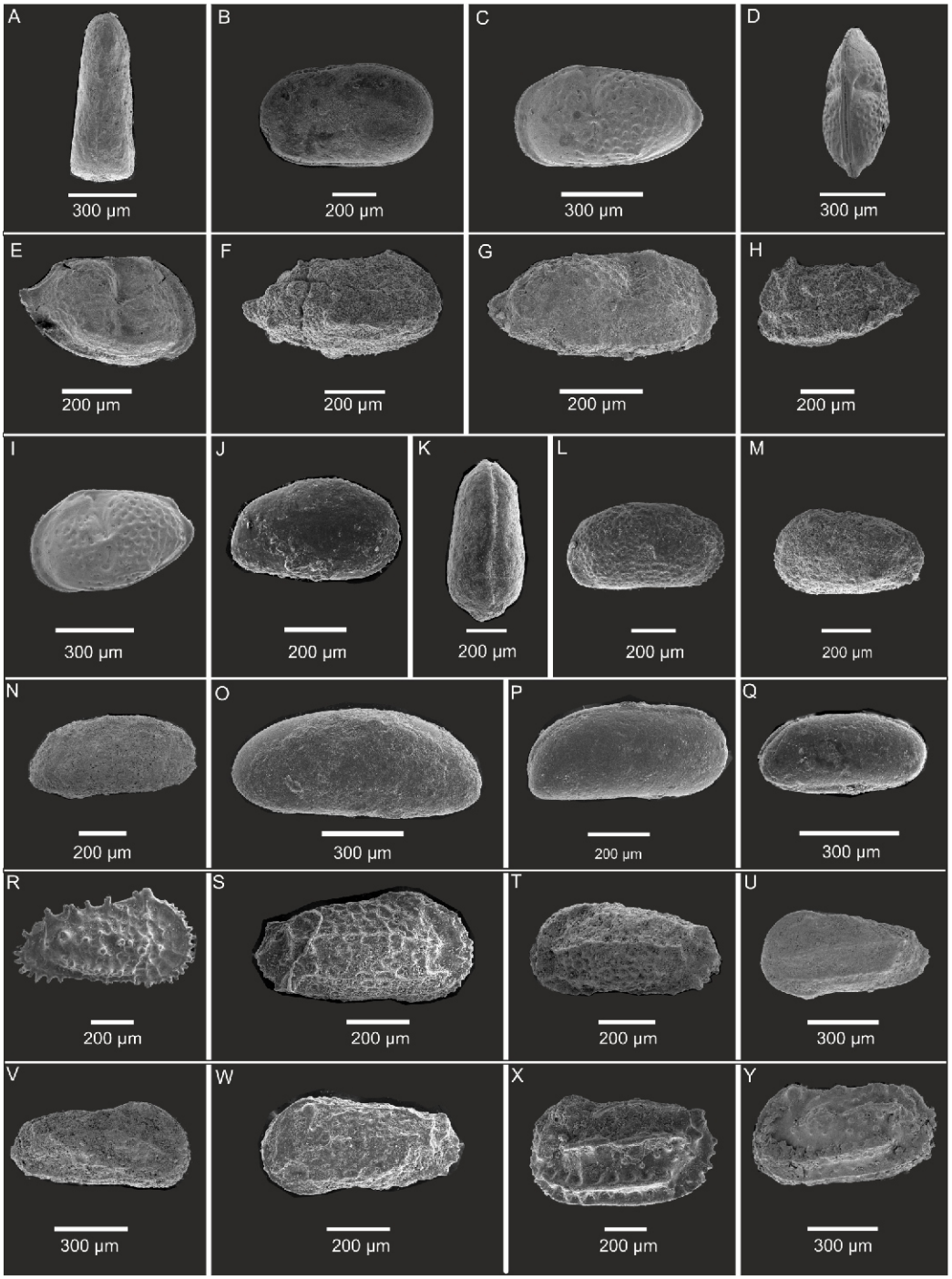

Fig. 7. Ostracod species identified from the measured sections

A – *Cytherella glypta* Doruk, 1977, shell, back view, Ereklidere 1 section, sample 4, Tortonian; **B** – *Cytherella vulgata* Ruggieri, 1962, shell, left exterior view, Ereklidere 1 section, sample 1, Tortonian; **C, D** – *Neomonoceratina helvetica* Oertli, 1958: C – left cover, external view, Ayrancı 1 section, sample 2, Burdigalian; D – carapace, back view, Ayrancı 1 section, sample 2, Burdigalian; **E, F** – *Neomonoceratina mouliana* Sissingh, 1972; E – shell, right external view, Ereklidere 2 section, sample 4 Tortonian; F – shell, right external view, Ayrancı 2 section, sample 10, Langhian; **G** – *Neomonoceratina interiecta* Bonaduce, Ruggieri, Russo, Bismuth, 1992, right carapace, external view, Ereklidere 2 section, sample 4, Tortonian; **H** – *Neomonoceratina laskarevi* (Krstic and Pietrzeniuk, 1972), left carapace, external view, Ereklidere 1 measured stratigraphy section, sample 3, Tortonian; **I** –*Schneidrella dromas* (Schneider, 1939), shell, left external view, Kıraman section, sample 4, Tortonian; **J** – *Cyprideis anatolica* Bassiouni, 1979, right carapace, external view, Ayrancı 2 section, sample 27, Tortonian; **K** – *Cyprideis seminulum* (Reuss),1958, shell, back view, Ayrancı 1 measured stratigraphy section, sample 16, Tortonian; **L** – *Miocyprideis konyaensis*, Bassiouni,1979, right carapace, external view, Ereklidere 1 measured stratigraphy section, sample 4, Tortonian; **M** – *Celtia quadridentate* (Baird, 1850), shell, right external view, Ayrancı 1 measured stratigraphy section, sample 4, Burdigalian; **N** – *Krithe papillosa* Bosquet, 1852, right carapace, external view, Ayrancı 2 section, sample 25, Tortonian; **O** – *Krithe monosteracensis* (Sequenza, 1880), shell, right external view, Ayrancı 2 section, Sample 23, Tortonian; **P** – *Krithe citae* Oertli, 1961, shell, right external view, Ayrancı 2 section, sample 23, Tortonian; **Q** – *Krithe langhiana* Oertli, 1961, right carapace, external view, Ereklidere 2 section, sample 4, Tortonian; **R** – *Acantocythereis hystrix* (Reuss, 1850), right carapace, external view, Kıraman section, sample 1, Langhian; **S, T** – *Costa edwarsii* (Roemer, 1838): S – left carapace, external view, Kıraman section, sample 3, Tortonian; T – left carapace, external view, Ereklidere 1 section, sample 4, Tortonian; **U** – *Costa tricostata* (Reuss, 1850), shell, right external view, Kıraman section, sample 3, Serravallian; **V, W** – *Cistacythereis pokornyi* (Ruggieri, 1962): V – shell, left external view, Ayrancı 1 section, sample 16, Tortonian; W – left carapace, external view, Kıraman section, sample 2, Serravallian; **X** – *Carinocythereis antiquata* (Baird, 1850), shell, left external view, Ereklidere 1 section, sample 3, Tortonian; **Y** – *Carinocythereis carinata* (Roemer, 1838), left carapace, external view, Ereklidere 2 section, sample 3, Tortonian

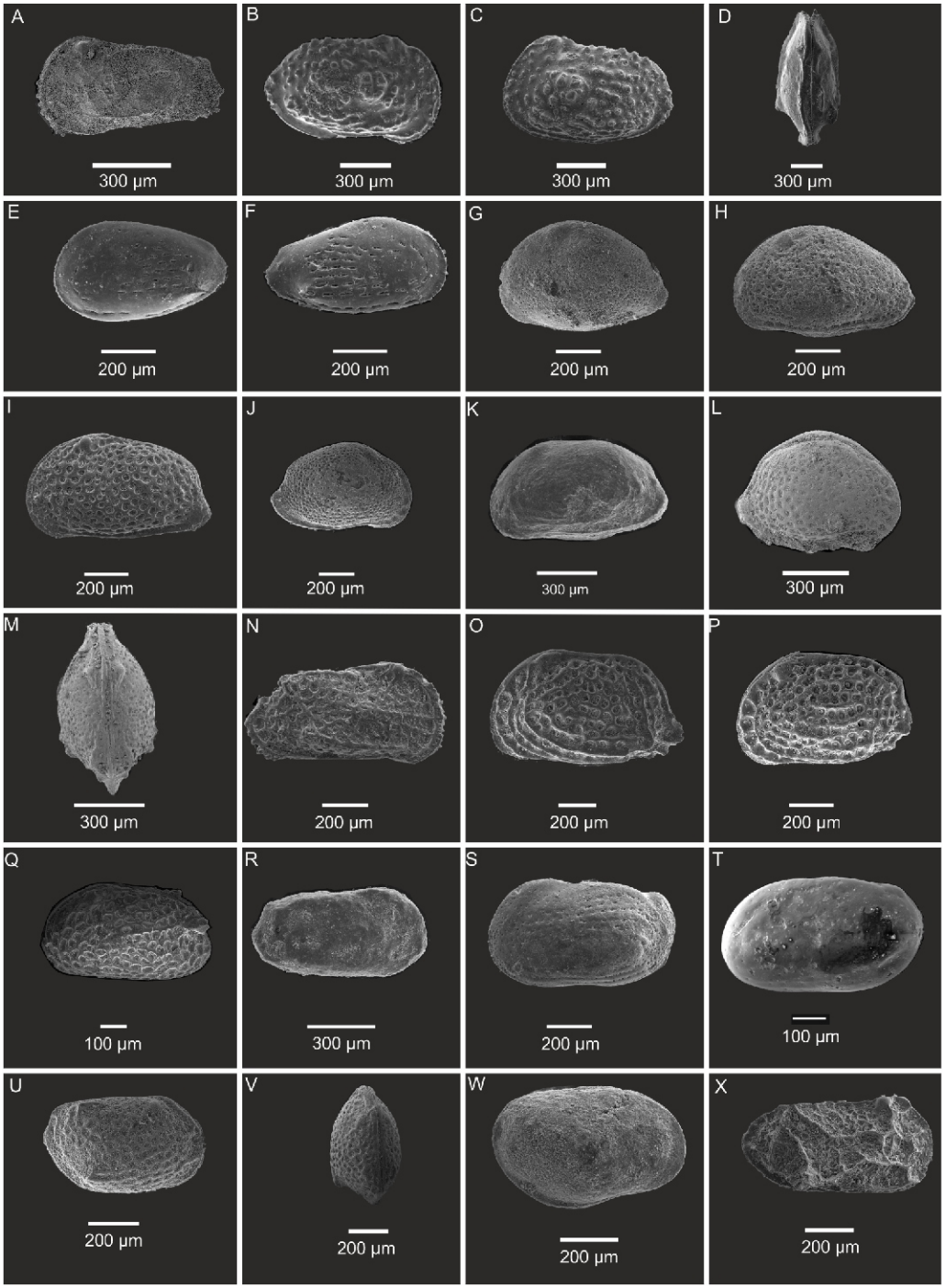

Fig. 8. Ostracod species identified in the measured sections

A – *Hiltermanicythere rugosa* Costa, 1952, left carapace, external view, Ereklidere 1 section, sample 4, Tortonian; **B, C** – *Echinocythereis scabra* Muenster, 1830: B – right carapace, external view, Ereklidere 2 section, sample 3, Tortonian; C – left carapace, external view, Ereklidere 2 section, sample 4, Tortonian; **D** – *Ruggieria tetraptera tetraptera* (Sequenza, 1880), shell, ridge view, Ereklidere 1 section, sample 4, Tortonian; **E, F** – *Thalmannia hodgii* (Brady, 1866): E – left carapace, external view, Ereklidere 1 section, sample 4, Tortonian; F – right carapace, external view, Ereklidere 1 section, sample 4, Tortonian; **G** – *Aurila soummamensis* Coutelle and Yassini, 1974, left carapace, external view, Ayrancı 1 section, sample 3, Burdigalian; **H** – *Aurila ducasseae* Moyes, 1961, shell, left external view, Ayrancı 1 section, sample 9, Serravallian; **I** – *Aurila freudenthali* Sissingh, 1972, left carapace, external view, Ereklidere 2 section, sample 2, Tortonian; **J** – *Aurila convexa* (Baird, 1850), right carapace, external view, Ereklidere 1 section, sample 4, Tortonian; **K** – *Aurila ulicznyi* Sissingh, 1972, shell, left external view, Ayrancı 1 section, sample 12, Serravallian; **L, M** – *Pokornyella deformis minör* (Moyes**,** 1965): L – shell, right external view, Ereklidere 1 section, sample 4, Tortonian; M – shell, ridge view, Ereklidere 1 section, sample 4, Tortonian; **N** – *Hermanites haidingeri minor* (Reuss, 1850), right carapace, external view, Ereklidere section, sample 2, Tortonian; **O** – *Tenedocythere prava* (Baird, 1850), left carapace, external view, Ereklidere 2 section, sample 1, Tortonian; **P** – *Tenedocythere salebrosa* Uliczny, 1969, left carapace, external view, Ereklidere 2 section, sample 3, Tortonian; **Q** – *Urocythereis favosa exedata* Uliczny, 1969, left carapace, external view, Kıraman section, sample 4, Tortonian; **R** – *Occultocythereis* cf. *bituberculata* Reuss, 1850, shell, right side view, Kıraman section, sample 1, Serravallian; **S** – *Cytheretta semiornata* (Egger, 1958), shell, left external view, Ereklidere 1 section, sample 4, Tortonian; **T** – *Loculicytheretta pavonia* (Brady, 1866), Shell, left external view, Ereklidere 1 section, sample 4, Tortonian; **U, V** – *Loxoconcha alata* Brady, 1868: U – shell, right external view, Ereklidere 2 section, sample 4, Tortonian; V – Shell, ridge view, Ereklidere 2 section, sample 4, Tortonian; **W** – *Loxoconcha rhomboidea* (Fischer, 1855), shell, right external view, Ereklidere 1 section, sample 3, Tortonian; **X** – *Loxoconcha cristatissima* Ruggieri, 1867, right carapace, exterior view, Ereklidere 2 measured stratigraphy section, sample 1, Tortonian

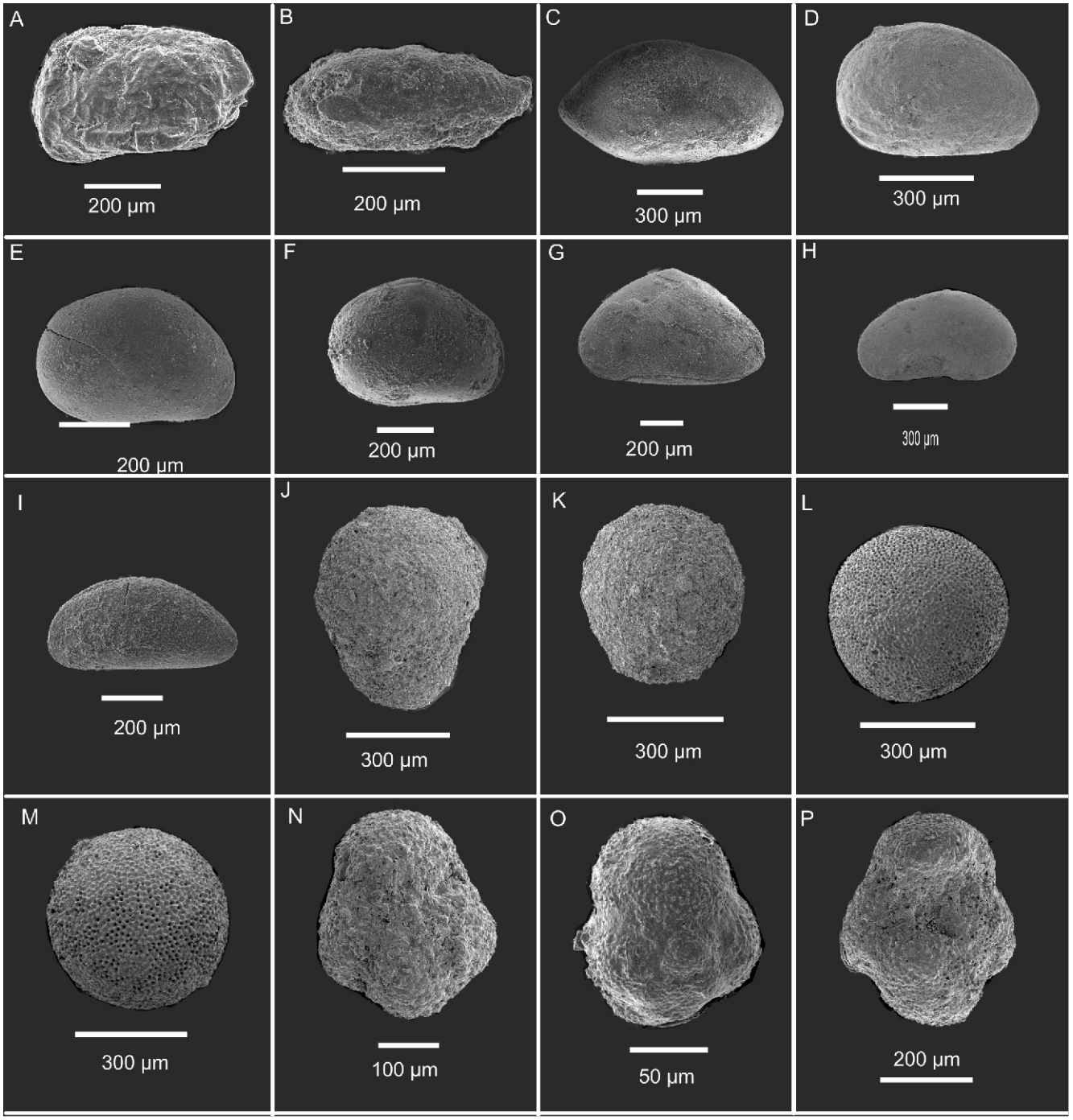

Fig. 9. Ostracod and foraminifera species identified in the measured sections

A – *Eucytherura gibbera* Mueller, 1894, shell, left side view, Kıraman section, sample 5, Tortonian; **B** – *Semicytherura boldi* Ducassae, 1967, shell, left view, Ayrancı 1 section, sample 7, Serravallian; **C** – *Cytheropteron alatum* Sars, 1866, shell, right external view, Kıraman section, sample 3, Serravallian; **D** – *Xestoleberis glabrescens* (Reuss, 1850), shell, right external view, Ayrancı 2 section, sample 5, Burdigalian; **E** – *Xestoleberis ventricosa* Mueller, 1894, right carapace, external view,Ayrancı 2 section, sample 23, Tortonian; **F** – *Xestoleberis communis* Mueller, 1894, shell, right external view, Ereklidere 2 section, sample 1, Tortonian; **G** – *Propontocypris* (*Ecpontocypris*) *pyrifera* Mueller, 1894, shell, left external view, Ereklidere 1 section, sample 4, Tortonian; **H** – *Argilloecia conoidea* Sars, 1923, shell, right external view, Kıraman section, sample 5, Tortonian; **I** – *Paracypris polita* Sars, 1866, shell, left external view, Ayrancı 2 section, sample 8, Langhian; **J** – *Praeorbulina glomerosa curva* (Blow, 1956), side view, Ayrancı 2 section, sample 5, Burdigalian; **K, L** – *Orbulina suturalis* Brönnimann, 1951, side view, Ayrancı 2 section, sample 5, Langhian; **M** – *Orbulina universa* d'Orbigny, 1839, Ayrancı 2 section, sample 19, Serravallian; **N–P** – *Globorotalia* cf. *margaritae* Bolli and Bermudez, 1965: N – side view, Ayrancı 1 section, sample 21, Tortonian; O – rise view, Ayrancı 1 section, sample 21, Tortonian; P – abdominal view, Ayrancı 1 section, sample 21, Tortonian

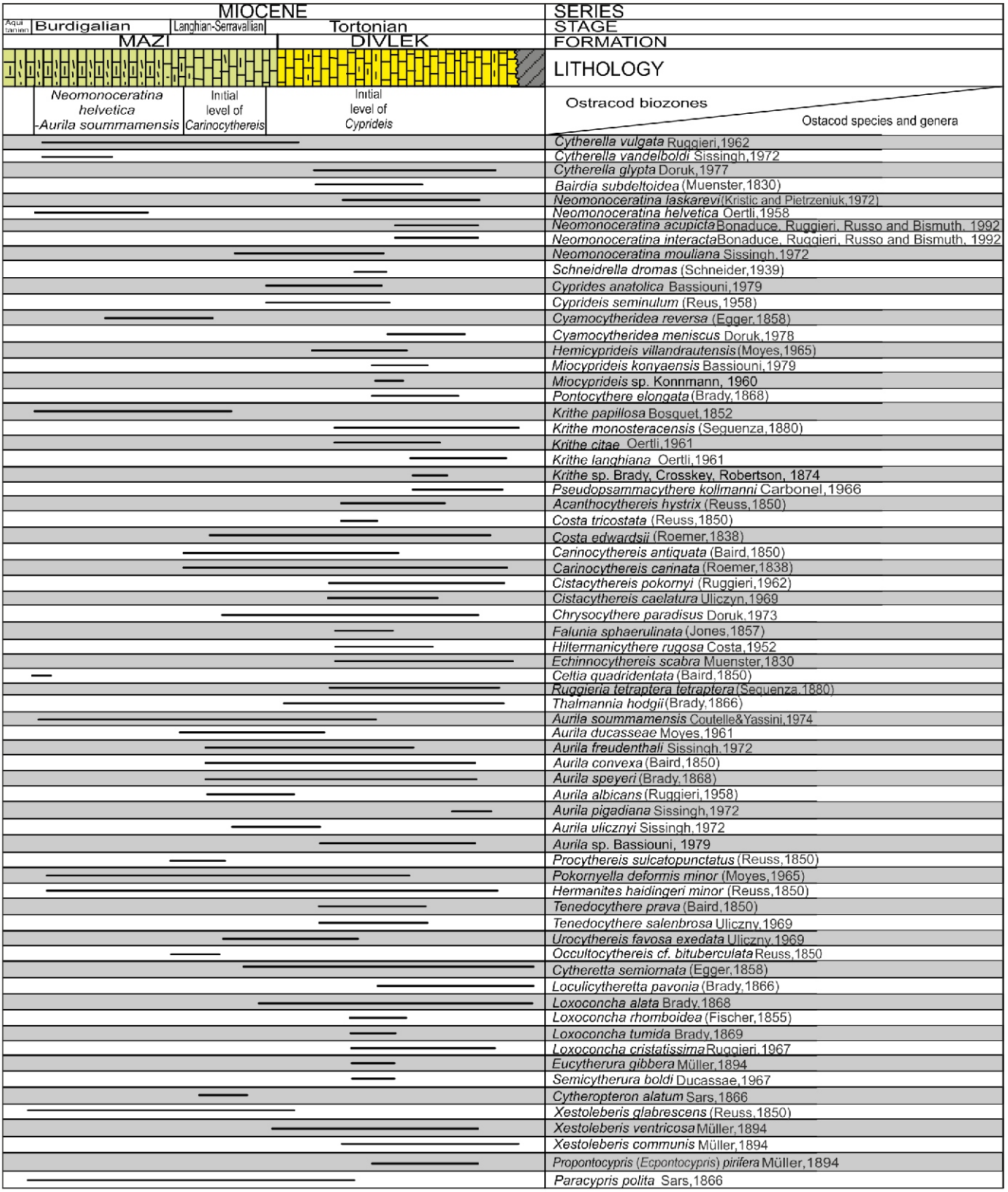

Fig. 10. Generalized stratigraphic section of the study area

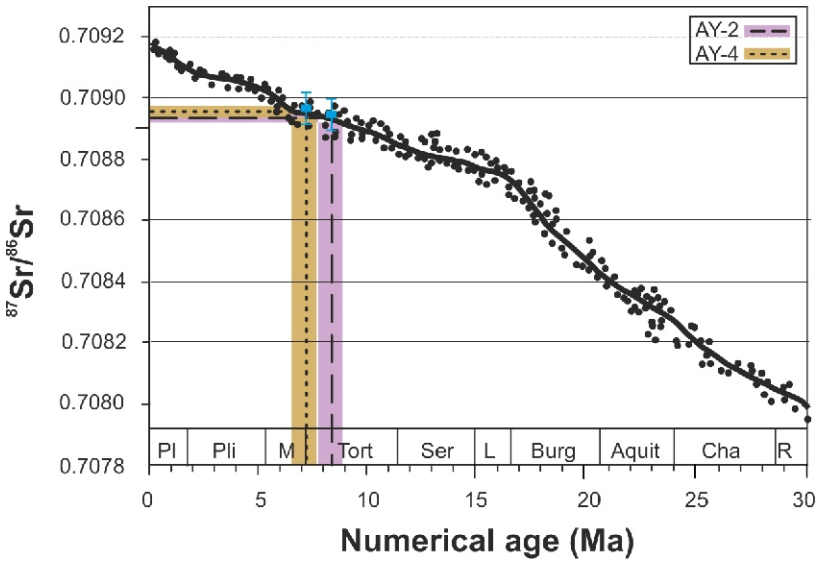

Fig. 11. Strontium isotope variation curve for the Miocene interval (McArthur et al., 2001)

Ruggieri, Russo & Bismuth, 1992, *N. laskarevi* Kristic & Pietzeniuk, 1972, *Schneidrella dromas* (Schneider, 1939), *Cyprideis anatolica* Bassiouni, 1979, *Costa edwardsii* (Roemer, 1838), *Carinocythereis antiquate* (Baird, 1850), *C. carinata* (Roemer, 1838), *Cistacythereis pokornyi* (Ruggieri, 1962) and *Chrysocythere paradisus* Doruk, 1973.

A g e. – Upper Serravallian–Tortonian.

L o c a l i t y. – The fossils of this zone were recovered from samples 14–16 and 18 of the Ayrancı 1 section and samples 20, 22 and 25–30 of the Ayrancı 2 section within the Divlek Formation.

CHRONOSTRATIGRAPHIC UNITS

Burdigalian. The Burdigalian was determined in the dark cream-coloured claystone-clayey limestone levels of the Mazı Formation outcropping around the Ayrancı Dam in the region studied. The ostracods recorded are comparable to the ostracods found at the same stratigraphic levels in Mediterranean countries that belong to the *Neomonoceratina helvetica-Aurila soummamensis* Biozone (Table 1).

Langhian. The Langhian was identified in the dark cream-coloured claystone-clayey limestone levels of the Mazı Formation outcropping to the north of Divle village. The taxa characterizing this stage can be compared with the ostracods found at the same stratigraphic levels in Mediterranean countries (Gökçen, 1984; Tanar, 1989; Tanar and Gökçen, 1990; Şafak, 1993; Şafak and Donat, 2014; Şafak and Nurlu, 2018). The initial level of *Carinocythereis* also indicates the Langhian Stage, supported by the *Praeorbulina glomerosa curva* planktonic foraminiferal Biozone defined in the study area.

Serravallian. The Serravallian was found in the dark cream-coloured claystone-clayey limestone levels of the Mazı Formation outcropping to the north of Divle village. The taxa characterizing this level can be compared with the ostracods found at the same stratigraphic levels in Mediterranean countries (Gökçen, 1984; Tanar, 1989; Tanar and Gökçen, 1990; Şafak, 1993; Şafak and Donat, 2014; Şafak and Nurlu, 2018). The *Orbulina universa* planktonic foraminiferal Biozone characterized in the area studied also supports identification of that level with the continuation of *Carinocythereis* recorded in deposits of the Serravallian Stage.

Tortonian. The Tortonian was determined in the light cream-coloured claystone-clayey limestone levels of the Divlek Formation outcropping in Divle and Çatköy. The taxa representing this stage can be compared with ostracods from the South Aegean Islands (Pliocene; Sissingh, 1972), Northern Aegean-Greece (Pliocene; Stambolidis, 1985), and Turkey (Tortonian; Doruk, 1979, 1993; Şafak et al., 1996, Şafak, 1997, Şafak and Nurlu, 2018, Ilgar et al., 2019), supporting the presence of *Cyprideis* throughout the Tortonian Stage. *Cyprideis seminulum*, one of the most common Tortonian ostracod species described in this study, has been reported in the Pannonian (Kollmann, 1960) of Austria and Hungary and the upper Miocene-Pliocene of Turkey (Bassiouni, 1979; Şafak, 1996). The ostracod *Loculicytheretta pavonia* reported in this study has also been found in the Pliocene (Doruk, 1973) and Tortonian (Avşar et al., 2006) in Turkey.

In the Ayrancı Basin, the ostracod biozone identified corresponds to the *Neomonoceratina helvetica-Aurila soummamensis* Biozone. This zone is equivalent to the *Loxoconcha linearis* and *Neomonoceratina helvetica* zones in the Tethys zonation of the Burdigalian (Krstic, 1975). It also corresponds to zones A and B of Carbonel and Jiricek (1977), representing the Burdigalian–Helvetian in the Tethys, and the NO-3 and NO-4 zones in the Eggenburgian–Ottnangian of the Paratethys. Similar to the *Neomonoceratina helvetica* Superzone, the *Neomonoceratina helvetica-Aurila soummamensis* Biozone has been identified in the Adana, Gözne/Mersin, Antakya and Karsanti basins (Šafak and Ünlügenç, 1992; Nazik, 1993; Şafak, 1993). The *Carinocythereis* Biozone is observed from the beginning of the Langhian. It corresponds to the *Cytheridea paracuminata verrucosa*, *Carinocythereis semiornata*, *Acantocythereis hystrix,* and *Cytherella vandenboldi* biozones of the Tethys (Krstic, 1975; Table 1). Similar zonal representations have also been found in other studies, such as of *Carinocythereis pokornyi* and *Verrucocytheris verrucosa* in the Serravallian and the *Bythocypris lucida*, *Eocytheropteron inflatum-Acanthocythereis hystrix* Biozone in the Langhian of the Paratethys.

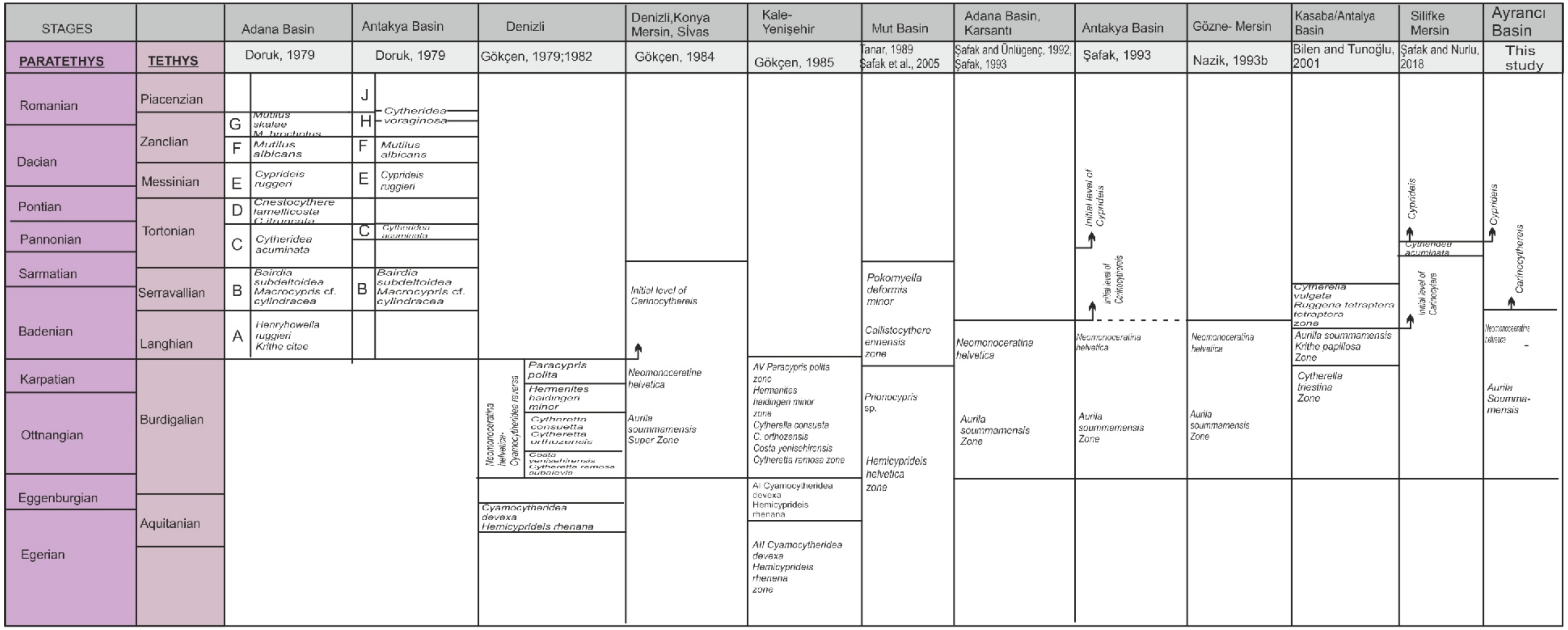

Fig. 12. Comparison of the Middle–Upper Miocene ostracod zones with zones reported in the Miocene of Turkey

Table 1

Comparison of the biozones revealed in the study area with biozones in other regions

Neomonoceratina helvetica-Aurila soummamensis Zone			Carinocythereis Zone			Cyprideis Zone		
Kristic (1975)	*Loxoconcha linearis* *Neomonoceratina helvetica*	(Burdigalian)	Kristic (1975)	*Cytheridea paracuminata verrucosa* *Carinocythereis semiornata* *Acantocythereis hystrix* *Cytherella vandenboldi*		Kristic (1975)	*Falunia stellata* *Pseudopsommocythere kolmanni* *Elofsaniella amberi*	(Serravallian Tortonian)
Sokac (1978)	*Loxoconcha linearis linearis* *Neomonoceratina helvetica* *Cytheridea ottnangensis* *Obitacythereis ruggieri* *Bythoceratina vandenboldi* *Cytherella postenticulata*	(Burdigalian-lower Langhian)	Sokac (1978)	*Cytherella postdenticulata* *Carinocythereis pokornyi* *Verrucocytheris verrucosa*	(Upper Langhian) (Serravallian)	Sokac (1978)	*Loxocorniculum sarmaticum* *Loxoconcha quadricornis* *Parakrithe vermuiiti* *Buntania multicostata* *Cyprideis ruggieri*	(Lower-Middle Tortonian)
Jiricek (1983)	*Neomonoceratina helvetica* *Ruggieria carinata* *Psedopsommocythere kolmanni-Neomonoceratina helvetica* *Neomonoceratina helvatica-Cytheridea ottnangensis* *Cytheridea paracuminata-Paracyprideis triebeli*		Jiricek (1983)	*Bythocypris lucida* *Eocytheropteron inflatum-Acantocytheris hystrix* *Carinocytheris carinata-Phyloctenophara* *Cytheridea macarica-Aurila mehesi* *Krithe langhiana* *Krithe citae* *Bosquetina carinella* *Cytheralla postdenticulata* *Cyamocythereis dertonensis* *Carinocythereis carinata*	(Langhian-Serravallian) (Serravallian-Early Tortonian) (Langhian) (Langhian Serravallian) (Serravallian)	Jiricek (1983)	*Carinocythereis carinata* *Carinocytheridea dertonensis*	
Gammudi and Keen (1993)	*Aurila soummensis*	(Burdigalian)				Gammudi and Keen (1993)	*Ruggieria tetreptera tetraptera*	
Led and İsmail (2016)	*Actinocythereis spinosa-Acanthocythereis hystrix*	(Burdigalian)						
Gökçen (1984)	*Neomonoceratina helvetica-Aurila soummensis*							
Tanar (1989)	*Prinococypris sp.* *Hemicyprideis helvetica*	(Burdigalian)	Led and İsmail (2016)	*Chrysocythere cataphracta muricata-Cytheretta Africana* *Dispontpcypris schweijeri-Bythocypris*	(Langhian) (Serravallian)	Faranda et al. (2008)	*Cytheretta semiornata* *Cyamocytheridea meniscus*	

DISCUSSION

Previous studies of the Ayrancı Basin have not mentioned the presence of Middle Miocene lithological units. This research, however, provides a detailed analysis of the Miocene succession, specifically the Divlek and Mazı formations (Fig. 10). The Mazı Formation, the first Miocene unit consisting of claystone and clayey limestone, overlies the Kıraman Ophiolitic Mélange and was deposited during the Burdigalian to Late Serravallian intervals. The Divlek Formation marks the end of the Miocene Epoch in the region (Murat and Temur, 1995).

The ostracod biozone identified in the Ayrancı Basin through this study is the *Neomonoceratina helvetica-Aurila soummamensis* Biozone. This corresponds to the *Loxoconcha linearis* and *Neomonoceratina helvetica* biozones of the Burdigalian Tethys zonation (Krstic, 1975). Additionally, it corresponds to the *Neomonoceratina helvetica* Superzone, representing the Burdigalian to Helvetian in the Tethys with Zones A and B, and in the Paratethys, it corresponds to the Eggenburgian–Ottnangian NO-3 and NO-4 zones. In the Burdigalian, *Neomonoceratina helvetica-Aurila soummamensis* Biozone include *Loxoconcha linearis linearis* Carbonnel, 1969; *Neomonoceratina helvetica* Oertli, 1958; *Cytheridea ottnangensis* (Toula, 1914); and *Obitacythereis ruggieri*, along with *Bythoceratina vandenboldi* Ruggieri, 1960, and *Cytherella postdenticulata* at the beginning of the Langhian, as listed by Sokac (1978).

In the Tethys, this biozone is characterized by the *Neomonoceratina helvetica* and *Ruggieria carinata* biozones, the *Pseudopsammocythere kollmanni* and *Neomonoceratina helvetica* biozones, and the *Krithe citae-Krithe langhiana* Biozone. In the Paratethys, it corresponds to the *Neomonoceratina helvetica-Cytheridea otnangensis* Biozone and the *Cytheridea paracuminata-Paracyprideis triebeli* Biozone (Jiricek, 1983).

CONCLUSIONS

A total of 73 samples from five stratigraphic sections in the Ayrancı Basin have yielded 69 ostracod species listed in Appendix 1. Based on these collections, the initial occurrences of *Carinocythereis* and *Cyprideis* were established in the Burdigalian-Langhian-Serravallian and Tortonian units. In the upper Burdigalian–lower Langhian of the Ayrancı Basin, the *Neomonoceratina helvetica-Aurila soummamensis* biozone have been identified. This zonation is consistent with the general zonation of the Tethys-Paratethys region. Additionally, it has been recognized as a zone fossil for the Burdigalian interval within the Tethys-Paratethys region. This zonation delineates equivalent stratigraphic levels observed in Neogene ostracod zones documented in southern Anatolia, particularly in the eastern Mediterranean area. The ostracod species identified from the Ayrancı Basin represent lagoonal and neritic environments, primarily epineritic and infraneritic. The prevalence of allochthonous ostracod genera in the Ayrancı Basin reefs indicates a complex and interconnected ecosystem with diverse ecological niches.

A shift from terrestrial conditions during the Campanian–Early Miocene to a marine transgression (*Neomonoceratina helvetica-Aurila soummamensis* Biozone) has been noted for the first time in the Ayrancı Basin. The transgression continued southward during the Middle Miocene (Langhian–Serravallian) marked by the first appearance of *Carinocythereis*, while oolitic limestones (first appearance of *Cyprideis*) were deposited throughout the Late Miocene (Tortonian). This depositional pattern is particularly evident in the central part of the Ayrancı Basin, with poorly preserved fossils, indicating the complete retreat of the sea by the end of the Tortonian. However, the Ayrancı-Karaman route (east of the Ayrancı Basin) is characterized by fewer oolitic deposits, indicating a less active transgression in these areas. Strontium isotope ages for the Divlek Formation gave ages of 7.1–8.4 Ma.

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APPENDIX 1

Acanthocythereis hystrix (Reuss, 1850)
Argilloecia conoidea Sars, 1923
Aurila albicans (Ruggieri, 1958)
Aurila convexa (Baird, 1850)
Aurila ducasseae Moyes, 1961
Aurila freudenthali Sissingh, 1972
Aurila pigadiana Sissingh, 1972
Aurila soummamensis Coutelle & Yassini, 1974
Aurila sp. Bassiouni 1979
Aurila speyeri (Brady, 1868)
Aurila ulicznyi Sissingh, 1972
Bairdia subdeltoidea (Muenster, 1830)
Carinocythereis antiquata (Baird, 1850)
Carinocythereis carinata (Roemer, 1838)
Celtia quadridentata (Baird, 1850)
Chrysocythere paradisus Doruk, 1973
Cistacythereis caelatura Uliczny, 1969
Cistacythereis pokornyi (Ruggieri, 1962)
Costa edwardsii (Roemer, 1838)
Costa tricostata (Reuss, 1850)
Cyamocytheridea meniscus Doruk, 1978
Cyamocytheridea reversa (Egger, 1858)
Cyprideis seminulum (Reus, 1958)
Cyprides anatolica Bassiouni, 1979
Cytherella glypta Doruk, 1977
Cytherella vandelboldi Sissingh, 1972
Cytherella vulgata Ruggieri, 1962
Cytheretta semiornata (Egger, 1858)
Cytheropteron alatum Sars, 1866
Echinnocythereis scabra Muenster, 1830
Eucytherura gibbera Müller, 1894
Falunia sphaerulinata (Jones, 1857)
Hemicyprideis villandrautensis (Moyes, 1965)
Hermanites haidingeri minor (Reuss, 1850)
Hiltermanicythere rugosa Costa, 1952
Krithe citae Oertli, 1961
Krithe langhiana Oertli, 1961
Krithe monosteracensis (Seguenzac, 1880)
Krithe papillosa Bosquet, 1852
Krithe sp. Brady, Crosskey & Robertson, 1874
Loculicytheretta pavonia (Brady, 1866)
Loxoconcha alata Brady, 1868
Loxoconcha cristatissima Ruggieri, 1967
Loxoconcha rhomboidea (Fischer, 1855)
Loxoconcha tumida Brady, 1869
Miocyprideis konyaensis Bassiouni, 1979
Miocyprideis sp. Kollmann, 1960
Neomonoceratina acupicta Bonaduce, Ruggieri, Russo & Bismuth, 1992
Neomonoceratina helvetica Oertli, 1958
Neomonoceratina interiecta Bonaduce, Ruggieri, Russo & Bismuth, 1992
Neomonoceratina laskarevi (Kristic and Pietrzeniuk, 1972)
Neomonoceratina mouliana Sissingh, 1972
Occultocythereis cf. *bituberculata* Reuss,1850
Paracypris polita Sars, 1866
Pokornyella deformis minor (Moyes, 1965)
Pontocythere elongata (Brady, 1868)
Procythereis sulcatopunctatus (Reuss, 1850)

Propontocypris (Ecpontocypris) pirifera Müller, 1894
Pseudopsammacythere kollmanni Carbonel, 1966
Ruggieria tetraptera tetraptera (Sequenza, 1880)
Schneidrella dromas (Schneider, 1939)
Semicytherura boldi Ducassae, 1967
Tenedocythere prava (Baird,1850)
Tenedocythere salenbrosa Uliczny,1969
Thalmannia hodgii (Brady, 1866)
Urocythereis favosa exedata Uliczny,1969
Xestoleberis communis Müller, 1894
Xestoleberis glabrescens (Reuss, 1850)
Xestoleberis ventricosa Müller, 1894